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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

MATERIALS RESEARCH LABORATORIES

MELBOURNE, VICTORIA

REPORT

MRL-R-921

EXTRACTS FROM SYMPOSIUM
COUNTERSURVEILLANCE '83

Materials Research Laboratories,
Melbourne, 27 and 28 April, 1983

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ABSTRACT

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PREFACE

This volume contains the texts of unclassified papers and discussion from the symposium "Countersurveillance '83" held in the John L. Farrands Building at MRL on the 27 and 28 April, 1983. The four sessions were devoted to:-

I   Service requirements
II   Surveillance, the threat
III   Psychology of detection by humans and machines
IV   Countermeasures

The papers in Session II do not, in general, describe specific research efforts - rather, they are intended, taken together, to give an overview of surveillance techniques, existing and projected, seen as threats to be countered. It is hoped that the reverse side of this coin will be revealed at a symposium on surveillance techniques at DRCS some time in 1984.

Both papers and discussion are reproduced here as nearly as possible as they were presented. Editing has been kept to the minimum necessary to maintain intelligibility and preserve the required security classification.

Several illustrations appearing in the paper "Multisensor Surveillance" are copyrighted and permission has been granted for their reproduction in these proceedings. Those concerned are figures 5 and 6 of Landsat 4 satellite photographs, reproduced by permission of Aviation Week and Space Technology, McGraw Hill, Inc. and figures 8 and 9 of aerial photographs, reproduced by permission of IEEE Inc.

Proceedings were opened at 9.20 am on the first morning by Dr P. Dunn, A/Director MRL, who welcomed the participants to MRL and wished them success in their efforts. From then on deviations from the timetable were never more than a few minutes, and we offer a particular note of thanks to our chairmen of the sessions for their firm but unobtrusive control that achieved this.

The editors wish to place on record their thanks to all members of MRL and in particular the staff of Optics Research Group, for their cheerful assistance in the organizing of this symposium.

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MULTI-SENSOR SURVEILLANCE

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ABSTRACT

The factors governing performance of a surveillance system are reviewed and some of the necessary trade-offs are considered briefly. A number of examples of current systems is given. Future trends in surveillance are forecast.

1. INTRODUCTION

Recent advances in technology will have far-reaching effects on the art and science of surveillance. Three areas are particularly significant. First, the development of arrays of sensors, both linear and planar, with spacing of the order of tens of microns and dense coverage, has already revolutionized imaging instruments for the visible and infrared regions of the spectrum, both by simplification of the scanning system and by improvement of performance. Second, rapid advances in millimetre-wave techniques and manufacturing methods have reduced sizes and costs to the extent that it is no longer unreasonable to think of "staring" imaging systems at 90 GHz or even higher. Third, the continuing exponential rate of developments in speed, size and cost of computing equipment will make real-time processing and display of images a reality within a few years; one field in which this will have a large impact is synthetic aperture radar (SAR). Now is an opportune time to review the capabilities and limitations of generic surveillance systems.

This paper will consider only sensors for that part of the electro-magnetic spectrum from 300 mm or 1 GHz (microwave) to 300 nm (near ultra-violet), thereby excluding the important discipline of electronic surveillance.

2. SOME POSSIBLE SURVEILLANCE SCENARIOS

Surveillance requires one or more of the operations of detection, location, identification, classification and tracking, sometimes simultaneous, sometimes sequential. An important consideration is that data and information obtained by a surveillance system must be available on a suitable time scale to contribute to command and control functions.

Some possible surveillance scenarios are listed below:

Peace time	:	Intelligence gathering
Time of tension	:	Accelerated intelligence gathering
		Monitoring of logistics build-up
		Troop, vehicle, aircraft, shipping movements
Conflict	:	Barrier maintenance
		Target identification and location
		Force movements
		Assessment of own force effectiveness
		Intelligence gathering

3. IMPORTANT PARAMETERS OF SURVEILLANCE SYSTEMS

Important characteristics of systems which need to be considered are:

Package size and mass
Range at which surveillance is needed
Resolution, field of view, beamwidth
Signal/noise ratio, contrast and colour discrimination
Use of characteristic features such as emission or absorption lines
Capability for identification and classification
Day/night operation
All weather operation
Operation in rain, snow, fog, dust, haze, smoke
Covertness
Susceptibility to countermeasures
Revisit time (for satellite systems)
Timeliness of data

Different missions place emphasis on different performance characteristics of the surveillance sensors. For example force movements and logistics build-up can probably be monitored by a satellite system with low resolution and a re-visit time of days, whereas target identification and localization needs a high resolution, all weather, real time capability.

4. CLASSES OF SURVEILLANCE SYSTEMS

We can classify systems into classes shown in Fig 1, although some systems will fall into more than one class. Notice that current active laser systems usually use incoherent detectors, although future developments may use coherent detection.

In general, active systems cannot be considered covert, although the use of techniques such as spread spectrum can reduce the probability of intercept significantly. Passive systems are often covert, although if a particular aircraft or satellite is known to carry surveillance sensors and if its overpasses can be tracked, then the system is not covert.

Systems which use coherent detection and active transmission can be designed to yield a Doppler output which can be used to obtain line-of-sight velocities and limited signature information from propellor or turbine blades, engine fans, etc. They can also be designed for resistance to countermeasures by use of spread spectrum techniques. A disadvantage of active systems is that they are likely to alert the surveyee at a greater range than the surveyor can obtain the information he seeks. Some active millimetre wave systems are "almost covert" as a result of their narrow beam width and careful choice of operating wavelength to take advantage of atmospheric attenuation. Wide band systems can usually yield much more definitive identification and classification information.

5. TRANSMISSION THROUGH THE ATMOSPHERE

One of the factors influencing the choice of a system is the effect of the atmosphere. Fig 2 shows the attenuation of a horizontal atmospheric path at sea level for a relative humidity of about 50% as a function of frequency. The peaks of high attenuation are the result of absorption by molecules in the atmosphere. Despite these peaks, there are a number of bands in which the attenuation is low, less than 1 dB per kilometer. Over the range we are considering, the "windows" are in the visible, the well-known bands in the infrared part of the spectrum, a number of bands in the millimeter region, and the whole region of frequencies below 40 GHz.

If the atmosphere contains particulates such as rain, fog, dust or smoke, the frequency dependence of the attenuation becomes even more complicated. As an example, Fig 3 shows the effect of rain and fog. Haze, smoke and other particles produce the same general trend of increasing absorption with frequency but with different fine structure. Thus, it is generally true that for all weather, long range operation, longer wavelengths are the most useful, but then we come up against the all important parameter of resolution.

6. ANGULAR RESOLUTION

The resolution of the unaided human eye is about 1 arc minute, or 0.3 milliradian, corresponding to 30 cm at 1 Km or 1 inch at 100 yds. The functions of identification and classification usually require the highest possible resolution; we will use the unaided human eye as representative. The aperture required to yield this resolution at other wavelengths is listed below:

Wavelength	Frequency	Band	Aperture
500 nm	6×10^{14} Hz	Visible	3 mm
10μ	3×10^{13} Hz	Thermal IR	60 mm
3 mm	100 GHz	mm-wave	18 m
300 mm	1 GHz	Microwave	1.8 Km

For microwave surveillance systems, real apertures with dimensions of the order given above are out of the question. However, synthetic aperture radars (SAR) achieve high angular resolution by using sophisticated signal processing to combine coherently the returns from a large number of pulses which were emitted over a length of this order. This technique also affords considerable immunity against simple-minded countermeasures. A number of military synthetic aperture radar systems are operational and the field is one of intensive and rapid development. Fig 4 is a SAR image of a part of Oakland Bay, near San Francisco and shows the Oakland Bay Bridge and a number of vessels and their wakes. The images are of almost photographic quality. However SAR imagery poses severe data processing problems. Current systems record data photographically, in a manner analogous to a hologram. The image is generated by re-exposing the developed film, usually on the ground and some time after the mission. Digital recording and processing of the data offers a number of advantages, but the data rates involved are of the order of 100 Megabits per sec. At present, data processing rates are slower than this by at least an order of magnitude, but real-time processing will be possible within 5-10 years. A further example of SAR imagery is discussed in Section 8, Fig 10.

7. SYSTEM TRADE-OFFS

In a short overview such as this, it is clearly impossible to examine in detail all the conflicting requirements of a multi-mission surveillance system. However I do want to point out two of the most important trade-offs.

The previous section shows clearly that the longer wavelengths are not suitable for high resolution surveillance, yet the shorter wavelengths suffer most from atmospheric and obscurant effects. Thus we are forced immediately to one of the most important trade-offs: long range performance under adverse conditions or high angular resolution.

Another trade-off is ground resolution against total field of view and along-track ground speed or frame rate of the sensor. These are obviously related to the total data rate of the sensor, which is often limited by a data link such as from a satellite, RPV or forward observer. The data rate is also an important consideration where extensive computer manipulation of the data is required, as for instance in classification of ground cover or surface types, or in SAR processing.

As a specific example, the following table gives a comparison of some important system characteristics for radar systems over a wide range of wavelengths.

CHARACTERISTIC	MICROWAVE	MILLIMETER WAVE	OPTICAL
TRACKING ACCURACY	1	2	3
CLASSIFICATION/IDENTIFICATION	1	2	3
COVERTNESS	1	2	3
VOLUME SEARCH	3	2	1
ADVERSE WEATHER PERFORMANCE	3	2	1
PERFORMANCE IN SMOKE	3	3	1

(1 POOR : 2 INTERMEDIATE : 3 GOOD)

8. EXAMPLES OF CURRENT SURVEILLANCE SENSORS

The foregoing brief outline has shown some of the factors which must be considered in choosing or designing a surveillance system for a particular mission. It is clear that to cater for different types of mission it will be necessary to use a suite of different sensors, chosen to make best use of the synergism between them.

I will now give some examples of data obtained from recent surveillance systems.

Figure 5 shows a black and white copy of a false colour image obtained from the thematic mapper aboard the Landsat 4 satellite. The original is from Aviation Week for Jan 1983. The satellite is at a height of 700 Km and the data is from the infrared bands. Ground resolution is 30 m. The area is New Orleans, with the Mississippi River winding through the city, and Lake Ponchartrain and the cause-way across it at the top. Note the airfield and the barge traffic on the river. Fig 6 is an enlargement of a portion of this image. (The colours in the original image provide much better

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feature discrimination than the shades of gray of the reproduction). The resolution is limited by the printing processes; the digital data is capable of much higher resolution than is shown here.

Figure 7 is an image from a forward-looking infrared (FLIR) imager built by EMI and flown in an aircraft over the Thames in London. Tower Bridge and the Tower of London are conspicuous. The image was made in sunlight as the roof tops are hot and shadowed sides of buildings are cold. Resolution is 0.5 mr at centre, field of view 14° x 20°, band used is 8-14μ. In the previous paper, Dr Gambling has shown other IR images.

Figures 8 and 9 show the capabilities of a mechanically-scanned, airborne imaging radiometer operating at 90 GHz (~3 mm). These images were obtained in 1978; since then there have been accounts in the open literature of subsystems suitable for "pushbroom" operation, with greatly improved performance, but it is probably significant that no further examples of images have been published since then.

Again the originals are in colour, which makes the temperature scale much easier to interpret. The upper half of both figures is a photograph covering the same region as the millimetre-wave image shown in the lower half. Fig 8 shows an area near Chincoteague, Virginia, with part of Chincoteague Bay at upper left. The high school running track appears hot while areas of water reflect the sky, which is cold at these wavelengths. Fig 9 shows the airstrip at Wallops Is, Virginia. The paved areas appear hot and water cold. Metallic objects also appear cold by reflecting the sky; roofs of airfield buildings are cold as are aircraft. The cold spot at the end of the runway in the mm image is an aircraft preparing for take-off; another is parked near the hangar.

Finally an example at the long wave end, at 2.5 cm wavelength: Fig 10 was obtained from the Shuttle Imaging Radar experiment, SIR-A during the Space Shuttle flight of November 1981. The instrument is a synthetic aperture radar operating at 1.28 GHz (L band) and has a ground resolution of 40 m. The image data has a very large dynamic range, which makes it very difficult to present all the detail on a single photo. It shows the Wollongong - Pt Kembla area of NSW - the water storage areas for Sydney are conspicuous. The reason for choosing this particular image is because of the very bright spots just off the coast. They are bulk carriers, used for carrying coal but anchored at the time of this pass. The intense return is the result of many metallic corners which form very effective corner reflectors at L-band. The man-made, built-up areas along the coast produce a very large return for the same reason.

Synthetic aperture radars at this wavelength also show complex patterns on the sea surface, some of which are related to underwater features such as sandbanks.

9. THE FUTURE

(a) Information Processing

In a modern battle, the outcome is likely to be decided by force-multiplier effects of imaging surveillance systems, electronic surveillance systems and related ESM and EW systems. A major problem is the collection, processing, display, and analysis of information on a time scale which is compatible with the rapidly changing situations which are encountered.

We need to keep abreast of developments in information processing capability so as to assist highly trained operators to assimilate information with the least possible strain and effort, but at the same time we must resist the temptation to expect that vital decisions requiring judgement and experience can be made exclusively by computers.

In the narrower field of surveillance systems we need to give close attention to the minimum system which offers the maximum versatility in respect of possible missions, exploiting complementary features but also seeking graceful degradation resulting from partial failure. In particular we need to integrate the information display systems so that all essential data is readily available to the operator in a timely way, yet he is not overwhelmed by the mass of material.

On the optimistic side, if we extrapolate current developments in very large scale integration (VLSI) and very high speed integrated circuits (VHSIC), it is clear that the all-pervading effects of cheaper, faster, and smaller electronic circuitry will continue to accelerate capabilities in fields important to surveillance, such as processing, compression, display and dissemination of information; indeed it is military requirements of this kind which drive the development process.

The ability to store and retrieve enormous quantities of data, such as details of terrain, vegetation and man-made structures for an area the size of Australia and to navigate and designate targets with pin-point accuracy in all weather will impact military planning and tactics. The ability to compare surveillance scenes point by point over a wide spectral range will make camouflage much more difficult than it is today.

(b) Space-based Surveillance

High resolution surveillance from space requires that the satellite orbit be of minimum height, which means that to cover points on the Earth at high latitude, orbits of high inclination are required. This in turn means that to provide complete coverage with a limited field of view, the satellite revisits a particular point at intervals of many days. However, there is one orbit for which this is not true:- an equatorial one, although of course in this case the satellite only overflies points on the equator.

Australia is in a unique position to take advantage of this, since we see our main threat coming from the north, across the equator. For the singular case of an equatorial orbit, the revisit time is simply the period, which for a satellite at a height of 650Km (the minimum height to give a life time of at least 5 years) is 98 mins.

A more useful orbit might be one at an altitude of 1300Km, for which

the period is 112 mins. At this height, an aperture of 0.6m would give a ground resolution of 5m at 500nm wavelength. By using a sensor whose field of view can be tilted 45 degrees to the satellite track (the French SPOT satellites will be able to do this), coverage to 13-1/2° either side of the equator would be provided. A satellite in such an orbit is visible from northern Australia, so that data can be received on Australian territory. The map in Fig 11 shows the ground coverage of such a satellite and also shows the portion of the orbit over which ground stations at North West Cape, Darwin, and Rockhampton could receive satellite data directly.

Thus, whereas the USA and Russia need a constellation of many satellites to provide surveillance of each other, one or two satellites in near-equatorial orbit could meet many of Australia's needs.

There is another source of satellite data which we should be making much better use of than we are. The latest in the LANDSAT series, LANDSAT 4, carries both a multispectral scanner (MSS) with a ground resolution of 70m, the data from which is compatible with data from earlier LANDSAT sensors, and a thematic mapper (TM) which has higher resolution (30m in all but the longest wavelength IR band), response in 3 IR bands out to 12 microns and more precise calibration. Australia already has the Australian Landsat Station which routinely collects and processes MSS data, and the Fraser government approved a $10M update for TM data collection and processing. Within the limitations of the sensors and their orbits we should be able to acquire invaluable experience in extracting useful surveillance data at minimal cost. As an example, New Zealand has obtained information on shipping from this source.

(c) Millimetre Waves

In the past, the need for the highest possible resolution has driven us to sensors in the visible and IR bands and we have had to accept the limitations caused by night-time, cloud, fog, smoke, etc. In the near future, 5 to 10 years, I believe that millimetre wave systems will be developed to the extent of providing the necessary resolution with much improved all-weather performance. Extrapolating even further ahead, there is no fundamental reason that a synthetic aperture radar should not operate in the mullimetre wave band.

(d) RPV's

A number of short range stand-off surveillance scenarios e.g. battlefield surveillance near or beyond the forward edge of the battle area, the "horizon extension" function for a naval task force, appear to be well matched to the capabilities of RPV's. Australia has the necessary technology background to develop in-country the vehicles and sensors, the communications and control links and the ground-based information processing centre. Fig 12 shows a Canadian RPV known as the "Flying Peanut". We should be able to get some Industry Assistance funding to build something of the kind in Queensland.

CLASSES OF SURVEILLANCE SYSTEMS

PASSIVE		ACTIVE	
REFLECTIVE	EMISSIVE	COHERENT	INCOHERENT

REFLECTIVE

Require source of illumination usually sunlight

Most optical systems

Some IR systems

Some mm-wave systems

EMISSIVE

Sense thermal emissions

Most far IR systems

Most mm-wave imaging systems

COHERENT

All system below ~ 300 GHz

Doppler sensing available

Spread spectrum techniques applicable

INCOHERENT

Most laser systems

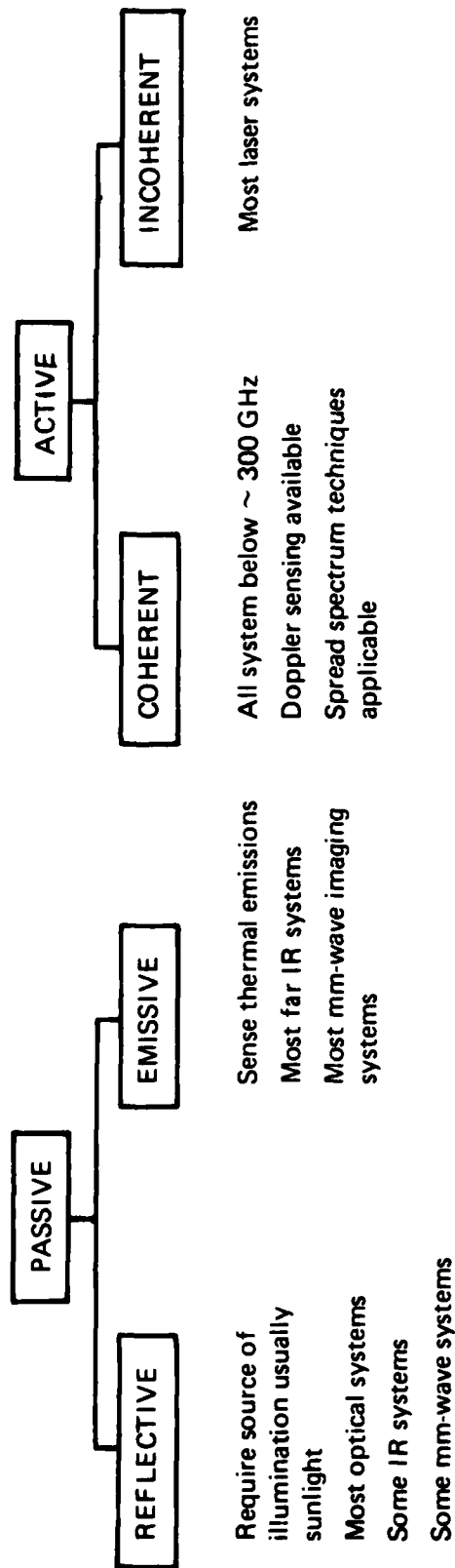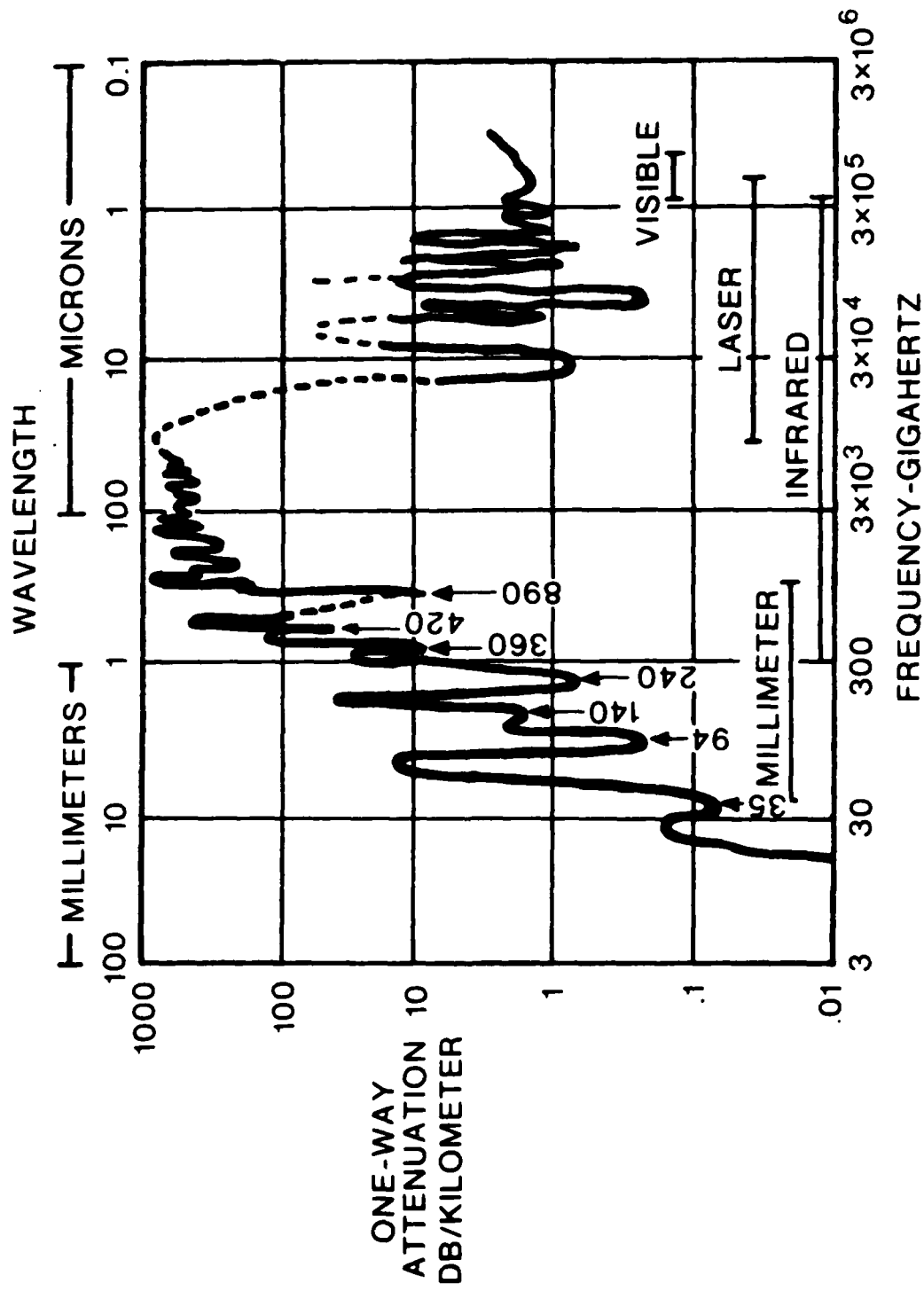Figure 1

ATMOSPHERIC ATTENUATION VS FREQUENCY

Figure 2

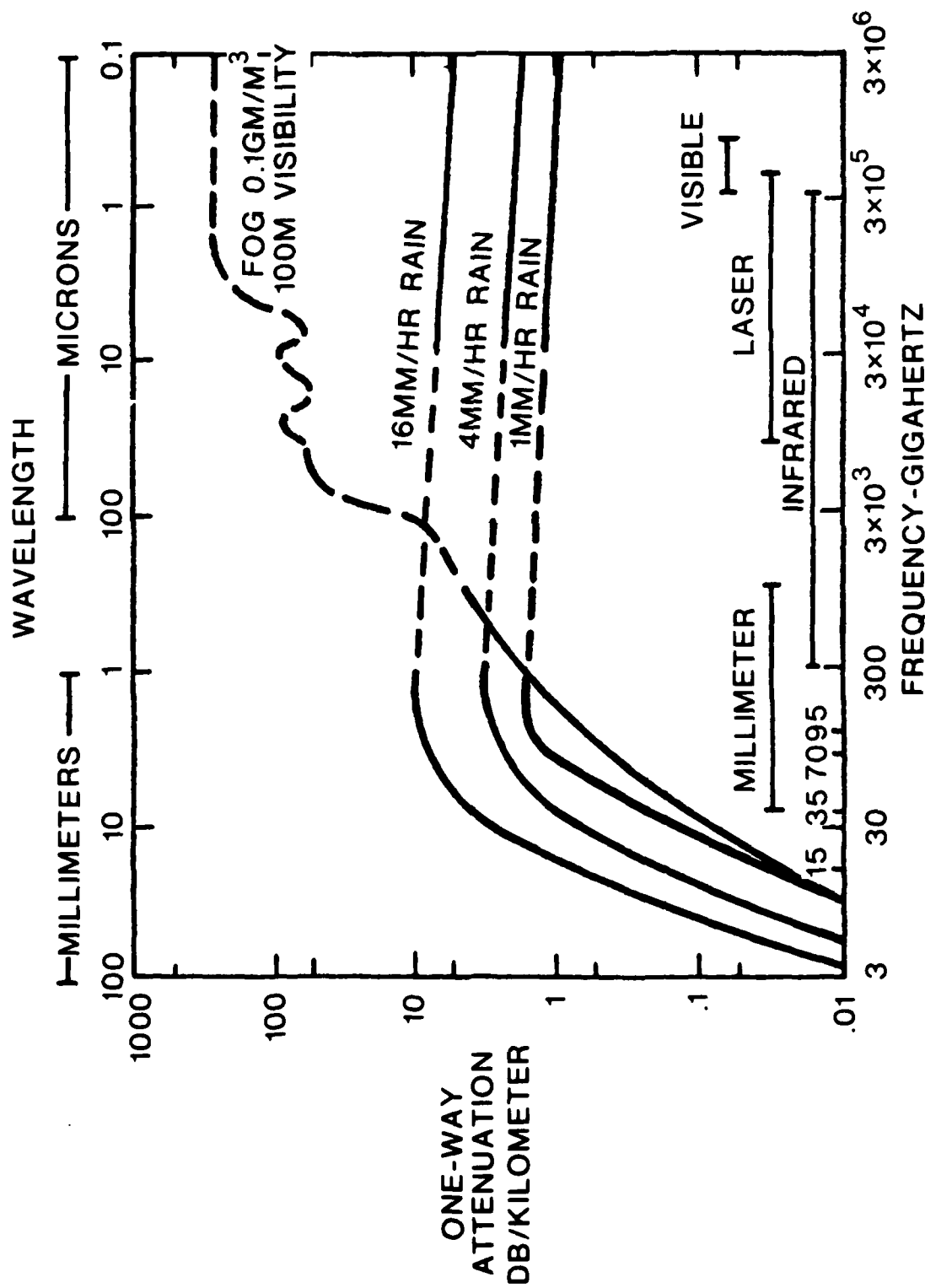# RAIN AND FOG ATTENUATION VS FREQUENCY
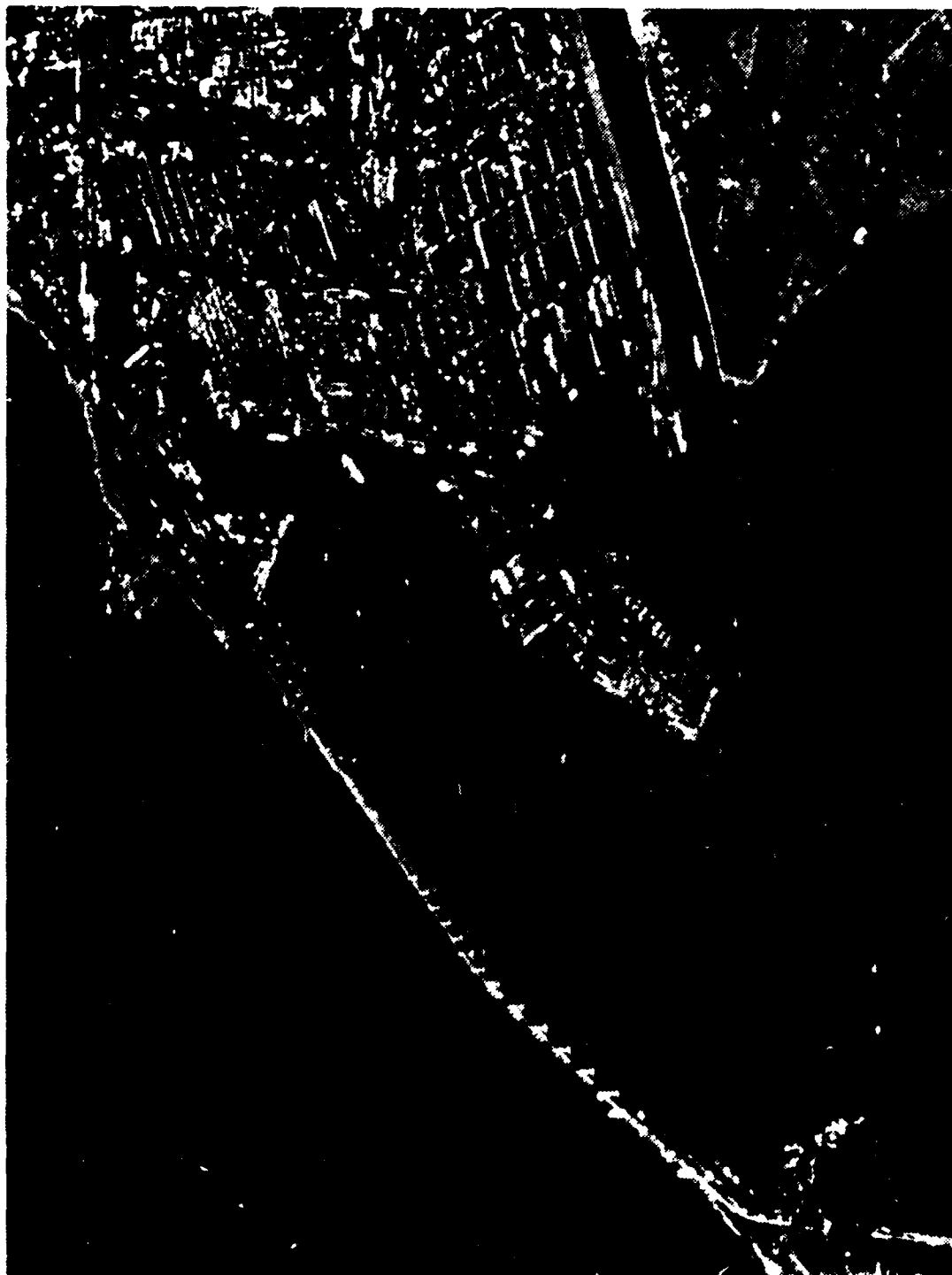

Figure 3

Figure 4
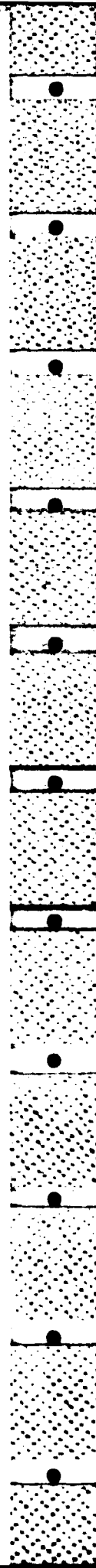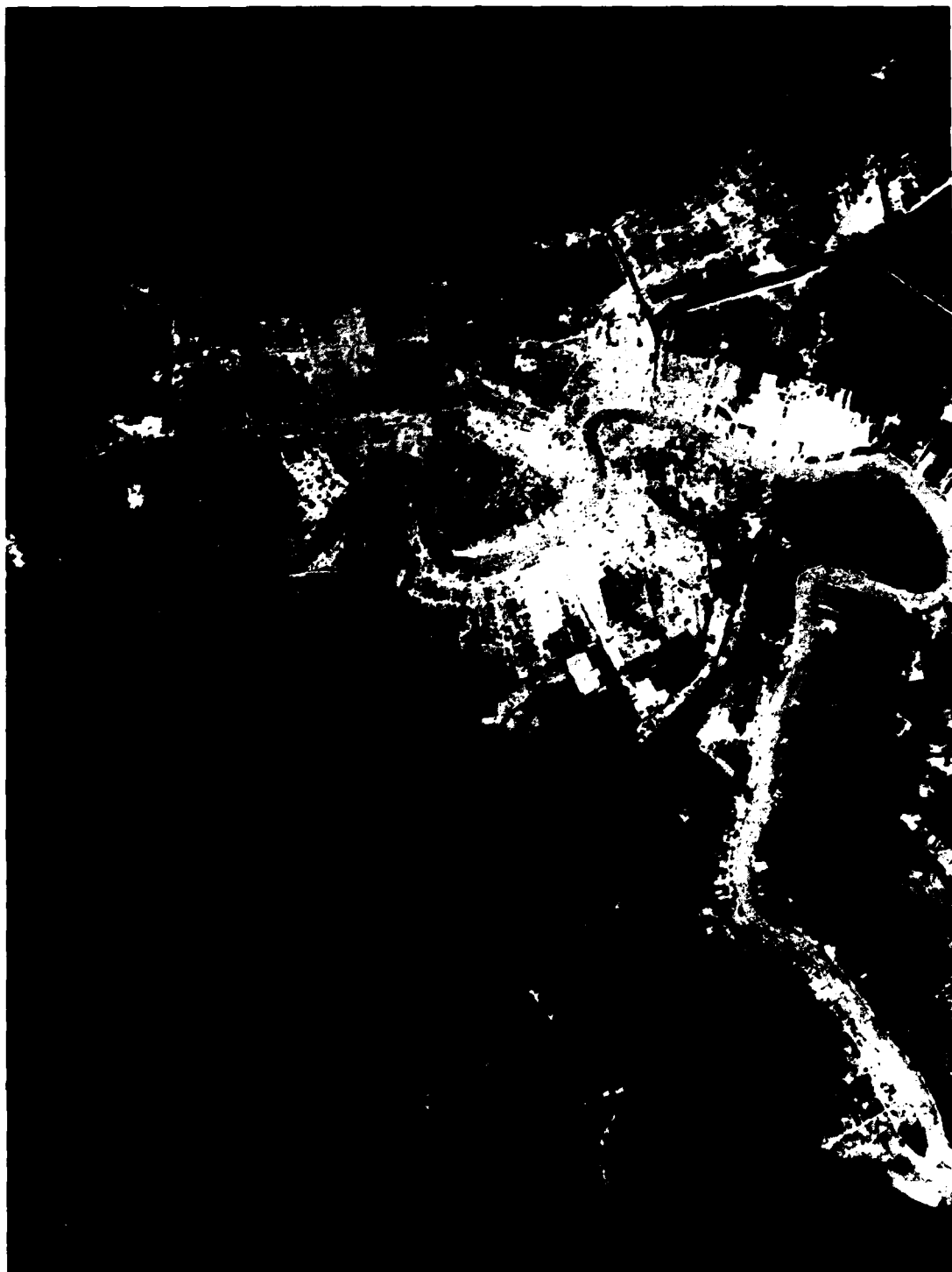
Figure 5

Figure 6
C Aviation Week and Space Technology, McGraw Hill, Inc. Jan 31, 1983

Figure 7
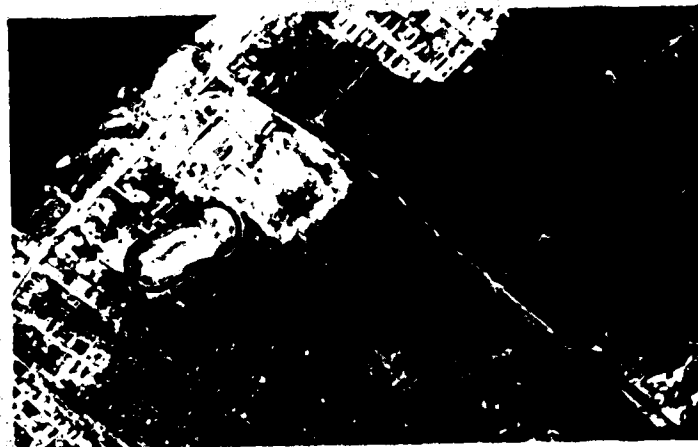
186　　　　　291°K

A 10-GHz scans of a portion of Chesapeake Virginia; the temperature scale on the bottom. At top a photograph of the same region for comparison. The data were obtained with a 2-inch aperture horn scanning antenna from an altitude of 440 m with a spatial resolution of 80 m.

Figure 8

Copyright C 1976 IEEE Transactions on Microwave Theory
and Techniques, MTT—24(11), 786—793, Nov 1976, by
J.P. Hollinger, J.E. Kenney and B.E. Troy Jr.

A 90-GHz image of the runway area at Wallops Station, Virginia, is shown along with an aerial photograph of the region. The antenna temperatures 171–215 K have been compressed in order to enhance the range from 215 to 305 K. The imaged area is 870 by 2900 m.

Figure 9

Figure 10

GROUND COVERAGE OF EQUATORIAL SATELLITE,
1300 km HEIGHT, ±45° FROM NADIR

VISIBILITY OF SATELLITE IN EQUATORIAL
ORBIT FROM GROUND STATION

Figure 11

Figure 12

PASSIVE COUNTERSURVEILLANCE - AN OVERVIEW

P.J. Beckwith

Department of Defence
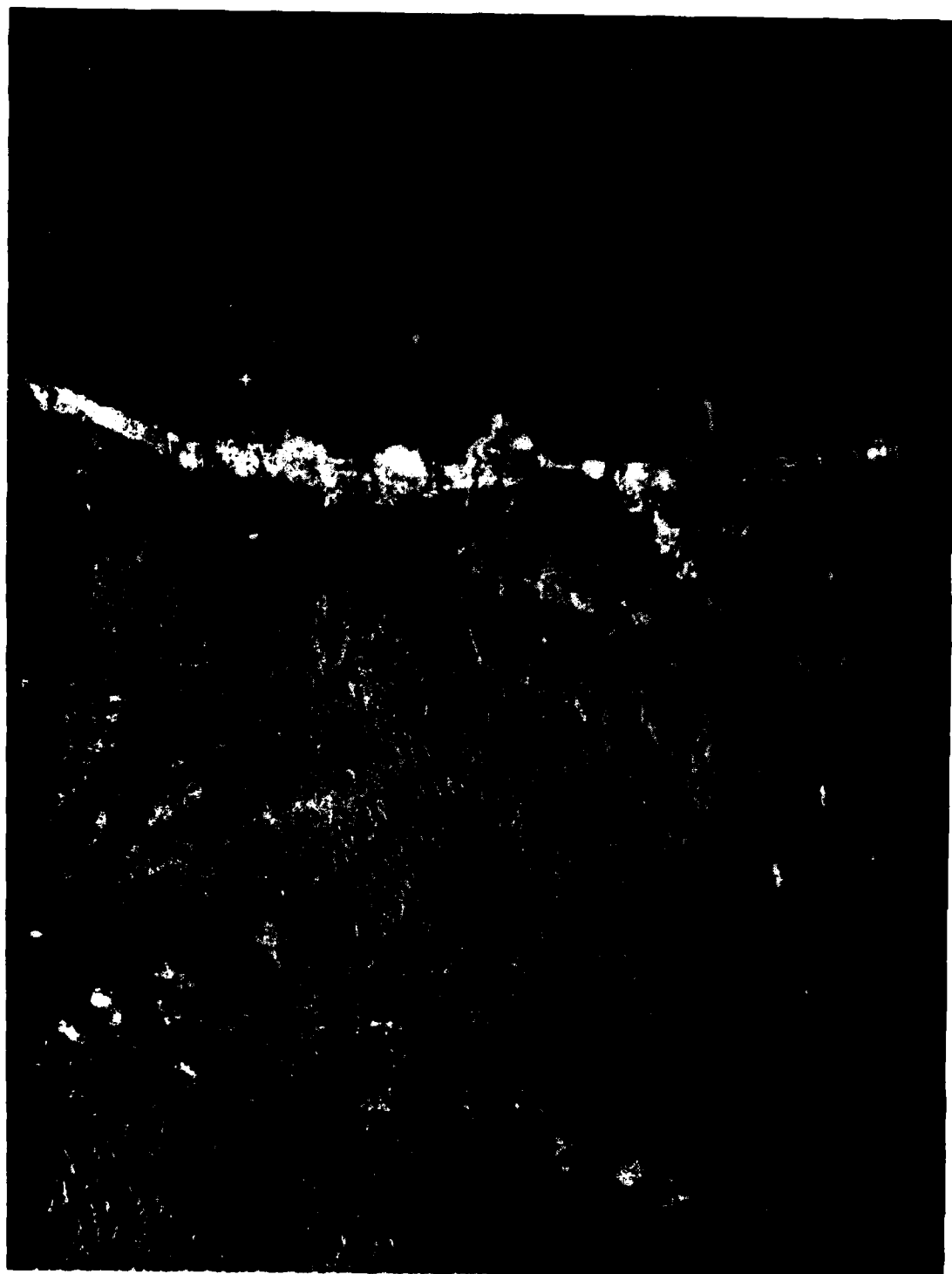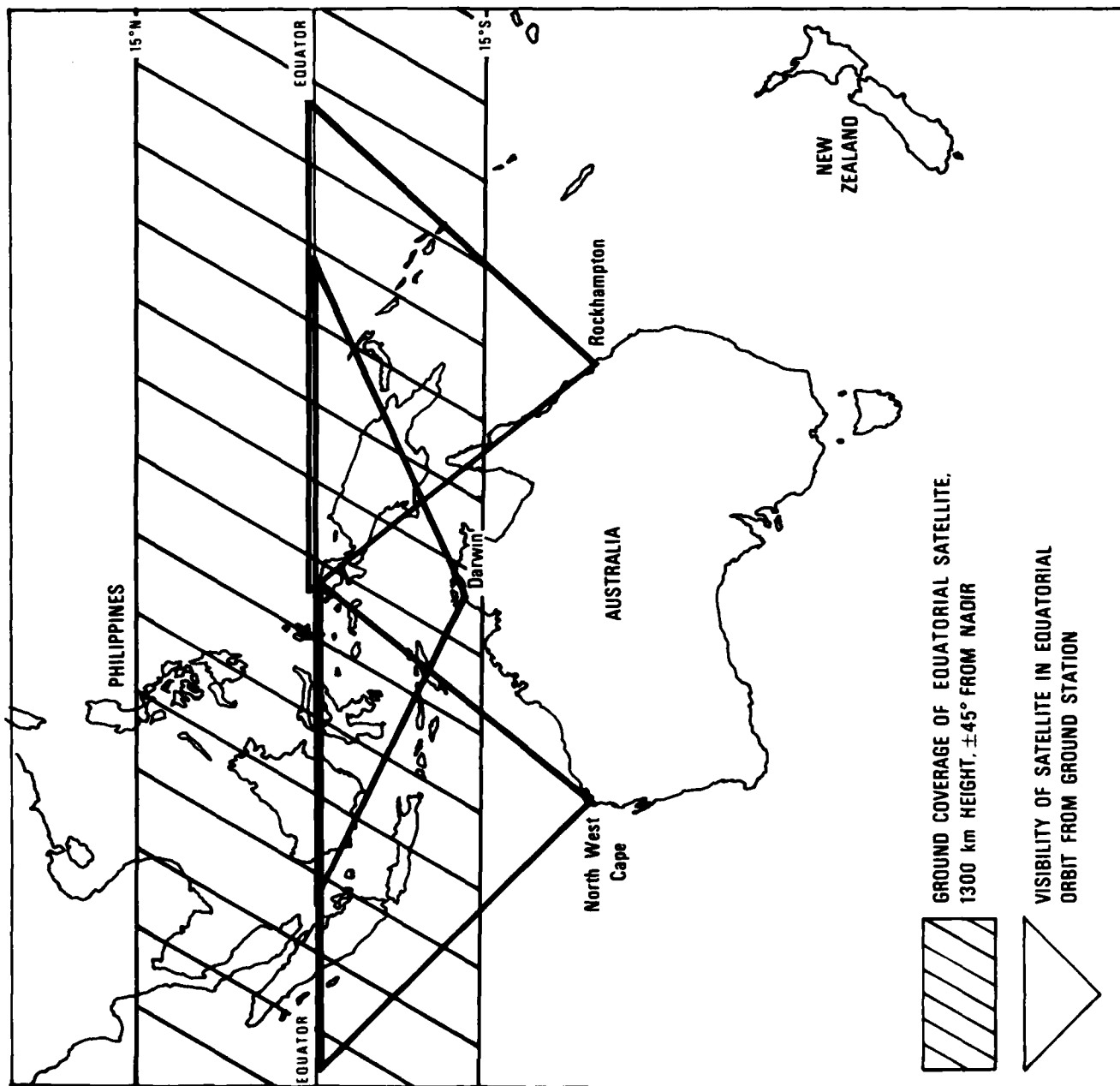Materials Research Laboratories
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ABSTRACT

This paper is an assessment of the directions of current overseas passive countersurveillance research, based on recent discussions at RSRE, BAe, RARDE and SCRDE in the UK, and at MERADCOM and the US Army Natick Labs in the USA. The fields examined include traditional camouflage in the visible and near-IR based on background matching and disruptive patterning, radar signature reduction by means of coating or scattering nets, and passive thermal IR countermeasures using low-emissivity coatings and screening techniques. Some mention will be made of overseas psychophysical research, although this field is still undeveloped.

1.   INTRODUCTION

In November 1982 the author was able to visit a number of overseas establishments involved in passive countersurveillance research. These establishments were, in Great Britain, the Royal Signals and Radar Establishment (RSRE), British Aerospace Dynamics Group (BAe) at Bristol, the Stores and Clothing Research and Development Establishment (SCRDE) and the Royal Armaments Research and Development Establishment (RARDE). In the USA two laboratories were visited, namely the Mobility Equipment Research and Development Command (MERADCOM) at Fort Belvoir, VA and the US Army Natick Research and Development Laboratories near Boston. This paper represents a summary of the activities of these establishments as they relate to the fields of interest in this symposium.

It is evident that the above is not a complete list of laboratories active in passive countersurveillance research, and it is not intended to present the following as being a complete review. It will however represent at least a sample of overseas opinion, and will give indications of the work being done at each of these establishments.

2.   CONVENTIONAL CAMOUFLAGE

The major activity in this area was the disruptive pattern painting (DPP) of vehicles, entirely in the USA. MERADCOM, the US lead laboratory in this area, is still confident of the value of DPP, although the present US standard (MERDC) pattern is no longer well regarded. Attempts are being made to standardise on the German 3-colour pattern, which showed up well in comparative trials in Europe last year (1982). Since an important drawback of DPP lies in its added logistic overhead it is noteworthy that a new paint and painting system is intended for the US Army, namely CARC (Chemical Agent Resisting Coating). This will most likely be polyurethane, and will in any case be applied in professional painting centres rather than at unit level. The inflexibility inherent in this system is being accepted.

The German pattern is a fairly high-contrast outline breaker. Another approach being developed (at MERADCOM) uses a background-matching technique involving area-mapping of defocussed photographs. The resulting pattern has performed impressively in walk-up experiments, but is complicated and may prove too difficult to apply and maintain. By contrast, informal comparative trials aimed at finding suitable paint schemes for Saudi Arabia have led to a monochrome design for desert conditions. The long range and chancy backgrounds in desert regions are evidently not conducive to the good performance of DPP. In this case the preferred colour was a light desaturated buff.

3.   THERMAL INFRARED AND RADAR COUNTERSURVEILLANCE

3.1 Special Paints

Both the UK and USA have programs in this area. MERADCOM is reviewing binder resins in order to identify types with adequate transparency in the thermal infrared wavelength bands, and is investigating the effects of pigment particle size on emissivity. RSRE have experimented with low-emissivity paints, and are quoting emissivity values of around 0.5; such values might not dramatically decrease an infrared signature, but could be used to make recognition difficult.

The problems with anti-radar paints are well known: these paints tend to be heavy, thick, narrowband and (particularly) expensive. One of their most appropriate applications appears to be in countering mm-wave radars, and MERADCOM is evaluating known magnetic pigments for their performance in this frequency range. Some experiments have been done (also at MERADCOM) on the use of conducting dipoles in a paint medium. The problems here involve the need for a dielectric spacing layer underneath the dipoles, and difficulties in quality control.

3.2 Thermal and Radar Shielding

Hard shields with low thermal emissivity are being applied to vehicles on an experimental basis at RSRE. These shields are made by carbon deposition to a thickness of about $1 \mu m$ on aluminium sheeting forming a diamond-hard coating (DHC), and have emissivities in the range 0.1 to 0.2. The aluminium sheets can be formed after deposition, for example to give a stepped profile so that observers see reflections of the ground rather than of the sky. The material is suitable for covering high-mounted exhausts provided soot contamination is not a problem, but is mechanically fragile and expensive, and is less suitable for covering large areas, such as vehicle hulls, which might be mildly warm.

The thermal shielding of gun barrels is also being investigated at RSRE, particularly with respect to the problem of solar loading. The spectral characteristics of surfaces which have low emissivity in the thermal infrared are like those of solar water heaters, and preliminary experiments at RSRE suggest that normal convection may not be enough to cool them. Some sort of forced-air cooling is being considered.

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SCRDE has developed a flexible shielding material called TSW (Thermal Shielding Woodland) which is made by laminating together two dyed polyethylene sheets with an evaporated aluminium layer between them. The overall emissivity is quoted at 0.2. This material is potentially extremely cheap and is intended for use under conventional camouflage netting over stationary vehicles on a throwaway basis. Problems encountered with sky reflections have been partially countered by the addition of black patches, which, however, raise the average emissivity to about 0.5. A pressure-sensitive adhesive backing has been tried on the TSW sheet with a view to covering large areas of a vehicle with it, but apparently the application of such material requires both experience and preparation, and results so far have been discouraging.

The deficiency of TSW is that it acts as a radar mirror, and since most high-value installations can be identified by both thermal infrared and radar this deficiency could be important. MERADCOM is working with a light woven cloth containing 8µm-diameter stainless-steel needles for radar absorption. This material, called TRESS for Tactical Reflected and Emitted Energy Suppression System, has high thermal emissivity but is incised for good coupling to the air. A double layer of this material draped over a vehicle both suppresses the thermal infrared signature and scatters the radar, and it was claimed that neither solar loading nor 50°C metal surfaces have been found to be a problem in winds above 5 mph. Forced-air cooling is being retained as an option in case this claim proves optimistic. MERADCOM would consider a fitted kit for temporary use over mobile vehicles, a system which should have tactical usefulness in open country.

The question of personal thermal shielding is being considered at the US Army Natick Laboratories. Two approaches are being investigated, namely ventilation and low emissivity. The ventilation approach has involved double-skinned clothing with an air gap of about 10 mm and a number of exterior vents, and a double-skinned helmet and double visor. This outfit has not proved successful so far, problems being bulk, creasing and heating by the wearer's breath. The low-emissivity approach is based on a fabric being developed under contract by Battelle Laboratories. This fabric is coated with a permeable plastic film on which is evaporated very thin, nearly-transparent layers of nickel and copper, the whole is then protected by a layer of polyethylene. The manufacture of this material is still at a laboratory scale, and the performance of garments which may be made from it is not yet known.

4. PSYCHOPHYSICAL ELEMENTS

A good deal of work is being done in both the USA and the UK on human responses to thermal imager systems, which has tended to become a somewhat specialised field. Since neither of the US laboratories visited were involved in this field no comment will be made in this paper concerning recent developments in that country. RARDE in the UK is involved in evaluating the US (Night Vision Laboratories) and UK (British Aerospace) models of detection rates versus image parameters. Preference was shown for the NVL model for

static displays, but the BAe model had advantages in search situations. Experimental work on the relation between flicker and contrast thresholds was being done at RSRE, and should have reached publication stage by now.

In a more general area an interesting recognition experiment is being commenced at RARDE based on feature rearrangement of human faces displayed on a television screen. At other laboratories experiments on slewing search are being done at RSRE and on search in cluttered backgrounds at BAe. In both cases eye movements can be monitored. A long-standing program in visual modelling based on neurophysiological premises is being carried out at British Aerospace, and is approaching the stage of being able to generate detection probabilities from pictorial inputs, although it is understandably expensive of computer time.

5. CONCLUSIONS

The defeat of visual surveillance by means of conventional camouflage techniques is still considered important, but most of the techniques have been established. An exception is disruptive pattern painting, which requires detail work. Protection against radar surveillance relies principally on diffusing nets, for stationary ground-based forces, and absorbing paints, which are being developed. Attention to radar signatures at the design stage would simplify the countersurveillance task. Protection against thermal imagers relies on two approaches: low surface emissivity and shields with low surface temperatures. The former approach appears suitable only where surface contamination is unlikely, although data for some kinds of contamination (such as dust) are so far unavailable. Difficulties can also be encountered with sky reflections. The low surface temperature approach, achieved by good thermal coupling to the air, is operationally more robust, since it does not rely on particular surface properties, but mechanical fragility is still a problem. In both approaches some kind of forced-air cooling may be required to cope with solar loading.

THE TIME IT TAKES TO SEE

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ABSTRACT

Although perception is experienced as immediate, considerable computation occurs on the input within our central nervous system. A distinction needs to be made between data-driven (bottom-up) and conceptually-driven (top-down) processes. These processes interact over time to determine our perception of people and objects. When the data are complex or incomplete the role of data-driven processes is lessened and conceptually-driven processing plays a greater role. Data-driven processes are relatively automatic, whereas conceptually-driven processes take more time to operate. Effective camouflage will weaken automatic processes and mislead conceptually-driven processes.

1. INTRODUCTION

Despite our experience of perception as an immediate process, it takes time to see. In pre-computer days the fact that one is not aware of taking time to see was taken as evidence against any occurrence of extensive computational processes. Common objects such as a chair are seen immediately and there is no consciousness of any inferential or computational process going on. We are not aware of our brain saying "chairs must have a place on which to rest one's posterior portion, usually have a back support and often legs: this object has those, therefore it is a chair". The problem of the lack of consciousness of a process which provides us with basic information is the sort of pseudo-problem that engages philosophers but has little practical relevance to our understanding of perception. Clearly perception does involve a considerable amount of processing over time. However it was thought that such inferential processes would be too slow to account for the speed with which pattern recognition occurs.

The advent of the modern computer has provided us with insights into how very complex processing can take place within microseconds, and milliseconds can seem quite a long time. While the visual system and central nervous system operates in the millisecond domain, there is nonetheless sufficient time for a lot of the computations which current pattern recognition models imply are necessary for object interpretation.

In this paper we will be reviewing some of the temporal parameters of the visual process from the perspective of an information processsing framework.

When considering the basic operations which underly object perception an important distinction needs to be made between data-driven (bottom-up) and conceptually-driven (top-down) processes. Data-driven processes are processes like contour detection, figure-ground segregation, etc., which apply relatively routinely to the properties of the stimulus registered on the retina of the eye. Conceptually-driven processes are concerned with wholistic properties of the object, inferences about the potential class of object and past experience with similar configurations. These processes interact over time to dertermine our perception of people and objects. When the data is complex or sparse the role of data-driven processes is lessened and conceptually-driven processes play a greater role. Data-driven processes are relatively automatic, whereas conceptually-driven processes take more time to operate. A goal of effective camouflage will be to weaken automatic processing and mislead conceptually-driven processes.

2. DATA-DRIVEN PROCESSING

Work in the neurophysiology of vision has given considerable insight into the early stages of visual information processing. Since the discovery by Hubel & Wiesel (1962) of neural cells responsive to specific features of the environment, models of human pattern recognition have emphasized the decomposition of the visual stimulus into feature properties which are processed in separate channels. Detection mechanisms respond to features and objects are encoded according to feature-lists. These lists are then compared to lists in memory to aid object recognition.

The processing of these features is considered to be a relatively automatic process and to occur in parallel with many features being processed at the same time. Early models stressed an hierarchical form whereby simple features are combined into more complex features at higher structural levels in the central nervous system.

One of the major difficulties with the feature approach to the visual system is that features need to be defined. The early neurophysiological work defined features almost by accident in terms of those properties, like bars and edges and movement, which triggered responses in nerve cells. More recently there has been an attempt to look at the visual system in terms of a system of filters. By thinking in terms of fourier analysis and spatial frequency it has been possible to classify cells in terms of their responsiveness to certain sine-wave frequencies and to represent stimuli in terms of their spatial frequency components (De Valois, 1982).

While there is a lively debate in the vision literature between those who adopt a feature approach and those who use a fourier approach (Albrecht, 1982) both approaches have in common a view of information processing involving decomposition of the retinal image by detector mechanisms which produce outputs which are integrated at some higher level in the system. Workers applying a fourier approach have been concerned with specifying some of the temporal aspects of the system. Low spatial frequencies have been considered optimal stimuli for the transient channels which register movement and change in the

environment. High spatial frequencies are considered optimal stimuli for the sustained channels whose function is to process fine detail information related to spatial location and position. Temporal modulation of sine-wave gratings of 1 cycle/degree has been detected by some subjects in our laboratory when the modulation involves only a couple of milliseconds in duration. Higher spatial frequencies of 10 cycle/degree or more have a higher threshold of the order of 60 to 100 msec.

The finding that under certain conditions the visual system can resolve very small temporal modulations of a stimulus indicates that some of the current ideas about visual persistence need to be qualified. Many people have considered that there is a lag of the order of 100 msec or so during which the visual system integrates information into a sensory store (Stanley, Howell & Smith, 1980). Our research (Smith, Howell & Stanley, 1982) implies that some detector processes do not have much lag whereas others are slower and allow integration. Different filtering or feature extraction processes have different temporal parameters. There are functional consequences of this in that we often "know" that something has moved before we "see" what it is. Movement information is encoded faster than form and detail information. The interpretation and identification of the object involves an interaction between the data-driven and conceptually driven processes and takes more time so that a duration of the order of 80-200 msec or longer may be required in some situations.

Temporal-spatial interaction is central to data-driven aspects of information processing. Under normal circumstances the eye is subjected to movement as a matter of course. There are small involuntary eye-movements which appear to play a role in maintaining an effective input to the higher levels of the visual system. If by optical means precise correction is made for every eye-movement then the resulting 'stablized image' fades and disappears after a few seconds. When there is no change of stimulation through eye-movments, the retinal image ceases to be an effective input to the central nervous system. There is some evidence that the fade-out of the retinal image is not an all or none affair but proceeds by a fragmentation of the features of the image (Pritchard, 1961).

3. CONCEPTUALLY-DRIVEN PROCESSES AND EYE-MOVEMENTS

Eye-movements are of course essential in the pick up of visual information. There is a large literature on eye-movements in a number of experimental and real-life situations (Monty & Senders, 1976; Senders, Fisher & Monty, 1978). The procedure adopted by research workers has often involved the presentation of a picture or object which is sufficiently large (say 20 deg of visual angle or more) so that it does not all fall on the foveal region of the retina in one fixation. Thus the viewer must move his eyes and inspect the pattern, fixating each section that he wishes to see clearly. When observers are given non-specific instruction such as 'just look at the picture' it is assumed that they look at those parts of the scene which carry most information, i.e. the distinctive features present. Noton and Stark (1971) found that eye-movements are related to the contours in the pictures which subjects are viewing. The sequences of fixations are called 'scan paths' and form broad sweeps from feature to feature, rather than random patterns. Subjects tended to have characteristic scan paths for a given picture and different scan paths for different pictures. For a given picture each subject

tended to have a different scan path. Typically a path lasted about three to five seconds and involved about 10 fixations. They usually occupied about 25-35 per cent of viewing time, the remaining time being taken up with less regular eye-movements.

Fixation patterns vary depending upon search instructions given to the observer, suggesting that the strategies governing these fixation patterns are to some extent conceptually-driven and under voluntary control (Gould, 1976). In the absence of a governing search strategy, an automatic process selects the successive fixation points (Shiffrin & Schneider, 1977). This automatic process may favour complex or "interesting" areas of the display rather than uniform areas. With training the fixation points may favour likely target positions rather than locations where experience has taught that targets are never located (Shiffrin & Schneider, 1977). Hence attention will be directed towards irregularities (such as bushes in an open field), and this tendency to focus upon likely areas may be improved by experience.

Fixation times in visual searches are typically in the order of 200-300 msec, with better trained searchers tending to make more frequent and shorter duration fixations (Gould, 1976). However, as the demands of the visual task increase by an increase in irrelevant input, the searcher responds by an effective narrowing of the functional fovea and by an increase in fixation time (to approximately 450 msec) in an attempt to cope with the increase in information available in a single fixation (Mackworth, 1976).

4. CONTROLLED SEARCH AND AUTOMATIC DETECTION

To provide a model which explains the empirical findings of visual search investigations, Shiffrin and Schneider (1977) have proposed a theory of information processing based upon two fundamental processing modes: controlled search, and automatic detection. Controlled search is highly demanding of attentional capacity, is usually serial in nature with a limited comparison rate, is easily established by the subject, and is strongly dependent on load.

Automatic detection refers to relatively well learned targets stored in long term memory, is demanding of attention only when a target is detected, is parallel in nature, is difficult to ignore or to suppress once learned, and is virtually unaffected by load. Automatic detection can be employed in the case of a search for any member of a well-learned category (for example, parts of a man or his infantry equipment). Studies have shown that automatic encoding of arbitrary collections of characters can develop after prolonged training. For a relatively demanding and unfamiliar task, around 1500 trials may be necessary to establish automatic detection (Shiffrin & Schneider, 1977). Evidence from field studies supports the need for experience in target detection. During the Vietnam conflict "a pilot's ability to detect camouflaged targets improved during the first four to ten weeks of operational experience ..." (Lintern, 1974, p3).

Treisman and Gelade (1980) have investigated the conditions under which either automatic detection or controlled serial search processes need to be invoked for the successful identification of a target. They proposed that a visual scene may be initially encoded as a set of features along a number of separable dimensions. The term dimension refers to a complete range of variation (such as colour, orientation, or shape), whilst feature refers to a

particular value on a dimension (khaki, upright, man-shaped). Perceptual dimensions do not necessarily correspond directly to distinct physical dimensions.

Focal attention integrates the separable features into unitary objects, and once they have been correctly registered the compound objects continue to be perceived and stored as such. Without focussed attention, features cannot be correctly related to each other and conjunctions of features can be formed on a random basis and in certain cases illusory conjunctions of features may be formed. Conceptually-driven or top-down processing can effectively occur when in a familiar context, and when focussed attention is prevented (for example by brief exposure or overloading). Under these circumstances likely objects can be predicted, and their presence can be checked by matching their disjunctive features with those in the display. In the highly redundant and familiar environments in which we normally operate, this should seldom lead us astray; however when the environment is less predictable or the task requires conjunction of features to be specified, we are ty pically less efficient.

The theory of feature integration states that individual features can be detected prior to the directing of attention upon the target. The correct identification and location of a target usually involves a conjunction of features relating to several dimensions: these operations are demanding of attentional capacity and their completion may follow the detection process by a finite time, especially in the case of identification where a cognitively difficult conjunction of a number of features is required.

5. SUMMARY

The time it takes to see depends upon a number of factors: the duration of automatic or data-driven processes, the extent to which performance is primarily dependent on such processes or whether conceptually-driven processes are involved. Automatic processes involve a number of distinct detector mechanisms operating in parallel. Some operate very rapidly in real time, others are much slower.

Focal attention is important in the process of integration of features. When attention is limited by overload or limited exposure of the visual field, then conceptually-driven processes play a greater role in object identification. Controlled processes are slower than automatic processes, involve serial comparisons, and are more under the influence of conceptually-driven processes.

Our second paper in this session will draw upon the issues raised here in the practical context of detection of camouflaged soldiers in field trials.

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COGNITIVE PROCESSES IN TARGET ACQUISITION

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ABSTRACT

The need for a better understanding of cognitive processes is highlighted. Results of field trials assessing target acquisition performance and observers' expectations as to the major target cues to acquisition are presented. The structural relations between target features are noted, and proposals for experimental quantification of the role such relations play in acquisition are outlined. The application of the results of such work to both perceptual recognition training and camouflage design is described.

1. INTRODUCTION

Arising from the work of the MRL Optics Research Group over the last decade have come two major current concerns associated with perceptual processes. These are:-

1. Establishing whether and how disruptive patterning operates;

2. Devising reliable and generalisable procedures for the laboratory assessment of field detectability by the aided or unaided human observer of military targets.

The first of these involves the development of an explicit theory of patterning and then testing that theory. Current practice in patterning lacks any formal statement of the principles guiding selection of either colours or pattern elements, though various principles have been implicit in some design work.

The second concern listed above will be discussed more fully by David Skinner [1]. There are, in fact, a great range of problems arising here - questions of the appropriate instructions for the use of instruments, of specification of the task for field observers, of appropriate methodology for field and laboratory trials, and of the nature of the perceptual task involved in using laboratory instruments for assessing detectability.

2. A COGNITIVE MODEL FOR TARGET ACQUISITION

These areas cannot be tackled without a thorough understanding of both the spontaneous (or passive) and reflective (or active) processes involved in human visual perception. Consider the representation of target acquisition shown in figure 1.
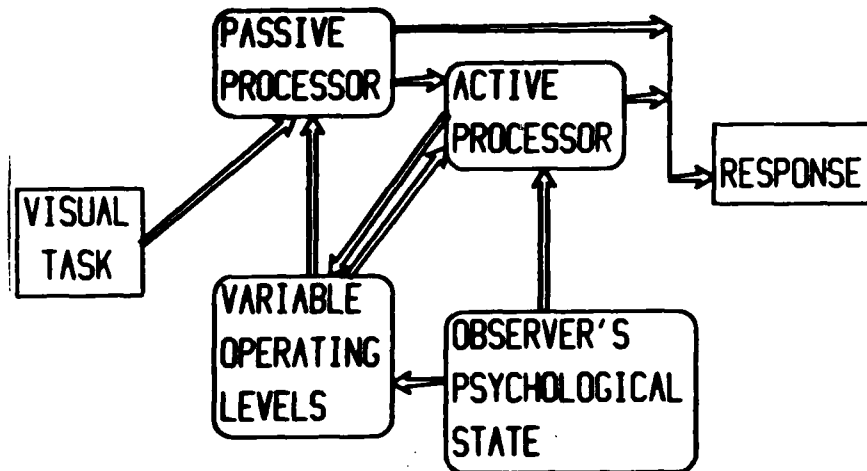

FIGURE 1. Cognitive components in visual target acquisition.

The PASSIVE PROCESSOR aspect is appropriate to operating on the Blackwell-type threshold data. Inclusion of the concept of ADJUSTABLE OPERATING LEVELS for the passive processor incorporates the signal detection theorists' approach. Concern for how the OBSERVER'S PSYCHOLOGICAL STATE influences operating levels is often indicated by visual modellers, but there is a dearth of quantifying data which can be related to signal detection theory. Psychological and human factors researchers have examined the effects of workload and stress on visual tasks associated with reading displays, but there has been little consideration of how these factors modify military surveillance performance. Finally, concern with the observer as an ACTIVE PROCESSOR - in the sense of piecing together a whole from some of its parts, or having fixation locations and/or durations partly dependent on previous information - has had virtually no attention from those involved in military surveillance. It is not that people have been unaware of the cognitive aspects - at a 1978 NATO Symposium on Visual Modelling, held in the United Kingdom [2], a number of speakers referred to the fact that human variability and adaptability was a factor unaccounted for in models, and this was highly likely to be one major reason for field studies not correlating well with model predictions. One example was that provided by John Sabey of Royal Signals and Radar Establishment* who found that subjects on thermal imager trials recognised vehicles from only a couple of ill-defined blobs on a screen. This recognition occurred because subjects were familiar with the target signatures and expected only a small range of target types. Such observations emphasise the need for us to pay attention to the active processes of target acquisition.

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* reference 2, p. 9-18; discussion notes.

Aware, then, of the likelihood that structural relationships are used to extend human performance in a way not predicted by current visual models; that there is a need for a better understanding of the principles underlying patterning as a form of camouflage; and that current training programs for visual recognition all appear to be premised on recognition of individual features and their spatial relationships, it seems most appropriate that we examine how - if at all - detection and recognition depend on the interaction of features.

3. FIELD STUDIES

As a first stage in this we carried out two field studies [3] which not only have provided useful information as studies of perception, but also gave myself and others invaluable experience in the possibilities and limitations of field experimentation. The purpose of the first study was to gather data on soldiers' prior expectations of the likely causes of detection of enemy M113 vehicles, and to relate these to subsequent reports of the actual causes of detection. This study was carried out in collaboration with Capt. Simon Webb of 1 Psych Unit, and, with the cooperation of 2 CAV Rgt., was "piggy-backed" on their reconnaissance exercise, "Flashing Sabre" in the Cobar region in April-May 1982. Due primarily to inadequate actual sightings during the exercise (~ 40% of the original estimate provided to us), information on actual sightings was too sparse for proper analysis. However a methodology for assessing expectations in the field was developed. It also became clear that the quality of data needed for answering the type of question we were asking could not reasonably be obtained under field exercise conditions.

Building on this experience a more structured investigation was carried out by Capt. Webb and myself at Holsworthy - again with the assistance of 1 Psych Unit and 2 CAV Rgt. personnel. This was an experiment involving a two-phase (detection, recognition) search for partially obscured military objects viewed from a fixed location over a 60° field-of-view. Comprehensive data on expectations of the likely causes of detection were gathered for each soldier, together with order of sighting and timing information on the detection phase, and timing and actual causes of recognition in the recognition phase. Analysis is directed towards determining whether the level of expectation and rigidity of expectation for a particular target feature affect detection or recognition performance in a systematic manner related to the availability of that feature. The expectations measure had a test-retest reliability check built into it and this check indicates that 12 of the subjects who provided a full set of search and expectations data operated at a useful level of reliability. Due to difficulties (now overcome) in decoding timing data recorded in the field the further analysis of results from this experiment has been delayed.

4. PROPOSAL FOR LABORATORY STUDIES

Experience with this field work, together with the comments of others who have been involved in field studies of perceptual performance, have highlighted the enormous difficulty of answering theory-based questions using field data. It therefore seemed appropriate that, for the immediate future, effort on understanding the role of cognitive processes in target acquisition

be based primarily on laboratory work using monochrome displayed images. This eliminates problems of stereoscopic vision and some depth cues, together with colour. The results should be directly applicable to much thermal and radar imagery, as well as displayed images from image intensifier devices.

An important result from fundamental studies on visual search tasks is that there are certain task types which are very rapid and increasing the number of possible targets has little effect on search time. These have been classified as automatic detection tasks[4]. Tasks become automatic only after vast amounts of practice, and it is then very difficult to change a subject's response pattern. Another type of task is one which is somewhat slower, easily modified, and almost linearly dependent on the number of possible targets. These have been classified as controlled search tasks. With extended practice, a task that is initially a controlled search task can move towards being an automatic task.

This distinction has potentially important implications for both design and assessment of camouflage, particularly for disruptive patterning. Suppose that what we commonly call detection has two stages - the first a low-level "knee-jerk" type response of the form "That might be something I'm looking for in/up/out there", and the second a subsequent focussed attention phase involving foveal and/or parafoveal fixation. Our assumption would be that the first stage involves a spontaneous, single-perceptual-feature detection process, while the second stage involves a constructive cognitive process. This is rather similar to the first stage being an automatic detection process with the second stage corresponding to a controlled search. The first stage would be characterised by a relatively low confidence level held by the observer in the reality of detection and a moderately high false alarm rate, whereas the second stage would be characterised by a high confidence level and very low false alarm rate.

To examine this distinction in the context of disruptive patterning we ask:-

"Does stimulus uncertainty differentially affect high and low false alarm rate detection?"

A procedure for answering this question would be as follows:-

1. Use a single target type, such as ☐ , embedded in a noise field (e.g. random dots, or arcs).

2. Have subjects search for the target in a briefly exposed scene under a single presentation, forced - choice procedure. Adjust exposure time to obtain two different false-alarm rates, (F-A.R.), for example:

    rate 1: 0.2 < F-A.R. < 0.4

    rate 2: 0.0 < F-A.R. < 0.05

3. Now use any one of a set of target types derived from the original target by eliminating parts of the features,

    e.g.

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Repeat (2) for this target set.

4.   Examine the exposure times needed under the different conditions to
        see if there is a significant interaction between target set and
        false-alarm rate class.

        Suppose there is a differential effect with stimulus uncertainty
such that the higher level detection (low false-alarm rate) shows a greater
dependence on stimulus uncertainty. Then this would strongly suggest that
disruptive patterning can only utilise low contrasts, and may be of only
marginal use. However, if exposure times in both cases are markedly increased
by uncertainty then patterning can be expected to be effective using contrasts
comparable to those involved in first stage detection. Obviously the type of
surveillance you wish to counter is a critical factor in designing
countermeasures, and a detailed knowledge of the processes by which detection
occurs should be used in such design.

        In closing, I would like to make a few comments to put this work in
context. I claim no great expertise in the field of perceptual psychology -
others here having considerably more knowledge and experience than I do.
However there is obviously a need to have people working on the human aspects
of visual perception within both the Armed Forces and the Defence Research
community. The underlying assumption in what I have presented here is that a
link has to be established from the vast academic body of knowledge on visual
perception to the various tasks of military surveillance and
countersurveillance. Such links must be forged both through absorbing the
available literature and by providing oneself with the necessary theoretical
and experimental links. The program outlined here is directed towards doing
just that.

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Detecting camouflaged targets - theory into practice

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ABSTRACT

This paper takes some of the predictions from Visual Information Processing
theory with regard to expected performance in the task of camouflage
detection. The dichotomy of serial processing/automatic detection is
discussed in the light of experimental results. It is concluded that
serial processes are usually required for the detection of a camouflaged
target. A corollary of this is the implication that a single 'critical
feature' probably does not exist for typical camouflaged targets. From
these experimental results, further issues are generated:

    a.   that the task of camouflage can be operationally defined as
the retardation of the detection processes;

    b.   that the experimental protocol of published camouflage
assessment trials should be re-evaluated in the light of the
present propositions;

    c.   that visual search instructions given to soldiers in the
field may be modified to take account of the time it takes
to see.

Our first paper in this session reviewed some aspects of visual information processing which may have application in the search/detection paradigm. The aim of the present paper is to apply these principles to the practical domain of camouflage assessment. The experiments described were designed to indicate whether the reviewed information processing models satisfactorily describe the task of camouflage detection.

Whilst the task of assessing military camouflage represents a practical area where psychological theories should be applicable, it has been cautioned that visual information processing models have several deficiencies with regard to these practical tasks. The models have mainly been based on the analysis of laboratory tests dealing with simpliefied or artificial targets and background scenes (Silbernagel, 1982). Although factors such as colour and texture effects with embedded figures have been studied in the laboratory (e.g. Bloomfield 1979) and these factors are clearly important in camouflage detection rates, the magnitude of the step from laboratory to field should not be underestimated:

> "...how to confidently extrapolate functions derived from simple stimulus situations to the processing of an object in the context of a real-world scene is not known" (Biederman, Mezzanotte, Rabinowitz, Francolini and Plude, 1981, p.154).

The difficulty of applying psychophysical models to the practical domain must lead to the inference that there is a real danger of undefined or poorly understood variables confounding the results of any camouflage detection trials. Despite the absence of a sound model relating to observer performance in camouflage detection, the process of assessing camouflage from measures of observer performance continues. Recent studies have described various methods for comparing the effectiveness of camouflage patterns. A summary of the important attributes of these trials is given in Table 1. Inspection of this Table indicates that a relatively large field of view (from 35 deg to 90 deg) is a common feature.

Although these reports share an absence of a conceptual bridge linking either the experimental protocol or the results with contemporary models of visual information processing, the use of wide visual angles implies that the experiments were designed in the belief that the search/detection process can proceed with a rapid rejection of non-target regions. Bailey (1972) has proposed a model of the search process which is based primarily upon mathematical considerations. He proposed that a single "glimpse" period of 1/3 second can provide sufficient information to allow a negative decision to be made with respect to each "glimpse aperature", or foveal field. However, the literature and the present study support neither the notion of single glimpse rejection nor single glimpse detection.

Table 1

Methodology of recent camouflage detection trials

Reference	Viewing time (s)	Visual Angle (degrees)	Observer/target distance (m)
Alderson & Overton (1972)	600	large	0 to 520
Bloomfield, Graf & Graffunder (1975)	90	34	.33 (slides)
Freeman, Jenkins & McNeil (1980)	15	90 (4 sectors)	50
Lintern (1974)	10	90 (3 sectors)	12 to 57
Whitehouse (1982)	25	40 (4 sectors)	slides
Smith, Skinner & Jenkins (1973)	30	55 (6 sectors)	50
Wynne (1972)	600	large	0 to 520
Bruzga (1980)	A "free format" experiment with observer moving slowly towards designated target area. Dependent variable was detection distance.		
Greef & Smith (1973)	Comparison of two uniforms under conditions where "both jackets were visible, but not too conspicuously", with results indicating that one item was "rather less conspicuous" than the other.		

In an early analysis of eye movements and fixation patterns, using a 40 by 40 deg. field, Williams (1966) had indicated that targets are not recognised at a single glimpse. He introduced the concept of "target conspicuity" to explain his data. Conspicuity was operationally defined in terms of the number of times the target was looked at before detection. The Williams data could be interpreted as an antecedant of the notion that the detectability is related to cognitive load.

The proposition that processing time may be required for the detection of hidden targets has been more recenlty illustrated by Nodine (1978). Nodine's study monitored eye movements in a search of a 24 by 24 deg. field. The target, a word concealed in a line drawing, could be classed as an example of a camouflaged target. Although only 1/3 of the targets were detected in his experiment, it was reported:

> "the major reason for failure ... was not inadequate sampling of the target areas. Of the 35 targets that were missed, 31 were sampled. Thus getting the eye on the target did not guarantee detection" (Nodine, 1978, p.275).

Nodine's results indicated that if the target was viewed for approximately 1s, then the probability of detection was 86%. However his overall hit rate was only 30%. This demonstrates the confounding effect of a large complex field on relatively easy targets. We would assert that the overall level of difficulty of the Nodine task was not primarily due to the camouflage effectiveness, but due to the high cognitive load involved in rejecting non-target areas.

In short, our proposition is that both theoretical models and practical results can be interpreted as indicating that relatively long viewing times may be required for the cognitive operations involved in detecting a camouflaged target. It should be recalled, however, that the occurrence of short latency "automatic" target detection has also been proposed (see Stanley and King). Automatic detection can be employed in the case of a search for a member of a well-learned category. it could be argued that for human targets, the array of possible target elements (parts of the human body) should qualify as members of a well learned category, particularly for military observers.

However the process of camouflage has been conceived as interrupting the normal perceptual processing of targets: "The purpose of employing camouflage is to degrade a potential target's signature, so as to deny an enemy observer detection or acquisition information." (Braaten, 1980, p.15). The implication of this is that automatic processing is prevented by camouflage. The Shiffrin and Schneider model allows for this disruption of automatic processing, even for well-learned targets, for the special case of "threshold" targets (Shiffrin and Schneider, 1977, p.168). On trials with threshold targets serial comparison processes are invoked.

In summary, the review of visual information processing theory and a consideration of some experimental results have led to the conclusion detection/rejection processes may involve high cognitive load, and that significant processing time will be required for each foveal field. On the other hand, typical camouflage assessment trials are implicitly based upon the assumption of rapid detection/rejection decisions for each fixation point. The point has been made that the link between theories based upon laboratory experiments and "real-world" stimuli is tenuous. The experimental work described in this paper was therefore aimed at making an initial link between visual processing theory, and the practical issue of camouflage assessment.

EXPERIMENT 1: THE TIME IT TAKES TO SEE

The aim of this experiment was to use "real-world" stimuli in a controlled experiment to determine whether camouflaged targets, were primarily detected by automatic processes, or alternatively whether relatively long latency high cognitive load processing was required.

METHOD

Subjects

Subjects were 42 civilians between the ages of 25 and 40 years who were on a government sponsored ski holiday; plus a group of 32 army officers and enlisted men who were employed in clerical duties in a city environment.

Apparatus

Colour slides were rear-projected on a screen to form a display of 9 by 14 deg. when viewed at 120 cm. The equipment automatically presented each slide of 2 s, followed by a pause of 1 s. Reaction time (RT) was recorded using a timer activiated by the onset of each slide.

Stimuli

A set of 80 stimulus slides was selected from a large bank of slides of men in Australian Army uniforms, with or without camouflage paint on the exposed skin. The selected group of slides provided a wide range of detectability; some contained large targets in the foreground, some targets were concealed among bushes, whilst others contained no target at all.

Procedure

Subjects were instructed to press the "YES" key if they detected a target, and to press the "NO" key otherwise. After 10 practice slides, the 80 slides were shown. The centres of the targets were distributed over an area defined by a mean radius of 1.2 deg., standard deviation 1.1 deg from the centre. The observer could respond up until the onset of the next slide. In the absence of any response, default scores of "NO" and RT of 3.1s were recorded.

RESULTS

In laboratory experiments using letters and shapes it has been reported that longer RTs occur for items of greater task load. For the present study the task load was operationally defined in terms of the average probability of detection based on one group of subjects, the 42 civilians. The distribution of task load is shown in Table 2. The value for task load is from zero (low load, target seen by all observers) to 1 (high load, target seen by no observers). The special category of very low load items was chosen to have a disproportionate number of cases because of the importance of this group to the concept of automatic processing.

Table 2

Frequency distribution of task load

Task Load	Frequency
(low) < 0.05	24
0.05 to 0.3	15
0.3 to 0.7	18
> 0.7	23

The false alarm rate was 5%, which is in line with the results of similar studies (Teichner and Mocharnuk, 1979).

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Comparison of Civilian and Army results.

The results for the two groups, civilian and army, were quite similar. This is indicated by the correlation coefficient for average RT for each item, based on the two groups ($r = 0.97$), and a similar correlation for average load for each item ($r = 0.97$).

Reaction Time and Task Load.

The relationship between task load and RT for "NO" responses for all subjects is shown in Figure 1. These data indicated that RT was unaffected by task load and was high for all negative responses. In contrast, task load has a systematic linear effect on RT for "YES" responses ($r = 0.95$) as shown in Figure 2.

DISCUSSION

The experiment under consideration was designed to establish whether or not observer performance with real-world stimuli could be related to visual information processing models. In order to maintain control over environmental variables, the stimuli were photographic slides, however the field-relevance of photographic slides has been accepted by other investigators (Whitehouse, 1982).

Visual information processing theory proposes that automatic detection can occur under certain conditons. However the present results do not support the concept of automatic detection in a valid camouflage detection task. There is a consistent increase in RT with task load for YES responses, and this range of RT is not compatible with automatic detection.' Only for items of trivial difficulty where the target was detected by all subjects did the RTs approach 0.5 s, the expected latency for automatic detection. The results support the explanation that the RT/load relationship was due to feature-integration processing.

The plot of RT with load for NO responses (Figure 1) shows that there is a relatively constant average RT of approximately 2.3 s for NO responses. This indicates that there is no easy way to reach a NO conclusion. To reject a region as a target candidate is always associated with a high demand upon attentional capacity in this type of task.

The present study has shown that with a relatively small angle complex field, detection times can approach 3 s for difficult targets, and rejectin times are always greater than 2 s. The inference from these results is that large aperature displays in camouflage detection trials, whilst adding realism to the trial in terms of face validity, may add to the unexplained variance. Time and mental processing effort will be spent in a large display trial while the observer is looking at the non-target regions. The relevant aspects of the camouflaged object are only under test when the observer is looking at the target region.

EXPERIENCE 2: GLIMPSE APERATURE IN PRACTICE

The previous experiment led to the conclusion that "large" display fields are incompatible with the serial processing model of camouflage detection. This finding raised the question of a definition of the functional foveal field, or "glimpse aperature". The literature relating to foveal field indicates that an interaction with task complexity and with time can occur, and although essentially foveal processing is possible up to 10 deg, peripheral information may be suppresssed in viewing a complex field (e.g. Taylor, 1983; Mackworth, 1965). An experiment was designed to aid in the definition of functional foveal field in the present type of task.

METHOD

Subjects

The subjects were 20 university students, aged 18 to 25 years.

Apparatus

The slide projection equipment described in Experiment 1 together with 30 slides selected to cover the range from relatively easy to relatively difficult. Eye movements were monitored using a twin track (vertical and horizontal) chart recorder connected to eye movement monitoring equipment.

RESULTS

In order to consider eye movement scanning during the search task, only slide/subject combinations with a RT of 2s or greater were used. For the 30 slides and 20 subjects, there were 391 items with latencies greater than 2s. Of these, 63 were associated with a positive response and 328 resulted in a NO decision.

The total range of horizontal eye movement was measured for all 391 items. The values fo YES responses were: mean 6.0 deg, s.d. 2.87 deg. The scanning of NO responses was slightly larger: mean 7.38m, s.d. 2.47.

DISCUSSION

The results obtained can be interpreted as giving an initial estimate of the functional fovea on this type of task. Particularly in the cases of negative responses, it is reasonable to assume that the observer was giving consideration to the entire field width of 14 deg. Thus the diameter of the funcitonal fovea is given by:

$$FOVEA = TOTAL FIELD - SCAN$$

Since the scan diameter is approximately 7 deg, functional fovea is also 7 deg diameter.

This value is compatible with other reports. For example, Nodine (1978) reported a mean eye movement to target of about 5 deg, indicating that the functional foveal diameter was approximately 10 deg. Nodine's stimuli were line drawings, whilst in the present experiment it might be argued that real-world photographs were more complex than Nodine's stimuli. A reduction in functional foveal field would therefore be compatible with Mackworth's (1965) predictions.

Whilst further verification of the inferences relating to foveal field in camouflage detection tasks is clearly required, the present results may be taken as a working hypothesis for use in the design of future camouflage assessment trials.

GENERAL DISCUSSION

Our study has been aimed at interpreting camouflage search/detection tasks in terms of visual information processing theory. The results are in line with theoretical propositions, and are compatible with other practical studies which have been published. With regard to the design of future camouflage detection experiments, we would suggest that a trial with a display field width of 90 deg, combined with a viewing time of 10 s places an unnecessarily high demand on the observer (e.g. Lintern, 1974). The consequences predicted for such an experiment would be low reliability, and spuriously high estimates of camouflage efficacy.

Since there is little evidence from the eye movement literature that individuals conduct a truly systematic search of a large field, and given the evidence that brief fixations of the target do not result in detection even for relatively low load targets, a large field experiment which returns high detection probabilities must be interpreted as relating to only the most obvious targets: targets which can be detected by automatic processes.

INSTRUCTIONS FOR SOLDIERS

Training in visual surveillance tends to assume that an instantaneous decison, particularly a negative decision, can be reached for a candidate target areas in a single, rapid glimpse. Visual information processing theory and a range of empirical evidence suggests otherwise. A brief glimpse of the target area in a large field does not necessarily lead the searcher to return his attention to that area for the period of time necessary for target detection. Training procedures should include an emphasis that vision in this context is a slow process. Search instructions could, for example, suggest a single rapid pass of the area to allow for automatic detection of easy targets. This should followed by a 3 s consideration of the area in 7 deg steps.

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FIGURE 1

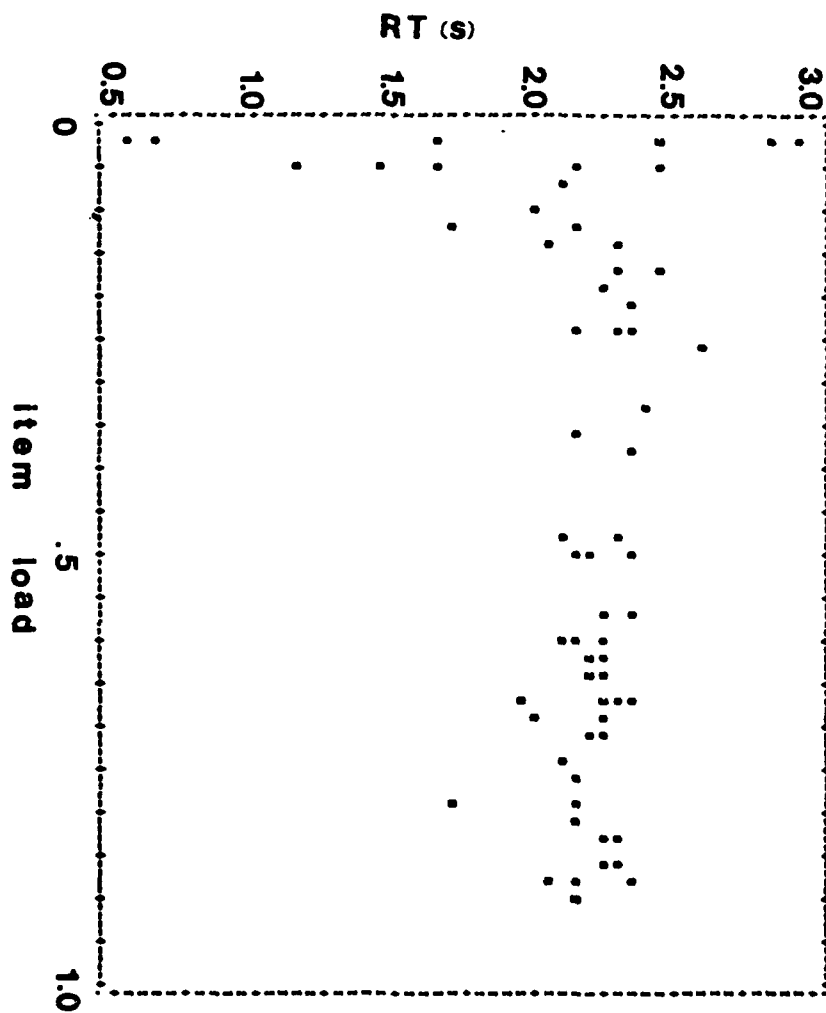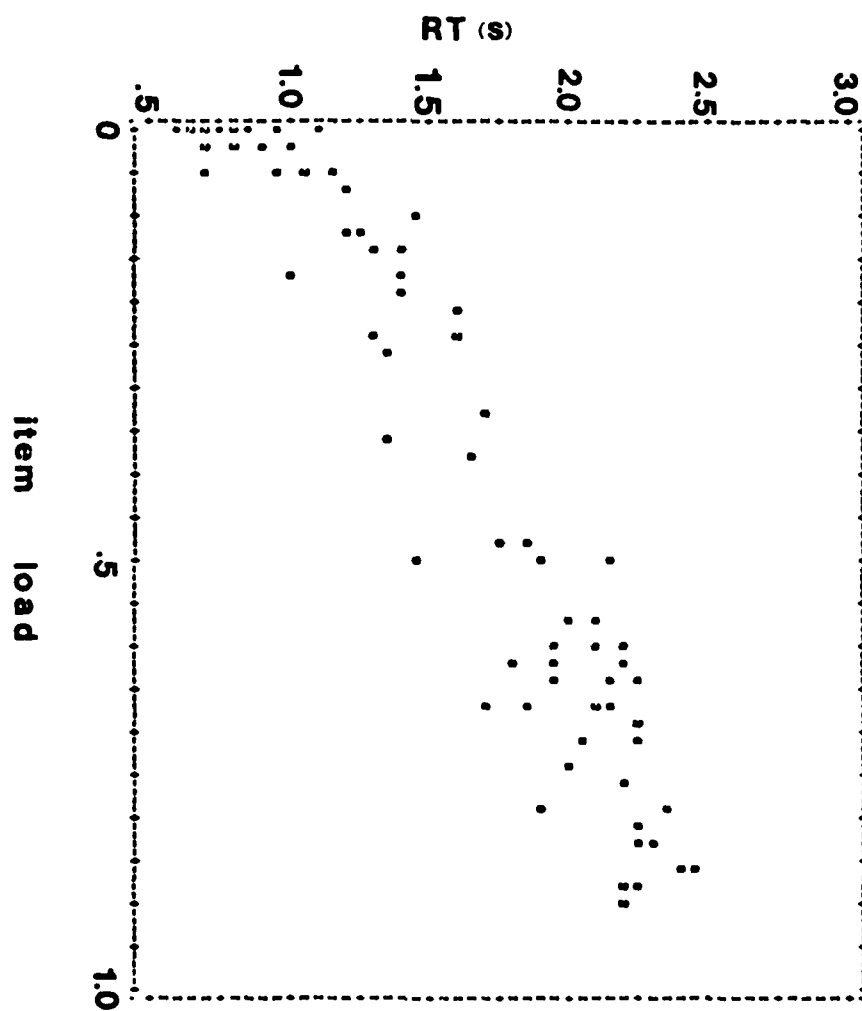Mean RT for NO Responses with Mean Item Load.

FIGURE 2

Mean RT for YES Responses with Mean Item Load.

THE ROLE OF 1ST PSYCHOLOGY UNIT
IN THE CONDUCT OF FIELD RESEARCH

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ABSTRACT

It has been well established in the human factors literature
that the behavioural scientist has a substantial contribution to make
in the conception, design and development of physical equipment.
While this provides a wider context for this paper, its focus is more
down-to-earth.   While re-emphasising this contribution it speaks more
on the role that one particular psychology unit can play in the
development and implementation of field research.

It discusses the facilities available for consultation and
implementation as well as the organisational implication of the role
of the unit.   The paper concludes by describing some of the pitfalls
likely to be encountered when conducting field research in a military
environment.

1.   INTRODUCTION

The background to 1st Psychology Units presence at the
Countersurveillance Symposium is contained in the correspondence on
Army Research Request 1153/81 "Psychology of Detection."   A brief
summary of that correspondence is that it brought to the notice of
sections of the Defence scientific community the existence of a military
unit staffed with professionals who could conduct and comment upon
scientific research.   On our part it became another opportunity to
continue to develop what was becoming an operational research facility
concerned with the practice rather than the policy of operational
research, i.e. we are concerned with the efficiency and effectiveness
of the Army in any potential land battle.

Consequent to the above, a relationship fostered by the
Directorate of Operational Requirements and the Staff Officer (Science)
of Headquarters Field Force Command (HQ FF Comd) was established with
MRL to develop and conduct a series of investigations which came under
the general headings of "Psychology of Detection" and "Disruptive
Pattern Painting."   In the first instance these investigations were
limited to the construction of survey questionnaires and interviews as
an "add on" to an exercise already planned and in the process of being
conducted: this was the reconnaissance/cavalry exercise "Flashing Sabre"
carried out at Cobar in N.S.W.   The information gained provided input
into controlled field experiments using troopers drawn from the same
cavalry unit.   These were also of an exploratory nature which sought to
determine the strategies used by the troopers to detect and identify
camouflaged objects.

Research into the two areas listed above is ongoing and
1st Psychology Unit will be playing a continuing role in the development
of suitable methodologies for laboratory and field research.

2. AIM

The aim of presenting this paper today is to encourage you to
consider the impact and interface of the behavioural dimension in research
conducted in the physical sciences.   This dimension includes ergonomic
or human factor variables, information processing and signal detection
variables as well as those more difficult to quantify; i.e. personality
and attitudinal variables.

Another reason is to provide information on the way in which
psychological input can be provided for the determination and subsequent
analysis of the human component; and pragmatic input on the implementation
of research designs (although I note that one Oxford Dictionary meaning of
pragmatic is meddlesome).

At a lower level our role could be viewed as a linking function
between the development of a research design; and the obtaining of subjects
and locations to implement it.   At a more important level we are able,
as it were, "to walk with the scientist and talk to the military."   By
this I mean that our military role, experience and links, both formal and
informal, are valuable for the facilitation of field research.

3. ORGANISATION AND ROLE OF THE UNIT

1st Psychology Unit is a Direct Command FF Comd Unit which means
that its superior is the General Officer Commanding (GOC) FF Comd.   In
practice he exercises his command through his Staff Officers, in particular
the Concepts Section of Development Branch of Headquarters FF Comd.
Within the unit, tasking is done by the Officer Commanding.   The staff
available consists of two Regular Army psychologists, three Army Reserve
psychologists and an attachment of a New Zealand Defence Force psychologist
for a two month period. (Figure 1)

Because of its direct command status, the unit can liaise, after
minimum formality, with other FF Comd units in the Australian Army.   With
the approval of Headquarters   Training Command it can liaise directly
with Army Training Schools.   This approval is, in general, readily given.

In summary, the unit has relatively easy access to the users, and the
trainers of users, of equipments being developed.   Its role therefore makes
it ideally suited to act in an interface relationship between scientist and
ultimate user of the scientist's product.

Of the five tasks in the stated role of the unit,(Figure 2) the
one most important currently is development and assistance in operational
research projects.   However, our size and nature make us best suited to
relatively short term (up to twelve months) action oriented research.   In
this context we can be best utilized in consultant, experimental design
and data collection roles.   Let me now describe the contribution we can
make from both a psychologists and a military unit point of view.

4. A PSYCHOLOGISTS CONTRIBUTION

The ways in which a psychologist may contribute from his professional background may be described as follows:

a. An understanding, through usage, of scientific enquiry including the use of scientific method and statistical analysis; with training based on the scientist-practitioner model (Perry, 1979). By this I refer to training which emphasises the equal importance of, firstly, experimentation which is valid, able to be replicated and which produces robust results; and secondly, the interaction between the scientist and the client who facilitates such experimentation. It is the kind of training which helps a client focus upon the specific problems to be solved, the behaviours desired (for example, of equipment operators), the information required for decision making, and negotiates a compromise between what is desired and what is feasible in a language understandable to the client;

b. Provide help by defining an appropriate research strategy given the task to be undertaken. Flanagan and Dipboye (1981, p.41) list four such strategies which are as follows:

   (1) <u>Theory Based</u>. Studies that make explicit tests of a specific theory or use a theory to derive hypotheses. We may want to think of this as concept driven research.

   (2) <u>Hypothesis Stated</u>. Studies which state a priori predictions; and these may be exploratory investigations such as those conducted for the Psychology of Detection.

   (3) <u>Active Intervention</u>. These are action research studies structured in, usually, four stages. The first consists of collaborative effort between client and researcher in diagnosing and defining what is required. Secondly, heavy emphasis is placed on data gathering and preliminary diagnosis prior to action planning and implementation. Third, there is careful evaluation of results before action is taken, and finally, feedback to the client after such action is taken on data gathered to assess the effects of action.

   (4) <u>Implications for Application</u>. Studies where serendipitious results from research findings might be used to solve practical problems. As an opposite to concept driven research we may wish to think of this as data driven research.

c. A third contribution may be in an analysis of the trade-off between technology and human capacity. This is what Goclowski (1978, p.21) describes as human resources in design trade-offs. This is "an approach utilizing design option - decision trees for identifying major design decision points so that trade-off studies may be influenced through consideration of the human resource impact."

In the main these trade-offs have been, and are, determined by cost. A decision may be that it is currently easier and cheaper to train a human being to perform some function than it is to develop a technical system to replace the fallible human element. An example might be the introduction of robotics into the major car assembly industry. The suggestion being made is that there are decision points in technological development, including the initial conceptual phase, where the choice of a future direction to take can be enriched by an understanding of the human resource impact.

An example of how these ideas can be applied is given by Eason (1980) in a paper entitled "Dialogue Design Implication of Task Allocation Between Man and Computer." In it he emphasises mans adaptability in open ended situations and superior ability in resolving ambiguity and uncertainty. A way of describing the relationship is to liken it to one of human - technological symbiosis. In it each element contributes those characteristics it is best suited for; with the result being a totally efficient system. This used to be called human factor engineering.

Without going into too much detail it is worth indicating some developments in the human factors field which may be applicable. One is the area of fatigue or mental overload, another is the reliability of human performance. Moray (1982) recently reviewed studies conducted on subjective mental overload with the aim of establishing the point at which an operators performance deteriorates to an unacceptable level. He suggests further research into self reporting of mental overload, the way in which task instructions create the perception of the performance required, rate of information processing and the complex interaction of these variables. Related to Moray's work is that of Adams (1982) on human reliability. He sees a danger in thinking about human reliability in the same terms as machine reliability. Among a number of reasons is the difficulty of defining what could be units of human performance; particularly when intangibles such as expectancy of outcome and operator motivation are taken into account. A suggested method of measurement is probability estimates of error based on factors such as stress, fatigue, number of sub-tasks to be performed and individual differences.

There is an awareness amongst the military that "the new technology is bound to affect greatly the individual soldier, and thorough study is (thus) called for of the problems of human endurance, and generally of the psychological and physical restrictions imposed by the modern battlefield which will be so very different from that of the past." (Rasiulis,A. 1981, p.27) This awareness needs to be translated into a terminology which embraces the operational environment of the soldier and the technical environment of the scientist.

The purpose in briefly describing these studies is to emphasise the point that behavioural considerations, or human factors, must be constantly evaluated and integrated with ongoing technological development. It would be pertinent to suggest that they must be considered at the conceptual planning phase and at progressive decision points throughout equipment development.

At this point it is worthwhile summarizing what it is that can be offered from a psychologists background. It is the following:

    a. An approach to problem solving and problem identification which speaks the same language of scientific enquiry as that of the physical scientist;

b. A choice of research strategies based on our knowledge and understanding of the environment where the equipments under development are to be tested, and ultimately used; and

c. An orientation towards the human element in equipment design and operation which will complement that of the physical scientist.

5. A MILITARY CONTRIBUTION

Let me now move from the world of the ideal to the world of the real and present to you some of the down-to-earth considerations of implementing research within the military environment. This will be considered under the following headings; Funding, Tribalism, and the Conduct of Research.

FUNDING: As we all realize, those drawstrings on the bag of gold made available to us are drawn so tight that we are usually unable to conduct the research as we would like; or given the minimum required to ensure the validity of our results and outcomes. One way out of this is to draw upon available service facilities such as exercises already proposed and/or planned. A large number are conducted each year and the list is promulgated by HQ Field Force Command. A majority of these would be unsuitable as a "test bed" for research but others may provide the necessary environment and facilities. The suggestion therefore is that any anticipated research may "ride on the coat-tails" of a proposed exercise. Of course, all necessary approvals would need to be obtained as well as an assurance that such field research would not interfere with the training objectives of the exercise. However, it is an option available which is cost-effective and efficient if given forethought and planning. Obviously the greater the lead time the more likely it would be that the research could be written into the exercise directive, as an integral part of it.

TRIBALISM: This may be an unusual heading but it sums up the clannishness and parochialisms within the Army. Its net effect is that outsiders are treated with suspicion and scientists are regarded as boffins with their heads in the clouds. I would not argue that psychologists fare a great deal better but the fact that we are military officers and NCOs gives us acceptance and face validity. To gain that acceptance and facilitate research, scientists need to be aware of the military ethic, the importance of rank, the distinction between the fighting arms and services, the fear that commanders have of data collection and its implications of assessment of what they do and the general attitude towards "outsiders."

It would be wrong to say that we could provide all the answers and ensure a smooth passage for scientific research. What can be done is that we can give an indication of likely pit-falls and a knowledge, based on experience, of the most appropriate channels of command and communication to facilitate research.

CONDUCT OF THE RESEARCH: It is in the conduct of the research that we can provide help and advice which may mean the difference between success through co-operation by the participants, or failure because of the lack of that necessary co-operation. Perhaps the key element in field research is control; control in terms of ensuring the right subjects turn up to the right locations at the right time, that data collectors are organised and clearly instructed in what they have to do, and that participants are briefed in sufficient detail so that they know what they have to do, but not so much detail that they are overwhelmed.
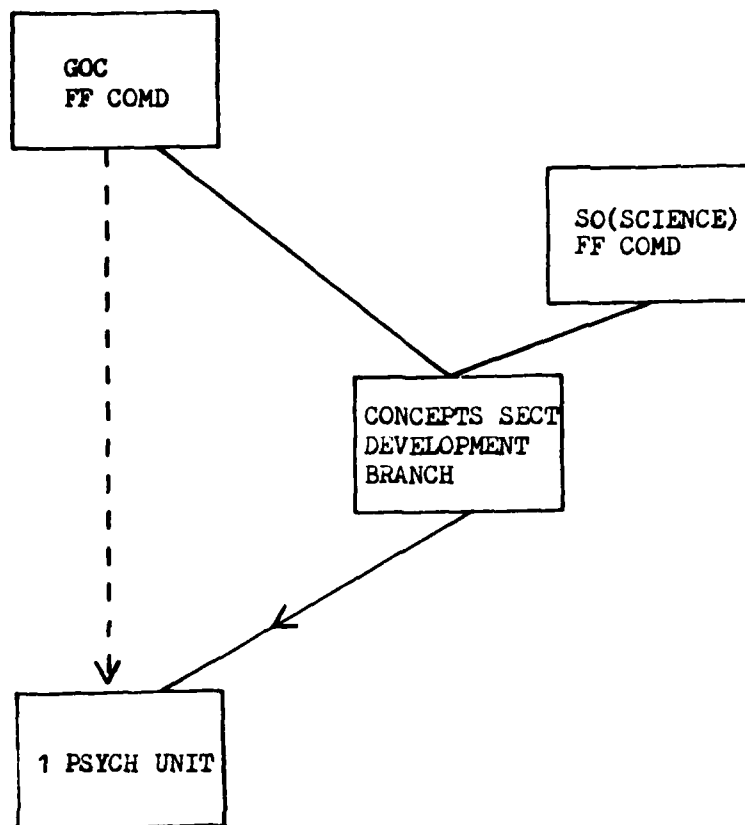
Control measures can be built into the research procedure at its conception or developed "on the ground." A balance between the two is recommended since that which is intended by the researcher may not always be acceptable to the commander of the facilities being used. This may be the case for a number of reasons such as: compromise of the exercise aim, of its tactical integrity and perhaps fear by the commander of unfavourable assessment because his troops are being measured or assessed. Therefore, a series of contingency plans is the most efficient method of planning research, always keeping in mind that these plans may go awry; and which invariably happens.

Balanced against the need for control in field research, is the wealth of naturalistic data (both quantitative and qualitative wealth) that comes from the participants. Since these will be the operators of the equipment being developed their views and experience are invaluable in determining the conditions under which that equipment will be used. Their attitudes will, in part, determine how well it is employed to make the most of its full potential.

6. SUMMARY

This paper has been presented with two major objectives in mind. The first is to convince you of the requirement, both initially and on a continuing basis, to determine the nature of the human interaction with the equipments you develop. The second is, to convince you that a facility exists which is bipartisan in nature and capable of establishing collaborative effort between the scientist and the military.

ORGANIZATION FOR TASKING

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│   FF COMD   │
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        ┊   ╲              ┌─────────────┐
        ┊    ╲             │ SO(SCIENCE) │
        ┊     ╲            │   FF COMD   │
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┌─────────────┐
│ 1 PSYCH UNIT│
└─────────────┘
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MANNING

ARA	ARES	ATTACHED
MAJ – PSYCHOLOGIST	MAJ – PSYCHOLOGIST	FROM NZDF
CAPT – PSYCHOLOGIST	CAPT x 2 PSYCH	CAPT(EQUIV) PSYCH
WO1		
SGT		
CPL		
PTE		

FIGURE 1.   TASKING AND MANNING OF 1 PSYCH UNIT

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The stated role of 1 Psychology Unit is to:

a. Advise the commander and staff on psychological aspects
    of personnel administration;

b. Assist in the prevention and management of mental ill-health,
    including advice on rehabilitation and consequent employment;

c. Advise in the selection of personnel for special tasks,
    postings, or training;

d. Assist in the identification and selection of potential
    in-service officers; and

e. Assist in operational research projects.

FIGURE 2.   STATED ROLE OF 1 PSYCHOLOGY UNIT

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DEVELOPMENT OF TEXTURE DESCRIPTIONS FOR IMAGES

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ABSTRACT

The functioning of visual disruptors is clarified, and the
need for quantification of texture detailed. A procedure is
described which will allow determination of the dimensions
of perceived texture similarity. An approach to determining
optimal mathematical descriptors of perceived texture
similarity is described, and applications of such a
mathematical description are briefly outlined.

1. INTRODUCTION

Recent developments in the practice of camouflage have seen the
widespread use of patterning on military objects. The development of these
patterns has been based - at best - on empirical testing of a small number of
patterns developed on the basis of hunches as to how patterning might
operate. The results of this approach have sometimes eventually produced what
appear to be quite promising forms of camouflage, though quantitative
evaluations have not always been very convincing. One of the major
difficulties in the design of appropriate patterns has been that of knowing
what shapes and sizes of pattern elements provide a human perceptual match
with terrain background. In this paper a brief discussion of patterning is
presented, and a methodology for quantifying the spatial characteristics of
natural scenes is outlined.

2. VISUAL TEXTURE AND DISRUPTIVE PATTERNING

By visual texture is meant those spatial variations in colour
(brightness, hue and saturation) giving a perceived regional uniformity but
with the colour variations being resolvable or nearly so. Figure 1 shows two
main foliage textures - the tree foliage, and the foreground grass.

Figure 1.   Examples of foliage textures - tree, and grass.

Obviously an extended region of these trees viewed from a kilometre or so distance would present a rather different texture.

As described in an earlier paper [1] disruptive patterning is assumed to operate in two ways. These are by providing colour variations within the target perimeter which

1.   are colorimetrically and spatially consistent with target backgrounds.

2.   reduce detectability of known visual cues.

The first of these is most relevant to variable shape targets such as uniforms and nets, while the second applies to fixed shape targets such as aircraft, ships, and vehicles. Consideration of this second aspect of patterning was given in the earlier paper.

In order to examine and use patterning systematically so as to obtain visual texture matching it is necessary to quantify textures in terms consistent with the judgements people make of texture similarity. Such quantification would aid systematic camouflage design, provide a communication or specification tool for science and engineering, and would enhance the feasibility of target enhancement through foliage texture subtraction.

The method proposed here for quantification uses judgements
regarding texture similarity to provide a matrix of measures of perceived
texture similarity for a set of textures. Using multidimensional scaling of
these measures will then allow the determination of the number and nature of
the perceptual dimensions underlying such judgements. Mathematical
descriptors will then be developed such that each element of a set of
descriptors correlates strongly and uniquely with each perceptual dimension
determined. Figure 2 represents this process schematically.
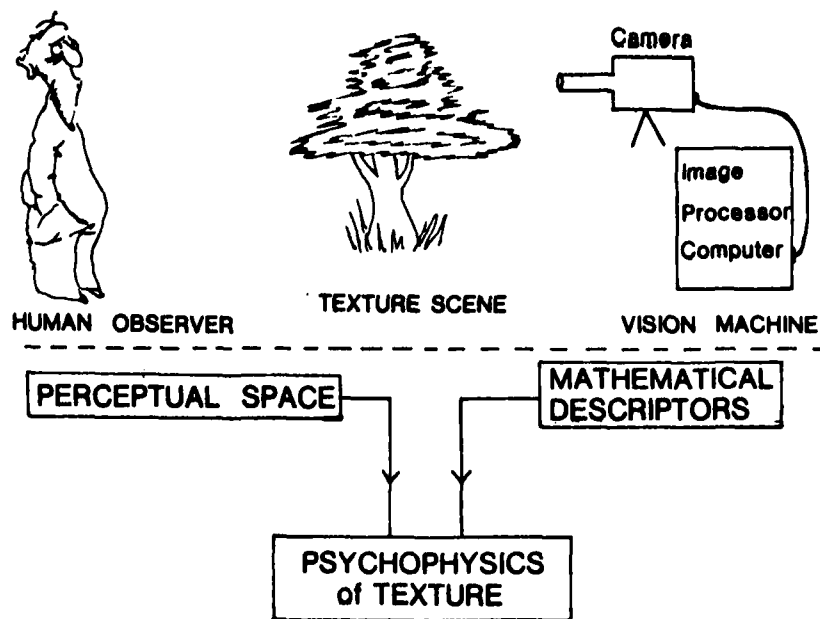
Figure 2.   The process of quantifying visual texture.

3.   MEASUREMENT OF PERCEIVED TEXTURE SIMILARITY

A set of N texture samples, covering the range of textures of
interest is selected. A measure of judged proximity for these measures on a
pairwise basis is required. Subjects will be shown three textures side-by-
side, with the left and right hand textures being judged for degree of
similarity to the central texture. Each texture will be placed in the centre
and all possible pairs of textures will be compared to the central texture,
with each texture in a pair being presented on both left and right hand
sides. This requires N^3 comparisons. Subjects will judge which of the outer
two textures is more similar to the central one. From these comparisons a
matrix of judged similarities can be derived.

Determination of the dimensions of space needed adequately to represent the set of textures as points with the obtained interpoint distance is carried out using multidimensional scaling. This technique was used by Wright [2] in a study of chroma similarity judgements and the results were consistent with there being two dimensions appropriately labelled hue and saturation. It has also been used by Harvey and Gervais [3] in their study of one dimensional fourier synthetic textures which indicated three dimensions underlying similarity judgements. The technique has also been used in studies of sound perception as well as in sociological studies. It therefore seems an appropriate procedure for determining the dimensions underlying judged similarity of natural textures.

The procedure outlined in the preceding paragraphs is proposed as a means for producing a methodology for the spatial characterisation of Australian visual and infrared backgrounds. Current work is oriented towards ground-based observation of natural foliage, and the use of black-and-white photographic negatives as the primary data source.

4. MATHEMATICAL DESCRIPTORS OF TEXTURE SIMILARITY

Suppose a segment of "uniform" texture is digitised and the discrete 2-d fourier transform found. This gives a set of values, (F_{ij}, i = 0, 1,... N-1, j = 0, ,..., M-1), of the spatial frequency function. From this a subset of values ($F_{m\ell}$) is selected, from which a summary measure, S_{Fm}, of texture is derived such that S_{Fm} correlates strongly with the mth dimension of perceived texture similarity as determined by the earlier psychophysical experiment. The simplest form of S_{Fm} is a linear sum

$$S_{Fm} = \sum_{\ell=1}^{L} a_{m\ell} \, F^{*}_{m\ell}$$

where the $a_{m\ell}$ are weighting coefficients. S_{Fm} is a mathematical descriptor of texture based on spatial frequencies. Analogous descriptors are derived corresponding to the other perceived dimensions of texture similarity.

The above description details how measures of texture on various dimensions are obtained. Any texture is then located in texture space by the set of values (S_{Fi}, i = 1, 2, ... D) where D is the number of dimensions in texture space. The similarity of two textures is then determined by simply calculating the Euclidean distance between them. Descriptors based on cooccurence matrix values, or on local pixel luminance statistics (means, standard deviations, etc.) can be similarly defined.

The selection of weighting factors, $a_{m\ell}$, is based on maximising the correlation between judged texture similarity dimensions and calculated values of the corresponding texture descriptor. This maximisation can be achieved using the statistical technique of canonical correlation.

The choice of image descriptors will be guided by a knowledge of the characteristics of the human visual system. Assuming that texture judgements are made mainly on the basis of foveal images, and also assuming a typical form of the visual contrast sensitivity curve, those spatial frequencies (or

pixel spacings for cooccurrence matrices) likely to be significant may be chosen and initial weights given. Since the eye is maximally sensitive to contrast at 2.5 to 3.5 cycles per degree, and texture is concerned largely with the higher spatial frequencies, greater weighting would be given to these higher frequency components.

A further consideration in choosing image descriptors is that oblique as well as horizontal and vertical descriptors be available. This is certainly possible with both fourier-based descriptors, and those based on cooccurrence matrices.

5. APPLICATIONS OF TEXTURE QUANTIFICATION

Current and past studies of detectability in complex scenes either generate artificial scenes using random dots, or randomly-placed arcs, or discs, or else use samples of natural scenes recorded photographically. Problems arise with both approaches - with the first there is doubt about the relevance of the background to real scene backgrounds, while the second raises problems of both sample generality and in some cases, difficulties in obtaining appropriate samples. Visual texture quantification will allow more representative texture background generation, and also quantification of scene spatial characteristics for a sample. This should make any evaluation using complex backgrounds more able to be repeated or assessed for relevance by other workers.

Another possible use for a quantified texture description is the possible utilisation, in display instruments, of texture subtraction using framestore technology and parametric texture statistics appropriate to a small number (e.g. 10) of expected backgrounds.

6. CONCLUSION

The preceding sections have outlined a two-part procedure for developing a psychophysics of foliage texture. The first part involves the determination of the number and nature of the dimensions underlying perceptions of texture similarity. The second part is the derivation of mathematical descriptors, derived from pixel grey levels, which match these dimensions. The procedure may not produce fine discrimination of textures comparable to the human's ability to discriminate finely, but should provide results of adequate discriminating power to guide patterning practice in visually unfamiliar areas such as thermal and radar images, as well as providing statistics for realistic background generation for target acquisition studies.

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AUTONOMOUS SURVEILLANCE IN THE VISUAL SPECTRAL REGION

B.E. FURBY and B.D. RONEY

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AUTONOMOUS SURVEILLANCE IN THE VISUAL SPECTRAL REGION

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ABSTRACT

An autonomous surveillance system is one which is capable of detection, identification and tracking of fast targets in real time. The equipment needed to carry out these operations includes a TV camera, digitizer and a digital computer: the design of the computer hardware and the development of the software are very difficult because several Mbits of data must be processed in real time.

At present suitable algorithms are being evaluated for the identification and tracking of ship targets and the results of the two techniques developed are described. Fourier descriptors provide a method of identification which can be superior to the human operator and real time correlation tracking methods are approaching useful times by reducing the number of points in the window.

1. INTRODUCTION

The requirement for real time autonomous detection, identification and tracking of targets for the guidance of weapon systems has arisen due to the sophistication of modern weapons, the short time of the engagement, the limitations of the human operator and the lack of target information. Developments in the missile guidance field could be used to produce autonomous surveillance systems.

Autonomous guidance devices using sensors operating in the visual spectral region are made possible by developments in microminiaturization of TV cameras and electronic equipment in general and the speed and memory capacity of computers. Similar techniques could be employed to develop autonomous surveillance equipment which could be fitted on board ship, aircraft or land vehicles and either work completely independent of an operator or serve as a never tiring, fast response back up to an operator. A surveillance system which would detect, enhance, identify and track several targets simultaneously, would be optimum.

The targets of major interest to Weapon Systems Division, WSRL are ships and the aim of the work described in this paper is to assess the potential of various algorithms to carry out an identification, enhancement and tracking task against ships at sea. However, to explore such a potential in the case of target identification it has been found expedient to use pentominoes and aircraft silhouettes. Pentominoes were used to analyse the main factors of shape which generate particular descriptor characteristics. Aircraft plan silhouettes have been analysed by Wallace and Wintz and there were some promising results from their work.

This paper only concerns itself with two dimensional images - the plan view of

aircraft and the broadside silhouettes of ships. The justification for this severe limitation is to provide simplicity for preliminary assessment of the technique. In the case of ships it is tactically conceivable that the sensor could be manoeuvred to ensure that the ship is broadside at the time that identification is attempted and the sensor is close enough to the sea surface to provide a normal silhouette.

2. DIGITIZING EQUIPMENT

The equipment which has been constructed to investigate the autonomous image processing of shapes is shown in block diagram form in figure 1. Its main component is a digital store with the capacity to hold one frame of a 512 x 512 pixel black and white TV image, each pixel quantized to 64 grey levels. Input to this store is either from a black and white RCA 800 line resolution TV camera or from a Sony U-matic video recorder/player. Continuous sequences of single frames may be extracted from a recorded tape of a moving target using the single frame display capacity of the video machine. It has been found that contiguous frames of a sequence of video tape recording made on a moving platform were unuseable due to distortion of the image and it was found necessary to edit satisfactory frames.

The graphics generator provides the display with cross-hair and windows of specified size and these can be moved about the screen using the track ball. Two monitors are provided, one giving the input display and the other the contents of the store. The control of the transfer of data from the digital store to magnetic tape is effected by a Nova 1200 computer. The magnetic tapes are processed on the DRCS IBM 30/33 computer and the output is displayed on a Lexidata 3600 Image Processor.

3. IDENTIFICATION

Recognition is defined by Johnson (1) as the capability to differentiate between say a house and a tank. Identification is defined as the capability to specify the type of house or tank. The numbers of TV lines over the critical dimension of the target which are required to effect detection, recognition and identification are 2, 8 and 12 respectively: these are the numbers of lines considered necessary for an observer to classify the target. For autonomous identification there is no observer in the loop, however, if the sensor/computer combination can perform as effectively as a trained human observer at his best it will adequately complete the task. This is the aim of the work described in this paper but it should be emphasised that the autonomous technique does not need to be bounded by the limitations of the human operator.

Fourier descriptors have been used for the identification of shapes for many years (references (2), (3) and (4)), but it was only recently that Wallace and Wintz (5) developed an efficient technique for the removal of ambiguities. Recognition is the term commonly used in the literature for the classification of shapes but according to Johnson's criteria, identification would be more appropriate. In this paper Johnson's criteria will be used. This will provide some basis for comparison of the performance of autonomous techniques against the capabilities of humans. The aim is to provide an identification capability, consequently it is necessary to be able to differentiate between a destroyer and a tanker, or a Mig 23 and a Jaguar fighter aircraft.

3.1 Image Processing

The technique of identification uses the method of Fourier descriptors. The theory of Fourier descriptors is presented in Appendix I.

3.1.1 Shape Contour

The method of Fourier descriptors relies on a continuous sequence of x, y co-ordinates which describe a closed boundary. The co-ordinates are taken as the real values and the ordinates as the complex values. These boundary points may be determined by several methods. Threshold and gradient are two such methods. Threshold depends upon distinct contrast between the target and the background which is maintained around the entire shape. It is also necessary to know what value of threshold to choose. For these reasons it has serious problems when used for real targets against real backgrounds. For edge detections using a gradient method there are several operators to choose from and these are described in reference 6. Edge detectors were not found to work any better than threshold techniques in a real situation. Threshold has been found to be adequate for dark silhouettes on a light background, but for real situations a suitable algorithm has not yet been devised.

Boundary points are chosen as the grey level drops below a fixed value and, once at this low level, as it goes up through the level again. By scanning the image from left to right and storing the locations of the boundary points the complete image contour can be generated. This can be a very simple technique for images with a binary grey scale but representation of shapes defined by such a simple system may not be representative of the shape due to poor system dynamic response or poor camera adjustment. Change of grey level from black to white and white to black may be slow and it may not be the same for both directions.

3.1.2 Contour Location

A commonly used technique for describing a boundary is to use a chain code (7): however, the string of numbers resulting from the method would then need to be transformed into x, y co-ordinates. The method adopted here is described by the diagrams of figure 2. Counter-clockwise movement around the contour is guaranteed provided the algorithm is started at the top of the shape. Other sequences of search points have been tried without success for every type of contour. The sequence adopted is relatively inefficient but it does work successfully.

As the contour is traversed using the contour following algorithm it does not exactly follow the plotted contour, as it will cut corners for the concave facing outward corner. This will have little if any effect on the shape representation since this shape has already been distorted by non-linearities and slow response of the digitizing equipment.

3.1.3 Fast Fourier Transform

The Fast Fourier Transform (FFT) was developed by Cooley and Tukey (8) for a radix 2 and later developed by Singleton (9) for other values of radix. The latter algorithm was based on prime factors and although the number of program statements was considerably higher than for radix 2 the time taken for the computation of comparable numbers of elements was in fact less. It is therefore necessary to compare the time taken to process the data and the amount of storage space allocated to read only memory (ROM) to obtain an optimum design for the processor.

Probably the most important aspect of the choice of FFT is whether it is possible, in a reasonable time and storage space, to provide the algorithm with radix 2 points. Since the shapes that have been processed have the number of contour points somewhere between 100 and 300, it might be necessary to generate a hundred or more points to increase the number to the next radix. The problems of adding and

subtracting points was addressed in reference (10) and results from this work suggest that there are two satisfactory solutions:

(a) Draw a smooth curve through the boundary points and resample to the required accuracy.

(b) Use the general radix algorithm.

The first method was adopted by Wallace and Wintz (5). This technique is a form of preprocessing and involves a lot of computer time regardless of the number of points. The second method is the one adopted in this paper - it is anticipated that the overall computation time will be the lower of the two methods but this will have to be investigated in future work.

Once the computation has progressed to this point the shape is characterized by a set of Fourier coefficients, equal in number to the number of points. These coefficients which are complex can be separated into amplitude and phase.

3.1.4 Normalization

The normalization technique is described in Appendix I. There are 3 separate operations:

(a) Put $C_z(0) = 0$ to move the centre of mass to the origin.

(b) Divide $C_z(k)$ by $C_z(1)$ to normalize magnitude.

(c) Add $(\phi_1(K-k) + \phi_k(1-k))/_{(K-1)}$ to each phase angle to orientate the major axis and starting point to the real axis.

There are M solutions in all; the first is generated after the process described in (c) is applied. Other solutions are obtained by adding:

$2\pi(k-1)/_M$

to the phase at each frequency.

The M solutions are resolved using an ambiguity criterion. Reference 5 found that the best results were achieved by maximizing the function:

$$\sum_{k=-N/2+1}^{N/2} \text{Re}[C_z(k)]|\text{Re}[C_z(k)]|$$

which is a measure of the real positive energy. The first term in the equation is the real part of each coefficient while the second term is the absolute value of the real part of each coefficient. This criterion works well with the pentomino shapes and aircraft except for the U shaped pentomino. This particular shape is an unfortunate choice because its basic shape is close to a cardioid (K=2) for which there are K-1 solutions. Thus M=1 and it can have but one orientation. But the shape is also very close to an ellipse and it is found that due to errors in the digitization of the shape sometimes it is a cardioid sometimes an ellipse. Since the major axis of the two shapes are orthogonal, matching of the shape is possible sometimes and impossible at others.

For ships, since they are not bilaterally symmetric, the method described above for resolving the ambiguity is not possible. Ships do not sail upside down but they can have a mirror image, and therefore rotation about a vertical axis is required.

3.1.5 Matching of Target Shapes

If the processes of the preceding section have been followed the boundary curve of a target shape is characterized by a Fourier descriptor given by:

$$C_z(k) = A(k)\cos(\phi_k) + A(k)\imath\sin(\phi_k) \quad k=-N/2+1 \ .. N/2$$

where $A(k)$ is the amplitude, ϕ is the phase at frequency k and $\imath=\sqrt{-1}$. The amplitude is given by :

$$A(k) = \sqrt{(Re_k^2 + Im_k^2)},$$

where Re_k and Im_k are the real and the imaginary parts respectively. The phase is given by:

$$\phi_k = \tan^{-1} \frac{(Im_k)}{(Re_k)}$$

A comparison of the amplitude spectrums of a pair of shapes is shown in figure 3. The shapes are quite different and so are the spectrums. The sum of the square of the differences (SDS) at each frequency for the shape can be used as a measure of comparison between two shapes. If this sum is denoted by S_k then:

$$S_k = \sum_{k=-N/2+1}^{N/2} (A_R(k) - A_T(k))^2$$

where suffix R and T denote reference and test respectively. If there is little difference between two sums there is good match but the difficulty arises when the shapes are similar at the start as in the case shown in figure 4. Under these circumstances the sensitivity of the method must be sufficient to be able to differentiate between the two shapes. The system error plays an important part in the viability of the use of amplitude difference as a matching criterion.

A common method for matching the reference and test signals in radar and optical tracking is correlation (C). A correlation coefficient ρ is defined as:

$$\rho = \frac{1}{\sigma_R \, \sigma_T} \sum_{k=-N/2+1}^{N/2} (A_R(k) - \overline{A_R(k)}) \, (A_T(k) - \overline{A_T(k)})$$

where σ_R and σ_T are the standard deviations of $A_R(k)$ and $A_T(k)$ respectively. The value of ρ may vary between -1 and +1. The negative and positive extremes give perfect match, while zero gives perfect mismatch. In this case the value closest to +1 gives the best match.

The third method of matching characteristics is using Euclidean distance

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(ED). This is a common method used for shape recognition; it was successfully used by Wallace and Wintz (5) among others. It is a technique which uses both the amplitude and phase information of the Fourier descriptor. The distance between two points at the same frequency is:

$$d_k = (A_R(k)\cos \phi_R - A_T(k)\cos \phi_T)^2$$
$$+ (A_R(k)\sin \phi_R - A_R(k)\sin \phi_R)^2$$

The sum of these differences can be used as a measure of the degree of match; a perfect match results in a value of zero.

3.1.6 Errors

The errors associated with the transfer of shape to a Fourier descriptor are due to:

(a) Poor camera focusing.

(b) Poor dynamic response of system.

(c) Non-linearity across the camera vidicon.

(d) Limitations due to resolution of camera or recorder/player.

(e) Non-symmetry of pixel from camera.

(f) Sampling effects.

(g) Failure to faithfully follow the shape contour.

(h) Non-uniformity of contour sampling.

(i) Truncation effects.

It is very difficult if not impossible to individually compute the effects of these errors. However, it is known that a circle on an image gives a normalized amplitude of 1.0 at $C_z(1)$ and zero amplitude for the other coefficients. Black spots of different size were digitized and the amplitudes of the coefficients determined. The highest out-of-roundness occurred for the smaller spots as might be expected. It amounted to about 7% for spots measuring 10 pixels in size and decreased to about 2% for the 50 pixel diameter spots. If the sum of the differences squared is determined for the 10 pixel diameter there results a value of 0.005. Thus two shapes of the same contour could differ by as much as 0.005 for the SDS criterion and two shapes differing by this amount could be considered to be the same shape. The value for correlation is 0.95 and for Euclidean distance is 0.008.

3.2 Experimental Technique

The equipment is set up as shown in figure 1 using the camera as input to the digital store.

The camera is positioned such that the field of view is filled with a white card upon which are drawn black pentominoes. The set of pentominoes are positioned left of the display screen to allow for chopping of the image which results from changing the pixels from rectangular to square shape.

This image is transferred to magnetic tape in digital form. The camera is moved away from the set of pentominoes and the card is rotated approximately 45°. Thus a change in rotation and magnification is effected on each image in sequence. This is repeated until the shapes become too small to identify with the human eye when it is placed a distance of about 50 cm from the display monitor, ie less than 12 lines over each shape.

The number of lines over the shape is calculated from measurements of the width and height of the white sheet of paper upon which the shapes are drawn and the same measurements on the display on the LEXIDATA monitor. The magnification of each image can then be calculated. The smallest dimension (imagining a rectangle to be drawn around the shape) is measured and the number of lines equivalent to this dimension is calculated for each shape.

The technique described above is also used for aircraft and ship silhouettes.

3.3 Computed Identification

3.3.1 Pentominoes

The pentomino shapes which were used to compare the viability of the three matching criteria are shown in figure 5. The results of the computations are shown in table 1. This table shows that the match is close to 100% for the number of coefficients as low as 8 and for sizes of target down to 5 TV lines, which is well below the identification level specified by Johnson. It was found that the ambiguity resolving criterion did not rotate all of the shapes to the correct orientation. By removing the results which give a mismatch, the ED criterion gives the best performance. However, because of its relative simplicity and good matching results, SDS is considered to be the best criterion in this application.

The U-shaped pentomino will always give erratic ambiguity resolution because either the cardioid or the ellipse will predominate according to errors.

3.3.2 Fighter Aircraft

The set of twelve modern fighter aircraft used for testing the matching capability of Fourier descriptors for military targets is shown in figure 6. The results are tabulated in table 2.

Matching performance is not as high as for the pentominoes for any of the criteria. ED gives the best results: there is no difficulty with orientation. Reduction of matching performance is rapid as the shapes grow smaller. This is caused by the break up of the aircraft as the high frequency characteristics become smaller than one pixel. The tail is the first to become detached from the main part of the aircraft when it thins to zero thickness near the tailplane. The matching ... as the number of coefficients from 64 to 8.

... resulting from poor focus had a large effect on the ... reducing it to 0% in the one image tested.

... very little effect due to representation error at ... is obviously quite a large difference in total length ... when it is horizontal and the same line at 45°. The ... raised by √2 as it must travel in a horizontal and ... instead of an angular one.

3.3.3 Warships

The set of warships which are compared are shown in figure 6; and the results of the matching performance are given in table 3. Only two sets of results were obtained, one set for 64 coefficients and the other for 8 coefficients and both give similar results. It is thus concluded that 8 coefficients hold most of the shape information and all of the matching criteria give the same result.

The matching performance falls rapidly as the shape size decreases. The poor matching capability as the size of the shape is decreased is caused by the sudden disappearance of the mast and skeletal superstructure. This disappearance results from the low dynamic response of the digitising equipment, causing the structure to be represented at a higher value of intensity than its true value and therefore achieving a value which is higher than the threshold. In this situation the structure will begin to break off and pieces will become detached from the shape.

4. ENHANCEMENT

Target images are often obscured by the background scene, primarily because of the similarity of their grey level distributions. The grey level histogram of a ship and its immediate neighbourhood and that of the background scene are similar though their tails tend to be different. In a dynamic environment targets are not easily detected or identified and some form of image enhancement is required.

Many image enhancement algorithms have been proposed in the literature but their comparative performance with typical video tracking scenes has not been established. Two algorithms under consideration are the local area gain/brightness control (LAGBC) from reference (11) and the moment operator edge detection from reference (12).

In the LAGBC scheme the image intensity transformation is based on the local mean M_{ij} and the local standard deviation σ_{ij}. The transformed intensity:

$$I_{ij} = G_{ij} [I_{ij} - M_{ij}] + M_{ij}$$

where the local gain:

$$G_{ij} = \alpha M_{ij}/\sigma_{ij} , \alpha > 0.$$

This equation amplifies the local intensity variation I_{ij} about the local mean M_{ij}. The gain G_{ij} is locally adaptive, being proportional to M_{ij} to satisfy psychovisual considerations and proportional to σ_{ij} to accentuate local perturbations. The local mean and variance are calculated by means of a two dimensional low pass recursive filter. Enhanced scenes for $\alpha = 0.8$, 1.6 and filter cut-off frequencies $f_c = 0.225$ and 0.25 cpl show that considerable adjustment of the tails of the histograms are effected giving a greatly enhanced target.

The moment operator edge detection scheme is based on x, y moments of the image intensity function calculated on a local region surrounding each point. The results can be treated as a vector field and gives for each point in the scene a quantity that measures the probability that a point is an edge point, and a direction which is the direction of a possible edge through

that point. The effect of the algorithm on a scene is to enhance the edges of a target and thereby make it more clearly visible with respect to the background.

5. TRACKING

5.1 Principles of Scene Matching

Area correlation or Scene Matching algorithms rely on digital computations applied to the task of locating a reference image R within a search image S containing some perturbed variant of the reference. Where R and S are both represented as ordered 2-dimensional arrays of quantized grey levels, of size mxn and MxN respectively, the statistical measure of correlation coefficient, ρ, provides a measure of match at every point in S where a windowed extract of size m x n may be compared with the reference (see figure 8).

$$\rho(i,\ j) = Q_{RS}/(Q_{RR} \cdot Q_{SS})^{\frac{1}{2}} \qquad (1)$$

where

Q_{RS} is the cross-correlation term

$$= \sum_{k=1}^{m} \sum_{l=1}^{n} (S_{kl} - \overline{S})(R_{kl} - \overline{R})$$

Q_{RR} is the reference auto correlation

$$= \sum_{k=1}^{m} \sum_{l=1}^{n} (R_{kl} - \overline{R})^2$$

Q_{SS} is the search auto-correlation

$$= \sum_{k=1}^{m} \sum_{l=1}^{n} (S_{kl} - \overline{S})^2$$

The indices k, l applied to the search image elements refer to local coordinates in the window centred at point (i, j).

$\overline{R}$ and $\overline{S}$ are means evaluated over the reference and search image window.

$$\overline{R} = \sum_{k=1}^{m} \sum_{l=1}^{n} R_{kl}/m.n \quad \text{and} \quad \overline{S} = \sum_{k=1}^{m} \sum_{l=1}^{n} S_{kl}/m.n$$

The position of best match corresponds to the maximum computed value of $\rho(i,\ j)$, that is, to the highest peak in the correlation surface of ρ, ($-1 \geq \rho \leq 1$). The computational task is formidable - the correlation surface numbers $(M - m + 1).(N - n + 1)$ discrete values, while the internal summations leading to S, Q_{RS} and Q_{SS} each span m.n elements in the search window. The reference-only terms, R and Q_{RR} are evaluated in a prior step.

Attention has been devoted to reducing the computational effort engendered in the internal summations. In effect, a subset is sought of the reference image elements to some count level $p < m.n$, such that the subset contains the information needed to locate the target within the search image against competition from false match regions. Section 5.2 describes the approach and briefly summarises the findings. Those findings form the basis of a multi-level computational strategy developed in Section 5.3.

When tracking over an extended period, the imaged target may undergo geometric perturbations which progressively diminish the correlation with the original reference. Typically, geometric perturbations arise from magnification changes (eg on range closure) and/or from changes in orientation or aspect consequent on relative motion between the imaging sensor and the target. Under these conditions, it is advisable to apply some periodic transformation to the reference so as to retain identity with the perturbations. This is the principle of adaptive tracking. A very simple expedient, and one which avoids the complexities of compensating transforms, is to update the reference image directly from the search image. The update may take the form of a substitution, or of an additive component to the reference, whereby recent history dominates over temporally distant representations in the composite reference.

If an update technique is to function successfully, that is, retain track, it is vital that false matches are discounted otherwise the results would be immediately catastrophic with substitution updates, and hardly better with additive updates because of the high level of corruption entering the composite reference. With additive updates, target location errors must also be minimised to avoid feature blurring in the composite and so degrade image quality. In short, a measure of track confidence, applied to the outcome of the current search image, would be very helpful in adaptive tracking. Even in the non-adaptive situation, such a measure would be useful in deciding whether or not the current outcome should be accounted as a valid trackpoint or discarded as a probable false match.

The correlation coefficient is not particularly helpful in this regard. Experience has shown that image-to-image variation in the emergent p-maxima can be quite large, and that true and false matches are not usually differentiable on correlation coefficients from different images. Therefore, it is necessary to accumulate a history of track in order to set a correlation coefficient based decision threshold with any certainty, and even then, the threshold must be set 'high', to the forfeiture of a major proportion of the true matches, if false matches, with their disproportionate penalty, are to be excluded.

A study has been recently directed to an alternative measure of match based on the variance ratio or F-distribution. Because the F-distribution is available as a tabulated measure at several levels of confidence, computed values may be directly compared to establish an immediate confidence-of-track estimate without recourse to historical accumulation. Further, decision-making (eg accept as track-point?, accept as reference update?) can be readily equated to confidence level and the penalty commensurate with an erroneous decision.

In Section 5.4, the development of the F-statistic is described, and the results of some preliminary studies are reported. Although far from conclusive at this time, the studies of the F-statistic point to strong differentiation between true and false matches from image to image, and therefore, to a considerable potential for adaptive tracking.

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5.2 Computational Reduction - Single Level

There has been established a test set of reference image-search image pairs which form the basis of all trials reported in this and succeeding sections. A temporal sequence of 12 digitised frames was extracted from videotape records of an airborne data gathering trial. The images show a target ship against an ocean-sky background and were sampled at approximately 1s intervals. Sub images of size 16x16, encompassing the ship and immediate surrounds were isolated as a set of 12 reference images, thus yielding a total of 132 non-identical combinations of reference and search images in the test data set.

In order to establish reduced subsets of the reference image elements, four criteria of selection were examined, here designated as Types 1 through 4. A further combination of Types 1 and 2 in equal weighting is designated Type 5. The criteria were applied to order the image elements, so that subset selection to an arbitrary count level, p, could be accomplished by extracting elements 1 through p from the ordered set. The criteria were:

(a) Type 1 sought to extract the most dominant contributions to the cross-correlation term Q_{RS}, ie the highest absolute values of $(R_{K1}-R)$ and therefore the 'blackest' and 'whitest' elements in the reference image. The ordering process samples inwards from the extrema of the grey level histogram, alternating between the 'black' and 'white' tail regions to preserve, approximately, the mean value R.

(b) Type 2 sought to concentrate to regions which remain relatively immune to small geometric perturbations. Among elements of the reference image, those located on, or close to, grey level discontinuities (eg edge features) are more prone to image-to-image variation than those embedded in regions of uniform grey level. Grey level slopes were computed over neighbouring elements (3x3 window) and the ordering process was to ascending absolute slope magnitude.

(c) Type 3 was the converse of Type 2 and sought maximum slope elements.

(d) Type 4 sought to exclude non-target elements contained within the reference image by ordering to radial distance from the image centroid.

(e) Type 5 sought to exclude elements located at, or near, grey level discontinuities, whilst ordering to 'blackest' and 'whitest' elements. As noted, it combines Types 1 and 2.

The reference only terms appearing in the definitive equations for $\overline{R}$, Q_{RR} and Q_{RS} are modified for subset evaluation by the constraint $R_{k1} \in$ subset, and $m.n \rightarrow p$. Likewise, the correlation computations performed on a reduced subset were strictly limited to count level p for search image elements. For a given window position (i, j) in the search image, only those elements which corresponded in local coordinates to the reference subset were accounted in the internal summations to $\overline{S}$, Q_{RS} and Q_{SS}.

Figure 9 compares the selection criteria in plots of cumulative error count vs error at p = 20 elements. For comparison, the 'best' plot (p = 256, all elements) is also shown, and it can be seen that both Types 1 and 5 provide near identical performance, hardly inferior to the all-element case, even though the subsets contain only some 8% of elements. Type 3, as might be surmised, performed poorly, with Type 4 not much better. Type 2 performs well in location error up to its plateau region, but fails in overall

performance level. From this point, trial observations are restricted to Types 1 and 5 alone. Types 2, 3 and 4 are not further considered.

In summary form, other results emergent from trials in which the count level, p, was varied are:

(a) Increasing the count level to $p = 50$ produces results almost indistiguishable from the all-element case.

(b) Decreasing the count level drops the overall success rate (more false matches) but only marginally increases the error spread among true matches.

(c) Where false matches occurred, the peak at the true match location rarely ranked below 2nd or 3rd in magnitude, and located with small positional error.

(d) False match peaks did not locate in the immediate proximity of true match peaks.

Figure 10 is a schematic summary of the latter observations. In the true target region, the peak emerges at low p-level with some location error and possibly outranked by false target peaks. On raising p, the location errors decrease, and the true target peak dominates. Apart from a small positional error, the essential features of the all element correlation surface are now established. These observations have particular significance in the evolution of the multi-level approach.

5.3 Computational Reduction - Multiple Level

In the multi-level approach, computation is performed over 3 separate stages.

Stage 1 - the correlation surface is evaluated at some reduced count level p_1, with the aim of peak emergence without necessarily requiring that the true target peak attain dominance.

Stage 2a - the correlation surface is composed into cells of size approximating the reference image, and within each cell, the local (intra-cell) maximum is isolated. The cellular composition takes the form of a simple rectangular grid, and is quite arbitrary with respect to peak position. Its purpose is to isolate one value - the maximum - among those clustered in a peak region, and to force spatial separation between competing peaks. The cell size is consistent with the observation that false matches are spatially removed from the true match region.

Stage 2b - over all cells, the correlation coefficient is computed to count level $p_2 > p_1$ at the intra-cell maximum. The precision of p_2 level values provides better estimates for decision making in -

Stage 2c - the intra-cell maxima are ranked to retain a number, q, of candidate locations. All others are discarded from further consideration. Were it not that location error is residual from the p_1-surface, the overall maximum would constitute a match point. Instead, the candidate locations are treated as sampling points to local regions of the p_2 surface.

Stage 3 - Within a small window, of size r x 1, centred at each candidate location, the correlation surface is computed to p_2 level. The overall

maximum then constitutes the match point. With the provision of the small window, residual positional errors are corrected to locate on the p_2 surface peaks.

Figure 11 provides a schematic representation of the multi-level approach, and illustrates peak relocation at the higher level.

The parameters which govern the multi-level approach are

p_1 - the initial level of evaluation in Stage 1.

p_2 - the level of evaluation in Stage 2 for intra-cell peak

ranking, retain/discard decisions on candidate locations, and in Stage 3, for match point emergence.

q - the number of candidate locations retained for Stage 3.

r - the dimensions of the window for refinement of peak location in the immediate neighbourhood of candidate locations in Stage 3.

Extensive trials have been performed on the test data set to determine optimum values for the parameters above. Both Types 1 and 5 were examined, and on prior experience from the single-level trials of Section 5.2, p_2 levels were constrained to values of 20 and 50 elements. The results are summarised as:

(a) $q = 5$ is sufficient to ensure that the true target is contained among candidate locations.

(b) $r = 5$ is sufficient window dimension to accommodate peak location, and results are not improved at $r = 7$.

(c) $p_1 = 12$ provides a sharp threshold at which limiting optima are reached. That is, at $p_1 = 12$, $p_2 = 20$ multi-level, the results are almost exactly coincident with single level, $p = 20$, and the same holds true for $p_1 = 12$, $p_2 = 50$ and $p = 50$.

(d) With optimum parameter values ($p_1 = 12$, $p_2 = 20$ or 50, $q = 5$, $r = 5$), Types 1 and 5 provide almost identical performance. Grounds for preferment to one or other element selection process have not been apparent in the trials conducted to date.

Computational load in the multi-level approach is concentrated to Stage 1, where some 96% of overall load is expended to computation of the p_1-surface. As a consequence, there is small load penalty in evaluating to $p_2 = 50$ in preference to $p_2 = 20$ in the latter stages and this is more than offset by the superior performance, equivalent to all-element computation, gained at the higher level. The load reduction factor, in comparison with all-element calculations is well approximated by $p_1/m.n = 0.05$. This is a very significant saving for an approach which engenders no appreciable diminution in tracking performance.

5.4 The F-Statistic as a Measure of Match

The basis for employing an F-statistic as a measure of match rests with hypothesis testing derived from Simple Linear Regression theory. In essence, it is hypothesised that, at the match point, elements of the

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search image are a linear function of reference image elements corrupted by white noise.

$$S_{kl} = \alpha(R_{kl} - \bar{R}) + \beta + \eta_{kl}$$

where η_{kl} is uncorrelated noise, normally distributed with

mean = 0 and variance = σ^2.

The linear estimate of the search image elements, using estimates a and b is, under the hypothesis:

$$\hat{S}_{kl} = a(R_{kl} - \bar{R}) + b$$

and the sum of squared differences between observed and estimated search image elements

$$\varepsilon^2 = \sum_{k=1}^{m} \sum_{l=1}^{n} (S_{kl} - \hat{S}_{kl})^2 = \sum_{k=1}^{m} \sum_{l=1}^{n} (S_{kl} - a(R_{kl} - \bar{R}) - b)^2.$$

As previously, the equivalent subset formulation is reached by constraint on image elements to locate within the subset, and substitution m.n $\rightarrow$ p. Minimising ε^2 with respect to a and yields, for $(2 \leq p \leq m.n))$ -

$a = Q_{RS} / Q_{RR}$, which is normally distributed with mean = α,
      variance = σ^2/Q_{RR}

$b = S$, which is normally distributed with mean = β, variance = σ^2/p.

$\varepsilon^2 = (Q_{SS} - a.Q_{RS})$, which is distributed as $\sigma^2 \chi^2_{p-2}$.

Hence:

    $Q_{RR} \cdot (a - \alpha)^2/\sigma^2$ is distributed as $\chi^2_1/1$

    $p.(b - \beta)^2/\sigma^2$ is distributed as $\chi^2_1/1$

$(Q_{SS} - a.Q_{RS})/(p - 2)\sigma^2$ is distributed as $\chi^2_{p-2}/(p-2)$

and all three are independent.

To test the hypothesis that the reference and search images are identically related apart from a possible difference in means, set $\alpha = 1$ and use the F-statistic

    $f_1 = (p-2).Q_{RR} \cdot (a - \alpha)^2/(Q_{SS} - a.Q_{RS})$

which is distributed as $F(1, p-2)$.

A more stringent test, which has not yet been examined, is that of further requiring that the means should be identical, ie $\beta = \alpha.R$ for which:

$$f_2 = (p - 2)(Q_{RR}(a-\alpha)^2 + p.(b-\beta)^2)/2.(Q_{SS} - a.Q_{RS})$$

is distributed as $F(2, p-2)$. Note that the F-statistics f_1 and f_2 are completely formulated in terms of the quantities evaluated for p, ie $\bar{R}$, $\bar{S}$, Q_{RR}, Q_{SS} and Q_{RS}.

Some preliminary trials have been conducted using the multi-level approach on the test data set, matching to minimum f_1 in place of maximum ρ. In summary form:

(a) With the optimum parameters and also with all elements accounted (p = 256), the f_1 calculations were 100% successful in true matches but produced a slightly greater error spread than the equivalent ρ calculations.

(b) With non-optimum parameters, ie where ρ calculations produce a few false matches, f_1 calculations were 100% successful, but with greater error spread.

These early results give some indication that the F-statistic is a better discriminant between true and false match locations, but not quite as precise in location, compared to the correlation coefficient. They tend to confirm the supposition that the F-statistic is suited to decision making (eg accept match point as a track point?, accept the search image as a reference update in adaptive tracking?), and raise the possibility of modifying the multi-level approach to locate on correlation coefficient and decide on F-statistic, particularly in Stage 2 when the search is reduced to a small number of candidate locations.

Further trials are presently in planning to confirm, and perhaps modify, the optimum parameter values, and to compare computed F-statistics with tabulations of the F-distribution.

6. CONCLUSIONS

6.1 Identification

Although the work described in this paper has demonstrated that Fourier descriptors have considerable potential for the identification of two dimensional target shapes, there are several problem areas to be resolved. These are:

(a) Retention of protuberances and skeletal structures as the size decreases.

(b) Specification of a representative value of matching criterion for identification.

(c) If ED matching criterion is used the ambiguity resolving criterion should be checked for suitable performance.

The useful results of the work are:

(a) SDS method is adequate in most instances.

(b) 8 coefficients are sufficient to contain enough information of the shape for identification purposes.

The results suggest that 24 lines over real target shapes are necessary to obtain an identification of better than about 70%. But this figure could be considerably improved by changing the technique of shape definition which is supported by the results obtained with pentominoes.

The military targets chosen were deliberately similar in shape and therefore the technique was given a difficult test. It is anticipated that the technique would have little difficulty in differentiating between say

carriers, destroyers and tankers or fighter aircraft, helicopters and commercial aircraft.

6.2 Enhancement

The two algorithms studied, LAGBC and moment operator, have demonstrated that enhancement techniques give improved target detection and identification capability.

6.3 Tracking

The computational strategies have proved surprisingly powerful in effecting a very considerable reduction in the computational load normally associated with scene matching algorithms. In particular, the multi-level approach promises to reduce the load to 5% of that engendered in all-element matching, without dimunition in location accuracy or in true match success. There appears to exist a promising potential in the use of the F-statistic as a discriminant between true and false matches, and as a measure for decision thresholds in adaptive tracking techniques.

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TABLE 1: MATCHING OF PENTOMINIES

No.of Coeff-icients	Match Algorithm	Matching as a percentage (Total=6)									
		Min. no of points for set/ Min.lines over target for set/orientation									
		108	96	68	73	56	52	55	46	37	37
		11	10	8	8	7	6	6	5		
		$-\frac{\pi}{4}$	$-\frac{\pi}{2}$	$-3\frac{\pi}{4}$	$-\pi$	$-5\frac{\pi}{4}$	$-3\frac{\pi}{2}$	$-7\frac{\pi}{4}$	0	$-\frac{\pi}{4}$	$-\frac{\pi}{2}$
64	SDS*	100	100	100	83	83	100	83			
	C	100	100	100	83	83	100	83			
	ED	100	100	100	100	100	100	100			
32	SDS	100	100	100	83	83	100	83	83	83	100
	C	100	100	100	83	83	100	83	100	83	100
	ED	100	100	100	100	100	100	100	100	100	100
16	SDS	100	100	100	83	83	100	83	83	83	67
	C	100	100	100	83	83	67	83	83	67	67
	ED	100	100	100	100	100	100	100	100	100	100
8	SDS	100	100	100	100	100	100	83	100	100	100
	C	100	100	100	100	100	83	100	100	100	80
	ED	100	75	75	75	100	100	80	80	100	50
4	SDS	100	50	50	85	100	50	67	50	67	17
	C	67	50	67	67	67	50	67	50	50	50
	ED	80	100	50	80	75	100	60	80	75	75

* SDS Sum of Difference Squared
  C Correlation
  ED Euclidean Distance

** Boundary where number of coefficients goes down to next radix 2.

TABLE 2: MATCHING OF FIGHTER AIRCRAFT

No. of Coeff-icients	Match Algorithm	Matching as a percentage (Total=12)								
		Min.No. of points for set/min.lines over target/orientation								
	Threshold=30	110	110	83*	69	65	63	28**	41	18
		24	24	19	18	17	15	14	12	
		$-\frac{\Pi}{4}$	$-\frac{\Pi}{4}$	$-\frac{\Pi}{2}$	$-3\frac{\Pi}{4}$	$-\Pi$	$-5\frac{\Pi}{4}$	$-3\frac{\Pi}{2}$	$-7\frac{\Pi}{4}$	0
64	SDS	75	75	58	33	58				
	C	75	75	58	42	42				
	ED	92	92	50	67	67				
32	SDS	67	67	42	33	50	17			
	C	75	75	25	25	33	17			
	ED	92	92	42	58	66	8			
16	SDS	67	67	42	50	42	17		17	
	C	75	75	42	33	33	17		8	
	ED	92	92	50	58	67	8		17	
8	SDS	75	75	58	50	42	33	0	17	
	C	58	58	25	50	58	50	0	17	
	ED	83	83	58	83	67	8	0	25	
	Threshold=40									
16	SDS	33	42	50	17	58	58	25	25	33
	C	33	42	33	17	42	50	25	17	33
	ED	58	75	50	75	75	58	25	75	0

* Breakup of shape started at this size

** Out of focus

TABLE 3:   MATCHING OF WARSHIPS.

No. of Coeff-icients	Match Algorithm	Matching as a percentage (Total=4) Min. No. of points for set/min. lines over target					
	Threshold = 45	233	213	196	172	128	112
		24	23	21	19	16	14
64	SDS	100	75	75	75	50	25
	C	100	50	75	50	25	25
	ED	100	75	75	75	50	25
8	SDS	100	50	75	50	33*	25
	C	75	75	75	25	33*	25
	ED	100	75	75	75	33*	25

*   3 results only.
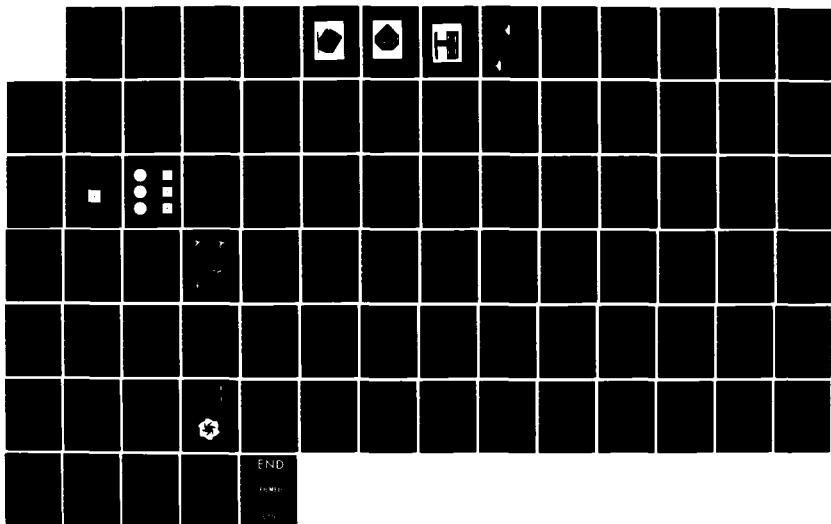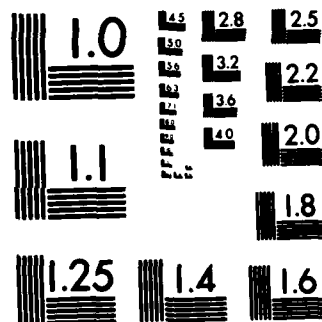
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A
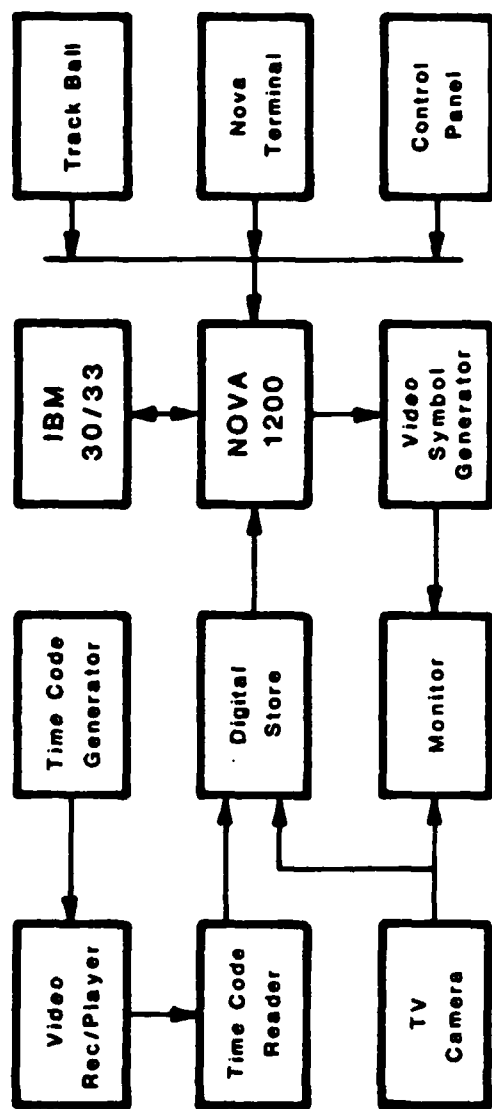
Figure 1: Block diagram of digitizing equipment.
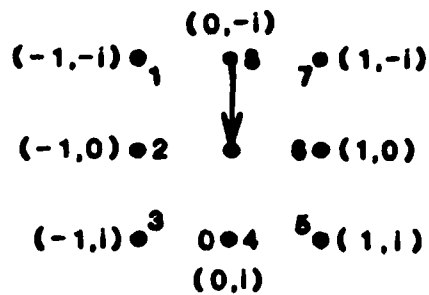
POINT	LOCATION	ROTATION FACTOR
0	$(0, i)$	$\frac{1}{C}(-1 + i)$
1	$(-1, -i)$	$\frac{1}{C}(1 - i)$
2	$(-1, 0)$	$\frac{1}{C}(1 - i)$
3	$(-1, i)$	$\frac{1}{C}(1 - i)$
4	$(0, i)$	$\frac{1}{C}(1 - i)$
5	$(1, i)$	$\frac{1}{C}(1 - i)$
6	$(1, 0)$	$\frac{1}{C}(1 - i)$
7	$(1, i)$	$\frac{1}{C}(1 - i)$
8	$(0, -i)$	$\frac{1}{C}(1 - i)$

$C = 2$ FOR DIAGONAL DIRECTION OF ARROW

$C = 1$ FOR HORIZONTAL AND VERTICAL DIRECTION OF ARROW

LOCATION x ROTATION FACTOR = NEXT LOCATION

$i = \sqrt{-1}$

(a) BOUNDARY FOLLOWING ALGORITHM
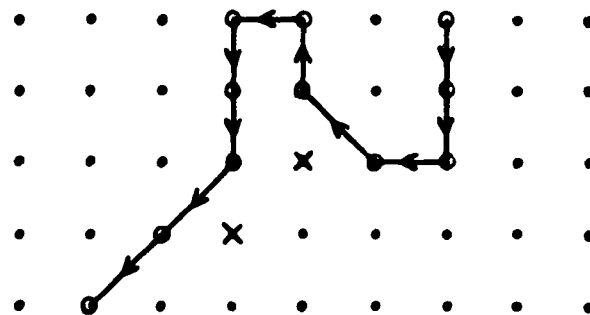
o   Edge pixels

o—→o   Path of boundary following algorithm

x   Ignored edge pixels

(b) PATH FOLLOWED BY BOUNDARY FOLLOWING ALGORITHM.

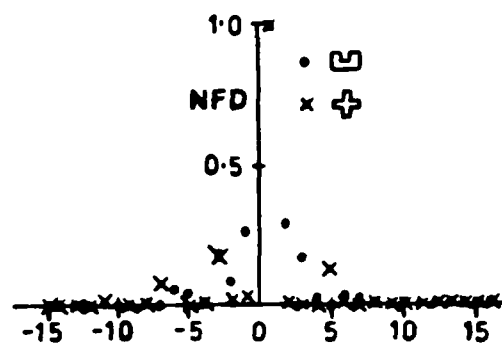Figure 2. Method of boundary following.

Figure 3:   Normalized amplitude spectrum of pentominoes
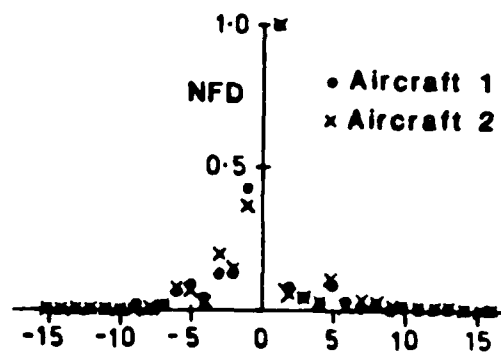

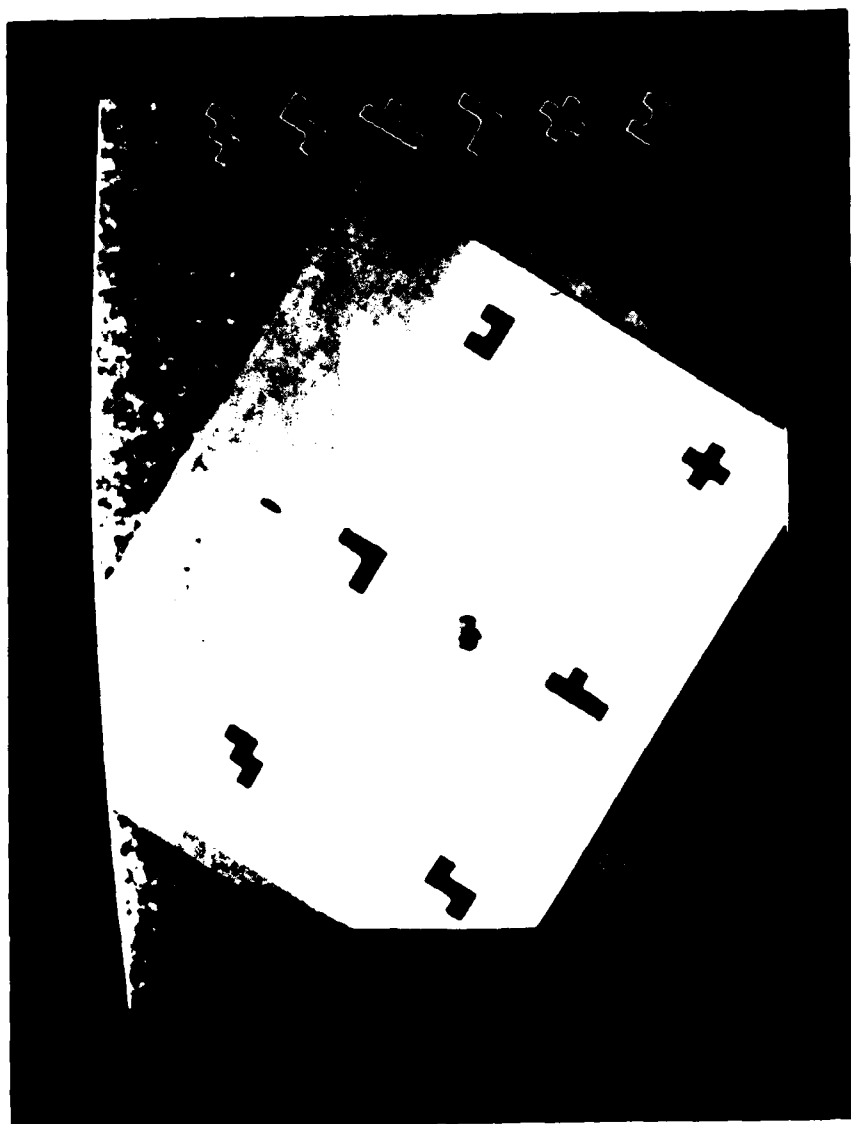Figure 4:   Normalized amplitude spectrum of aircraft.

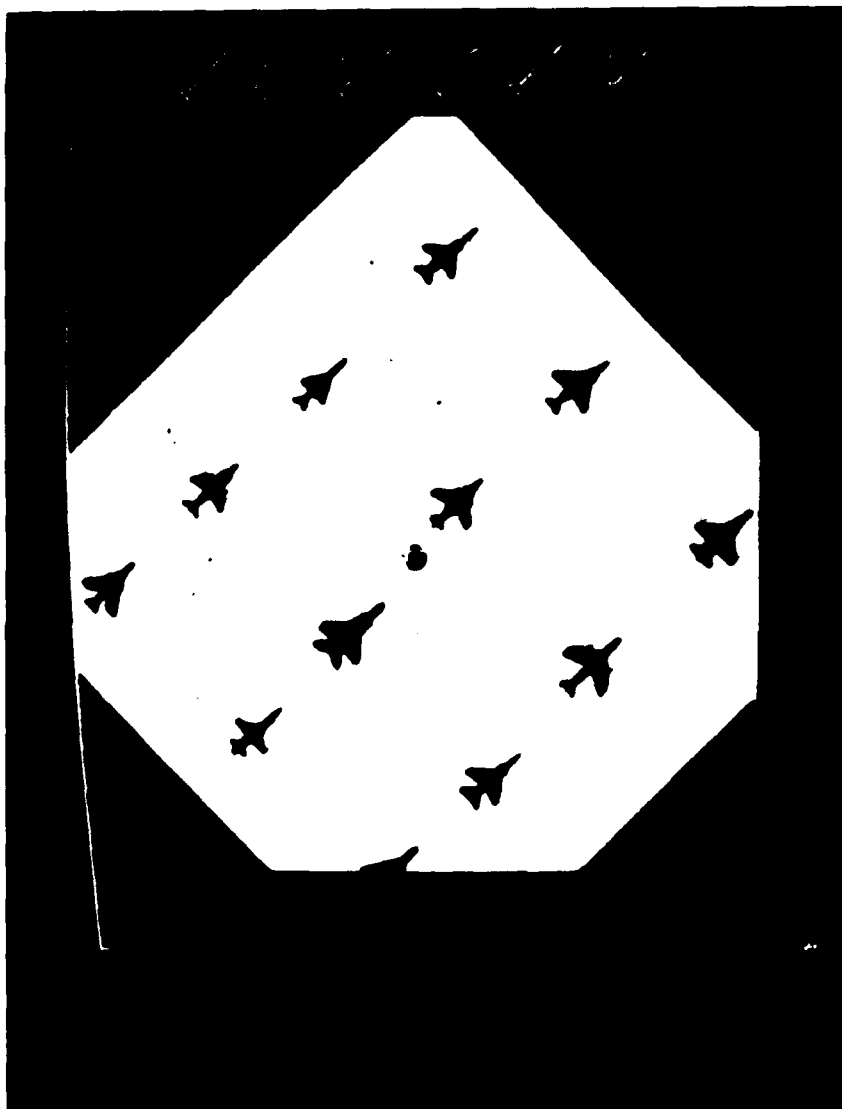Figure 5: Display of pentominoes, together with boundary and IDFT.

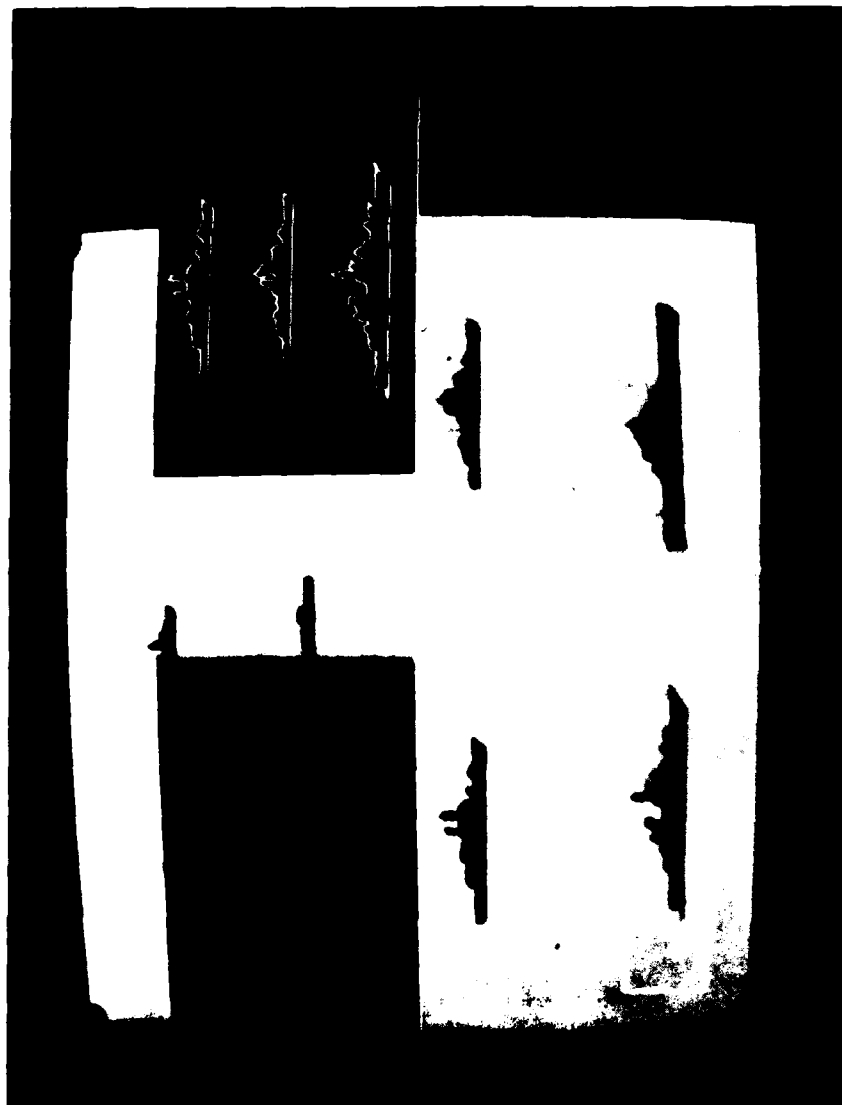Figure 6: Display of fighter aircraft together with boundary and IDFT.

Figure 7: Display of warships together with boundary and IDFT.

SEARCH IMAGE Size M x N

CORRELATION SURFACE

WINDOW (m x n)
Scanned over the
Search Image

Size $(M-m+1) \times (N-n+1)$

TARGET = Perturbed Variant of the
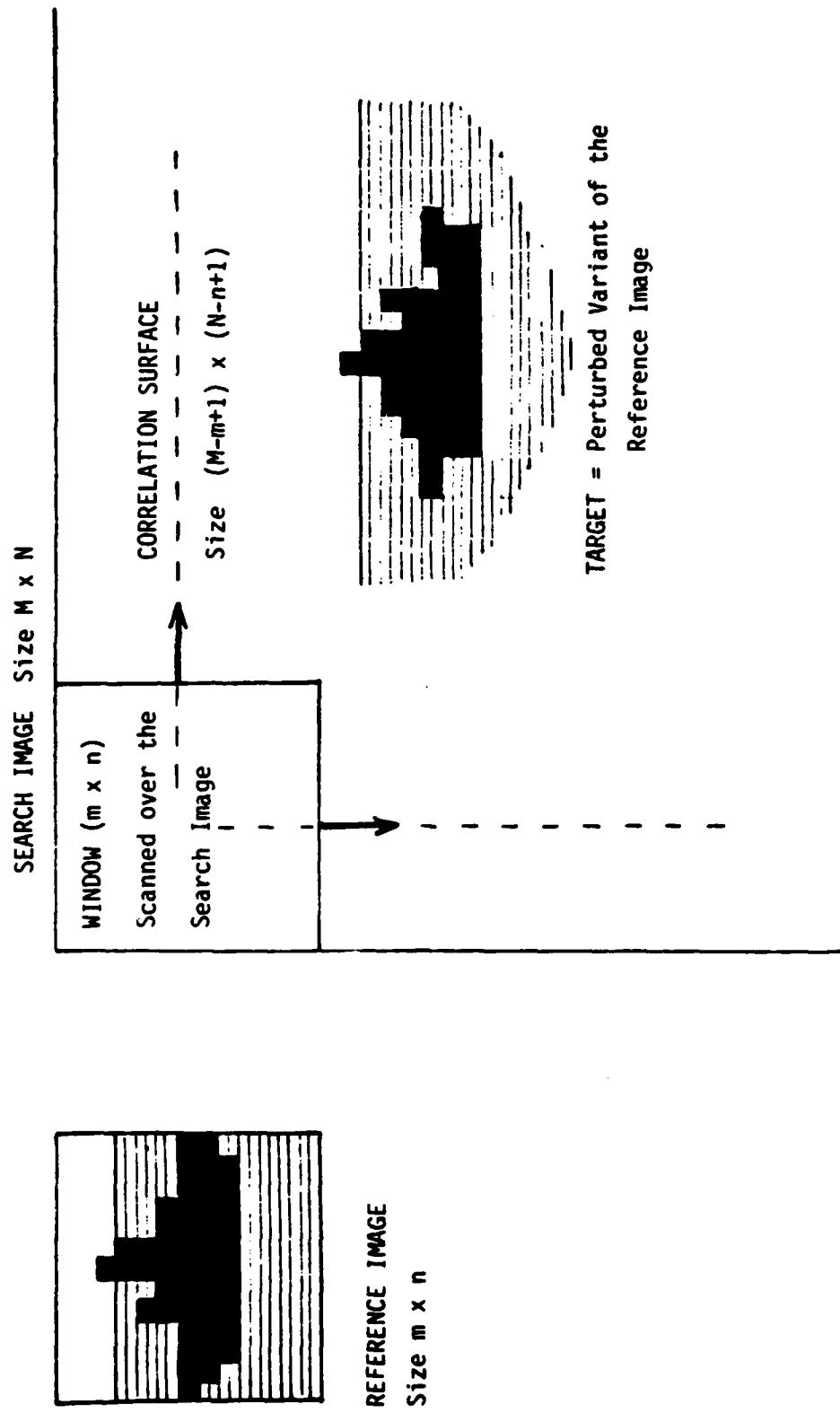Reference Image

REFERENCE IMAGE
Size m x n

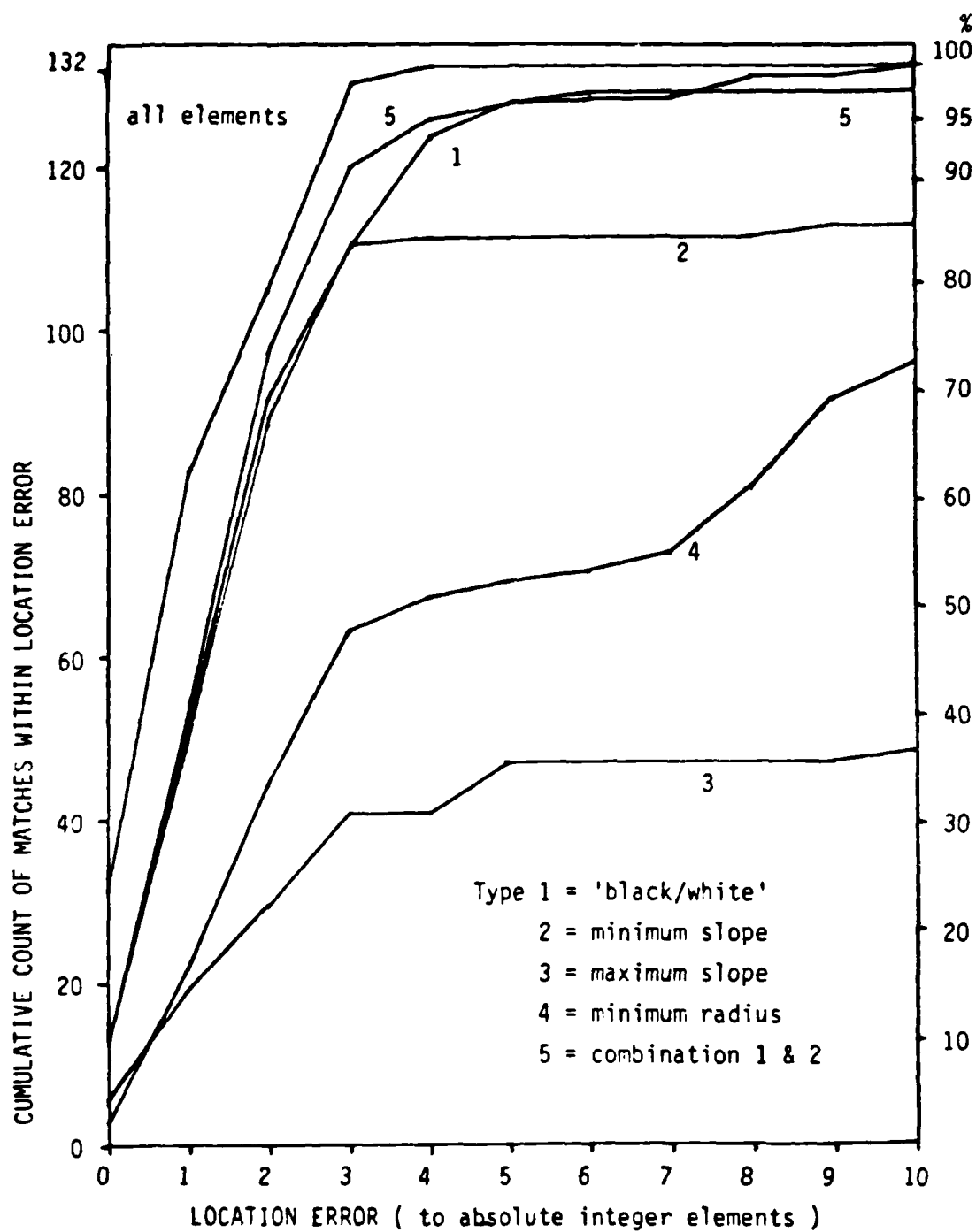Figure 8: Schematic illustration of the scene matching process.

Figure 9: Performance plots for reference subset elements selection processes types 1 to 5 at element count level, p=20.
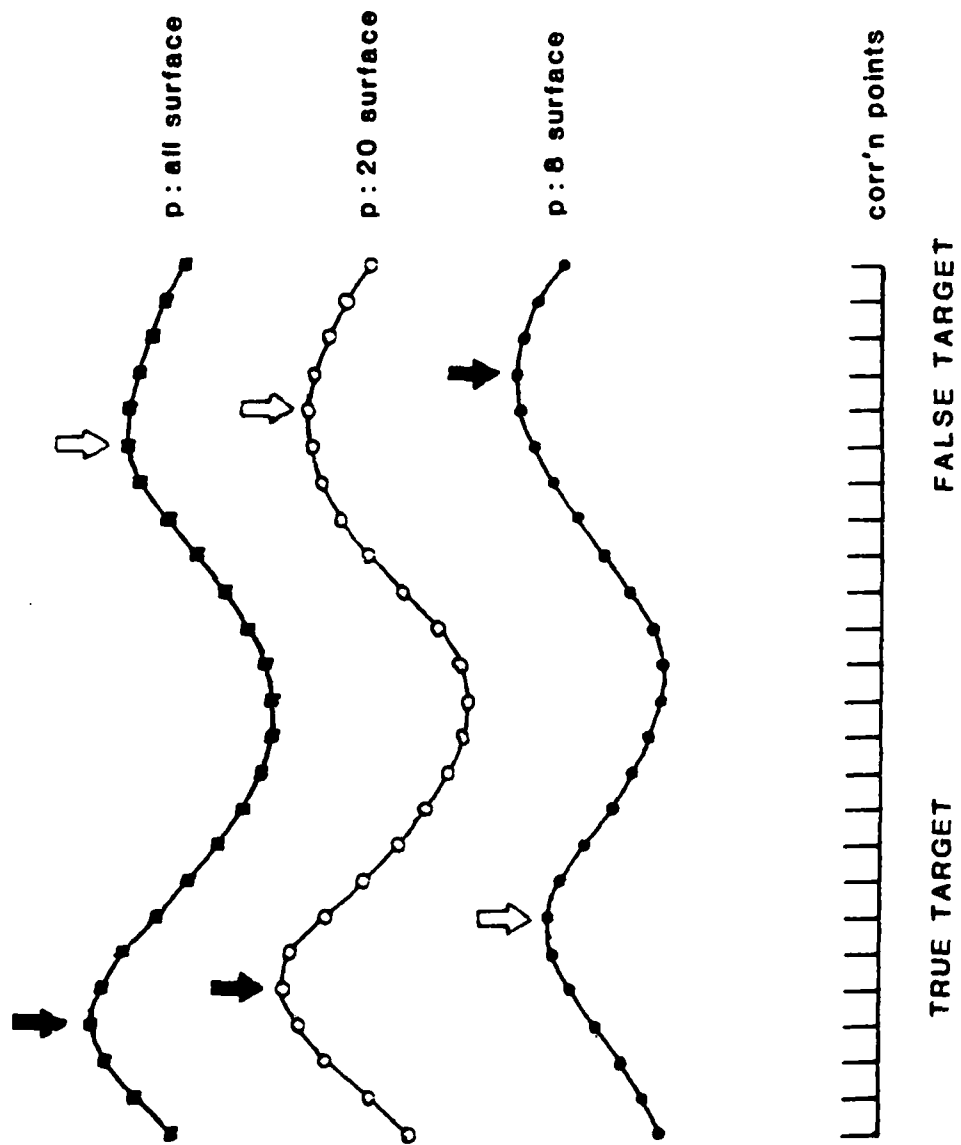
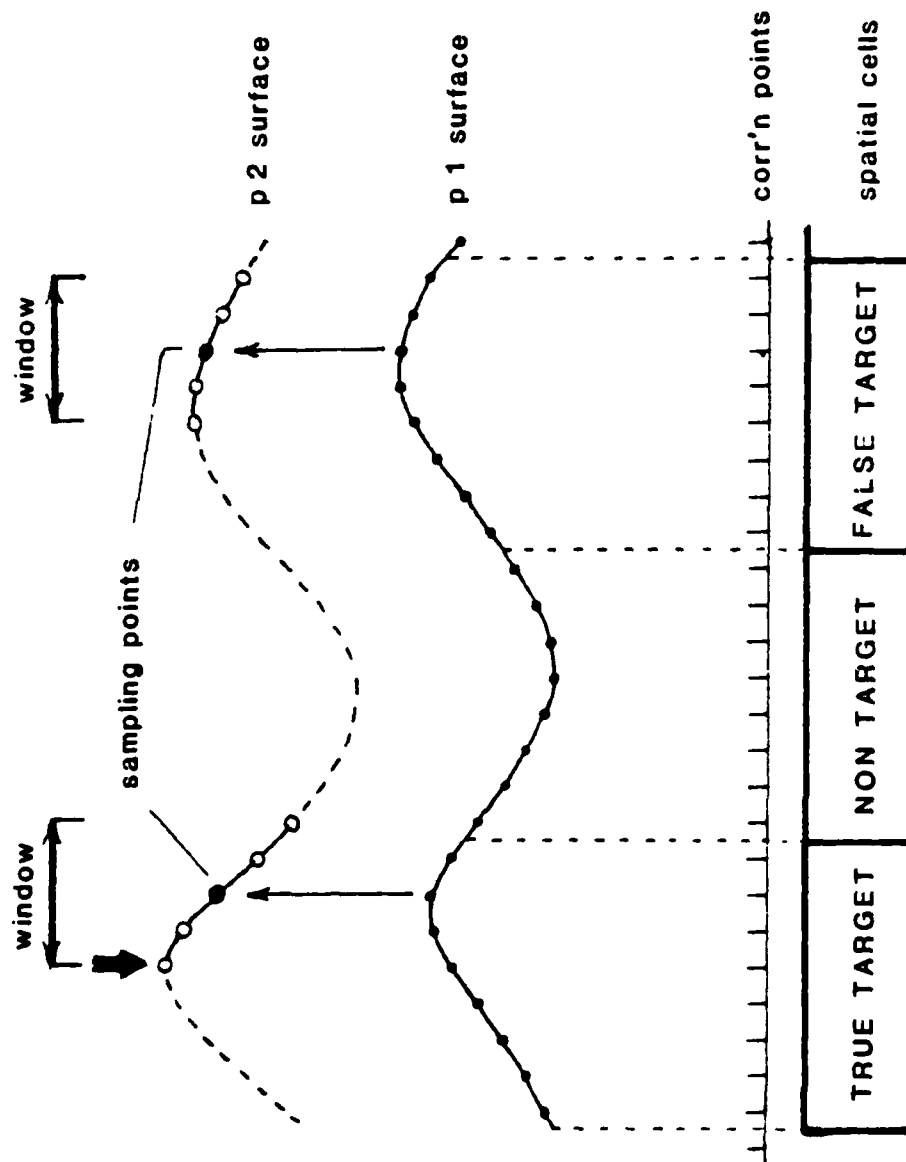Figure 10: Correlation peak emergence as the reference subset count level, p, is raised.

Figure 11. Schematic of the multi-level approach.

APPENDIX I

THE THEORY OF FOURIER DESCRIPTORS AND HOW THEY MAY BE USED TO CHARACTERIZE SHAPE

I.1 Theory of Fourier Descriptors

The theory of Fourier descriptors has been described in several publications in the open literature, eg references I1, I2 and I3. However in none of these publications is there a complete coverage of the method by which Fourier descriptors may be used to characterize the shape of two dimensional images of targets. The object of this appendix is to explore the theory of Fourier descriptors and show how they may be used to characterize target shape.

A discrete Fourier transform (DFT) is given by:

$$C_x(k) = 1/N \sum_{m=0}^{N-1} x(m)W^{km} \quad k=0, 1, 2 \ldots N-1 \quad \ldots(I1)$$

where $W = exp(-\imath\, 2\pi/N)$ and N is the number of samples. The inverse discrete Fourier transform (IDFT) is given by:

$$X(m) = \sum_{k=0}^{N-1} C_x(k)W^{-km} \quad m=0, 1, 2 \ldots n-1 \quad \ldots(I2)$$

Equations (I1) and (I2) are a Fourier transform pair, ie, transformations from the space domain to the frequency domain and back again can be made using the two equations. These two equations are taken from reference I4. In the two dimensional space domain a shape may be described by its boundary contour and, since the continuous contour is periodic as it is traversed more than once, it satisfies the periodicity condition of the DFT. If the complex coordinates of the contour are inserted for the values X(m), starting at any point and proceeding in an anticlockwise direction around the contour, then the contour will be characterized by the set of coefficients $C_x(k)$, k = 0, 1, 2 ...N-1 in the frequency domain. This set of coefficients is known as the Fourier descriptor of the shape.

The conditions which must be fulfilled to enable the contour coordinates to be inserted into equation I1 are:

(a) The sampling should be uniform.

(b) The sequence of boundary points should progress in an anti-clockwise direction around the shape.

(c) The contour should describe a closed boundary.

The uniform sampling condition stated in condition (a) follows from the theory of the DFT which assumes uniform sampling. However, it has been shown in reference (I3) that convergence is more rapid if non-uniform samples are taken. Furthermore the complexity of the computation is considerably increased if the sampling is uniform because it would be necessary to effect some smoothing. Since there appears to be an improvement in convergence, it would seem to be an advantage not to enforce the requirement for uniform sampling provided that an unacceptable error is not incurred. Condition (b) is applied to enforce a normal increase in phase angle in the correct direction and results in placing the first

harmonic at a fixed location in the frequency domain. The final condition is necessary to ensure that by following the boundary a periodic function is generated. Such a condition is met by adding points at appropriate locations if necessary.

By expansion of equation I1 there results:

$$NC_x(0) \quad = X(0) + X(1) \quad\quad\quad\quad .... \ X(N-1)$$

$$NC_x(1) \quad = X(0) + X(1)W^{(-1)(1)} \ .....X(N-1)W^{-(N-1)(1)}$$

$$NC_x(N-1) = X(0) + X(1)W^{(-1)(N-1)} ....X(N-1)W^{-(N-1)(N-1)}$$

The order of the amplitudes in the frequency domain are as shown in figure I1 if the boundary is followed in an anti-clockwise direction and is polygonal in shape. The order is:

(a) a is the maximum amplitude which equals the co-ordinates of the centre of mass of the shape.

(b) b is the second highest amplitude which equals the radius of the circle generated by the coefficient $C_x(0)$ to $C_x(N-1)$ if $C_x(\ell)=0$ where $\ell>1$.

(c) j is the next highest amplitude if the shape is predominantly of aspect ratio greater than 1.5.

(d) The coefficient with next largest value depends on the finer detail of the shape, ie:

   (i)   i if there are three sharp points.

   (ii)   h if there are four sharp points.

   (iii) For more points the maximum value moves towards f.

   (iv)   If the extremities are bulbous rather than sharp the maximum value moves from b to e.

The coefficients are the N lowest frequencies evenly distributed about the zero value. If the contour is considered to be traversed in a time 2π seconds than the frequency limits extend between

$$\frac{1}{2\pi}(-N/2+1) \text{ and } \frac{1}{2\pi}(N/2)Hz,$$

ie   -N/2+1 and N/2 per total contour length

The order described in items (a) to (d) above is not convenient for high pass filtering or truncation and does not correspond to Fourier transformation by optical means. Re-ordering (centre ordering in particular) can be effected by using the Shift Theorem (??). Referring to the diagram in figure I1 it can be seen that by shifting the samples in a circular manner so that a replaces f, then the samples would be symmetrical about the centre of mass value. From reference (??) if the amount shifted is h then

$$Z(m) = X(m+h)$$

and

$$C_z(k) = W^{-kh} C_x(k) \quad k=0, 1, 2 \ldots N-1 \quad \ldots(I3)$$

Now, if $h = N/2$,

$$W^{-kh} = \exp(ik\pi) = (-1)^k.$$

Upon multiplying each value of $X(m)$ in equation (I1) by $(-1)^k$, it can be shown that the ordering of the coefficients will be symmetrical about the centre (centre of mass value). The IDFT would also need to be multiplied by $(-1)^k$ when returning to the space domain. The result of this shift is shown in figure I2. Now, in order to truncate the number of coefficients from N to N' all that is required is to change N to N', in the IDFT.

I.2 Normalization

To be able to match two sets of coefficients, each set must be invariant to:

(a) Translation.

(b) Magnification.

(c) Rotation.

(d) Contour starting point.

The normalization technique used is that developed by Wallace and Wintz (I5).

I.2.1 Translation

Invariance to translation is easily effected by equating the coefficient $C_z(0)$ to zero. This operation results in the centre of mass of the shape being placed at the origin in the space domain.

I.2.2 Magnification

In Section I1 it was shown that the maximum value of the amplitude occurs at $C_z(1)$ provided the contour has been followed in an anti-clockwise direction and the coefficients have been circularly shifted. Normalization can then be effected by dividing the coefficients by $C_z(1)$. This results in $C_z(1)$ equalling 1 and all other coefficients having a value less than 1.

I.2.3 Rotation

Rotation of the shape about the centre of mass is effected by adding an angle to the phase of each coefficient. If, for example, a rotation of θ is required, this can be brought about by multiplying equation (I1) by $\exp(i\theta)$, viz:

$$C_z(k) = 1/N \sum_{m=0}^{n-1} x(m) W^{km} \exp(i\theta) \quad \ldots(I4)$$

Thus, if $\theta = 2\pi$, rotation has been completed once and in the space domain the shape is at its original location. By linearity, rotation of

the contour in the space domain by an angle θ is equivalent to multiplication of each component by $\exp(\iota\theta)$ in the frequency domain.

The choice of θ depends on the shape. Consider an ellipse-rotation by an angle which aligns the major axis with the real axis would seem to be a good choice. There are two angles which will do this and therefore there are two solutions. For a triangle there are three solutions and for a square four solutions. Each solution gives the same shape with a different starting point in the space domain regardless of the angle taken. In reference (I5) a normalization multiplicity M of the coefficient $C_z(K)$ is defined, where $C_z(K)$ is the coefficient of the second largest amplitude, and is given by:

$$M = |K - 1|$$

A theorem is formulated which states 'The requirement that $C_z(1)$ and $C_z(K)$ have zero phase angle can be satisfied by M different orientation/starting point combinations'.

Assuming that the starting point is on the major axis of an ellipse, $C_z(-1)$ is the second highest amplitude and therefore by subtracting the value of the phase at $C_z(-1)$ from all the coefficients describing the ellipse, the ellipse will be rotated such that its major axis is aligned with the real axis. But there is an ambiguity in that a further rotation of π degrees will also result in the same alignment. Thus an ambiguity resolving criterion must be formulated - such a criterion would depend on the type of shape that is being analysed. Reference (I5) has developed a criterion which works well for the aircraft shapes analysed. This criterion is a maximization of the function:

$$\sum_{k=1}^{n-1} Re[C_z(k)] \ | \ Re[C_z(k)] \ | \qquad \ldots(I5)$$

Equation (I5) is equivalent to adding together the square of the individual contributions along the real axis of each coefficient. If each solution is taken in turn and equation (I5) is determined, the maximum value gives the optimum criterion.

During the discussion of the rotation of shapes the starting point was assumed to be on the axis. A rotation without any change in the starting point would result in a mirror image of the shape about the imaginary axis. If equation (I5) were applied to the mirror image two equal values would be obtained. Thus it is necessary to apply a combination of orientation and starting point movement to resolve normalization ambiguities.

I.2.4 Contour Starting Point

The starting point can be rotated around the contour using equation (I3). A shift through an angle $-\phi$ can be effected by adding $-\phi k$ to the phase angle of each coefficient, ie put

$$h = -\phi N / 2\pi$$

into W^{-kh} and there results $\exp(\iota\phi k)$. The best normalization process that can be devised is one where both the major axes of the shape are in line with the real axis of the coordinates and the starting point is on the real axis at Re=+ve. This situation is effected by ensuring that

the phase angle of the coefficient $C_z(1)$ and $C_z(K)$ equal zero simultaneously.

At $C_z(1)$ the phase angle, $P(1)$, is given by:

$$P(1) = \psi_R + \psi_S \qquad \ldots\ldots\ldots\ldots\ldots(16)$$

and at $C_z(K)$ the phase angle is given by:

$$P(K) = \psi_R + K\psi_S \qquad \ldots\ldots\ldots\ldots\ldots(17)$$

The two equations (16) and (17) are simultaneously made zero by adding $-(\psi_R + k\psi_S)$ to each phase angle. Substituting for the values of ψ_R and ψ_S from equations (16) and (17) there results:

$$(P(1)(k-K) + P(K)(1-K))/(K-1) \qquad \ldots\ldots\ldots\ldots\ldots(18)$$

which is the angle which must be added to the phase of each coefficient to align the major axes of the shape with the real axis and rotate the boundary starting point to coincide with the real positive axis.

This operation results in one solution only, there are M-1 other solutions. These other solutions are obtained by rotating the shape through $-2\pi/M$ radians and keeping the boundary starting point where it is. This latter operation is brought about by adding $+2\pi k/M$ to each coefficient, ie for each new solution a total angle of:

$$2\pi(k-1)/M \qquad \ldots\ldots\ldots\ldots\ldots(19)$$

is added to each coefficient.

To optimize on the best solution equation (15) is applied.

I.3 Synthetic shapes

By following the normalization procedures described in the previous section, it is possible to build up synthetic shapes. This is shown in figures I3 and I4. Each shape has been plotted using a total of 32 points and, consequently, for the more complex shapes the contours are not smooth. The smoothness of the plots could be improved by increasing the number of points, however, these plots demonstrate some problems which might arise if attempts are made to use the extreme values. One amplitude at a single frequency other than the amplitude of 1 at $C_z(1)$ has been plotted and phase at all frequencies was made equal to zero. The introduction of equal phase angle at the single frequency and at $C_z(1)$ causes rotation of the shape.

If the phases are different then there is some rotation and some change in the position of the starting point.

If further amplitudes are added more and more complex shapes may be described as is shown in figure I5. By changing the phase of one frequency relative to another gives a different shape, not in its basic form but in its skewness. A shape very similar to an aircraft can be made using as few as 4 amplitudes and the wings can be made to move with changes to the phase of one amplitude only. This is also demonstrated in figure I4.

Because the number of points output can be chosen, a radix 2 FFT can be used for the inverse transformation, resulting in a very simple software package. The technique described above, could have considerable potential in the animation of graphics where a small number of characteristics could describe complex shapes and movements could be simply effected by changing a few values of phase.

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| No.	Author	Title
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I2	Richard, C.W. and Hemami, H.	"Identification of Three Dimensional Objects Using Fourier Descriptors of the Boundary Curve". IEEE Transactions on System, Man and Cybernetics, Vol. SMC-4, No. 4, July 1974.
I3	Persoon, E and Fu, K.	"Shape Discrimination Using Fourier Descriptors". IEEE Transactions on Systems, Man and Cybernetics, Vol. SMC-7, No. 3, March 1977.
I4	Ahmed, N. and Rao, K.R.	"Orthogonal Transforms for Digital Signal Processing". Springer-Verlag, 1975.
I5	Wallace, T.P. and Wintz, P.A.	"An Efficient Three Dimensional Aircraft Recognition Algorithm Using Normalized Fourier Descriptors". Computer Graphics and Image Processing, Vol. 13, Pages 99-126, 1980.
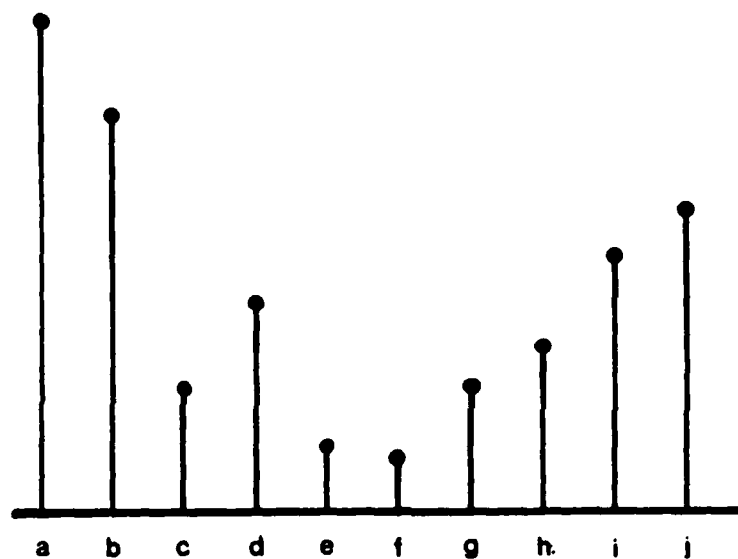
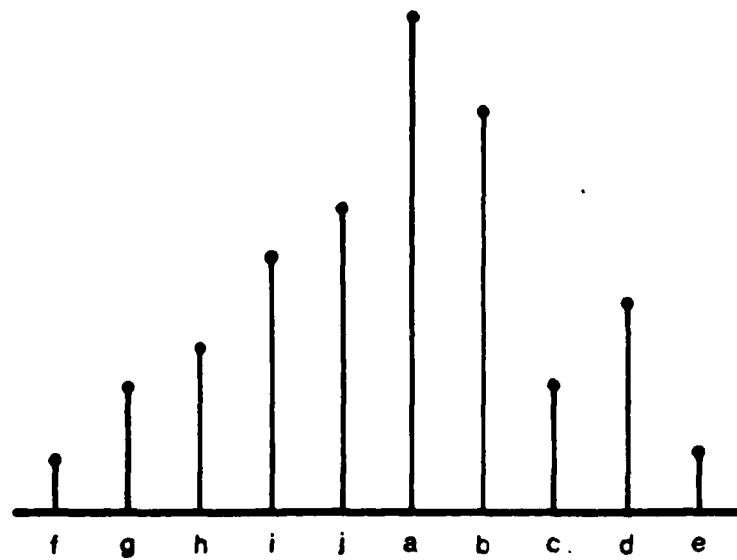Figure 11: Natural Order of Amplitudes in the Frequency Domain.

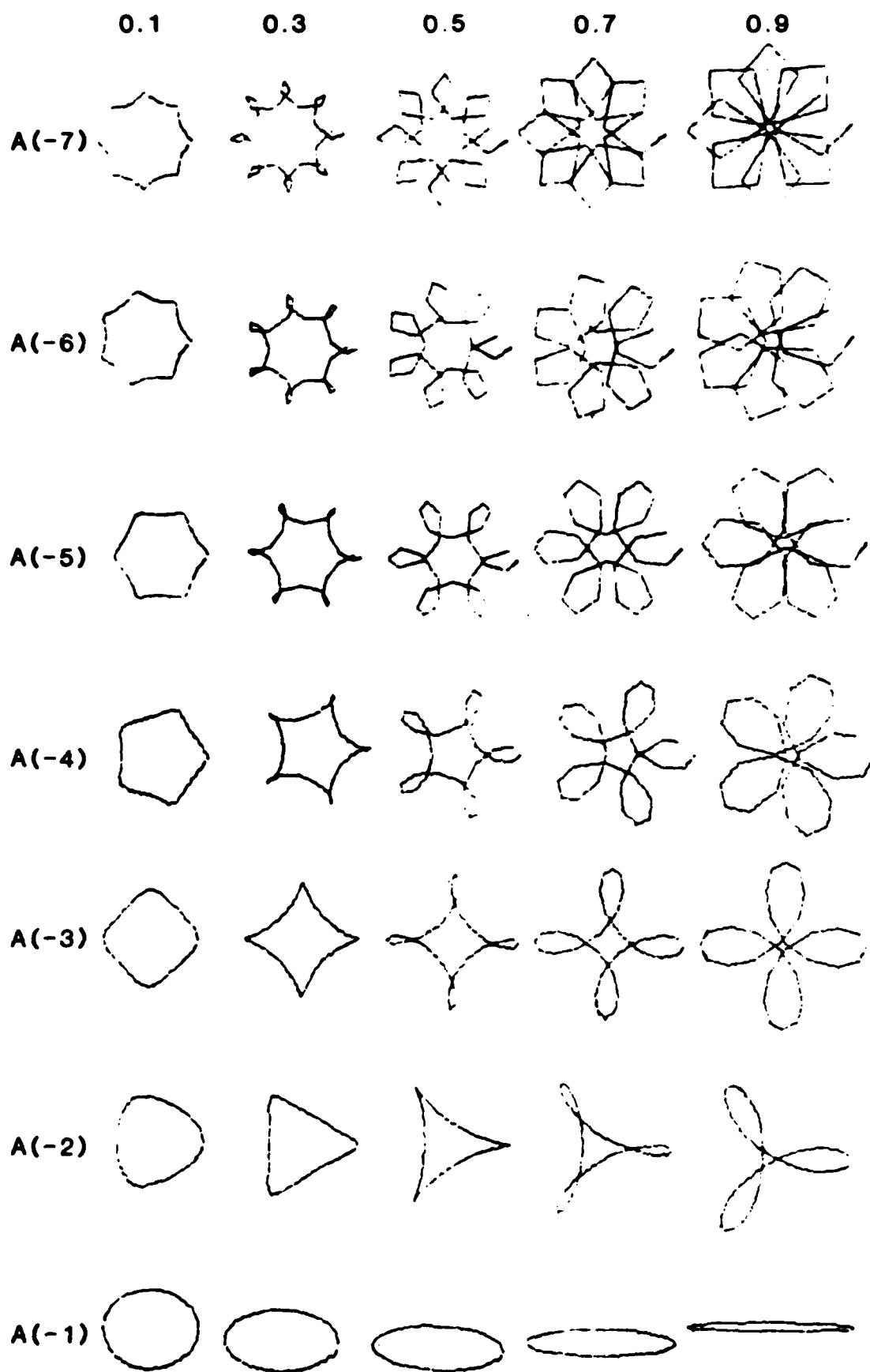Figure 12: Centre Ordered Amplitudes in the Frequency Domain.

Figure I3: Synthetic Shapes Produced by Varying the Amplitude Value at One Frequency Other Than A(1) for Negative Frequencies.
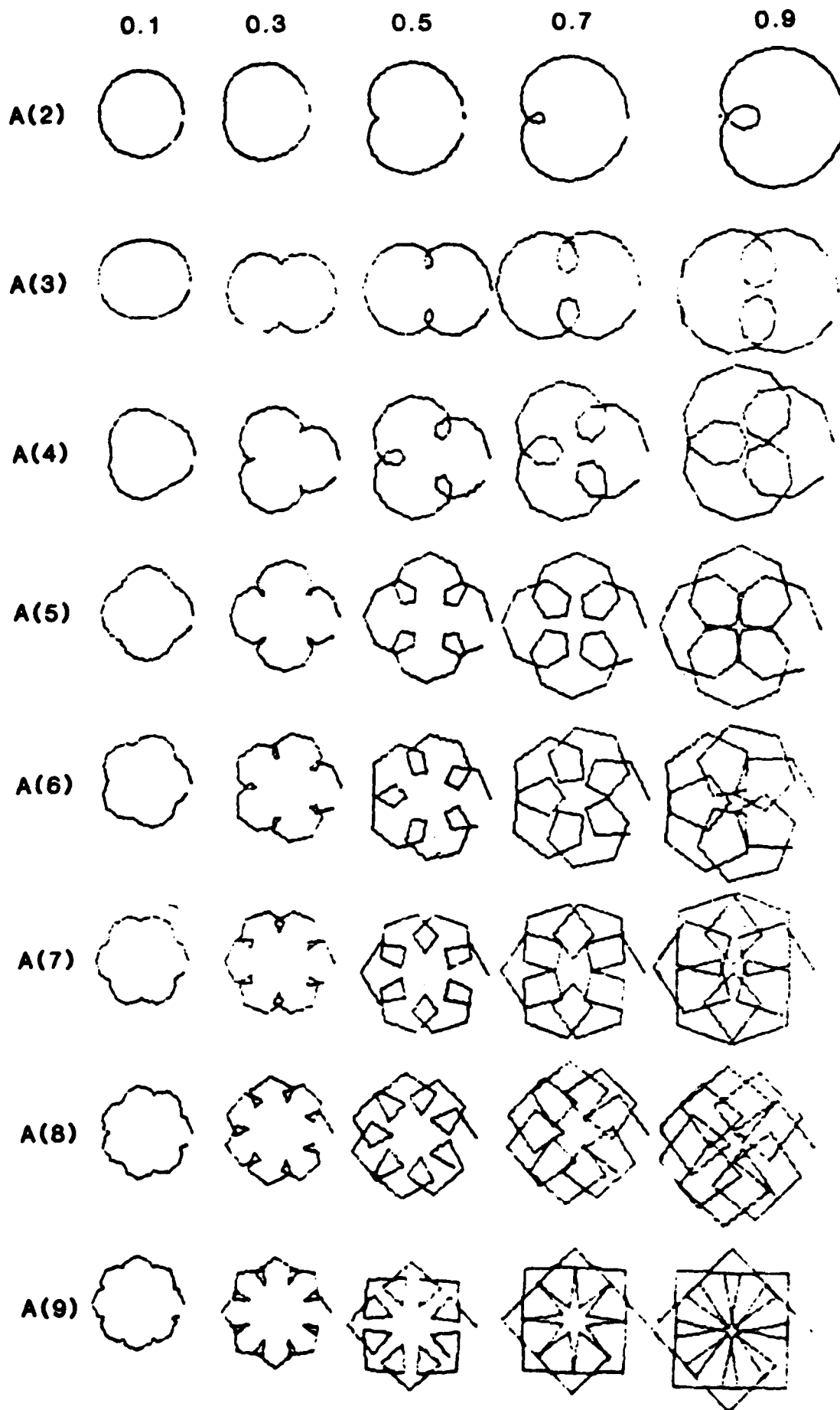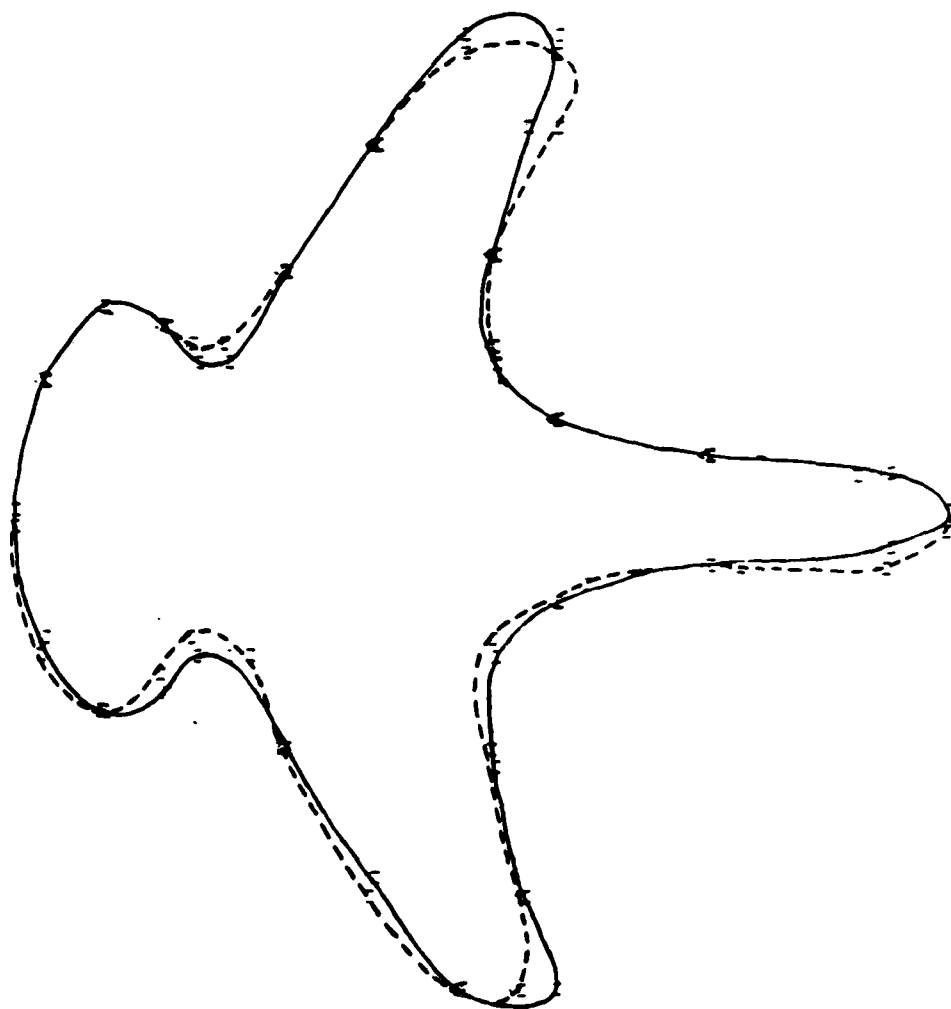
Figure 14: Synthetic Shapes Produced by Varying the Amplitude Value at One Frequency Other Than A(1) for Positive Frequencies.

_____ 4 amplitude values, all phase values zero.

- - - - - - - 4 amplitude values, one phase value non zero.

Figure 15: Synthetic Shape Produced by Using 4 Amplitude Values and Changes Introduced by Adding One Phase Value.

OPTICAL PROCESSING, ITS ROLE IN SURVEILLANCE

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ABSTRACT

The major attraction of coherent optics, from an image processing viewpoint, is the ability of such an optical system to perform two dimensional Fourier transforms (practically) instantaneously. Due to this property other linear transformations, such as amplitude filtering, complex (holographic) filtering, correlation and convolutions, may also be performed at the same high speed. Clearly these transformations have many applications in the automatic processing of surveillance pictures. Obvious examples are target recognition, target tracking, texture analysis and topographic feature extraction. There are a number of limitations which have led to delays in the implementation of optical processing in practical systems. These include the problem of getting data into and out of the system, a certain lack of flexibility in processing techniques and the cumbersome but sensitive nature of optical processors. Techniques to overcome most of these problems have been developed. These include recyclable spatial light modulators, CCD arrays, holographic optical elements and the hybrid optical digital processor. A description of a system being developed at ERL and incorporating many of these principles is given together with examples of the processing of surveillance type images.

1. INTRODUCTION

The power of coherent optical processing lies in the transformations facilitated by the Fourier relationship between the amplitude distributions in the front and back focal planes of a lens. If a transparency is placed in the front focal plane and illuminated by a collimated coherent beam parallel to the lens axis the image formed in the back focal plane is, to a close approximation, the (complex) Fourier transform of the amplitude distribution transmitted by the input transparency. If this latter is denoted by $f(x, y)$ then the amplitude in the back focal plane is $F(u, v)$ where:

$$F(u, v) = \iint f(x, y) \exp\left[-i2\pi(ux + vy)\right] dx\, dy \quad (1)$$

This is derived from the Rayleigh–Sommerfeld diffraction formula (ref 1).

Nearly all coherent processing transforms are ultimately due to this relationship. These include two dimensional filtering (real and complex), convolution and correlation. The attraction of optical processing is that these operations are carried out in an optical system almost instantaneously. Even using a Fast Fourier Transform (FFT) on an N x N array it still requires $N^2 \log N^2$ operations on a digital system to produce a single Fourier transform. For N of the order of 512 this is very time consuming; yet for surveillance purposes pictures of this size, or greater, are commonly generated at a high rate (e.g. 25 frames per second). Optical processing appears to be an attractive way to handle such image rates, provided the deficiencies of optical systems can be overcome. These deficiencies are largely related to input/output (I/O) of the system and processing limitations imposed by (1). A number of devices to enable I/O at (at least) TV rates are now

available. These include liquid crystal light valves, Pockles Effect light modulators and thermoplastic devices. The resolution of the first two systems is adequate for input images (up to 1024 x 1024) but not for holographic recording. Thermoplastic devices are suitable for holographic recording but not at TV rates. However it is believed that these types of devices are capable of handling most optical processing input requirements. Output is not really a problem either as various systems based on charge coupled devices (CCD) arrays of specially layed out detector patterns are commercially available. It seems then that I/O in optical systems is manageable and thus the remainder of this paper is devoted to a discussion of extending the processing capability of a basic optical system.

2.   PATTERN RECOGNITION

It is generally agreed (ref 2) that all proposed schemes for the machine classification of patterns fall into three catagories. These are:

    i.   Template matching/matched filtering.

    ii.   Feature extraction/decision theoretic.

    iii.   Structural/syntactic/linguistic.

To date the first of these has formed the bulk of optical pattern recognition research. This has arisen because of the ease of correlation with optical systems. It is now recognised that this approach has limited application to real world problems and research is now being extended to the second classification approach (ref 3). This approach requires more flexibility than is available on an all-optical system and has given rise to the current great interest in the hybrid optical-digital processor (HOP). Here the general aim is to use the optical part of the system to perform, at high speed, all two dimensional linear processing and the digital part to perform the non-linear and classification processing. It seems that the third 'linguistic' approach to pattern recognition has not so far been attempted optically. However it is believed that the HOP approach is adaptable to this method. In Opto-electronics Division of ERL a hybrid processing system is being developed to explore many aspects of image processing and pattern recognition. Figure 1 shows a block diagram of the system as it will appear when completed. A discussion on using a hybrid optical approach to one aspect of the surveillance function, the shape recognition problem, is now given.

3.   SHAPE RECOGNITION

The ability of a system to recognise and classify shapes is fundamental in many surveillance problems. The discussion here is weighted to autonomous classification but the approach could be integrated into a machine-assisted implementation.

Without getting involved in trying to provide an absolute definition of shape it is clear that at least two stages are involved in shape recognition. These are:

    i.   The enhancement and extraction of the boundary of the object in the image. This is the 'extraction' part of the task.

ii.   Transforming the boundary into a form where it can be
        compared with stored boundaries of known objects. This
        is the 'classification' part.

For example if the boundary has been extracted it could then be
stored as an array of x and y co-ordinates. These could be Fourier
transformed to produce the so-called Fourier description of an object.
These have invariances with respect to translation, rotation and scaling
which make them attractive from a shape classification viewpoint. The
actual boundary must be extracted however and this can be a very difficult
problem, particularly for noisy or complex scenes. Preliminary edge
enhancement of the scene can facilitate such extraction. Various optical
schemes have been investigated to perform this enhancement. These include
high pass filtering and image differencing. In the first of these the
input image is transformed as in equation (1) to produce the function F
(u, v). If a dot is used to block out values of F (u, v) near the optical
axis and a second lens used to perform a second Fourier transform of this
blocked image then the resulting output contains only high spatial
frequencies and is consequently 'edge enhanced'. An example of this can
be seen in figure 2. Another approach is to use a holographic 'shifting'
filter in the back plane of the first lens. This can be designed to
produce a simultaneous shifting in both the x and y directions, and a
phase reversed, in the reconstructed image. This output image is thus of
the form:

$$g\ (x',\ y')\ =\ f\ (x' + \delta x',\ y' + \delta y')\ -\ f\ (x',\ y') \qquad (2)$$

This function is squared by the detector system. Then values of
$g\ (x',\ y')$ are large only for points near the edge of objects and this
leads to an edge enhanced image. These, and other techniques, are being
investigated from a viewpoint of their robustness to random noise and the
effects of the presence of non-object-of-interest structure.

After such edge-enhancement, edge-extraction can proceed. This
is inherently a sequential operation and can thus be very time consuming
depending on the noise present. It is necessary to do this if a shape
classification scheme such as Fourier descriptions are being used.
However a different approach to shape classification is being investigated
for HOP implementation which avoids the boundary extraction phase altogether.
Under certain circumstances the preliminary edge enhancement can even be
avoided. This is the 'chord function' approach (ref 4) which is based on
sampling the two dimensional auto-correlation function of the object.
This function can be derived in near real time using an in-line system of
two lenses and two liquid crystal light valves. Information is directly
observable in this function on such aspects as the angles made by the
sides of the target and the relative length of these sides. An example is
shown in fig 2. Results of the research made so far into the use of the
auto-correlation function for pattern recognition are very encouraging.
It appears they are even useable when more than one target is in the field
of view (figure 3). At the moment a data base of target images is being
assembled and will be used to test the chord function/auto-correlation
approach on real images.

4. CONCLUDING REMARKS

Hybrid optical processing appears to have great potential for solving the problem of high speed target recognition in medium to large images. The major challenge is in developing suitable robust techniques which can be implemented on hybrid systems. The actual hardware implementation is not seen as a major problem.

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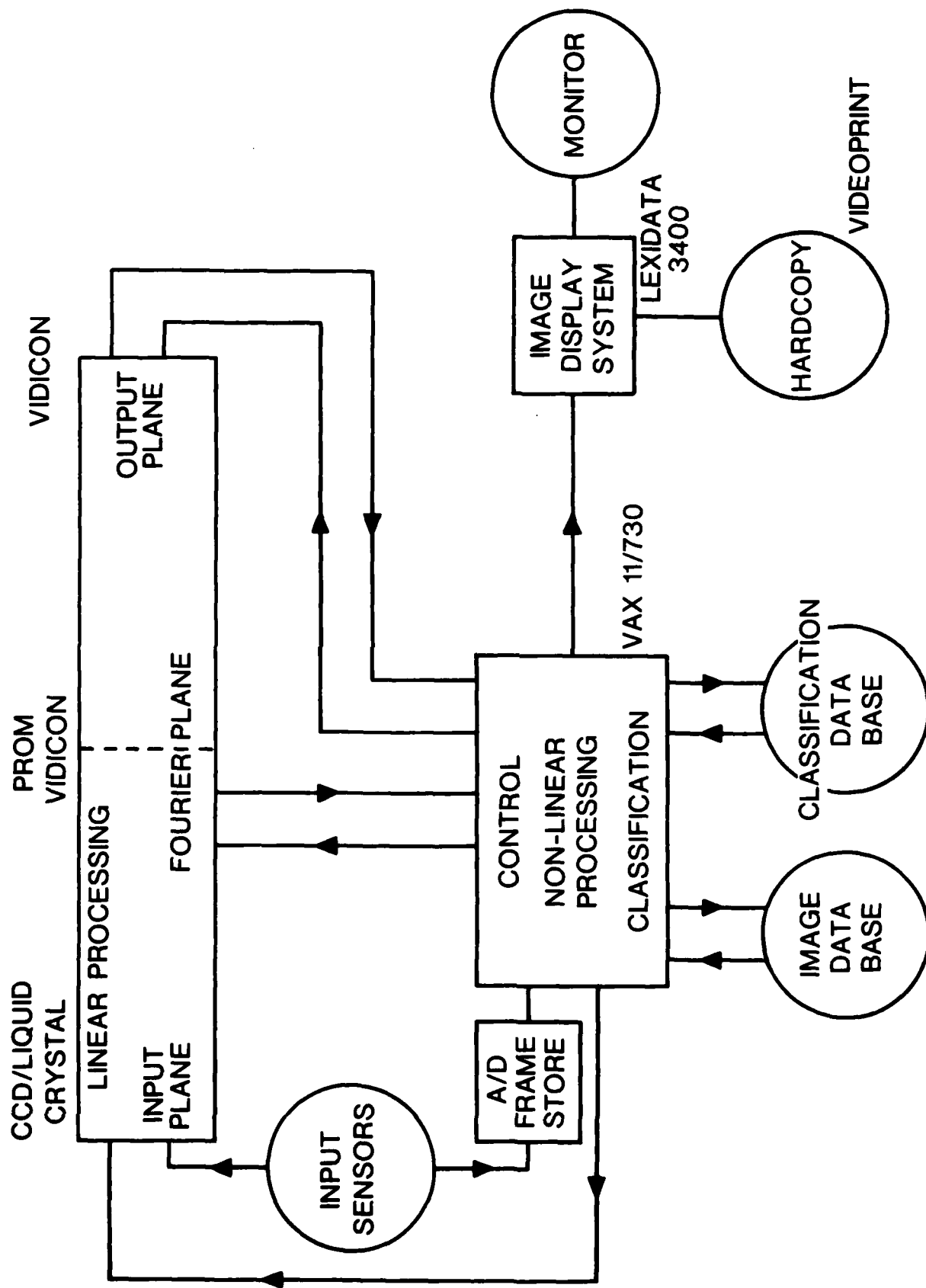
HYBRID OPTICAL DIGITAL PROCESSING FACILITY

Figure 1

CHORD FUNCTIONS

$f_m(r)$

radius r

1   2

$f_a(\theta)$

angle θ

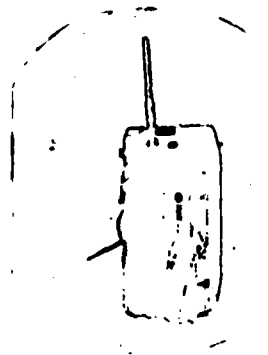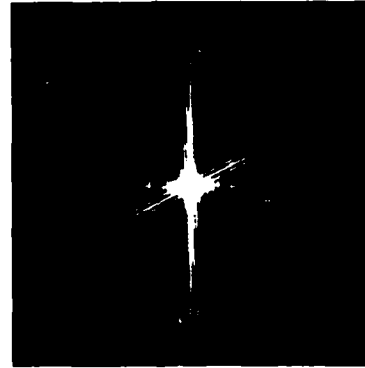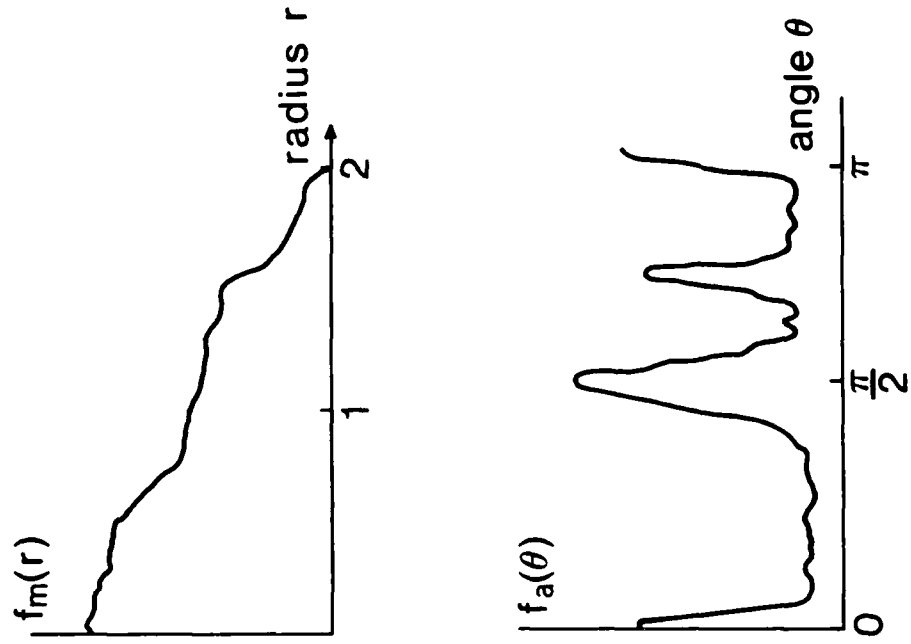0 $\frac{\pi}{2}$ π
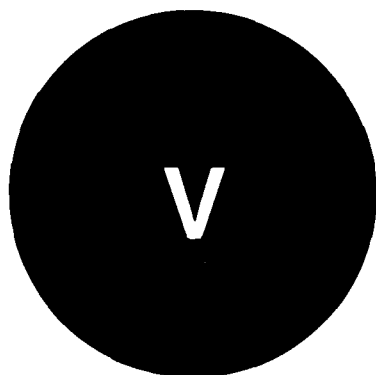
AUTOCORRELATION FUNCTION

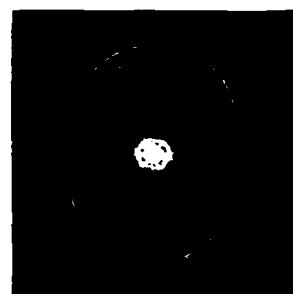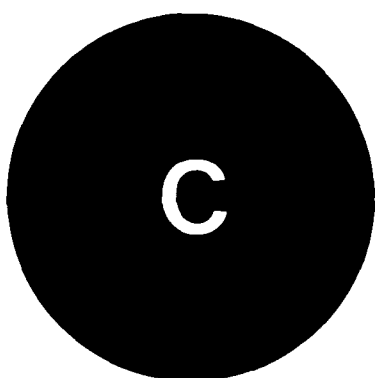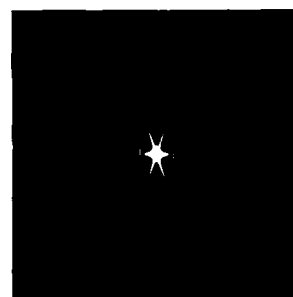# EDGE ENHANCED INPUT

Figure 2

INPUT IMAGE

AUTO CORRELATION FUNCTION

Figure 3

MULTI-TARGET IMAGES

Mr B.E. Furby.   What importance is there in the number of years training people have had in pattern recognition? It always amazes me that youngsters take a long time to recognise that a 2 is being written backwards.

Prof G. Stanley.   Aspects of developmental cue selection are very interesting. To what extent they provide a good model for the kinds of experience that are necessary for adult discrimination is problematic. Certainly, in the context of the various kinds of attentional tasks psychologists have been studying in a laboratory, it is found that for complex discriminations you might need a large number of trials, up to, say, fifteen hundred presentations of a given pattern before you can actually make reliable discriminations. It depends so much on the nature of the task and the nature of the person's experience beforehand, but with quite complex patterns which we have devised in the laboratory situation, you often need that many trials to make discriminations. The problem raised in the development of children making discriminations about reversal of letters really deals with the relationship between motor responses and preceptual processes. The child has to learn to co-ordinate how he writes with the properties of the stimulus. From a pattern recognition point of view particular problems in reverse letters arise because they are really the same pattern as the letter round the right way. It is only arbitrarily that we have given that pattern a particular orientation as a critical feature. From a pattern recognition point of view it is an added kind of problem that change in orientation may signify change in meaning, e.g. b and p.

Dr O.J. Raymond.   In relation to field trials of, say, the effectiveness of camouflage schemes and so forth, I wonder how much of the large amount of variance which is such a nuisance is caused by the variations of the visual acuity of the subjects? It would be interesting to know just how much it was. If it is significant, has there been any thought of measuring the visual acuity of each individual subject in order to remove that variance or to take it into account in some way?

Dr M.G. King.   Well, my work with the slides has been very neatly controlled. I've got extremely high correlations, about .97 between one group and another - incidentally between a civilian group and a non-specialist military group, which would suggest that at least in many cases we could use a civilian group as observers. Real specialist military groups are rather different, but a non-specialist in uniform does not really make an ace camouflage detector. Between one group of observers and another there is no difference, whilst one individual person may be affecting the results a little because he has poor eyesight, a group of about 10 or 15 observers would in most cases be quite a sufficient bank to wipe out that sort of problem.

Prof G. Stanley.   I think we can answer it in terms of a group of students that we used last year where in fact, because they were coming through our vision lab, we had a lot of other measures. I don't think the acuity measures had anything to do with the variance in relation to the task that Mike was running. The real variance comes in terms of the amount of time that people are spending on the actual decision processes. One would imagine that acuity would basically be involved in effecting the automatic processing level, but in these kinds of tasks the automatic processes are not the things that are

really taking the time. It's the thinking, the more elaborative processing involved in trying to identify the object which is taking the time, so I don't really think acuity is critical at all. Obviously if a person has very poor acuity it is going to present a problem. In some circumstances in fact, poor acuity may be an advantage because usually poor acuity means that you don't have some of the high spatial frequency detail. So in certain circumstances you may be picking up the blobs that are there and losing some of the high frequency information which is harder to camouflage. I think that is an interesting point but it is slightly irrelevant in terms of the issue Mike was talking about.

Mr D.G. Nichol. Dr King, you mentioned the fact that someone had suggested that there was a variable foveal field of view between one and ten degrees, depending on the complexity of the situation, has it in fact been suggested that there is a constant information bandwidth.

Dr M.G. King. Yes, that is the explanation that is usually offered.

Mr D.G. Nichol. You haven't measured the entropy, for example, of the targets.

Dr M.G. King. I don't recall this has been done and resulted in a one-to-one relationship between entropy and foveal field. I think people are fairly comfortable with that as being the underlying reason. I read recently that children's peripheral vision is worse than adults and one of the propositions explaining this finding was cognitive masking. Because the children are not as wise as us - not as much experience - so the world is a much more variable and complex place; and so they deliberately, as it were, go around masking in their peripheral vision. It is not that their eyes are limited: it is that their brains are limited.

Maj G. Botwright. It is a widely held view in the Army that if you give soldiers disruptive pattern painted vehicles or disruptive pattered uniforms you make the soldiers more camouflage conscious. That is he is more aware of taking countersurveillance measures on his own behalf. It there any evidence within the world of psychology to support this?

Dr C.J. Woodruff. I've seen nothing. I've heard that statement a number of times but I've seen nothing in the psychological literature to that effect. I don't know whether anyone else has.

Dr M.G. King. Usually a widely held view that holds up for quite a few years has got some underlying validity. If people are reporting this is what I seem to see, i.e. that guys are more conscious of camouflage, I certainly won't reject it even if there was a psychological theory against it.

Prof G. Stanley. I wouldn't think that there would be. If I may offer a lay opinion, it seems to me that experience would be valuable in terms of the kinds of arguments that we have been developing through these three papers, suggesting that one of the critical things in camouflage detection is in fact the kind of conceptual thinking that is going on. Clearly if a soldier is wearing a camouflage uniform, there are certain aspects of camouflage which have been highlighted by experience and that must help any discrimination. Just as Mike has demonstrated, you do get learning effects from these tasks as

trials progress.   People get better with the more judgements they have to make.

Maj P. Ferguson.   There is some anecdotal evidence from the British use of camouflage material, that it does sensitise the user if you like, to try to pick up camouflaged objects and people in the field of view in their environment. Perhaps this line needs to be followed up.

Dr D.J. Gambling.   Just a question relating to a somewhat different point of view. We are often asked to specify the performance of infrared surveillance equipment and that generally involves a non-resolved target. In other words we don't have a complex target - it may simply be one or two pixels wide but the background itself may be complex. Is there still a cognitive process taking place where the searcher is looking at a complex background but the target itself may be simple?

Prof G. Stanley.   If it is simply a figure-ground discrimination situation then presumably it is an automatic process and it ought to be relatively easy. But some figure-ground discrimination becomes difficult depending on the extent to which the ground is like the figure, so that it is difficult to answer that question directly. To the extent that the task is one which does enable the separation to occur in a straight-forward fashion, then it clearly can happen fairly quickly. I don't know whether my colleagues would like to say anything more on that because it is a bit difficult to answer the question without having a bit more information or specific examples.

Dr C.J. Woodruff.   I agree that we don't know the answer. But the target has got to be more than one pixel anyway to have any chance of recognition or any confidence of detection unless it's a completely blank background. Then, once it's more than one pixel, it really is a matter of people making a judgement as to whether the particular spatial arrangement of the pixels available is consistent or inconsistent with the spatial distribution of pixels coming from the background. And that's going to be a matter of judgement and hence, I presume, a cognitive process.

Dr D.J. Gambling.   I suppose you could go down to one pixel if there was movement for example.

Prof G. Stanley.   Movement, "has something moved?" is clearly an automatic process. The question of "what it is that's moved?" involves this conceptual elaboration. The judgement that some processes occur, or there is something there, is very different from the question, "What is it?". "What is it likely to be?" It is there where all the real time starts to occur. The quick "is something present", or "has something moved", can occur in a matter of a few milliseconds. It's the other question that in extreme form can take up to several seconds.

Lt Cdr P. Wilkinson, RAN.   I've got two questions really, on the recognition side. How much effect does aspect have? And the second one is, if you break down the silhouette, break down the outline of the ship, what effect will that have, such as stringing awnings or altering the super structure, when you're using a reduced number of points?

Mr B.E. Furby.   These are two questions that I am often asked.   I want to emphasize that we are working on a research task which hasn't got any definite end product yet - so we are looking at techniques to see how effective they are. We started off using the simplest situation we could think of - two dimensional targets with high contrast.   We realise, of course, that eventually when we do address the real situation, we must look at three dimensional targets.   The main effect this will have is to increase the number of images that we have to put into memory by quite a large number.   The situation for ships will not be as bad as that for aircraft, where there are many aspects.   Ships usually only float one way up, which reduces the total number, compared with aircraft, to one half.   The second question is about "breaking down" the silhouette - I think it could be quite disastrous.   At present it would be.   One of the problems we are having is that, if there are large changes of contrast over the target, then it is extremely difficult to draw the outline.   You can imagine that if you deliberately camouflage the target you have made the situation even worse.   Alternatively, I think, particularly with ships in the far distance, the effect would be small as the contrast reduces with range and as long as there is some difference between the ship, the sea, and the sky, there will be a good chance of obtaining the contour.   I know there are a lot of problems and a lot of questions to be asked.   We are trying to sort out all the simple problems first.

Lt Cdr P. Wilkinson, RAN.   And one further question is, with the imagery, is there a possibility of putting in measurements like length measurements, height measurements, as a recognition feature?

Mr B.E. Furby.   You would need some range information then, wouldn't you?   We have thought that knowing the range would possibly be a means of aiding identification but, of course, then we get away from the passive type sensor and need a laser or some other active detector.   We are going to include as many variables as possible in the study, but at the moment we are trying to keep our thoughts fairly narrow otherwise it's going to become too complicated.

Capt. N. Reynolds.   You seem to be assuming that there will be some form of global representation with a texture rather than people pulling out individual specific features and working with those to determine similarity.   Do you think that's a valid comment?

Dr C.J. Woodruff.   ies, I am assuming that people will make a judgement about texture similarity, just as people will make a judgement about colour similarity, and also I can control that to some extent, I think, by using limited exposure times, and getting a fairly spontaneous response to how similar textures are.   Now, the question really comes down to: "Are different people using different dimensions to make the judgements?"   The only way I could answer that is to get a number of different people and see if they are using different dimensions to make those judgements.   So I may find that the differences from one person to another are such as to preclude the possibility of getting an overall representation.   But I think, by making these multiple judgements, that you will be able to product a matrix for one person and find out what dimensions they use and carry out the same thing for another person.

Capt N. Reynolds.   But would you have the sensitivity to pick up those specific features?

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Dr C.J. Woodruff.   I don't know.   There's quite a bit of observational data you can pick up and you can then replicate it if necessary.   It takes a lot of time.

Prof G. Stanley.   It is a problem of using real textures, however, that just because they are real textures there could be just some aberrant feature that's picked up and used as the basis of discrimination for whether something is more similar or not.   There are lots of problems, but nevertheless I think it's really going to an interesting endeavour and one which will at least provide some step between the very theoretical work that has taken place on texture and the sort of thing that Bela Julesz and others have been doing.

Dr C.J. Woodruff.   Yes, although I must say that Caelli has recently been moving into two-dimensional textures and included in that very recently is some work where he has touched on natural textures.   So I think people have been laying the sort of element by element basis, but no-one's been tackling it all from diving in the deep end.   I think it might be time when fools will step in where angels fear to tread.

Prof G. Stanley.   I'm sure they'll have a good swim anyway.

Mr D.G. Nichol.   Just one comment Chris, I suspect that you'll have to look beyond Fourier transforms for your machine classification of texture.   At least in our experience, unless you get a very small local structure within the frame of view, all the energy gets concentrated in the DC region of the power spectrum and that's what we're going to be looking at and I think you might have to look beyond that to some other higher order processing rather than Fourier transforms except for very specific directional structures.

Dr C.J. Woodruff.   I think by averaging over many windows, we'll get some fair idea of the DC component anyway because you can subtract that out right from the start.

Mr D.G. Nichol.   I think you'll probably run into dynamic range problems which means basically if you saturate any of your signal your low frequencies are so strong you'll have to do some pre-processing;   perhaps, even before you look at images.

Dr C.J. Woodruff.   Yes, well you can't go to too high a frequency anyway because of the pixel separation of the pixels involved or what the human system can respond to.   So we can't use many frequencies on it.

COUNTERMEASURES TO THERMAL IMAGERS IN THE BATTLEFIELD

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ABSTRACT

A battlefield model has been developed specifically to study
the effects of countermeasures against thermal imaging systems. Emphasis
has been placed on modelling the performance of the thermal imagers in
detail to test the sensitivity of the battle outcome to the variations in
the type and level of the countermeasures used.

1. INTRODUCTION

The advantages of night vision devices in the battlefield are
apparent to all associated with the military environment. Also apparent
are the considerable advances made in the quality, ruggedness and portability
of such devices.

In parallel to these rapid advances in this technology, separate
although not isolated, groups of researchers throughout the world have
been devising countermeasures to degrade or even destroy night vision
systems.

Although countermeasures can be developed and their effectiveness
determined experimentally on a one-to-one basis, there is still a
requirement to determine their effectiveness in a complex environment,
ie a many-on-many situation, which arises in the battlefield.

In order to better understand this more complex interaction of
imagers and other battlefield elements a mathematical model of a battlefield
environment in which thermal imagers operate has been derived. The model
owes its existence to a cooperative programme between the USA, UK, Canada
and Australia, through TTCP Technical Panel QTP-10.

2. THE BATTLEFIELD MODEL

The battlefield model has been developed specifically to study
the effects of countermeasures against thermal imaging systems. Emphasis
has been placed on modelling the performance of the thermal imagers in
detail to test the sensitivity of the battle outcome to the variations in
the type and level of the countermeasures used. (See figure 1)

The model provides for the engagement of two (RED and BLUE)
opposing forces; no facility for the inclusion of fixed wing aircraft
exists. However, a helicopter is included which can carry air-to-surface
weapons or act as an observation post to provide information to other
weapon systems not equipped with thermal sensors.

3. USER INPUTS TO THE MODEL

The user provides inputs to the model which describe each
battlefield element. These are listed in figure 2.

4. TARGET CHARACTERISTICS

The user must provide the characteristics which describe the thermal characteristics of the target, that is how it appears on the battlefield to the various thermal imagers. These characteristics are:

T – the temperature of the target above background ($^{\circ}$C)

and H – the critical dimension of the target, which, for this work has been taken to be the height of the vehicle.

5. WEAPON CHARACTERISTICS

Although the thermal imagers and countermeasures to them are of prime interest in the model, it is important to represent the characteristics of other battlefield elements as realistically as possible. Consequently the weapon characteristics used are based on US and Soviet systems which exist or are likely to appear on the battlefield in the near future. The characteristics of the weapons represented in the model are shown in figure 3.

6. SENSOR CHARACTERISTICS

The performance of a thermal imager is described in the model by its MRTD curves. Where the imager operates with either a wide field-of-view (FOV) or narrow FOV, then the corresponding MRTD curves for both situations are included. A summary of the characteristics which must be supplied to the model are shown as figure 4.

The characteristics of some of the thermal imagers used in the model are shown in figure 5. These are typical of those in service, or destined for service in the future, for the USA and UK.

7. MODELLING THE THERMAL IMAGERS

The model of the thermal imager treats the case where a human observes for an optimum time the TV output of the thermal imager which is pointed in a particular direction. The imager is then pointed in a different direction for the same time interval. This process continues until a given search area has been covered. (See figure 6)

Upon detection of a potential target the coordinates are handed off to an appropriate fire control system. The fire control system observes and tracks the target until target recognition is obtained. At that time the weapon engagement sequence begins.

The model of the thermal imager is based on that developed by NV-EOL, Fort Belvoir in the USA. The model determines the perceived temperature difference of the target, at the imager, taking into account atmospheric attenuation. This temperature difference is then used as an input to an MRTD curve (see example in figure 7), which is essentially a performance curve for the imager. From this curve it is possible to extract the resolution of the target as presented to an observer. The resolution is determined as a spatial frequency; that is the number of resolvable line pairs per milliradian.

This information is then used to determine the probability of detection, and for this part of the model the methods proposed by Johnson of NV-EOL, which relate to the detection, recognition and identification of targets is used. The original model proposed by Johnson has been developed, updated and thoroughly validated by the Night Vision Laboratories.

Originally Johnson proposed that a target could be represented by an equivalent bar chart, having the same apparent temperature difference above background, and viewed under the same conditions. Further, he proposed that the ability to detect, recognise or identify the target is determined by the resolvability of the bar pattern, in particular the number of line pairs.

Johnson proposed 3 levels of perception

      1 for detection
      4 for recognition
      8 for identification

Field trials have indicated that more than 3 levels of discrimination are necessary and that the levels quoted here are also subject to some variation depending on the thermal scene. Typical levels of perception for different clutter environments are shown in figure 8.

8. ATMOSPHERIC MODEL

Part of the thermal imager model requires a knowledge of the prevailing atmospheric transmission, in the waveband $(8-14\mu m)$.

The model that we use is an empirical atmospheric transmission model for the $8-14\mu m$ band. It is based on LOWTRAN 5 for molecular absorption and on GAP data for aerosol attenuation. The program is written in FORTRAN, in the form of a Subroutine involving only 14 cards.

9. SUMMARY OF DETECTION MODEL

A flow chart showing the various steps in the determination of target detection is shown in figure 9.

In the flow chart P_∞ refers to the probability of detection given an infinite time. The probability of detection, $P(t)$, after time, t, has been defined by NV-EOL as

$$P(t) = P_\infty \ (1 - \exp(-P_\infty t/3.4\eta))$$

where η is the number of fields of view searched by the operator within his field of regard and
"3.4" is representative of the operators response; this is an average number based on NV-EOL field trials.

When determining whether detection has occurred a random number is drawn from a uniform distribution, lying between 0 and 1.

If r $\leqslant$ P_∞ , a detection occurs and the time of detection, t_δ, is determined by manipulation of the equation above. That is

$$t_\delta = -3.4 \ \frac{\eta}{P_\infty} \ \log_e \ (1 - \frac{r}{P_\infty})$$

If r $>$ P_∞ , no detection occurs.

10. COUNTERMEASURES

The model allows for inclusion and variation in the characteristics of the following countermeasures:

(a) camouflage;

(b) screen smoke;

(c) local smoke;

(d) active jammer.

The countermeasures are played in the model by their influence on various key parameters used in the imagers, target and environmental descriptions. For example, local and screen smokes are included as a reduction in atmospheric transmission, camouflage as a reduction in target to background thermal contrast and terrain cover as a combination of change in element size and a reduction in the target to background thermal contrast.

In the model two types of active jammer are considered

(a) **The manual jammer**

This is cued by a conventional thermal imager carried by say a tank; originally it was set up so that jammer is boresighted to main tank gun and used in preference to it; this doctrine has not proved successful and a new control logic will be investigated.

(b) **The automatic jammer**

This is cued by a smart sensor, which has high sensitivity and operated independently of the main conventional weapon system .

Jammer effectiveness is defined in the model by a kill probability, calculated from a subroutine which takes account of the laser jammer characteristics, that is

1. laser energy
2. beam divergence
3. wavelength

4. target range
5. atmospheric conditions which alter atmospheric transmission.

At present no facility exists in the model to simulate the effects of laser dazzle on imager performance. It is believed that in order to consider this topic it will be necessary to consider imager response in a more deterministic manner, as opposed to the probabalistic approach which has been adopted hitherto. Physics Division at MRL have already addressed this topic and it is expected that advantage will be taken of their expertise.

11. CONCLUSIONS

The model has been used in a TTCP simulation exercise, in which Australian and European scenario were considered. For these simulations a low clutter environment was chosen. Taking due recognition of the facts that results are certainly scenario dependent, and system sensitive the following were apparent:

1. Targets in defilade with small size and low temperature, needed little further signature reduction to significantly improve their survivability.

2. Mobile targets, suffering from larger thermal dimensions, needed considerable signature reduction to improve their survivability.

3. In the case of local smoke the critical parameter is the probability of detecting that a missile launch is imminent. Also of importance is that the time from threat warning to effective deployment of local smoke is as short as possible. The smoke duration has to be sufficiently long to defeat a missile fired from its maximum range.

4. The effectiveness of screen smoke depends on both the deployment time and duration of the smoke, and these obviously depend on the particular scenario. The advantage of screen smoke is that its effectiveness does not depend on threat warning, as in the case of local smoke.

5. The control logic used for manually deployed point jammer needs further consideration.

6. The automatic point jammer considerably improved the survivability of the force using the jammer.

7. It is very important to match countermeasures with one's own weapons taking into account the firepower of the opposing force.

More recently a limited number of simulations have been carried out with the European scenario, to investigate the effect of signature reduction (lowering Δ T) in a cluttered environment.

These results show that, in comparison to those obtained for a relatively low clutter environment

1. the survivability of targets in defilade is increased, for a lesser decrease in signature reduction.

2. the survivability of mobile targets is increased significantly in a heavy clutter environment, for a moderate reduction in signature.

BATTLEFIELD MODEL

Includes a description of battlefield terrain, battlefield elements of interest e.g. Tanks, APC, ATGM, Thermal Sensors and Countermeasures which may be used against these elements.

THERMAL SENSOR performance is defined using MRTD curves, together with target temperature (above surroundings), target size, atmospheric transmission, perception criteria.

COUNTERMEASURE options are LOCAL SMOKE, SCREEN SMOKE and CAMOUFLAGE played into the model through MRTD performance calculations, and POINT JAMMERS, i.e. laser damage or dazzle

TERRAIN MODEL is used to determine existence/ non existence of line of sight

    Method is optional

            - Probability curves for land and airborne vehicles

            - Stored contour map

Figure 1.   Description of Battlefield Model

INPUTS TO MODEL

WHICH DESCRIBE BATTLEFIELD ELEMENTS

Element   : Type

: Location, speed, direction

: Target characteristics

: Weapon characteristics

: Sensor characteristics

Figure 2.   List of Model Inputs

WEAPON CHARACTERISTICS

Type number

Minimum/maximum range

Requirement for line of sight

Reaction, reload time

Mean shell/missile speed

Maximum number of shells/missiles available

Enemy target types which can be engaged

Figure 3.   Definition of Weapon Characteristics

SENSOR CHARACTERISTICS

MRTD curves stored permanently
in model and selected as required

Field of regard (FOR)

Number of FOV in FOR

Maximum sensor range

Perception criteria

Figure 4.   Definition of Sensor Characteristics

1. SINGLE FOV (INFANTRY SIGHT) $9° \times 6°$

2. LONG RANGE TANK GUN $15° \times 9°$ / $5° \times 3°$

3. SHORT RANGE ATGW $26° \times 8.5°$ / $8.5° \times 3°$

4. LONG RANGE ATGW $9° \times 6°$ / $3° \times 2°$

Figure 5.   Imager types used in TTCP Simulations

IN FIELD OF VIEW

SCANNING SEARCH
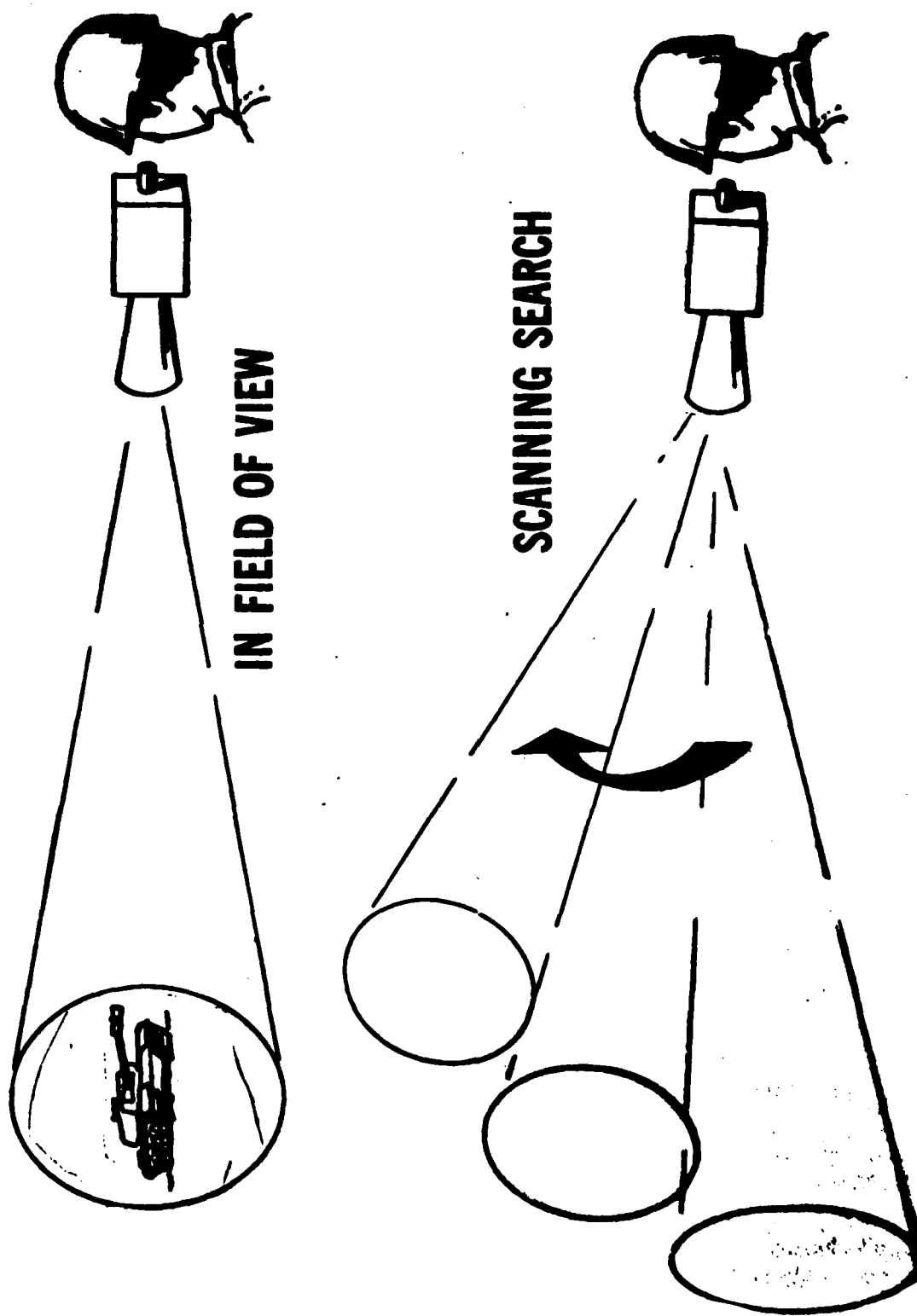
Figure 6. Search Procedure
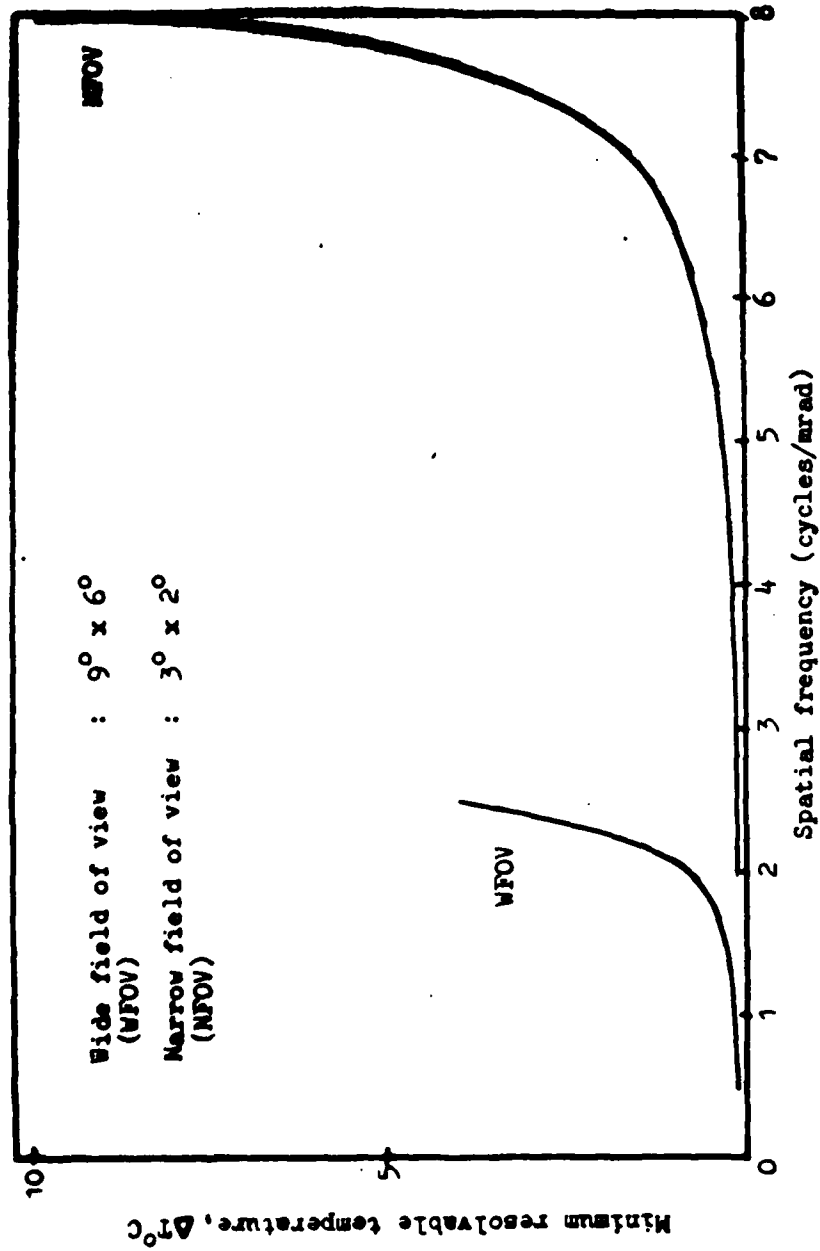
Figure 7. Medium/high performance thermal imager for long range anti-tank guided weapon system

TASK	$(N_{50})_d$
HIGHLY CONSPICUOUS TARGET (BRIGHT SOURCE, MOVEMENT, ZERO CLUTTER)	$\ll 1$
LOW CLUTTER (TARGET IN FIELD, ON ROAD)	1.0
TARGET IN MEDIUM CLUTTERED FIELD	2.0
HIGH CLUTTER (ZSU-23 IN ARRAY OF T-72'S)	3.0

Figure 8. Detection Criteria in various Clutter Backgrounds
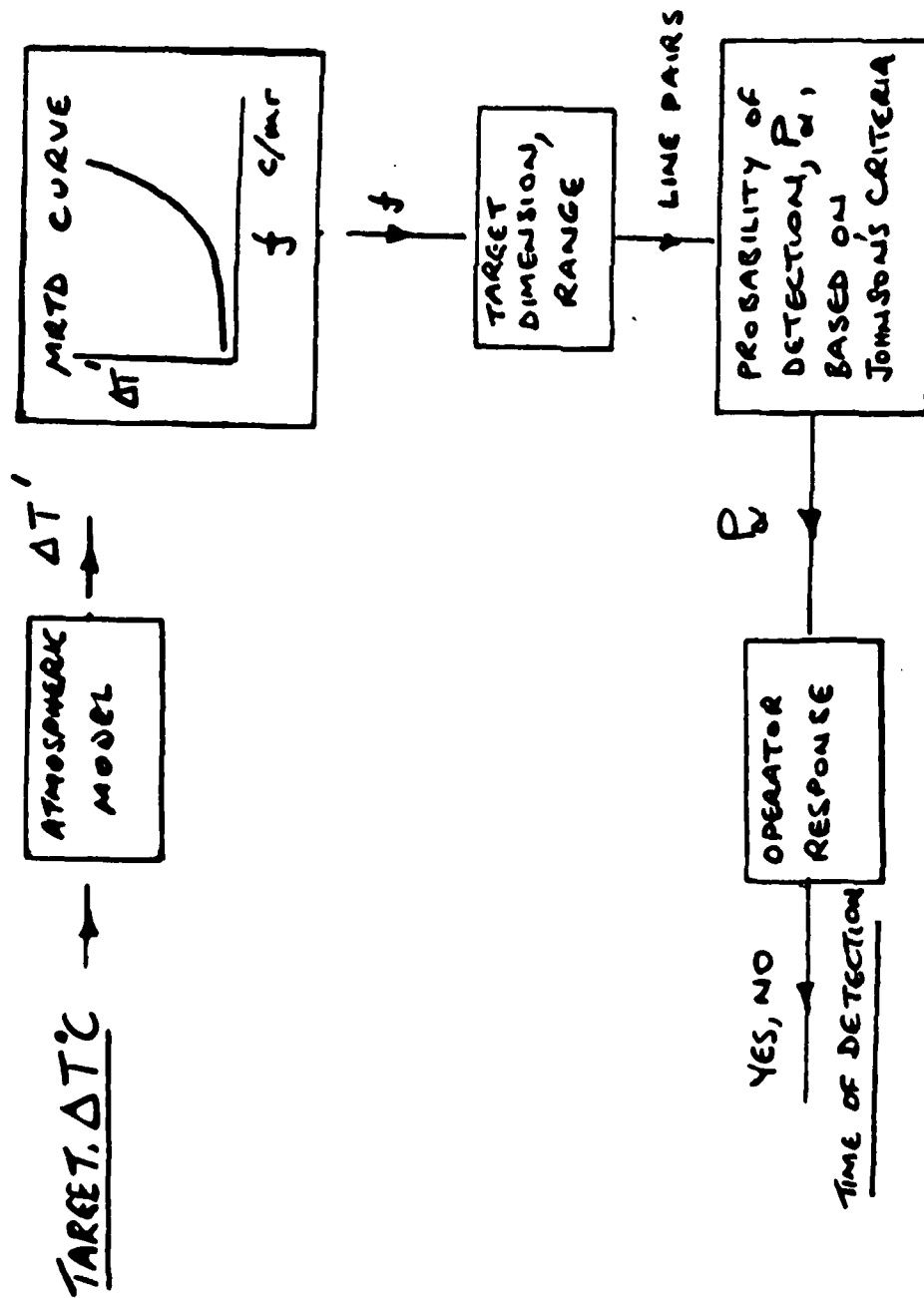
Figure 9. Detection Criteria in Model

TYPE	CLASSIFICATION	USE	PHASE
Camouflage	Passive/non-responsive	Army	1
Decoy	Passive/responsive	Navy	2
Local smoke	Passive/responsive	Army	1
Screen smoke	Passive/non-responsive	Army/Navy	1
Point jammer	Active/responsive	Army	2

Figure 10.   Countermeasure Types included in Model

LASER INTERACTION WITH THERMAL IMAGERS IN A
BATTLEFIELD MODEL

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ABSTRACT

Some extensions to the Electronics Research Laboratory (ERL)
battlefield model (J. Gardner's paper at this symposium) have been developed
to examine the role of lasers as a countermeasure to thermal imagers. These
extensions are mainly in the area of sensor characterisation, where the target
discrimination task is based on the signal-to-noise ratio associated with the
common minimum resolvable temperature difference (MRTD) curve, and target
tracking, where reaction times are based on established experimental work.

1. INTRODUCTION

This paper shows how laser interaction with a thermal imager can be
represented in a battlefield model. The battlefield model used to demonstrate
laser interaction is an extension of one developed at ERL (described by J.
Gardner at this symposium). The laser is assumed to interact with the sensor
at an intensity level that will degrade the image on the thermal imager's
display without causing any damage to the thermal imager system as a whole.
Image degradation is expected to affect both target acquisition and target
tracking by an observer.

The information flow chart of Figs. 1 and 2 gives an overview of the
data needed to drive the sensor model, and the context in which it will be
used. Figure 1 indicates that the model combines target characteristics with
atmospheric transmission parameters to give target acquisition parameters as a
function of range. Target acquisition involves a sequence of processes based
on these parameters and culminates in the detection of a target. The
detection process is a function of the minimum resolvable temperature
difference (MRTD) curve. The presence of a laser irradiating the sensor can
be regarded as an intrusion on the detection process which forms a part of the
overall target acquisition function. The target tracking function, shown in
Fig. 2, uses the same detection process to initiate and control cross-hair
movement. All these data are combined in the sensor model and manipulated to
produce results which can be summarised as probabilities of target acquisition
and tracking, and weapon kill probabilities. The flow chart sub-titles of
Fig. 1 and 2 will now serve as a basic outline for the remainder of this
paper.

2. TARGET CHARACTERISATION

The target characterisation block in Fig. 1 is illustrated by
Fig. 3. The target is assumed to have a signature temperature difference
ΔT which is reduced to $\Delta T^{\sim}$ at the sensor by atmospheric attenuation. The
sensor operates at a height H above ground level, and scans the predefined
search-field arc, SF, with a fixed field-of-view arc, FOV. As the sensor's
FOV scans the designated SF it may intercept a target, thus giving an observer
the opportunity to acquire it. The target subtends an arc, AST, at the
sensor, which is proportional to range or the distance from sensor to
target. The parameters SF, FOV, AST are defined in both azimuth and elevation
in the model.

3. ATMOSPHERIC TRANSMISSION

The model for the atmospheric transmission block in Fig. 1 is taken
from the ERL model [1]. The infrared radiation from the target is attenuated
by the atmosphere so that the target signature is reduced from ΔT at the
target to $\Delta T^{\sim}$ at the sensor. Atmospheric attenuation is caused by water
vapour and aerosols (smoke, fog, haze, etc). The water vapour component of
attenuation depends on atmospheric pressure, ambient temperature, and relative
humidity. The parameter describing the aerosol component is visibility
range. The model handles only broad-band absorption, and the appropriate
narrow-line absorption for laser radiation is not considered.

4. TARGET ACQUISITION

In the ERL model, the target acquisition process incorporates the
rate at which the sensor scans the SF with its FOV, the rate at which the
observer scans the sensor's display with fixations of the eye, and the
probability of target detection based on thermal imager MRTD curves. All of
these components are combined into one simple equation. However, in the MRL
model discussed here, the target acquisition process is sub-divided, and its
several components are implemented separately [2,3]. These components are
illustrated in the target acquisition block of Fig. 1 and can be conveniently
classified in two categories, namely waiting-time and detection. Waiting-time
deals with those aspects which delay the acquisition of a target, while
detection considers the role of the MRTD curve and signal-to-noise ratio (SNR)
in detecting the target.

4.1 Waiting-Time to Acquire a Target.

Target acquisition can be considered as four separate events with
time delays. The first event confirms a line-of-sight (LOS) between sensor
and target. A LOS event depends on the predefined battlefield scenario to
establish the possible times and places of target acquisition. The second
event occurs when a target appears in the display or field-of-view (FOV) of a
sensor, where the delay before a target appears will depend on the random time
intervals between changes to the FOV direction. In the third event a delay is

introduced as an observer scans the display with random glimpses until a glimpse falls within the ambit of a target. For the fourth event detection of the glimpsed target must occur, after which the target is assumed to be acquired. Events two, three and four are modelled by binomial waiting-time distributions and the method for implementing them is described below. A more detailed description of the four events can be found in sections 4.1.1 to 4.1.4.

The binomial waiting-time distribution is obtained from repeated independant trials that result in either a success with probability p or a failure with probability (1-p). The number of the trial on which the first success occurs is a random variable X which has a probability distribution given by

$$f(x;p) = p (1-p)^{x-1} \quad (x = 1,2,3, \ldots.) \qquad (1)$$

The mean of the distribution of X is called the average waiting-time and is given by $\mu = 1/p$. The cumulative probability distribution of X is given by

$$F(x;p) = 1 - (1-p)^x \qquad (2)$$

Where a waiting-time distribution is implemented in the model a value of p for the success of a trial is first calculated from parameters pertaining to an event in question. A random number r in the range 0 to 1 is then drawn from a uniform distribution. If $r < p$ then the specified event is assumed to have occurred. A tally is kept of the number of trials performed up to and including the trial where $r < p$, and following this event, the trial number is registered in a frequency distribution of waiting-time events. Both the frequency distribution of events and the proportion of successful trials are available for assessing the effect of a countermeasure on the average waiting-time of an event.

Each trial is assumed to occur at the end of a time increment called the glimpse period. This model assumes an increment period of 1/3 s, based on the average number of 3 glimpes or fixations per second by the human eye [3]. Waiting-time is therefore measured in units called glimpse periods.

4.1.1 Delays in Acquisition Attributed to the Predefined Battlefield Scenario.

The appearance of a target in a sensor's SF is an event fixed by the predefined battlefield scenario. Similarly, the availability a LOS between a sensor and its target is a predefined event that is conditional upon a target being in the SF of the sensor. These events are fixed by the scenario and will, therefore, determine the amount of time available to an observer in his acquisition task, and dictate the positions at which acquisition can occur. Some features that can be included in a scenario are as follows:

(a) Terrain contours, such as hills.

(b) The effects of terrain cover, such as trees, interrupting LOS to the target. If such objects are randomly dispersed over the terrain the probability distribution for obtaining a LOS is a function of range and object size. Not only can the probability for a LOS be obtained, but also a probability for the proportion of the target visible.

(c) Predefined target routes on the terrain which determine where a LOS
will occur between sensor and target.

(d) Predefined sensor and target speeds that fix the amount of time a
target remains visible to an observer.

4.1.2 *Average Waiting-Time Before a Target Appears in an Observer's Display, or in the Sensor's FOV.*

The direction of the sensor's FOV is assumed to change randomly
according to a waiting-time distribution. The average waiting-time is
determined by the amount of time needed by the observer to scan the display,
and the maximum slew rate at which the FOV can scan the SF without seriously
degrading the displayed image. Every time a change in the direction of the
FOV occurs, the new direction is randomly chosen from a uniform distribution
of directions within the SF.

4.1.3 *Average Waiting-Time Before an Observer Looks at, or Glimpses, a Target in the Display.*

This, again, is a waiting time random variable. The observer's eye
is assumed to scan the thermal imager's display at a constant rate of 3
fixations per second, where the fixations are uniformly distributed over the
display. The single-glimpse probability p_{sg} of the eye fixating on a target
is assumed to be given by Bailey's formula [3]. This is an empirical formula
derived from the experimental data from several independent sources, and
incorporates such effects as scene clutter, target size, and display size.

$$p_{sg} = 1 - \exp\left(\frac{-100 \log_e(10)}{G} \frac{a_t}{A_s}\right) \tag{3}$$

where

G = Clutter factor in the range 1 to 10,

a_t = Area of target on the display,

A_s = Screen area.

4.1.4 *Average Waiting-Time Before an Observer Detects the Target He has Glimpsed.*

Because target detection is a random process conditional upon a
target being 'glimpsed', it too will produce a waiting-time distribution. The
probability of detecting a target is obtained using the MRTD curve in
conjunction with the target characteristics ΔT and AST. The method for
calculating the probability of detecting a target is described in the next
section. The average waiting-time before a target is detected is only of the
order of two or three glimpses, because the probability of detection in most
cases is considered to be greater than 0.25.

4.2 The Detection Process.

In the above discussion target detection was the final event in a chain of conditional events. The first was that the target appeared in the SF of the sensor with a LOS between sensor and target. Next was the event where the target appeared in the FOV of the sensor. The third event occured when the observer's eye fixated upon the target in the display, and the final event happened when the target being fixated was discerned to be a target. For this final event the work of Rosell [4,5], which concentrates on the performance of the human eye in discriminating television images, is adapted to the requirements of the battlefield model.

4.2.1 Probability of Detecting Displayed Target Image as a Function of SNR.

Target detection on a thermal imager display can be shown [4,5] to be a function of the signal-to-noise ratio of the target image, given by

$$Z_D = (SNR_D - SNR_{DT}) \ , \tag{4}$$

where Z_D has the normal probability distribution $N(0,1)$,

SNR_D = SNR of the displayed target image,
SNR_{DT} = Threshold SNR at which the observer has a 50% chance of detecting a target when he looks at it.

4.2.2 Displayed SNR Derived from Thermal Imager Characteristics.

Rosell [4,5] showed that the displayed SNR is a function of ΔT and AST as follows:-

$$SNR_D = K \sqrt{\frac{\varepsilon}{k_D}} \ \frac{\Delta T\sim}{f \ Q(k_D f)} \tag{5}$$

where

K = Lumped Thermal Imager Constants,
ε = Aspect Ratio of the Target,
k_D = Required Discrimination Level (Johnson's criteria for detection, classification, recognition, identification),
$\Delta T\sim$ = Minimum Resolvable Temperature Difference of Target,
f = Spatial Frequency of the Target, where,
$\quad f = 1/(2000 \ AST)$ Cycles per milliradian,
Q = Aperiodic Noise Function of the Thermal Imager.

4.2.3 MRTD Curve as Measured in Laboratory.

The standard MRTD curve is measured in the laboratory using 4-bar charts of varying spatial frequency, where ΔT is found for each bar size. The following conditions are set when the 4-bar chart is used.

$SNR_D = SNR_{DT} = 2.5,$
$\varepsilon \quad = 7.0 \ =$ Aspect Ratio of Single Bar within a Chart,
$k_D \quad = 1.0 \ =$ Discrimination Level for Detecting a Single Bar.

Under these conditions (5) can be rearranged to give

$$MRTD = \Delta T\sim = 2.5\sqrt{\frac{1.0}{7.0}}\ \frac{f\ Q(f)}{K} \tag{6}$$

Typical MRTD curves are shown in Fig. 4. These MRTD curves can be used in conjunction with equation (6) to obtain a numerical solution for $Q(f)/K$. Then, for any target characteristics ϵ, f, ΔT, and value of k_D for the required level of discrimination, the SNR_D can be found for each of the probabilities of detection, classification, recognition and identification.

4.2.4 Laser Interaction with Thermal Imager.

A factor in the lumped thermal imager constants is the noise-equivalent-temperature-difference (NEΔT) which produces unity SNR at some point in the thermal imager electronics. This is easily measured in a laboratory.

A point laser source will produce noise at a point in the display, and wide-angle scattering of the laser beam within the sensor's optics will produce more extensive noise. The extent of the noise will be a function of the particular system and the measures taken to combat reflections.

Given that a laser illuminating a thermal imager will produce unwanted noise on the display, which affects the target image, the NEΔT can be measured with and without laser illumination and the displayed SNR modified as follows:-

$$SNR_{DL} = SNR_D\ \frac{NE\Delta T}{NE\Delta T_L} \tag{7}$$

5. TARGET TRACKING

Target tracking is the second area in which extensions to the ERL battlefield model have been made and these are illustrated in the target tracking block of Fig. 2. When a target has been acquired, a decision to engage it with a weapon follows. Before the decision to engage a target is made the observer moves the cross-hairs of the sensor on to the target. He then changes the FOV of the sensor from the initial wide angle to a narrow angle to facilitate recognition and tracking. The cross-hairs are brought to bear on the target to put them in the vicinity of the target after the change of FOV. To engage a target the observer must first recognise it and then anticipate whether or not it can be successfully tracked during the time it takes to lay ordnance on it, which includes time to aim and fire the weapon and flight time for the projectile.

Following the decision to engage, the weapon is subsequently set to aim at the target and fire. After firing, the sensor ceases to control an unguided weapon projectile, but with a guided projectile the observer tries to keep the sensor's cross-hairs on the target because they control the point of impact.

Crucial to the success of the whole tracking process is the observer's ability to detect the target and bring the cross-hairs to bear. If a laser interacts with the sensor after target acquisition, the detection rate is reduced and the probability of hitting the target with a projectile is also reduced.

5.1 Response Time to Bring Cross-Hairs to Bear on Target

Experimental evidence of human motor response times by Jagacinski et al [6], and Hammerton & Tickner [7], has been used in conjunction with the observations by Steinman & Kowler [8] of eye movements in pursuit of moving targets, to set up a tracking model under the following assumptions:

(a) A series of discrete cursor movements is required to bring the sensor's cross-hairs onto the target and keep them there.

(b) One cursor movement consists of a reaction time (RT) followed by a movement time (MT).

(c) Reaction and movement times are proportional to the index of difficulty, ID, which is given by Fitt's Law [6],

$$ID = \log_2\left(\frac{2 A}{W}\right) \tag{8}$$

where
    A = Cursor Distance From The Target,
    W = Size of the target,
and
    RT = 334 −   2 ID (ms), $\tag{9}$
    MT = 250 + 113 ID (ms). $\tag{10}$

(d) Movement velocity of the cursor is assumed to be uniform and is adjusted for the effects of anticipated target motion. Steinman & Kowler, [8] showed that when the observer expects motion the eye will anticipate the motion by initiating movement to the next expected target position. Movement occurs even when the expected direction of motion is unknown. The tracking model assumes, therefore, that eye movement is translated directly into a cursor movement of size (A+ΔA) in time MT, where ΔA is the distance the target is expected to move in time (RT+MT).

5.2 The Effects of Jitter and Target Oscuration on Tracking Performance.

The sensor's platform motion includes random jitter super-imposed on the current cursor position. This tends to frustrate the observer's efforts to keep the cross-hairs on the target.

Countermeasures obscure the target, and accentuate the effects of random jitter. They inhibit detection thereby depriving the observer of a point reference to which the cursor can be moved. When the observer is

deprived of a reference point, cursor motion is assumed to become erratic in both direction and magnitude, lowering the amount of time the cursor spends on the target.

Jitter is modelled by adding a random displacement to the current cursor position at every time increment. The observer reacts to the tracking error displacement in time RT and then commences to move the cursor onto the target in time MT. Corrective cursor motion can only be initiated when the target is detected. Once initiated, the corrective motion continues while the target can be detected, otherwise, both the speed and direction of cursor movement are randomly varied to simulate the erratic motion. Successful tracking of a target requires that the corrective cursor movements are able to counter the error displacements introduced by jitter and lack of visibility of a moving target.

5.3 Experimental Verification of Tracking Model Performance

The effects of random jitter on tracking performance described in section 5.2 are obtained from a heuristic algorithm. The heuristic nature of the algorithm requires experimental evidence for verification of the results, and this is provided by the work of Hammerton & Tickner [7]. They set up an experiment using a cathode ray oscilloscope, where a spot was moved from one side of the display to the other in about 10 seconds, while an observer tried to keep the cursor centered on the spot. The motion of the spot was random. At some time during the 10 second trial period the spot disappeared and then reappeared 2 seconds later. During each trial the total time the cursor was kept on the target was measured. These conditions simulate a tank moving at 60 km/hr across a sensor's FOV at a range of 1 km with periodic interruptions in the LOS to the target. The results of this experiment were as follows:

(a) With no obscuration the time on target was approximately 66%.

(b) Obscuration reduced the time on target by a period approximately equal to the time the target was obscured (2 seconds).

(c) Target recovery after obscuration was rapid (c.f. Fitt's Law (8)).

The performance of the tracking model is monitored with event counters. One counts the total number of glimpse periods over which tracking takes place, another counts the number of glimpses that the target was detected during tracking, and the third counter gives the number of glimpses that the cursor was on target. Thus, the proportion of tracking time that the cursor spends on the target can be found for visible and obscured conditions and compared to the experimental evidence [7] above.

6.   OVERVIEW OF THE BATTLEFIELD MODEL'S STRUCTURE

Figs. 5 & 6 show the basic block functions of a battlefield model and how they interrelate. The first block shown in Fig. 5 constructs the battlefield scenario. The next block repeats the battle scenario for a specified number of times, and the last block analyses the results. Inside the replication block, initial conditions are reset before sensor and weapon engagements are played. The sensor and weapon engagement block found indented in Fig. 5 is expanded in Fig. 6 to show a repetitive process, where a play of sensor engagements is followed by a play of weapon engagements for a predefined maximum number of glimpse periods. Within the sensor engagement box it can be seen that if the sensor has not acquired a target then the target acquisition model is played, else the tracking model is played. The target tracking model controls the weapon model by directing it in a predefined sequence of events that lead it to lay ordnance on a target.

7.   RESULTS

Contained within the data structures of the battlefield model are probability accumulators which record the occurence of events hitherto described. However, since the battlefield model is still undergoing software validation there are at present no dynamic results available. When validation is complete, a set of average waiting-times and the following conditional probabilities are expected to be available as a summary at the completion of each set of replications.

Pr [Search field	Replication Time]
Pr [Line of Sight	Search Field]
Pr [Field of View	Line of Sight]
Pr [Glimpsed	Field of View]
Pr [Detected	Glimpsed]
Pr [Acquisition	Detected]
Pr [Engage Decision	Acquisition]
Pr [Fire Projectile	Engage Decision]
Pr [Hit Target	Fire Projectile]

Meanwhile, a comparison of static detection probability versus range, with and without laser interaction, can be found in Fig. 7. The cumulative probability curves are for a tank in a front-on aspect to the sensor, and where the atmospheric transmission is assumed to 100%. For unity noise factor, N, the normal $NE\Delta T$ is implied, otherwise N represents a 5, 10, 50, or 100-fold increase in $NE\Delta T$ due to interaction by a laser.

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8. SUMMARY

Laser interaction with a sensor is expected to decrease the signal-to-noise ratio of a displayed target image and this will in turn affect the detection and *recognition processes*. The overall effect is expected to increase the time for target acquisition and decrease the time for which cross-hairs can be kept on the target. This latter effect is expected to decrease the number of kills of acquired targets. Thus the model described here together with measurement of NEΔT with and without laser interference should provide a simple method for the battlefield model to predict the acquisition and tracking performance of thermal imagers.

9.   REFERENCES

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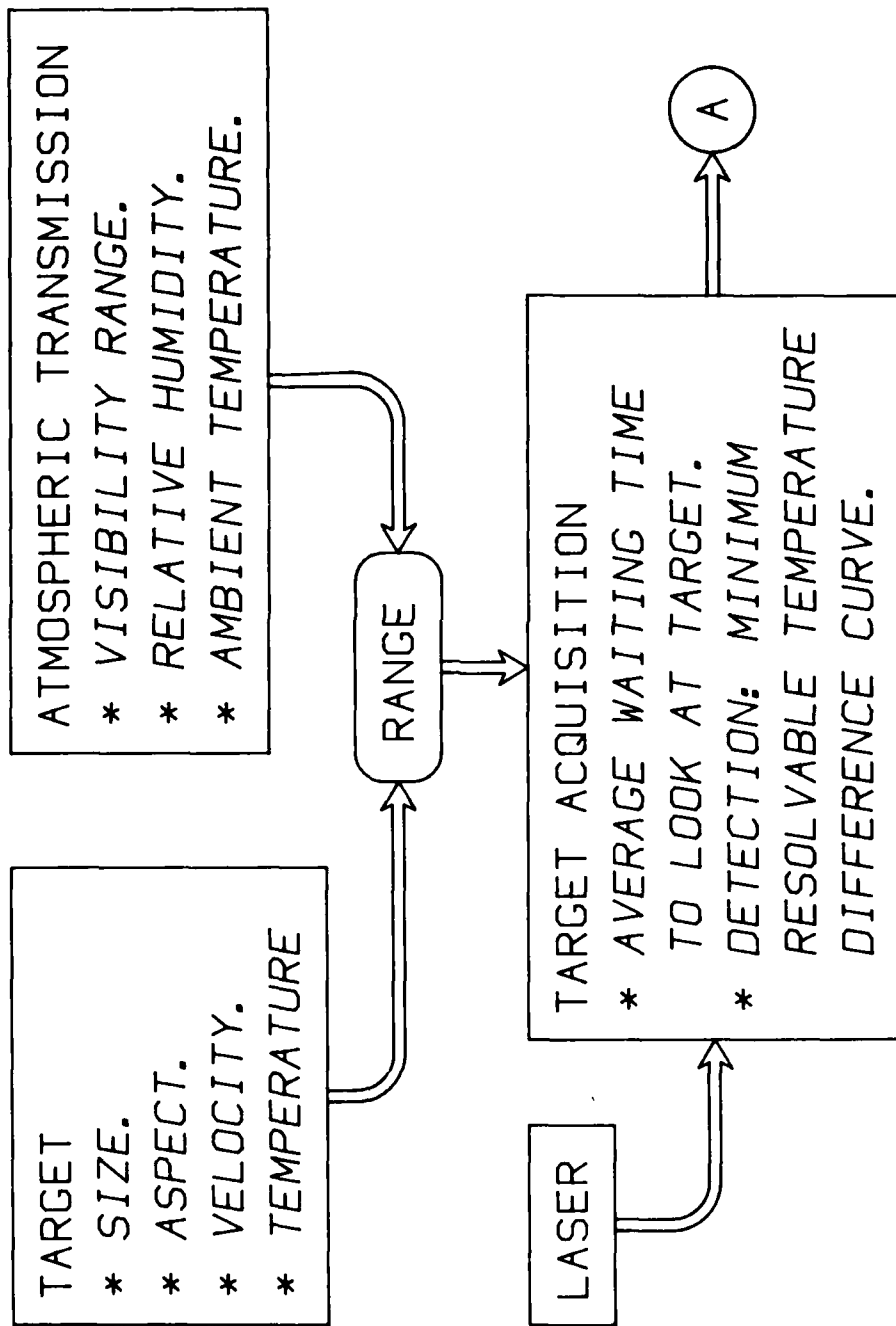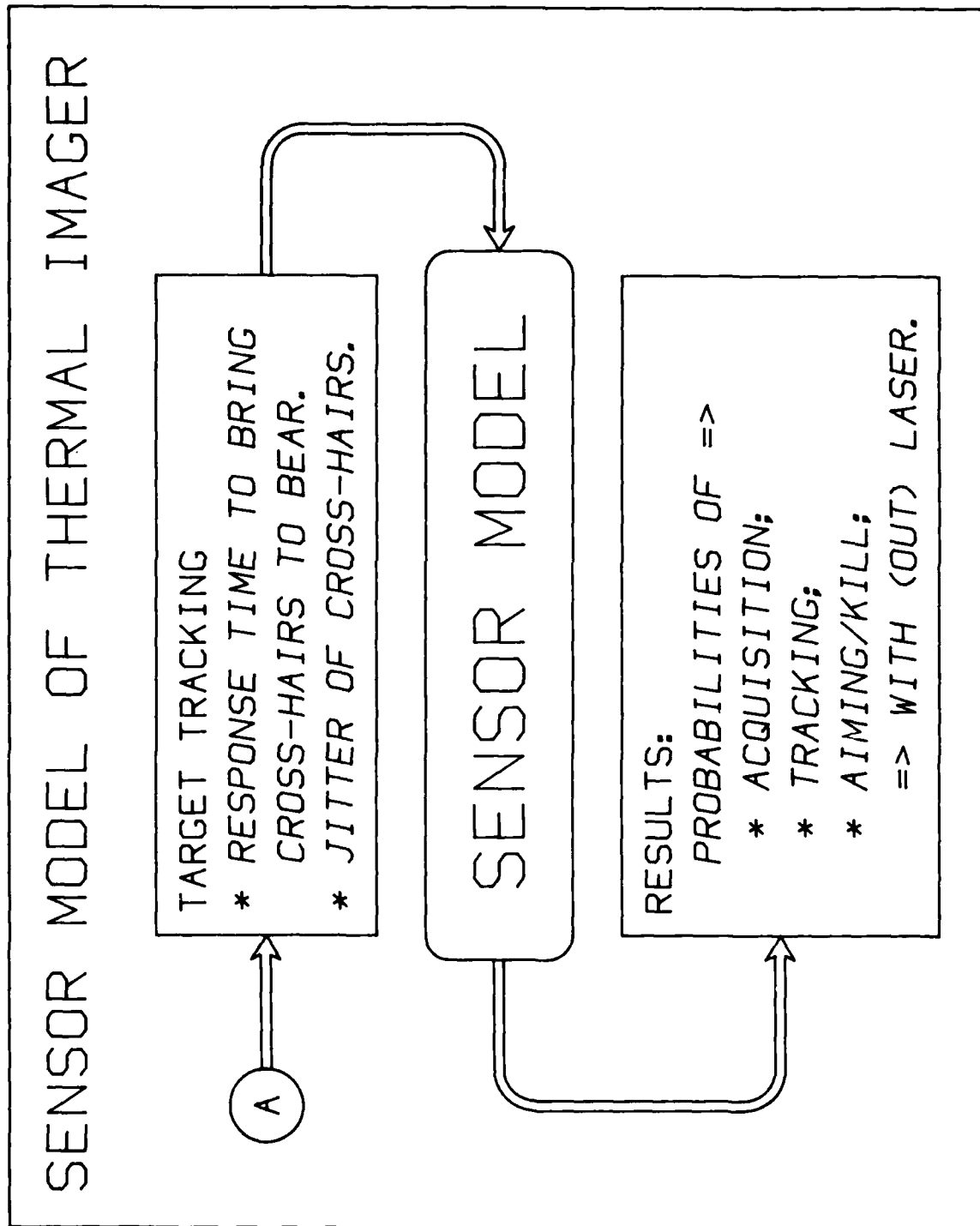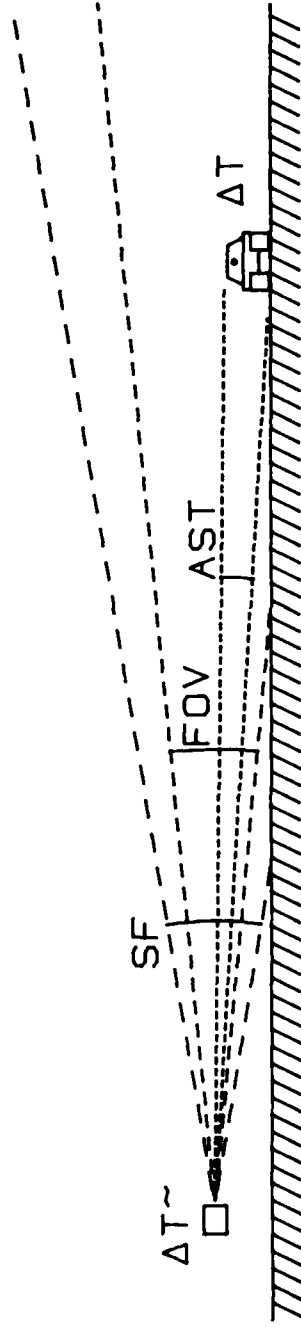
SENSOR MODEL OF THERMAL IMAGER

TARGET
* SIZE.
* ASPECT.
* VELOCITY.
* TEMPERATURE

ATMOSPHERIC TRANSMISSION
* VISIBILITY RANGE.
* RELATIVE HUMIDITY.
* AMBIENT TEMPERATURE.

RANGE

TARGET ACQUISITION
* AVERAGE WAITING TIME TO LOOK AT TARGET.
* DETECTION: MINIMUM RESOLVABLE TEMPERATURE DIFFERENCE CURVE.

LASER

A

FIGURE 1

SENSOR MODEL OF THERMAL IMAGER

TARGET TRACKING
* RESPONSE TIME TO BRING
  CROSS-HAIRS TO BEAR.
* JITTER OF CROSS-HAIRS.

SENSOR MODEL

RESULTS:
PROBABILITIES OF =>
  * ACQUISITION;
  * TRACKING;
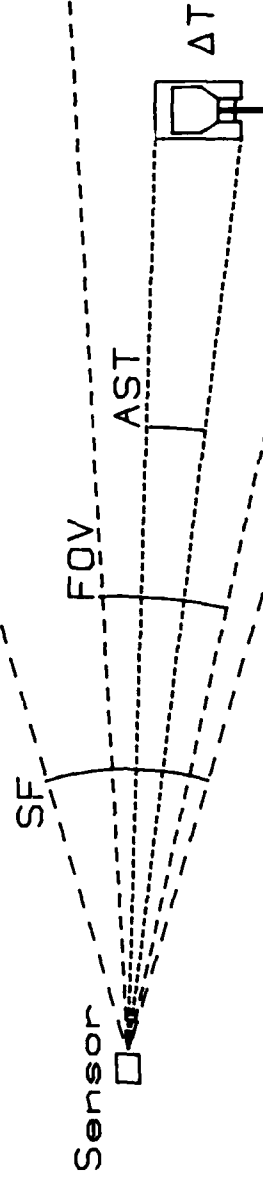 * AIMING/KILL;
    => WITH (OUT) LASER.

FIGURE 2

TARGET (CHARACTERISTICS)

SF = Search Field of Sensor.
FOV = Field-Of-View of Sensor.
AST = Angle Subtended by Target.

Sensor

H = Height of Sensor
Above Ground Level.
ΔT~ = Resolvable Temperature Difference.

FIGURE 3

TARGET ACQUISITION

* TYPICAL MRTD CURVES
  If AST (rad) => Angle Subtended by Target
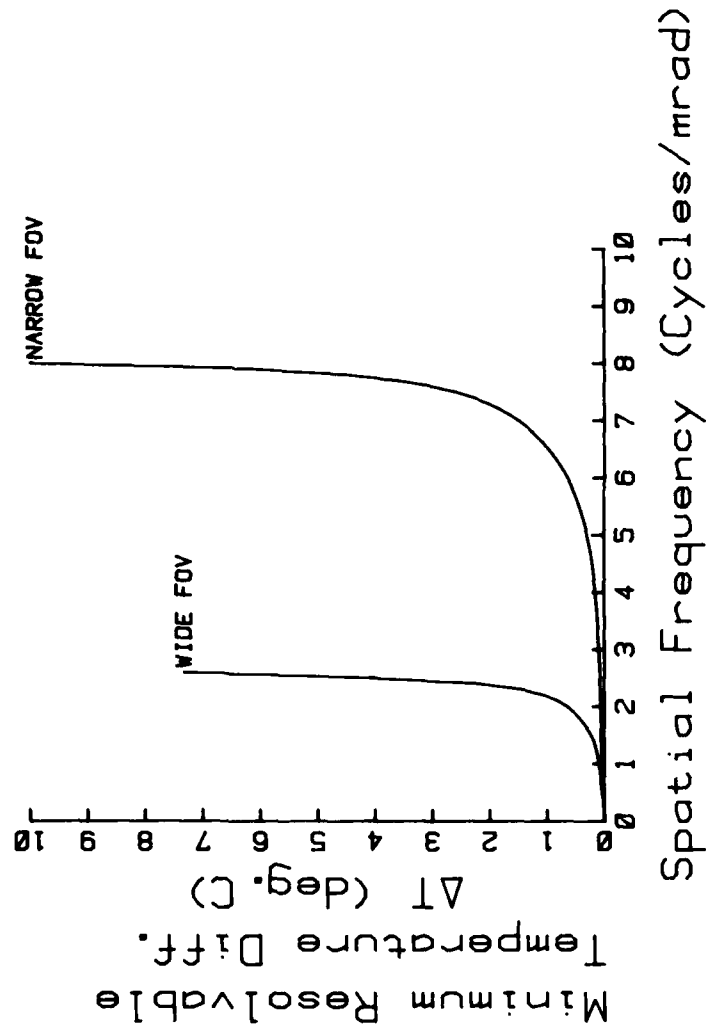 Spatial Fequency, f:=1/(2000*AST) (C/mrad)

FIGURE 4

SENSOR MODEL

* TO PLACE SENSOR MODEL WITHIN THE CONTEXT
  OF THE LARGER BATTLEFIELD MODEL.

INITIALISE BATTLEFIELD SCENARIO

FOR R TO MAXIMUM REPLICATIONS DO

RESET INITIAL CONDITIONS

PLAY SENSOR & WEAPON ENGAGEMENTS =>B

ANALYSE RESULTS

FIGURE 5

SENSOR MODEL

* TO PLACE SENSOR MODEL WITHIN THE CONTEXT
  OF THE LARGER BATTLEFIELD MODEL. => B

FOR GLIMPSE TO MAXIMUM GLIMPSES DO

> PLAY SENSOR ENGAGEMENTS
>
> IF SENSOR HAS NOT ACQUIRED A TARGET THEN
>
> > TARGET ACQUISITION MODEL
>
> ELSE
>
> > TARGET TRACKING MODEL
>
> FI;
>
> PLAY WEAPON ENGAGEMENTS
> (INCLUDING COUNTERMEASURES)

FIGURE 6

RESULTS

* COMPARISON OF DETECTION VS RANGE WITH/OUT
  LASER INTERACTION UNDER STATIC CONDITIONS.
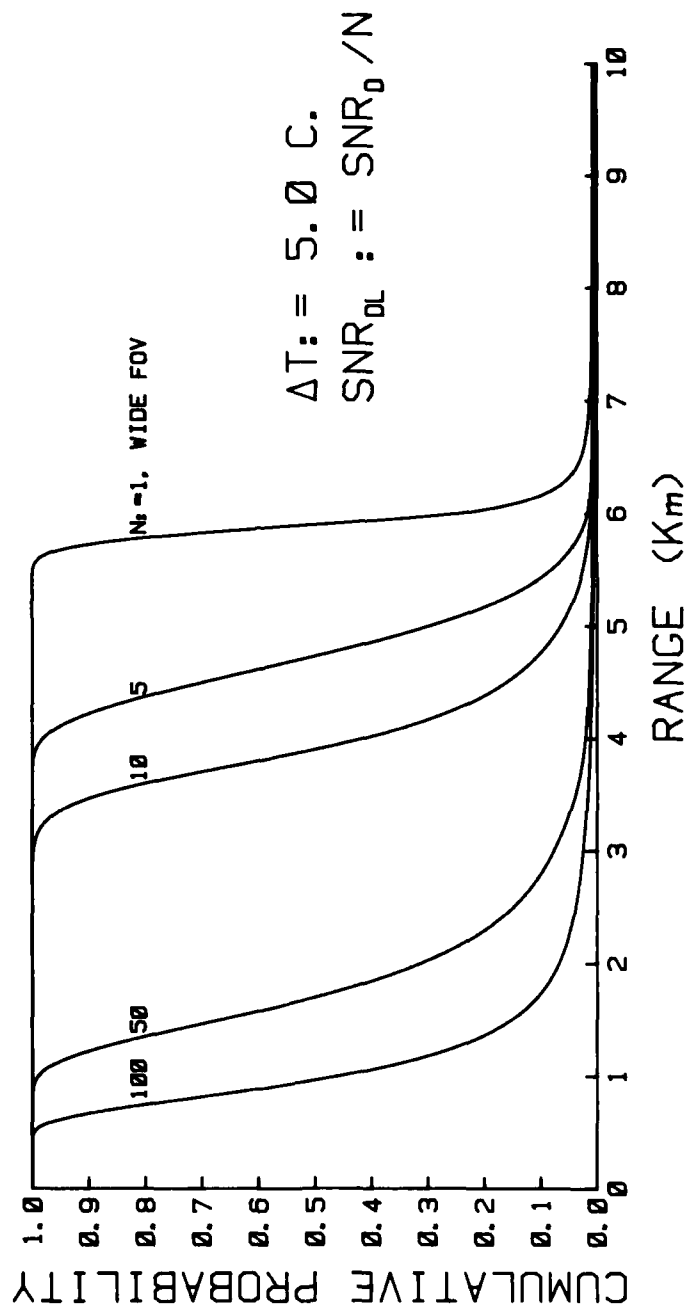 *(Dynamic results not yet available)*

$\Delta T: = 5.0$ C.

$SNR_{DL} := SNR_D / N$

FIGURE 7

TWO APPROACHES TO THE INSTRUMENTAL ESTIMATION OF DETECTABILITY

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ABSTRACT

Two different approaches are described to the problem of making a compact, portable device for the instrumental estimation, under field conditions, of visibility or detectability close to threshold. One instrument is a simplified veiling-glare visibility meter designed as an attachment to an SLR camera, and the other uses a novel technique for image spreading. Early experimental results are available for the former, and appear to be consistent with predictions. It is intended to establish which type of instrument provides the better correlation with detectability derived from multiple-observer trials.

1. INTRODUCTION

There is plainly an advantage to a combatant in reducing his visibility to the opposition. In modern warfare this implies not only being difficult to see in the conventional sense of the word, but also being difficult to recognize in an image produced from radiation at any wavelength. The objective of the research to be described is to provide a quantitative measure of the difficulty of recognition or detection either to the naked eye or to the eye assisted by optical devices or by wavelength converters such as thermal imagers.

Countersurveillance schemes are customarily compared by exposing them in each of ten or twenty different situations to each of up to two or three hundred different observers, and carrying out a statistical analysis of reported observations. This is clearly a costly and time-consuming process, particularly if the objects of interest are expensive to maintain and transport. Significant reductions could be effected in the development cost of countersurveillance systems if methods could be found to reduce the necessity for such trials, especially if it should prove feasible to bring the trials into the laboratory by the use of photographs. In this context, it may prove possible to use the technique developed by one of the authors [1] for producing photographs that combine scale-model vehicles with real scenery in a way that simulates the essential features responsible for the visibility of the original vehicles.

2. PRINCIPLE OF VEILING-GLARE METER

Most visibility gauges [2] have an optical system containing some means of degrading a visible image in a controlled manner. An observer uses this to look at a number of visibility standards, such as grids of various contrast, and notes the degree of image degradation which makes each standard undetectable. The same procedure is used to examine a subject image and to derive the amount of degradation necessary to make some feature, or the whole image, disappear. The gauge readings can then be used to interpolate the visibility of the subject among the known properties of the standards. Because the system is used only for interpolation, the results obtained should, in principle, be independent of the visual performance and perceptual criteria of the observer.

The common form of visibility gauge makes use of veiling glare, that is, of an overall uniform field of illumination that is added to the image of the subject. Usually, the brightness of the subject image is decreased as the glare is added, so as to keep the average illumination nearly constant. Where the visual task under investigation involves artifical illumination the veiling glare may be derived from a lamp within the gauge, a technique which leads to relatively simple designs [2]. For natural-light scenes, it is desirable to derive the glare from the subject itself, or to have some measure of automatic compensation for changes in the level and quality of daylight. A veiling-glare gauge clearly measures an effective visual contrast of the subject, independent of its size.

The principle of operation of the veiling-glare gauge to be described is shown in Fig. 1. The device illustrated is essentially a lens-erecting telescope having a focusing screen in the second focal plane. Within the objective lens are two ground-glass diffusing screens, which can be advanced to cover all or part of the aperture. Because these screens are at the entrance pupil, they behave similarly to an aperture stop, in that they reduce the amount of light available to form an image without themselves being imaged. However, most of the light intercepted by the screens is scattered to the image plane, to form the required veiling glare.

Preliminary experiments on the system of Fig. 1 showed that the image on the screen was not particularly sensitive to small movements of the scatterers along the optical axis, and it was therefore possible to position them outside the objective lens. This has the advantage that a commercial compound lens can be used, although the veiling glare generated by a simple two-scatterer mechanism in this position has marginal uniformity, and a more symmetrical geometry is desirable. The diffusing system actually used is similar in many ways to an iris diaphragm, and is shown in Fig. 2.

The practical form of the visibility gauge (Fig. 3) is relatively simple, since the viewfinder system of an unmodified SLR camera was used to provide all of the optics, and the diffusing diaphragm, with a micrometer read-out of leaf position, was placed directly in front of the objective lens. For viewing 35-mm transparencies, which include the visibility standards, use was made of a Fresnel lens having the same focal length as the camera lens, but a wider aperture.

An analysis of the operation of this device [3] leads to the conclusion that the relationship between instrument setting for extinction of a standard, and contrast of the standard, should be

$$\frac{b}{1 - b} = \frac{c - h}{eh} \tag{1}$$

where b is the fraction of potentially image-forming light intercepted by the diffusing diaphragm, c is the contrast of the standard, h is the threshold contrast for detection of a grid (at the spatial frequency of observation), and e is a geometrical factor. It would be expected that e would be constant, but that h would vary between observers at a given time, and would also vary from time to time for a given observer. However, plots of b/(1-b) against c should all be linear, with a constant (negative) intercept on the ordinate.

3.   RESULTS FROM VEILING-GLARE GAUGE

The factor b was calibrated as a function of diaphragm setting by measuring the amount of light transmitted through a pin-hole at the image plane when the camera was focused on a distant lamp. Standard-contrast grids were made by photographing strips of black paper on a white background with various amounts of under-exposure, to give negatives which were calibrated using a scanning microdensitometer.

Calibrations were made by a number of observers, after a little practice for familiarization with the device, and the results are shown in Fig. 4. The straight lines in this figure are least-squares fits, calculated using an algorithm that assumes the lines have a common, but unspecified, intercept on the ordinate. A set of independent linear least-squares fits was also calculated without this constraint, and an analysis of variance demonstrated that the change in variance was not significant.

The threshold contrasts for the observers, at the time of calibration, can be derived from the fitted lines according to Eq. 1. These were found to vary between 0.018 and 0.03, in good agreement with a published value [4] of 0.02 for the spatial frequency of the grids used.

It is clear from Fig. 4 that the experimental scatter of calibration points is somewhat higher than desirable, although a single standard contrast of around 0.25 could probably be used to define a calibration with adequate precision. This scatter can be attributed to three factors:

(i)   the extremely non-linear behaviour of the mechanism for opening the leaves on the diaphragm

(ii)   the fact that most measurements are made with the leaves nearly closed, which places stringent tolerances on the construction of the diaphragm, and

(iii)   the inexperience of the observers in psychophysical experiments.

It seems probable that future models of this instrument could be made to give less experimental variation by the use of a revised mechanism for the diffusing diaphragm.

Although this instrument has not yet been applied to the measurement of visibility in countersurveillance research, the calibration results give rise to confidence that visual contrast can be measured in the field using a simple portable instrument with a one-number observer calibration (the slope of the line). Unfortunately, there is not the same level of confidence that visual contrast measured in this way is a good correlate with detectability. Whilst there can be no doubt that it is one of the factors contributing to detectability, it may be that other factors, particularly angular size, are equally important.

4. IMAGE-SPREADING GAUGE

Because of this an instrument is being developed which measures a combination of image contrast and size. The idea is to have an optical system with a variable point-spread function, that is, a variable high-spatial-frequency cut-off to the modulation-transfer function. This would be expected to give a nearly constant average illumination, since virtually no light flux would be scattered out of the system. One way of doing this would be to take an SLR camera as before, but this time simply defocus the image. However, it would seem preferable to have a system that was capable of finer control and simpler analysis.

The principle behind an image spreading system can be demonstrated by considering a black surface containing two differently-sized white discs that are ideal Lambertian emitters. These are shown in cross section at the bottom left-hand corner of Fig. 5. It is relatively simple to calculate the distribution of light flux incident on any plane above the surface, and this is shown on the right-hand side of the figure. At the surface itself, the distribution of flux is rectangular, but at other positions the flux spreads out as shown. The peak flux in each of the distributions decreases as the plane of observation retreats, but it decreases faster for the smaller disc. It follows that, for a single disc, if the plane of observation is moved until a fixed threshold contrast is reached, the separation required will be a calculable function of both disc size and visual contrast.

It is proposed to use the controlled image spreading described above in an optical layout similar to that of Fig. 6. An objective, probably a standard camera lens, would be used to focus an image sharply on a ground-glass surface. This would represent the emitter in Fig. 5, and the flux distribution at a given separation would then be sampled by a second ground glass surface. This could form part of a prism-erector system, which would be followed by an eyepiece having the same focal length as the objective. When the two ground-glass surfaces are in contact, the observer will see an upright life-sized image with a slight loss of detail. Rigid translation of the objective and the first ground surface will then give the controlled image spreading.

Exactly what this instrument measures is a function of the shape of the subject. For a roughly circular subject, an approximation is

$$\ell^2 = k\Omega c \tag{2}$$

where ℓ is the separation for extinction, k is some constant, Ω is the solid angle subtended by the subject and c is the contrast of the subject. For a

long thin subject, the corresponding equation is

$$\ell = k\theta c \tag{3}$$

where θ is the angular width of the subject. It is not clear whether this sort of function should correlate with detectability, and the easiest way to find out is probably to try it. This instrument has not yet been built, and there are therefore no experimental results to report.

5. FUTURE WORK

It is planned to investigate detectability in a cluttered field by generating pseudo-random patterns on an oscilloscope screen, with one pattern element distinguishable from the remainder by virtue of its size or contrast. Detectability will then be measured directly, as that fraction of the large number of observers who can indicate correctly the position of the target element. Measurements will also be taken of each pattern using both visibility meters, and correlations measured. At the same time, it is intended that the two visibility meters will be used in all field trials associated with the MRL countersurveillance program, to give some measure of correlation of meter readings with observations under conditions approaching those likely to be met in practice.

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4.   A.P. Ginsburg, "Specifying relevant spatial information for image evaluation and display : an explanation of how we see certain objects", Proc. Soc. Inform. Displ. Vol. 21 (3), pages 219-227, 1980.
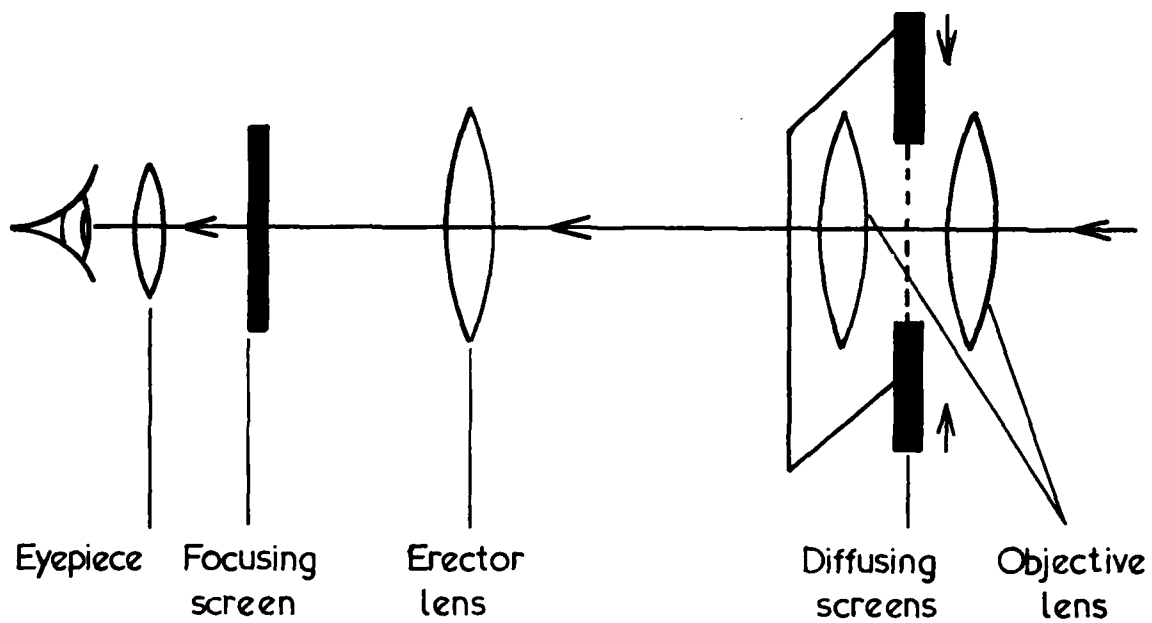
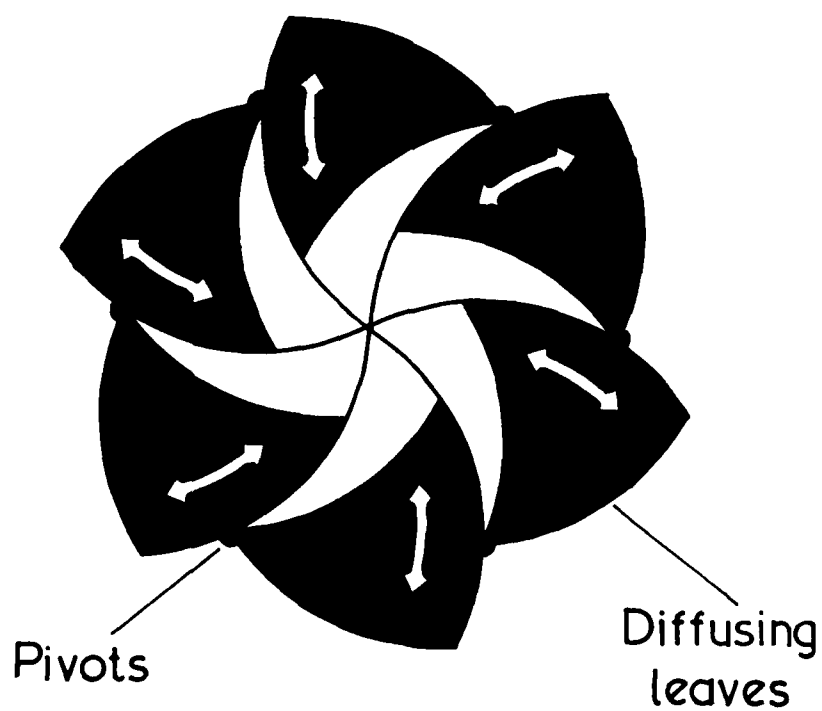Fig. 1.   Principle of operation of veiling-glare visibility gauge.
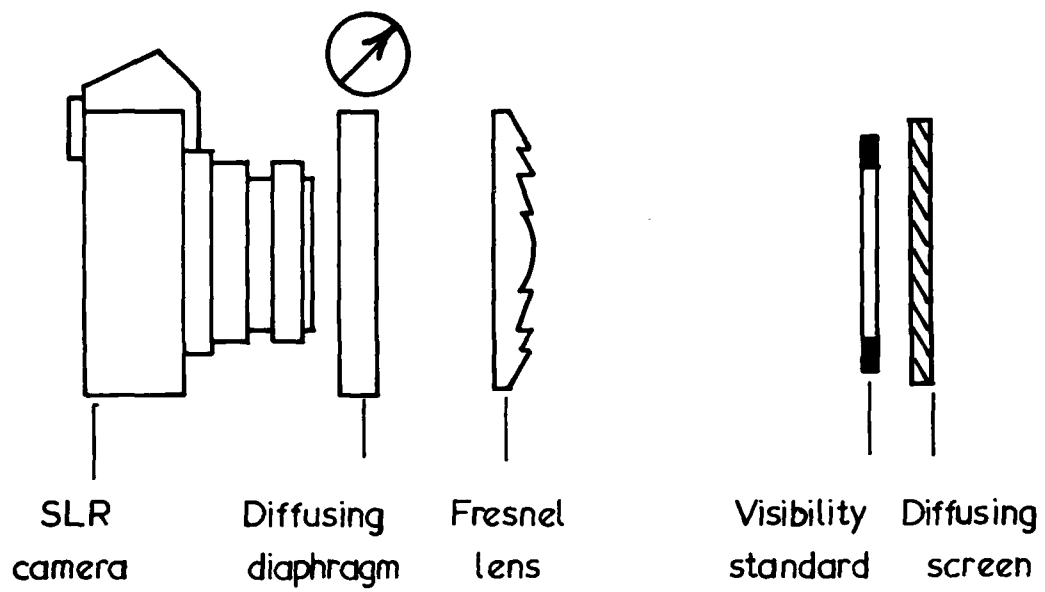

Fig. 2.   Geometry of diffusing diaphragm.

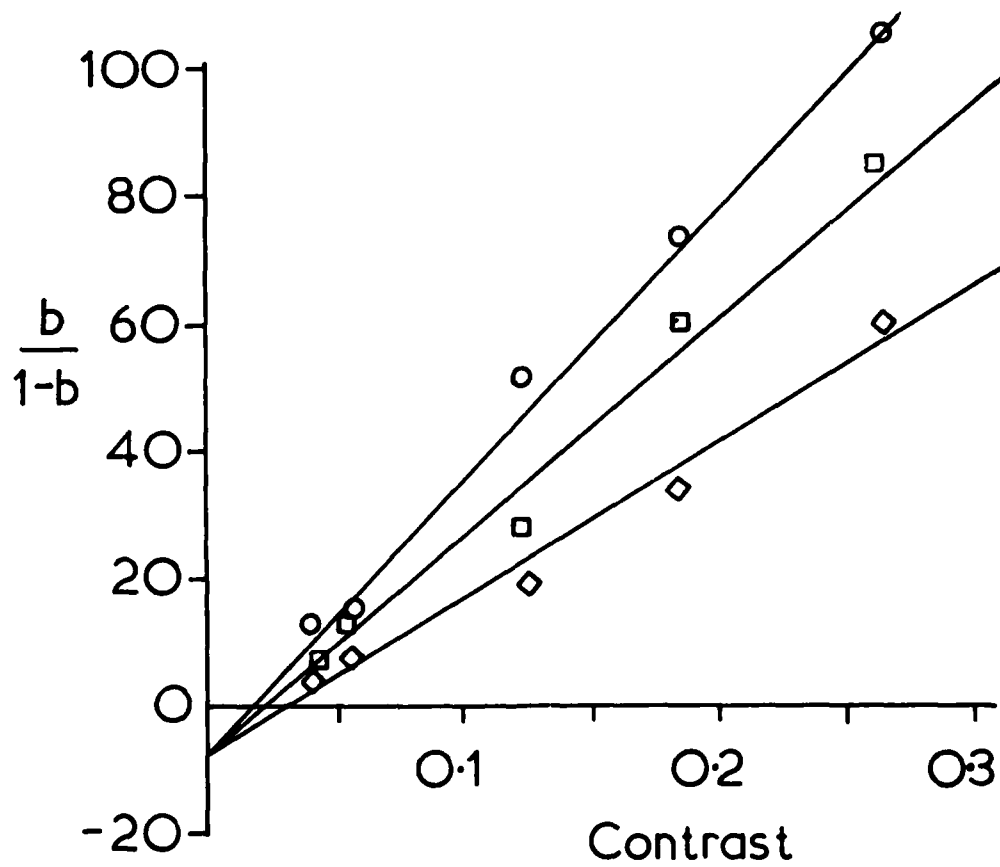Fig. 3. Practical form of veiling-glare gauge.

Fig. 4. Experimental calibration of veiling-glare gauge for three different observers.
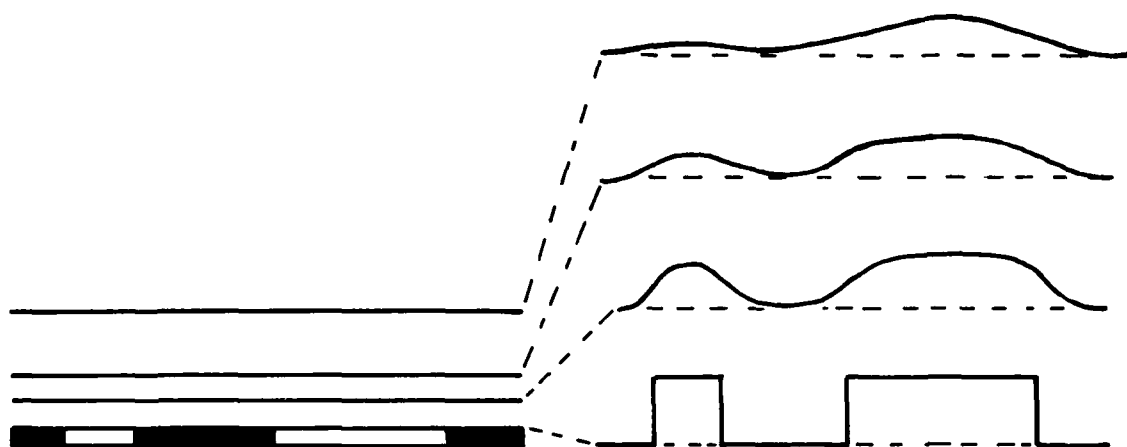
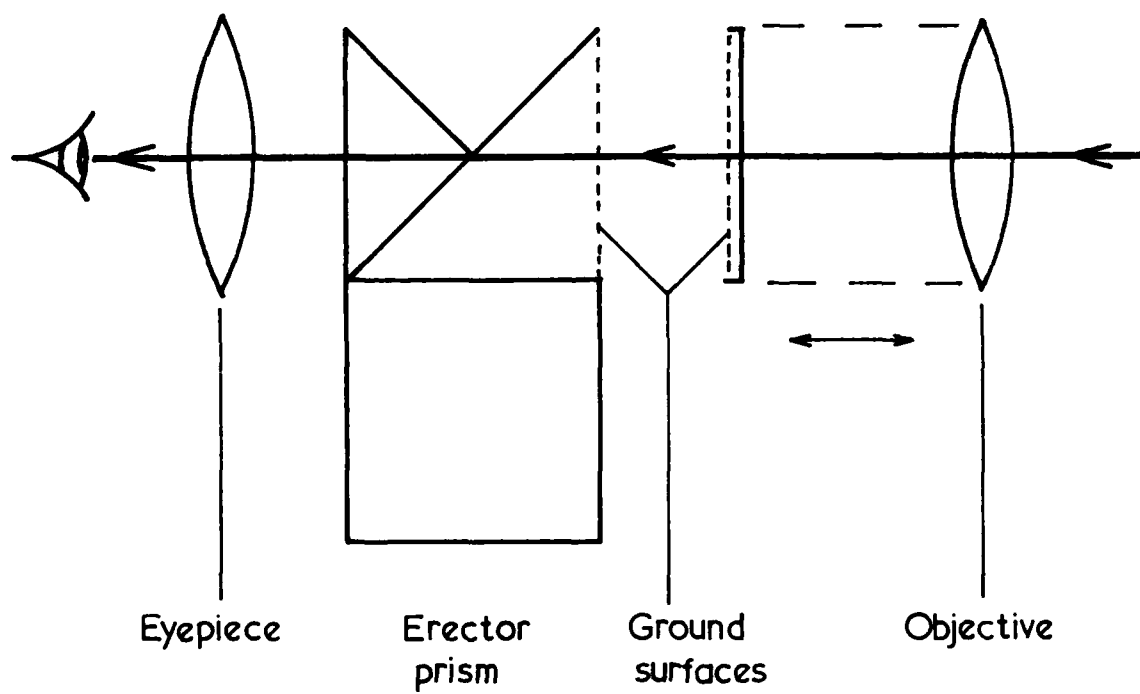Fig. 5.   Demonstration of principle of image spreading.

Eyepiece   Erector   Ground   Objective
                prism   surfaces

Fig. 6.   Proposed form of experimental image-spreading visibility meter.

MILLIMETRE WAVES - A PROBLEM FOR THE FUTURE

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ABSTRACT

An optically-pumped millimetre-wave laser which is being developed at MRL is described. Some of the proposed activities within the countersurveillance area for which the laser source is required are also presented.

Physical means of absorbing millimetre waves by materials are also briefly discussed. Some areas of countersurveillance technology in the millimetre-wave domain pertinent to expertise available in Physics Division, MRL, are outlined.

A.   MILLIMETRE-WAVE LASER

One of the new sources being developed at MRL is of the optically-pumped variety in which a low-pressure gas is excited by the output of a carbon-dioxide laser, with subsequent lasing of the low-pressure gas in the sub-millimetre or millimetre region. A schematic diagram, together with a simplified energy-level diagram, is shown in Fig. 1. There are a large number of wavelengths at which laser action has been achieved in the sub-millimetre to millimetre region. A variety of molecules have been used as the laser medium; some of the molecules which give relatively-strong laser action are shown in Fig. 2, together with their associated wavelength range. Laser action occurs on a number of discrete wavelengths within the quoted range. Fig. 3 is a more detailed diagram of the proposed laser system which is expected to produce millimetre wave outputs of about 100 mW using a CO_2 laser which delivers about 1 kW.

Some of the proposed activities within the countersurveillance area for which the laser source is required are shown in Fig. 4. The millimetre region is of primary interest for most of these activities, though investigations making use of scale models may require appropriate scaling of the wavelength down into the sub-millimetre region.

B. MILLIMETRE-WAVE COUNTERMEASURES

1. INTRODUCTION

This part of the paper outlines some areas of countersurveillance technology in the millimetre wave domain pertinent to expertise available in Physics Division, MRL.

Effective countersurveillance coatings can best be developed by a systems approach. Such an approach examines the object, determines which features contribute most to its radiation signature, and then decides the best method of changing their contributions. The method selected will probably combine optimisation of the design with selective application of radiation absorbing materials.

2. DESIGN

The analysis of echoes from complex shapes of objects is not too difficult because echoes from basic components interact in simple fashions to produce the overall echo. Reasonable estimates of the echo can be obtained through mathematical modelling.

A computer program has been published[1] which predicts the microwave echoes of simple shapes such as cones, wedges etc. The output from this computer program can be reduced to simple empirical rules to assist further analysis, and experimental scale modelling. These rules may also assist the Services in the interpretation of images derived from battlefield radars.

3. ABSORPTION

The problem of absorption of incident radiation by a medium can be divided into two parts:

a) the coupling of the energy of radiation into the medium, and
b) the absorption of radiation within a given thickness of the medium.

3.1 Coupling Techniques

Coupling of radiation energy through the surface of a material can be achieved in two ways. The material properties can be modified near the surface or the surface can be geometrically modified, for example by corrugating it, to provide the necessary impedance match. Matching is achieved by the latter method when the depth of the indentations approaches a quarter wavelength of the incident radiation. The short wavelengths of millimetre waves may enable this technique to be incorporated in the design of millimetre radiation absorbing materials.

100

3.2 Material Absorption

In classical theory absorption properties are determined by the dielectric constant and permeability of the medium. The dielectric constant of a material can be modified by addition of other materials, discontinuities or dipoles such as needles. The permeability of a material can be similarly modified by adding ferro or ferrimagnetic powders or small metallic loops.

Classical theory can be used to design an infrared or microwave absorbing coating optimized for particular environments. Relevant theory is readily available[2,3] and can easily be extended to enable practical design studies to be carried out.

3.3 Absorption Through Resonance

The absorptive properties of materials are very much increased when components of the medium resonate with the incident radiation. The resonating components are typically corrugations, small metallic needles or loops which act as dipole antennae.

3.3.1 Needle Systems: When the lengths of needles in a medium approach half a wavelength of the incident radiation resonance occurs and the radiation is strongly absorbed through its electric field component. The electric field is re-radiated and scattered, and the energy of the scattered field is absorbed by the dielectric. The dielectric losses are enhanced by the presence of discontinuities and impurities.

3.3.2 Loop Systems: Analogous magnetic interactions occur between radiation and loop antennae. The magnetic field of the radiation is strongly absorbed by the antenna, if resonating, and may be guided into an absorber, or re-radiated. The magnetic field component interacts preferentially with ferro and ferrimagnetic materials. The magnetic interaction cycles the ferro or ferrimagnetic material through a hysteresis loop and the energy absorbed by the material (apart from that dissipated in the antennae) is proportional to some power of the incident magnetic field strength. Such antennae may shield a metal plate from microwave radiation.

Some advantages in the way of improved efficiency and general microwave absorption properties may be achieved by mixing dielectrics and ferrites.

3.4 Quantum Theory

Quantum mechanics provides a more fundamental understanding of the nature of absorption processes and may show the way to thin absorbing paints. Millimeter radiation may be absorbed by free or nearly free electrons in solids and liquids, lattice and molecular vibration and rotation, and by switching of electron spins of crystals.

Quantum theory provides an order of magnitude estimate for the absorption properties of molecules, ferrimagnetics and some solids composed of three atom molecules.

The design of a millimetre wave absorbing molecule or substance may require the application of various quantum theory approximations.[3] These methods provide information on the magnetic and electric susceptibility needed to estimate their absorptive properties.

The complexity of the interaction of various approximations suggest that a pilot study is needed to determine whether effort should be applied in this field to develop a substance of interest to DSTO.
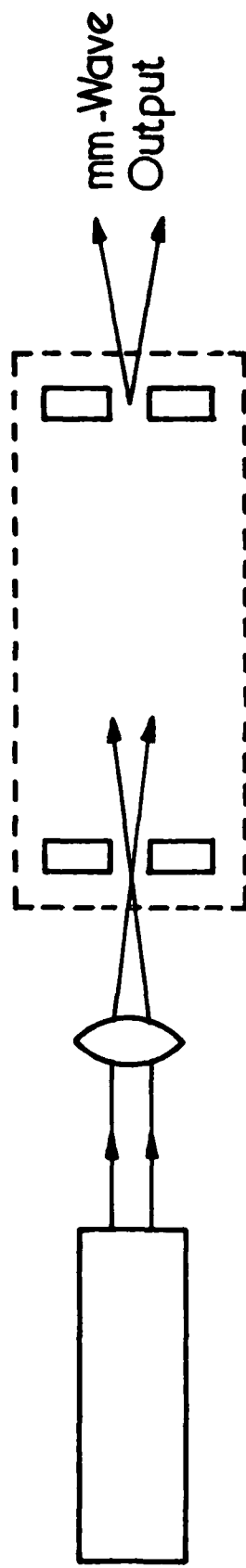
4.   CONCLUSION

The expertise available in Physics Division MRL, is pertinent to effort which could contribute to the three main areas of stealth technology outlined above. Such effort could comprise theoretical and experimental work aimed at

(a)   understanding and predicting the features of an object which dominate echoes in the millimeter domain

(b)   developing practical absorption coatings based on resonating/scattering electric-magnetic systems, and

(c)   understanding more fully the extent to which quantum theory can assist in the development of new materials able to absorb millimeter waves efficiently.

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OPTICALLY - PUMPED mm-WAVE LASER

mm-Wave
Output

mm-Wave Laser

CO₂ Laser   Lens

EXCITED VIBRATIONAL STATE

GROUND VIBRATIONAL STATE

λ mm-Wave

$\lambda_p \simeq 10\,\mu m$
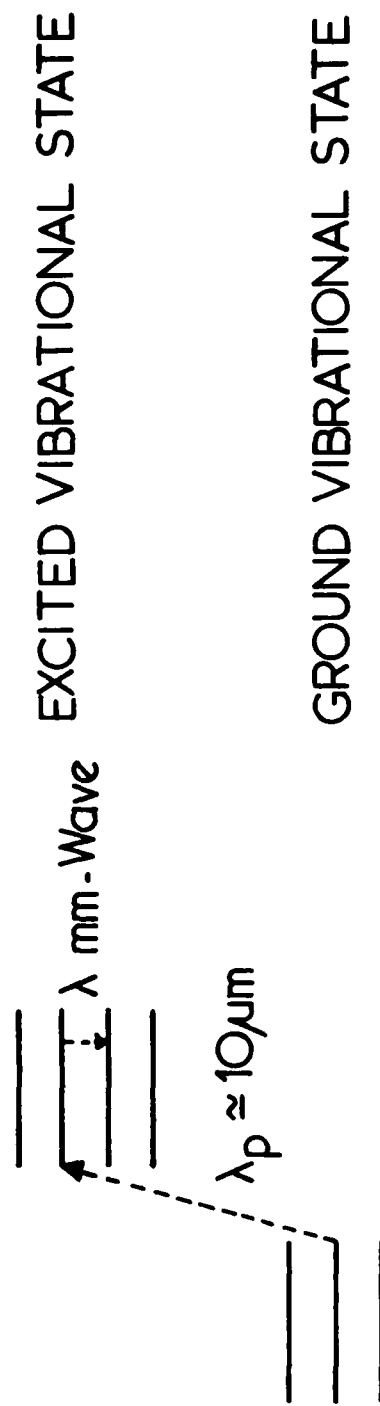
Fig. 1

MOLECULE	WAVELENGTH RANGE (mm) (Strong Lines)
CH_3F	0.19 – 1.22
CH_3OH	0.12 – 0.39
CH_3Cl	0.33 – 1.89
CH_3Br	0.26 – 1.97
CH_3I	0.38 – 1.25
HCOOH	0.31 – 0.58
$C_2H_4(OH)_2$	0.06 – 0.70
COF_2	0.48 – 1.90

Fig. 2
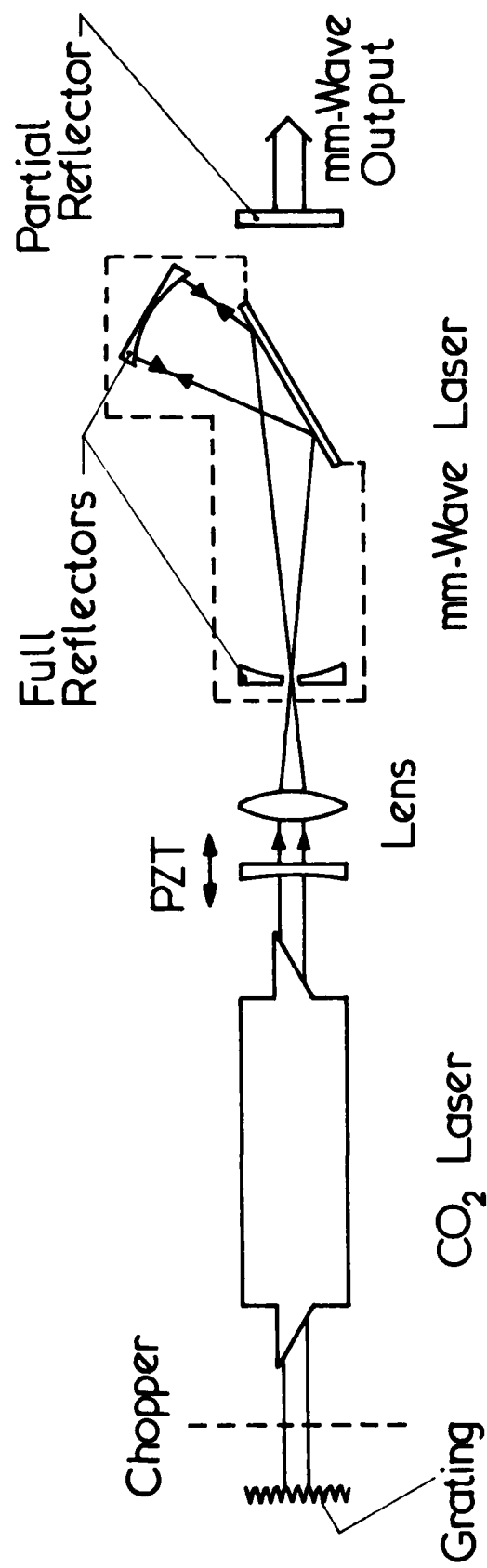
PREDICTED OUTPUT : CO_2 Laser $\approx$ 1 kW

mm-Wave Laser $\geqslant$ 100 mW

Fig.3

mm-WAVE COUNTER-SURVEILLANCE

1. Reflectometer Measurements :
   Reflective properties of various natural, constructional and coating materials.

2. Imaging :
   Slow, crude imaging system for static scenes to form images relevant to mm-wave camouflage situations.
   Shorter wavelengths and scale models may be used.

3. Psychophysical Experiments :
   Experiments on recognition and detection carried out on above images.

4. Image Processing :
   Image processing techniques presently being developed for visible and IR are applicable.

Fig.4

SESSION 4 - DISCUSSION

Mr M. Meharry. What was the source of the signature reduction characteristics used as an input to this model?

Mr J.G. Gardner. It came from other members of the TTCP panel in particular from the UK (RSRE) and the USA (Night Vision Laboratories). I think you have to remember that this was a TTCP exercise and that signature characteristics may not be wholly realistic. In the short term the panel is more interested in seeing that the model ticks over properly and produces what the panel thinks is a sensible result. Panel members use the model with their own data to carry out their own studies. This is why we want to work closely with Owen Scott, of IOC group, and to find out what sort of signature reduction we can achieve and then play this back into the model.

Maj D. Puniard. (To T. Pietsch) In both your model and Mr Gardner's model one of the premises, or one of the prime requirements, is intervisibility between the sensor and the target. Has there been any attempt to make use of real Australian digital terrain data in the way of contours and vegetation cover in the model?

Mr J.G. Gardner. We haven't gone too far but we have the facility to put in the actual contours. As far as vegetation is concerned, we have to play that in the model more as a background effect. This is done through the number of line pairs that are required for detection and recognition. Intervisibility data, including effects of vegetation is data we would love to get hold of.

Maj D. Puniard. There is digital data available for Australian maps.

Mr J.G. Gardner. Including vegetation effects?

Maj D. Puniard. Well the method of collecting the vegetation data may not be suitable for the model, I don't know.

Mr T.D. Pietsch. We did some work on simulated vegetation data where we measured the diameter of the object and its range from the sensor, or rather its density over the whole scene, in number of objects per square kilometre and we obtained a very simple formula for the probability of line of sight, which you can apply to most types of vegetation cover. The results of some work done at DRCS on the vegetation density in the Beaudesert region were used in the formula to see what results it gave, and it doesn't take a significant density of objects to interrupt the line of sight, something like 300 metres for a medium object density. So what you're talking about, in the context of the model, falls under the first probability that I described in the acquisition model. When you're talking about laser interference, the first probability can be set to 1.0 in the model without affecting the expected results. However if you want to consider a probability of line of sight in the model, then its only effect is to reduce the probability of target acquisition and therefore extends the acquisition time.

Mr J. Robinson. (To T. Pietsch) I know John Gardner has got to wait for World War III before he can validate his model but I'm just a little uneasy about the sort of assumptions that have been stacked up on one another. What are your plans for validating these models?

Mr T.D. Pietsch. None at the moment. I've tried in every aspect of building this model based on ERL's model, to get experimental results which I can say, "Yes this is what other people have got", and in doing so I am in effect validating the model. The critical parameter in any battlefield model is time and if you can go up to the man in green and say, "Is this a reasonable time to expect to acquire a target", and the battlefield model says "Yes, we're getting these typical times out", then we can say that the model is reasonably accurate. We must remember that these models are probability models and they rely on random events and you've got to run them a lot of times to get a probability of what's going to happen.

Mr J.G. Gardner. You can't really validate a battlefield model in total. I think you have to be very careful how you formulate and how you use these models. I prefer to see them used to look at relative effects, rather than absolute effects, anyhow. I think you can go a long way towards validating the various elements in the model, and the Night Vision Laboratory (detection) model, I believe, has had a lot of work put into it for validation. The other thing is we can, of course, keep our eye on experimental work that's going on and see if in fact we can tie, say, on a one-to-one basis, the effects of smoke against fixed targets. The main problem, of course, in our work is getting hold of Army thermal imagers to use in our work. If anyone here would like to lend us one now and then, we'd be very grateful.

Dr C.J. Woodruff. On this point about modelling, I wonder whether what's needed is not so much reliance on all this experimental data. That's good, but far more, some idea of the stability of the predictions of the models to the variations in those input parameters. So that if we find, for instance, that such things as the search strategy has changed from one procedure to another, we'd know how the predictions of the models change. If fixation times aren't three every second, they're in fact four every second, how much have the predictions of the model changed? If obscurations of a certain density change your contact range by a certain amount, how much does that change the predictions of the model? Isn't it going to be a far more valuable model if it's got that sort of tolerance/knowledge built into it?

Mr T.D. Pietsch. Well I don't think so. The number of times needed to run a battle in the computer model to reduce the statistical variation expected in the estimates of probability to an acceptable level is very large. In view of this, uncertainties in input parameters of the model are likely to be swallowed up in the statistical variation. With the number of runs currently being used to obtain results, the statistical variation is proving to be comparatively large.

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