AD-A010 709

EVALUATION OF LLLTV AND OTHER VISUAL SURVEILLANCE TECHNIQUES FOR VTS APPLICATIONS

Douglas W. Kay

Coast Guard Research and Development Center
Groton, Connecticut

January 1975

169102

Report No. CG-D-43-75

ADA010709

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Final Report

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22151

Prepared for

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D.C. 20590

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-43-75		AD-A010 707

4. Title and Subtitle	5. Report Date
EVALUATION OF LLLTV AND OTHER VISUAL SURVEILLANCE TECHNIQUES FOR VTS APPLICATIONS	January 1975
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Douglas W. Kay	CGR&DC 3/75
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
U.S. Coast Guard Research and Development Center Avery Point Groton, Connecticut 06340	744522.01
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Department of Transportation U.S. Coast Guard Office of Research and Development Washington, D.C. 20590	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Coast Guard Vessel Traffic System (VTS) monitors the flow of vessel traffic within certain harbors and waterways. The addition of visual surveillance to the existing radar and radio communication VTS capability had been proposed. To determine the effectiveness of visual surveillance in a harbor environment an ISIT type low light level television (LLLTV) camera system (Cohu, Inc., Model 2856) was evaluated at the R&D Center for this application. Also, other alternative visual surveillance systems were briefly considered, including SIT and intensified isocon type LLLTVs, laser-gated TV, and forward looking infrared (FLIR). It was concluded that restricted visibility, limited resolution of TV imagery, and the presence of many intense light sources in the field of view at night makes visual surveillance impractical in a harbor environment by rendering it least useful when surveillance is most needed.

PRICES SUBJECT TO CHANGE

17. Key Words	18. Distribution Statement
Vessel traffic system, VTS, low light level television, LLLTV, visual surveillance	Document is available to the public thru the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	18	$3.25/2.25

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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1.0 BACKGROUND

The watchstander in a VTS (Vessel Traffic System) operating unit relies primarily on radar and radio communications to track vessels within the system. Occasionally, when a vessel enters a harbor without identifying itself, or drifting buoys or debris enter a controlled area, the watchstander is unable to identify the radar return. To attempt to aid the watchstander in these instances and to possibly provide additional information on weather conditions and sea state, a visual surveillance system tailored to the needs of VTS has been proposed.

The purpose of this report is to give the results of the Research and Development Center's evaluation of LLLTV (Low Light Level Television) in general, and specifically the Cohu, Inc., Model 2856 LLLTV camera for this particular application, and to discuss briefly alternative visual surveillance systems.

2.0 SUMMARY

The results of the evaluation of LLLTV indicate that this mode of surveillance has only limited usefulness in a harbor environment due to restricted atmospheric visibility, limited resolution of the TV system, and the presence of many intense light sources in the field of view at night. These restrictions render the system least useful when it is most needed. Its use is not recommended in a harbor except for surveillance of a relatively small area where illumination can at least be partially controlled.

3.0 EQUIPMENT LIMITATIONS

3.1 System Sensitivity.

The ISIT (intensified silicon intensified target) vidicon tube installed in the Cohu Model 2856 camera requires $2x10^{-6}$ lumens-ft^{-2} of light for a usable TV image. For blue-green light (500 nm) this represents only 13 photons of light per resolution element per TV frame time. The camera is thus operating at the photoelectron noise limit and further image itensification is not possible. When using the 10:1 zoom lens (f 2.8), the minimum scene brightness required is then $7x10^{-5}$ foot lamberts. To obtain this brightness from a scene whose reflectance is 10 percent (twice sea water) an illumination of $7x10^{-4}$ lumens-ft^{-2} is required. Considering natural illumination only, a moonless night, even when clear, does not provide adequate illumination. At least a crescent moon (lunar phase of 60° from new moon) on a clear night, or a gibbous moon (lunar phase of 120° from new moon) on a cloudy night, is required to provide the required illumination. It is evident that if night-time surveillance is required 100 percent of the time at least some artificially produced lighting is required. Most large cities have an adequate amount of sky glow due to street lighting for camera operation, but in rural areas either auxiliary lighting or larger aperture lens will be required. Currently the largest aperture zoom lens which is available for TV application with automatic iris has an aperture of f 1.3 and a cost of $3500 (Cannon USA, Inc., Model

V8X15R-ND). Use of this lens with the Cohu camera would extend the system's sensitivity to starlight conditions, but the size of the lens requires extensive redesign of the camera's weather-tight enclosure.

3.2 Blooming.

(a) Contrast in the Night Scene. The biggest problem encountered when using television surveillance at night in a harbor located in or near a large city is not the lack of light but the extremely high contrast due to the presence of many bright sources of light within the field of view of the camera. For an example, assume the Cohu camera is at maximum zoom (150 mm focal length) and is viewing a nighttime scene illuminated by a quarter moon in which there is a 100 watt light bulb at a distance of one mile. With the 300 line resolution of the camera the contrast (ratio of brightness) between the image of the lamp and the background would be $2x10^6$ (two million) to one. The ISIT tube has a dynamic range of 10 grey scales, or a contrast of 32 to 1. Above this contrast bright images will bloom to a size considerably larger than the actual image; and at two million to one, extreme picture degradation results, obliterating other images within the field of view. Figures 1 through 4 show this nighttime blooming effect on a typical live scene. The scene which the LLLTV camera is televising is outlined in Figure 1. It covers a range of distance from 0.1 mile to the fence in the foreground to 3 miles to the hills in the background. The TV image of this scene in daylight is shown in Figure 2, and at night in Figure 3. Note that in Figure 3 the lights in the scene have caused the automatic light intensity control in the TV camera to reduce the camera sensitivity. In Figure 4 the automatic circuitry was disabled and the sensitivity was manually set to maximum. While this does bring out some of the lost background imagery, the blooming of the lights in the scene renders most of the image useless.

(b) Blooming Mechanisms.

(1) Contrast Dependence. There are two mechanisms of blooming in an ISIT camera system. At contrasts of 32 to 2000, blooming is caused primarily by the silicon diode matrix target of the ISIT tube. At contrasts of 2,000 to 10,000, the blooming is generated mostly in the lens and in the fiber-optic faceplate between the intensifier and the SIT vidicon. At contrasts above 10,000 damage to the image surfaces can result.

(2) Target Blooming. In normal operation the photoelectrons striking the target generate positively charged holes in the n-type substrate of the target. These holes normally travel to the nearest reverse biased p-junction of the diodes in the matrix where they are recombined. The charge pattern thus left on the diodes is then scanned with an electron beam to develop the video image. In the overload condition caused by excessive contrast of small bright images, the photoelectron flow creates so many holes in a small area that the diodes become forward biased and then repel the excess holes. These are then forced to recombine at other diodes outside the overloaded area. This outward spreading of charges causes the resultant video image to become substantially larger. The R&D Center measured the increase in image diameter

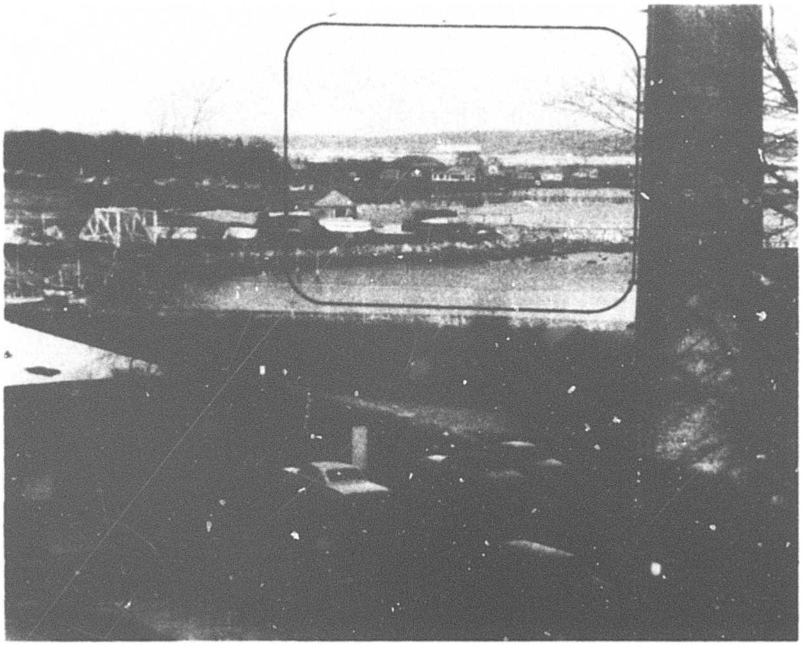

Figure 1. Scene being televised.

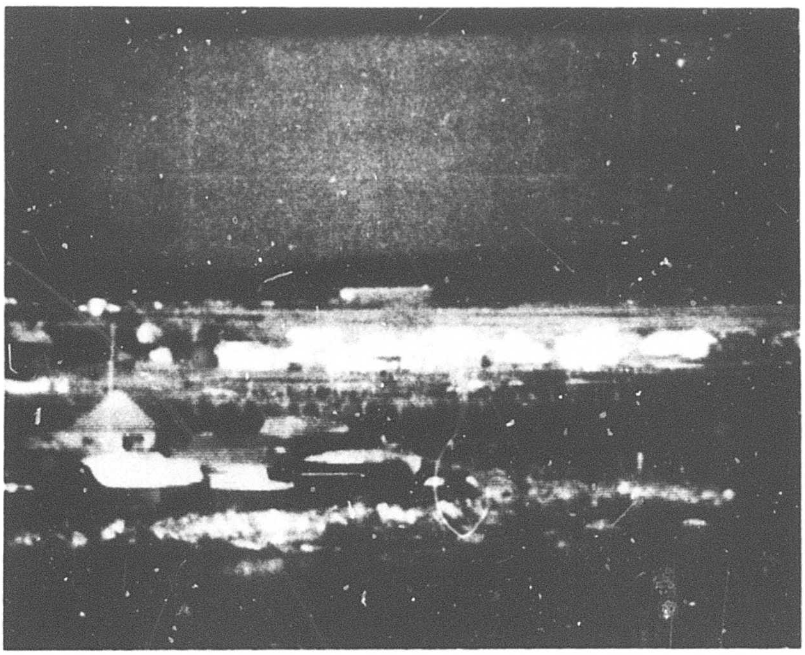

Figure 2. TV image of scene in daylight.

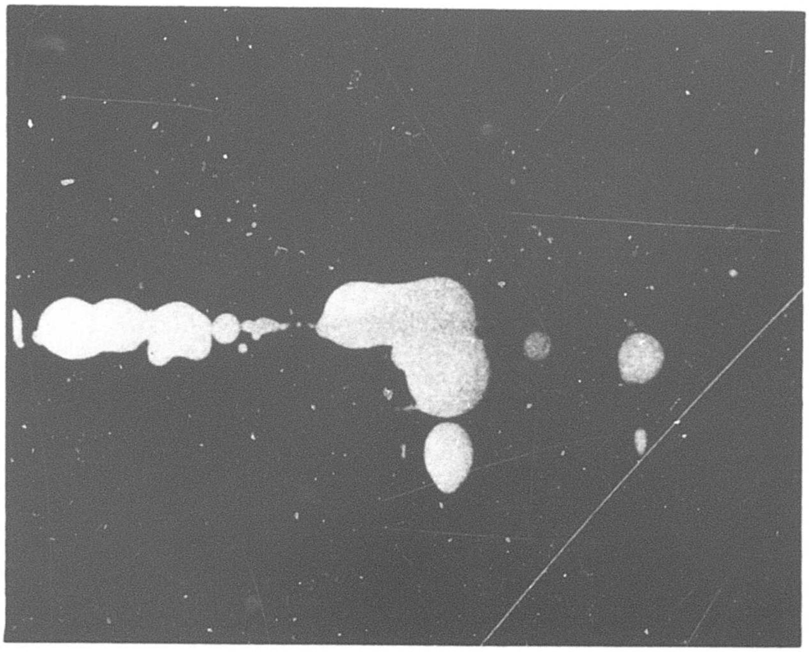

Figure 3. TV image of scene at night.

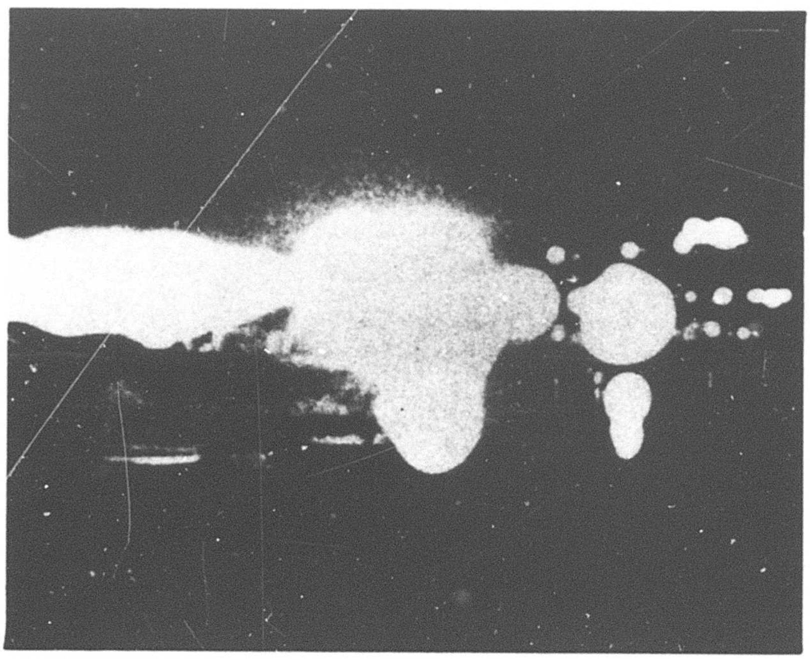

Figure 4. TV image of scene at night with camera's automatic intensity control circuit disabled and sensitivity set at maximum.

due to blooming as being a logarithm to the base 5 of the contrast above the overload point. At a contrast of 2000 this results in a bloomed image approximately six times the size of the actual image.

(3) Lens Blooming. Blooming in the lens is due to dispersion of light through the optical path and is a function of color. The zoom lens has a higher degree of dispersion than a fixed focal length lens due to the higher number of lens elements. At a contrast of 10,000, blooming due to a fixed focal length lens results in approximately 12 times increase in the diameter of the resultant image. Blooming in the zoom lens was not measured, but will be somewhat greater.

(c) Automatic Light Intensity Control. Cameras using ISIT vidicons are almost always provided with some means of automatically controlling light intensity because of the narrow dynamic range and poor overload response of the ISIT tube. The automatic circuitry also protects the image surfaces from excessively bright highlights. In the Cohu system, brightness at the image surface is controlled by a filter wheel as well as a motorized iris on the lens. Further control is achieved within the ISIT itself by varying the intensifier gain. When the contrast of bright images becomes severe, the bloomed image becomes a sizable portion of the total video (as in Figure 3). The automatic circuitry, responding to average video level, senses the large white area and reduces the light by closing the iris and adjusting the intensifier gain to compensate. While this protects the image surfaces from damage due to the bright sources, it also washes out any dimly lit background image. Operation of the Cohu camera with the automatic circuitry disabled is possible (as was done in Figure 4) but risks damage to the ISIT tube if contrast becomes excessive. With the automatic circuitry enabled, the Cohu camera is virtually immune to damage except by direct exposure to the sun for an extended period of time. At the R&D Center the camera was pointed at the sun for 20 seconds without damage. The R&D Center did not attempt to determine the actual time required for damage to occur. The ISIT tube was later accidentally burned during field testing apparently when a power outage occurred at night when the lens iris was open and the lowest density position of the filter wheel was in place. Before power was restored a bright light source in the scene created a spot of reduced sensitivity (burn) in the ISIT tube because the automatic circuitry was disabled by the power outage.

3.3 Resolution.

The resolution of the TV image produced by the Cohu camera is a function of the lens iris and is significantly poorer in the picture corners than in the center. The measured resolution is as follows:

Screen Location	Iris	Resolution (TV lines)
Right edge + corners	Closed	270
Left edge + corners	Closed	300
Center	Closed	400
Right edge	Open	170
Left edge	Open	200
All corners	Open	150
Center	Open	320

The field of view of the lens at maximum zoom (focal length 150 mm) is 4.6°. Assuming a resolution of 400 lines, this is 0.69 minutes of arc per resolution line. The human eye has a resolution capability of 0.5 to 1.0 minutes of arc. Thus the Cohu system, even at maximum zoom, offers practically no resolution advantage over the human eye in daylight. At night, however, the human eye response degrades to approximately 10 minutes arc while the camera changes to 0.79 minutes as the iris opens.

4.0 PSYCHOPHYSICAL LIMITATIONS IN TARGET RECOGNITION

Because of the multitude of variables involved, experimental results vary greatly whenever psychophysical limitations of human observers are considered. Therefore the prediction of the human response to line scanned (i.e., television) imagery can only be approximated. In discussing the human reaction to visual information there are three responses which are of concern. These are:

Detection - The observer correctly decides that something of interest exists in the field of view.

Recognition - The observer correctly classifies the detected object into its proper grouping (i.e., ship, buoy, sail boat, etc.).

Identification - The observer correctly indicates the specific object within the group or class of objects (i.e., the ship SS HARBOR QUEEN, Buoy #14, etc.).

In general, experimental results have shown that the detection of a target having 18 percent contrast requires that the target be subtended by at least four scan lines, and the recognition of a target requires at least 20 scan lines. This data was measured using military vehicles as targets on a uniform background with no noise. Also, measurements performed at the R&D Center showed that in order for a number to be identified eight scan lines must subtend its image under ideal conditions. Using this data we can predict that, under ideal conditions and using the Cohu camera with its lens at maximum zoom, an object at a distance of one mile would have to be at least 13.2 feet high in order to be recognized. Furthermore, the name or number of the ship or buoy would have to be painted in characters at least 5.3 feet high in order for it to be identified. Required sizes would be proportionally larger in cases where fog reduces contrast, high seas or other background clutter distracts the operator, or low light levels cause noise within the camera as well as reducing resolution. Improved recognition could be obtained by extending the focal length of the lens (i.e., greater magnification). A 2X extender for this purpose is available from Cohu which doubles the lens' effective focal length. Unfortunately, light output from the lens is cut in half by the extender, making it unsuitable for nighttime use.

5.0 ENVIRONMENTAL MONITORING

5.1 Precipitation.

All TV camera image tubes exhibit a "lag time" which is the time it takes the video output of an image to disappear after the object being viewed is removed. A result of this effect is the blurring of any rapidly moving object being viewed. While the lag time of the ISIT or SIT tube is considerably better than that of a conventional vidicon, it is still not fast enough to resolve the image of a falling rain or snow particle. Additionally, under most lighting conditions a rain or snow particle has almost no contrast against a background of other rain or snow particles. Because of these reasons, the Cohu camera was not able to directly indicate to an observer that precipitation was occurring. Instead, rain and light to moderate snow had the appearance of fog. It is possible in some cases to detect precipitation by observing its effect on nearby objects, for example, ripples in puddles, wet sidewalks, snow accumulation, etc.

5.2 Sea State.

R&D Center observations have shown that the best indication of sea state that can be viewed on TV is the motion of buoys due to the waves. TV can be used with some success to view the waves directly, but often the lighting conditions cause the waves to have the illusion of being at a different height than they actually are. In some cases, reflections of the sky from the surface of the water had the appearance of whitecaps even though no whitecaps were present.

5.3 Tides.

TV can be used to indicate the level of the tides by pointing the camera at a standard tide gauge on a dock or other fixed object within viewing range of the camera.

6.0 COST AND MAINTENANCE

The price of the LLLTV system purchased for the R&D Center evaluation was $12,000. This includes: the Cohu Model 2856 camera at $9,469; a Conrac television monitor, Model SNA 14/C at $550; the camera remote controls and pan-tilt unit at $1,230; plus miscellaneous cables and connectors. This equipment is the minimum needed for LLLTV surveillance. Two-way microwave links for video and control would add their cost to an operational system having a remote camera installation.

The primary cause of failure of this system will be the ISIT camera tube. The MTBF on this tube has not been measured but is estimated to be between 4,000 and 10,000 hours (8,760 hours equals one year). A constantly energized camera would have to have its ISIT tube replaced once or twice a year at a cost of $3225 for each new tube. Replacement of this tube is a delicate process requiring special tools and must be performed under low humidity conditions to prevent condensation problems when the camera is placed back in the field.

The R&D Center had a failure in the zoom motor of the lens while the camera was undergoing its tests. This or the other lens control motors will probably fail once a year depending upon their use. The motor's cost is insignificant, but again it requires disassembly of the camera.

The pan-tilt gearing requires lubrication twice a year.

7.0 ALTERNATIVES

7.1 Non-Blooming Target.

The RCA Corporation has produced an experimental non-blooming target for an SIT or ISIT tube. This target uses a "nonlinear structured sink design" consisting of small bars of p-type semiconductor between every other row of diodes in the target matrix. When an overload condition exists, the excess holes generated will recombine at the p-type sink bars rather than migrate to the surrounding diodes on the target. According to RCA, this structure reduces blooming due to the target well below the blooming caused by the lens. However, the higher cost and slightly lower sensitivity of the new target has caused RCA not to put them into production at this time.

7.2 Silicon Intensified Target.

The SIT vidicon tube is the same basic tube as the ISIT, but it does not have the first intensifier stage. It has the same blooming problem and picture graininess as the ISIT and only has 0.038 of the sensitivity. Its advantage is that, without the first intensifier, it is less likely to be damaged by bright light sources and it requires less circuitry in the camera. This, along with the lower cost of the tube itself, results in a total cost savings of $1300 over the ISIT camera (using Cohu GSA prices).

7.3 Intensified Isocon.

The isocon camera tube is similar in construction to an image orthicon camera tube except that the video signal is derived in a way that greatly reduces noise caused by dark current within the tube. Like the orthicon it has a knee in the brightness versus video response (gamma) characteristic as the target approaches saturation. Below this knee, video output is directly proportional to the brightness and a normal video image results. Above the knee the gamma decreases substantially, yielding only a small increase in video for a large increase in brightness. This video compression extends the tube's dynamic range to 1000 times the brightness at the knee, or more than 10 times better than the SIT tube. When blooming does occur in the isocon, it is a dark halo around the image of the light source through which bright background details can be seen, but low light level details are lost. When coupled to an image intensifier the isocon is less sensitive than the ISIT tube by a factor of about 10. In moderate light the intensified isocon is superior to the ISIT because of its higher resolution, the absence of picture blemishes which are so pronounced in the ISIT, and its superior resistance to overload due to bright point sources of light.

7.4 FLIR (Forward Looking Infrared).

(a) Description. The FLIR is essentially a device which produces a scanned image from a live scene much like television except that its light sensitivity is in the infrared spectrum (8-13 microns) rather than in the visible spectrum. The long wavelength response of the FLIR makes it possible to get a usable image at a greater distance through fog and haze than with conventional television. It is particularly useful at night where, because it responds to infrared (heat) radiation, images can be obtained in total darkness. FLIR is a relatively new technology and has a higher rate of failure than television at the current state of the art. It requires that the sensing element be cooled to liquid-air temperatures, making powerful refrigeration units a necessity.

(b) Operational Results. Tests of various FLIR systems at the Naval Weapons Labs, Dahlgren, Virginia, and the Naval Electronics Laboratory, San Diego, California, have demonstrated that, when visual visibility is less than one kilometer, the FLIR range is approximately four times greater than visual. FLIR range, however, is directly dependent upon the size of the particles in the air. Haze and smoke particles are small and the FLIR range is good. Rain, snow, fog and cloud droplets are much larger and reduce FLIR's range to twice visual or less.

(c) Cost. Currently the cost of a FLIR system is between $60,000 and $300,000 depending on resolution and sensitivity. At the current state of the art it does not appear that the cost justifies the increase in range over visual, especially because of the high occurrence of fog in most harbors and because, like TV, the resolution is limited.

(d) Classification. Because almost all FLIR equipment available today was developed for military reconnaissance, much of the equipment carries a security classification. As a result it is currently impractical to use FLIR in remote locations because of the need to provide guards and other security measures.

7.5 Laser Gated TV

(a) Description. The best visual surveillance in conditions of fog at night is provided by laser gated TV. In this system a laser is used to generate a very short pulse of light which is then formed into a divergent beam and aimed at the scene to be viewed. At the instant that the light beam arrives back at the TV after being reflected from the object being viewed, the TV is gated "on" long enough to let in only the reflected pulse of light. In this manner all reflected and scattered light before and after the pulse is received is not detected and thus does not affect the resultant image. Dispersed light due to the fog thus has minimum effect on the quality of the image. Tests at the Naval Electronics Laboratory Center, San Diego, show that at night laser gated TV provides an image at a range of approximately three times visual in fog within the limitation of the maximum range of the laser.

(b) Cost. The cost of a laser gated TV system is between $50,000 and $80,000, or approximately the same as FLIR.

(c) Drawbacks. In order to make the laser beam eye safe its power must be limited. Since the beam is divergent, its intensity falls off at a rate equal to the square of the distance it travels. This, added to atmospheric attenuation and scattering of the beam, greatly limits the maximum range of the system. In a practical system the maximum range is about a mile. Ambient light adds noise to this type of system, especially near the maximum range; and in daylight there is no practical advantage over regular TV. Another disadvantage is that the range to the target must be known beforehand in order to set up the gated TV timing, and thus it is not particularly adapted to visual search.

8.0 CONCLUSIONS

8.1 General.

The poor optical environment of a large harbor greatly limits the effectiveness of visual surveillance at the current state of the art. LLLTV, FLIR and laser gated TV all have advantages under certain situations, but no one system appears best for visual surveillance at all illumination levels or weather states. For optimum cost effectiveness, however, LLLTV appears to be the best compromise.

8.2 Cohu Model 2856 System.

(a) In many cases the effective range of TV surveillance is limited by resolution rather than weather state. The 10:1 zoom lens (15 to 150 mm focal length) supplied with the Cohu camera is effective up to approximately one mile for recognition of a tug boat or other small vessel. A longer focal length lens will be required for effective visual surveillance of small vessels at greater than one mile range.

(b) In general, the Cohu LLLTV camera is about as effective as a human observer would be under the same conditions. With binoculars the human observer would be superior. LLLTV is of advantage only where a vantage point needed for surveillance is not easily manned.

8.3 Application to San Francisco VTS

(a) One basic need for visual surveillance in a VTS system is to identify ships so that radio communication can be established. The resolution of the Cohu system tested at the R&D Center is not sufficient to read the identifying name or number on a ship in most cases, and its only use would be to show the VTS watchstander the type of vessel that is there. The effective range of the LLLTV system is one mile, so complete coverage of the harbor would require a large number of camera sites. An installation at Alcatraz Island would provide the greatest single camera coverage, but a vessel would have already been well into the VTS coverage area before coming within range of the Alcatraz camera.

(b) The limitations of LLLTV make it least useful when visibility is restricted and in darkness, when, for maritime safety, surveillance is most needed. In conclusion, it appears that an LLLTV visual surveillance system does not produce sufficient additional information over what is available from radar to warrant the expense of adding it to the existing VTS capability at San Francisco.

(c) Visual surveillance could be most effectively provided in a VTS controlled harbor by utilizing cooperating vessels within the system. The Coast Guard, using the existing bridge-to-bridge communications channel, could request visual reports of unidentified radar returns from ships in the vicinity of the object. This system is particularly effective because the targets which are of most concern to the Coast Guard are those which are near the traffic lanes where cooperating ships are likely to be, and the targets would be better seen from the traffic lanes than from a TV mounted on land.

9.0 RECOMMENDATIONS

9.1 An LLLTV system is not recommended for general surveillance of large harbors. It may, however, have limited application in small areas to provide coverage in a radar blind zone or in a narrow channel where vessels are certain to travel close to the camera and lighting can be controlled to some extent.

9.2 In cases where LLLTV is to be installed, the following is recommended:

(a) The SIT vidicon or the intensified isocon be used in the cameras rather than the ISIT. The SIT is more rugged, cheaper and less likely to be damaged by bright light than the ISIT. The isocon is useful where a greater resolution than provided by the SIT is required. The additional sensitivity of the ISIT is neutralized in the harbor environment because of the effect of the automatic brightness control which reduces system gain as soon as bright shipboard lighting enters the image, and its use is not recommended.

(b) Whenever possible, some form of auxiliary lighting should be used to illuminate the area to be viewed. This will lower the contrast between shipboard lighting and the remainder of the ship, which reduces blooming and aids identification.

(c) Eliminate as many bright lights in the nighttime background as is practical. This is most easily accomplished by mounting the camera as high as possible so it points downward at the sea surface rather than at the horizon.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1975-A-0004/110