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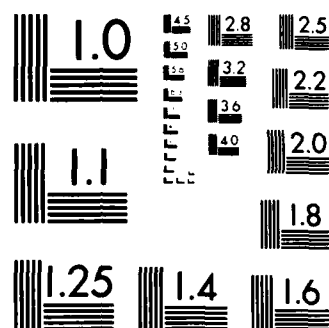
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# ONR LONDON CONFERENCE REPORT

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FOURTH INTERNATIONAL CONFERENCE ON ROBOT  
VISION AND SENSORY CONTROLS

J.F. BLACKBURN

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM										
1. REPORT NUMBER C-8-84	2. GOVT ACCESSION NO. AD A149524	3. RECIPIENT'S CATALOG NUMBER										
4. TITLE (and Subtitle) Fourth International Conference on Robot Vision and Sensory Controls		5. TYPE OF REPORT & PERIOD COVERED Conference										
		6. PERFORMING ORG. REPORT NUMBER										
7. AUTHOR(s) J.F. Blackburn		8. CONTRACT OR GRANT NUMBER(s)										
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Office of Naval Research Branch Office London Box 39 FPO NY 09510		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS										
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 19 November 1984										
		13. NUMBER OF PAGES 9										
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)  UNCLASSIFIED										
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE										
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.												
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)												
18. SUPPLEMENTARY NOTES												
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)												
<table border="0"> <tbody> <tr> <td>Computer Science</td> <td>Sensor-guided welding</td> </tr> <tr> <td>Robotics</td> <td>Three-dimensional sensing</td> </tr> <tr> <td>Robot vision</td> <td>Robot guidance</td> </tr> <tr> <td>Robot sensory controls</td> <td>Nonvision sensing</td> </tr> <tr> <td>Sensor-based manufacturing</td> <td>Knowledge-based sensory systems</td> </tr> </tbody> </table>			Computer Science	Sensor-guided welding	Robotics	Three-dimensional sensing	Robot vision	Robot guidance	Robot sensory controls	Nonvision sensing	Sensor-based manufacturing	Knowledge-based sensory systems
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<p>✓ The Fourth International Conference on Robot Vision and Sensory Controls was held in London from 9 through 11 October 1984. The conference covered the following areas: sensor-based manufacturing, vision systems, sensor-guided welding, three-dimensional sensing, robot guidance and sensory control, nonvision sensing, knowledge-based sensory systems, and advanced vision techniques.</p>												

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## FOURTH INTERNATIONAL CONFERENCE ON ROBOT VISION AND SENSORY CONTROLS

### Introduction

The Fourth International Conference on Robot Vision and Sensory Controls was held in London from 9 through 11 October 1984.

Forty-seven papers were presented covering nine categories: sensor-based manufacturing I, vision systems, sensor-guided welding, three-dimensional (3-D) sensing, robot guidance and sensory control, nonvision sensing, knowledge-based sensory systems, advanced vision techniques, and sensor-based manufacturing II. Thirteen nations were represented among the speakers, with the largest number, 17, coming from the UK and the second largest number, 11, coming from the US. The number of delegates attending was 170.

### Sensor-Based Manufacturing I

G.L. Pope (UK) described an implementation of a vision-processing algorithm to perform robot stack picking in a flexible manufacturing system's cell. He described in detail the stages of the algorithm from image collection to coordinate selection.

H. Jochnick described a vision system developed at ASEA, a Swedish robotics company, in parallel with their second-generation robot controller. The programming unit consists of a two-row alphanumeric display and a number of control buttons. The upper row of characters is used to display prompting and informative or error messages, while the lower row is used to label five keys to form a programmable menu. The five programmable keys and the numerical keypad are used for vision programming. A button with a camera symbol is used to enter the vision subsystem. Any other button will return to robot mode. A CRT monitor is used for displaying either camera video, edge data, or the two superimposed on each other. Under the PROG label, when programming vision systems the flow of programming goes from left to right. In this mode under TPICT (the command to take the picture) the

operator is given the option of adjusting the analog input circuitry with a contrast and brightness control, or of setting a sensitivity control for the classification of gradients. The next step is to place the object to be programmed into the system under the camera and depress the DEFINE button. The vision system will extract contours of the object, including contours inside the perimeter of the object. The operator can select a significant part of the surface by using a cursor and depressing SURFACE. The operator may depress VIEWRDY and cause the view of the model to be examined by the system. Several parameters will be extracted based on the features and an orientation algorithm. Statistical data are collected using the TRAIN label. The gripping point of the object is taught to the system by depressing ROBOTP. With the aid of the robot the object is placed under the camera, and the position is recorded by depressing ENDPOS. The operator opens the robot's grippers and removes the robot from the field of view. When the READY button is depressed, the system processes the object and creates a transformation from its internal representation of the object to the gripping point. The transformation is stored in the database.

In a paper entitled "Machine Vision--The Link between Fixed and Flexible Automation," D. Banks (US) described the elements of productivity currently achieved with machine vision. Banks predicted that low machine vision can be a bridge technology between fixed and flexible automation. Sensory automation is vital if computer-integrated manufacturing is to become a reality. Use of machine vision now expedites practical development of the technology as well as user expertise.

A paper by E.-J. Schmidberger (West Germany) described quality control for automobile chassis parts, including recognition of deformations such as cracks, overlaps, folds, and missing punched holes. Until now this quality control has been accomplished mainly by stationary sensors. The system for



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performing such tasks described in the paper includes an industrial robot which guides a camera to certain typical locations on the part's surface where deformations are most likely to occur.

#### Vision Systems

In a paper entitled "Solving Illumination Problems," D.A. Hill (UK) described illumination, optical, environmental, and sensor problems. The optical problems arise as a result of too much or too little reflectivity in the object and its surface curvature. Environmental problems associated with illumination include excessive heat, physical arrangement of the work place, and vibration of machinery. Among sensor problems are the interference of sensors with objects being sensed and vice versa. Excess illumination may be corrected by reducing the intensity of the source, introducing filters, or changing the direction of illumination. Insufficient illumination may be corrected by using two medium-sized sources instead of one larger one, changing the light direction, and checking the compatibility of the accessories with the light source.

The problem of lack of uniformity of illumination may be due to images, or shadows of components, which are part of the lamp providing the illumination. Another cause may be the sensitivity of cameras. The effectiveness of condensing lenses can be further improved by etching. Front illumination problems may benefit from the use of quartz halogen lamps with integral multi-mirror (or multi-facet) dichroic reflectors.

Lack of contrast may be corrected by a change of background. Offsetting one point of light against another so that they "interfere" with one another may reveal salient features.

P. Levi (West Germany) described the architecture and the operation of a linear processor array for iconic image processing. The fundamental data structure consists of two-dimensional (2-D) matrices. The elements of these matrices are essentially gray-scale intensity data (256 levels) and distance data

obtained by a laser scanner using triangulation. The parallel computer system consists of an array of 64 processors. An array controller supervises these processors. A microprogrammable address sequencer divides the input images into 64 windows. The gray-scale vision system can operate either in the single-instruction-multiple-data mode or in the multiple-instruction-multiple-data mode. The system is mainly designed for 3-D object descriptions which are needed for the part handling of an assembly robot. In the first step intensity and distance data are combined to get integrated intrinsic images. Internal 3-D models are based on linear oct-trees and are generated using distance data.

In a paper entitled "Vision--New Sight and Foresight," H.A. Laird (UK) described the components of vision systems which are commercially available, and examined their suitability for metal-forming operations. One area of application which he cited was the analysis of strain caused by deformation processes, which is a time-consuming process when one uses the conventional grid-circle-analysis technique.

L. Norton-Wayne (UK) described a set of 40 shapes for the benchmark testing of silhouette-recognition systems. Benchmark testing is essential if silhouette image processing systems are to be evaluated and compared objectively, and if the state of the art is to advance. The 40 shapes were selected to probe for particular weaknesses, which were described and explained. The set tests accuracy in orientation and location, and the ability to distinguish shapes which are similar.

D. Lake (US) discussed the use of solid-state imagers in complete cameras and camera systems. The first part of his presentation dealt with line-scan cameras, the second with matrix cameras, and the third with cameras which do not image directly through a lens but rather use fiber optics and intensifier tubes. Within each section, appropriate critical parameters were emphasized. Such parameters include resolution,

acquisition rate, monochrome versus color, dynamic range, noise, size, and ruggedness.

A 256x256-pixel, charge-coupled-device (CCD), solid-state image sensor was described by G. Boucharlat (France). This device was designed and developed for shape recognition and image-signal processing. It has square photosites with antiblooming, a pseudo-random access adaptable organization, an electronic exposure time control, and a sampled video output. It is built with metal oxide semiconductor-CCD technology. It possesses the advantages of small size, reliability, low power consumption, and insensitivity to electromagnetic field disturbances. Performance and operating modes for the device were presented.

#### Sensor Guided Welding

Z. Smati (UK) described a laser guidance system for robots. Adaptive arc-welding and seam-tracking systems rely on the successful combination of various technologies including position sensors, welding-power sources, manipulators, and industrial robots. Sensors are expected to be a key element in the development of any such adaptive automatic system. Arc-based sensors and optical sensors were reviewed by Smati, with special emphasis on laser systems using triangulation. A detailed description of an adaptive welding system based on a laser range finder was given. The system described has been used to control directly each axis drive of a four-degrees-of-freedom manipulative arm to follow complex paths; the algorithm used for image recognition was described. The application of this system to metal inert gas welding of pipes and the use of an industrial six-degrees-of-freedom robot for linear tracking was also discussed.

J.E. Agapakis (US) described general visual sensing techniques for automated welding fabrication. Welding fabrication involves preparation, process execution and post-weld inspection. A major problem in automating these steps and developing autonomous welding systems is

the lack of proper sensing strategies. Conventionally, machine vision is used in robotic arc welding only for the correction of pre-taught welding paths. In his paper, Agapakis described novel uses of machine vision for determining the weld bead and joint geometry. He also gave a detailed description of visual processing techniques and their application in welding fabrication.

"Flexible Eddy Current Sensors for Industrial Applications" was the subject of a talk by H. Clergeot (France). High-performance eddy current sensors were designed for use in imaging of a metallic surface. Sensors achieve high precision and stability, with rapid digital acquisition and multiplexing. The combination of fast, accurate, rugged sensors with the flexibility of digital treatment makes an arrangement which is useful for many industrial tasks.

Clergeot discussed applications such as distance measurement under adverse conditions--e.g., high temperature--and measurement of the thickness of a metallic layer. Another application is the use of a linear array of sensors for determining the profile of a seam. A numerical method was used to improve the image. The sensor is being tested for seam tracking and automatic arc welding.

R.V. Hughes (UK) discussed robot plasma welding with integral arc guidance. A prototype robotic welding system has been developed based on the plasma-arc process. Results thus far have shown that high-speed welding of materials such as stainless steel, nimonics, and titanium down to thicknesses as small as 0.25 mm is practical. An inertialess weaving system is under development, and a prototype unit has demonstrated the feasibility of the technique for compensating for weld fit-up inaccuracies during high-speed welding.

Machine vision algorithms for vision guided robotic welding were discussed by N.R. Corby, Jr. (US). Robotic welding systems in the past have primarily been taught a specific trajectory to be welded, along with appropriate

process parameters for welding that path. This has been satisfactory for less demanding applications, but application to part fit-up and in-process variations has given results that are less than satisfactory.

Real-time feedback control for machine vision has been suggested as a way to compensate for static and dynamic geometry variations as well as to control the welding process parameters. Robust forms of visual processing must be used to deal with the difficult visual environment. Corby discussed techniques for enhancing the scene, developing navigation data, and temporarily processing the scene to derive process control data, along with descriptions of the processing hardware employed.

G. Betz (US) described a general-purpose 3-D vision system and several applications. The system uses structured light and optical triangulation to digitize the surface of the workpiece. The vision system is an industrial product which has been installed and operated in both assembly line and batch manufacturing operations. The sensor and its modular construction were described. It can be easily configured to implement turn-key systems. He also described a more advanced 3-D vision system which is not yet in commercial production.

### Three-Dimensional Sensing

A new 3-D sensor for teaching robot paths and environments was described by M. Ishii (Japan). He proposed a new 3-D sensor which can simultaneously measure 3-D position and orientation of robot environments. The sensor consists of a camera using a position-sensitive device and multiple light-emitting diodes (LEDs) attached to robotic devices such as a robot's hand and a teaching device. Their 3-D position and orientation are computed in real time based on 2-D coordinate values of the LEDs in an image plane of the camera and geometrical relationships among 3-D positions of the LEDs. The 3-D sensor has advantages of simplicity and practical usefulness for

getting 3-D information about robotic devices at high speed. He described the experimental results of applications to visual detection of a robot's hand position and orientation, the teaching of robot paths, and the modeling of robot environments.

R.A. Jarvis (Australia) discussed range from brightness for robotic vision. Range determination has become an important component in sensory-based robotics research. Registered intensity/range data of good quality are important to robust, semantic-free, low-level 3-D scene analysis. Jarvis discussed the use of brightness variations in color imagery as a means of recovering range data. Some preliminary results of experimentation carried out in the computer vision and robotics laboratory at the Australian National University were presented, and future plans for development were discussed.

"3-D Reconstruction of Silhouettes" was the subject of a paper by G. Sandini (Italy). He presented a stereo algorithm to compute the location in space of flat objects (silhouettes). The algorithm is simplified by solving the correspondence problem only for the points of zero curvature of the shape contour. The points of zero curvature also provide good perspective invariants allowing the stereo images to be acquired from different viewpoints (to increase accuracy). Moreover, because the camera parameters and the viewing geometry are known, the matching between points of zero curvature was reduced from a 2-D problem by searching for matching along conjugate epipolar lines. The equation of the plane on which the silhouette lies was determined with a precision of at least 99 percent.

R.-C. Luo (US) described a system which combines 2-D vision and taction for 3-D object recognition. A video camera is used to obtain the top view of an object, and two tactile sensing arrays mounted on a robot gripper are used to measure information about the lateral surfaces of the object. Three-dimensional reference object models are established as a decision tree, and



recognition of unknown objects is accomplished through measuring and comparing input object features hierarchically with those of the reference objects associated with the decision tree. The advantages of this system over systems using visual or tactile information alone were discussed.

R.J. Fryer (UK) described the Strathclyde Artificial Retina and Cortex Heuristic Imaging Experiment (ARCHIE). This project is an investigation of a pipelined pseudo-parallel architecture for real-time derivation of the 3-D structure of a viewed scene. This system will have an interface to an intelligent database which will use the perceived structure, together with other clues such as color or texture, to interpret the scene and recognize objects. The overall configuration resembles some schematics of vertebrate visual systems, hence the acronym.

#### Nonvision Sensing

A paper on "A High Resolution Tactile Sensor" was presented by K. Komoriya (Japan). A high-resolution tactile sensor using a pressure-optical conversion technique has been developed. The sensor system consists of a transparent acrylic plate, an elastic sheet, a light-guide made of plastic fibers, and a  $32 \times 16$  phototransistor array. The elastic sheet, a sensing surface, is placed on the acrylic plate ( $56 \times 117$  mm). The light is guided with a light guide onto one end of the plate. There is total internal reflection of the light from the plate if no pressure is applied to the elastic sheet. Pressure applied to the sheet causes an optically active contact between the sheet and the plate, so the total internal reflection conditions are changed and the light illuminates the sheet. The sheet scatters the light back in the area of the pressure, and the patterns of the pressure area can be observed by a phototransistor array. The output of the array is transferred to the computer serially for tactile image processing. The system performed well during an evaluation experiment.

K.A. Marsh (UK) described a method for obtaining 3-D acoustic images of simple objects in air using an array containing only a small number of transducers. Each transducer provides a pulse-echo measurement in an appropriate incident direction. The algorithms involve probabilistic imaging procedures, use entire waveforms, and are based on the Kirchhoff approximation together with the assumption that the scatterer is a rigid body. The results of preliminary testing of these techniques were presented, using both synthetic and experimental data. The experimental data were obtained using transducers fabricated from a piezoelectric polymer which provided an operating bandwidth of 7 to 16 KHz, appropriate for imaging objects of centimeter dimensions.

A paper by J.M. Vranish (US), entitled "Magnetoresistive Skin for Robots," was presented by J.F. Blackburn. The paper proposes a tactile imaging skin for robot grippers based on magnetoresistive technology. In the design proposed, the skin would consist of a thin-film magnetoresistive array with sensor elements 2.5 mm apart covered by a sheet of rubber and a row of flat wires etched on a mylar film. Linear pressure and compression relationships are expected over a 20-dB range. By varying rubber stiffness, the pressure range could be set anywhere between 30 Newtons/m<sup>2</sup> and 3000 Newtons/m<sup>2</sup> for applications requiring sensitivity, and  $2.0 \times 10^4$  Newtons/m<sup>2</sup> to  $2.0 \times 10^6$  Newtons/m<sup>2</sup> for more rugged industrial uses. By varying rubber thickness, one could construct the skin to detect different compression ranges. For example, a thin skin (2.5 mm) could sense compression from 0.0025 mm to 0.25 mm, whereas a thick skin (7.5 mm), which is more compliant and conformal, could sense compression from 0.025 mm to 2.5 mm. Design, operation, and expected performance of the skin were described.

In a paper entitled "Application of Sensory Modules for Adaptive Robots," A.N. Trounov (USSR) discussed three

types of sensory modules--including contact pressure, slip displacement, and distance and inclination angle modules--which have been developed for adaptive grippers and control systems of industrial robots. He described the main characteristics of the sensory modules and discussed new material for tactile sensors with a wide dynamic range of tactile and force feedback which does not require amplifiers. A comparison with carbon-fiber and silicon-rubber tactile sensors was given. Trounov discussed the design approach for a single sensor and for modules integrated into a complex control system of adaptive robots.

J.B.C. Davies (UK) described a tactile sensor that was constructed using the variation in contact resistance between carbon fibers and a metal contact. Repeatability and accuracy are not high, but with suitable encapsulation and circuitry a very robust independent sensor has been produced. Feedback can take the form of a continuous variation in resistance or discrete changes in LED illumination.

#### Robot Guidance and Sensory Control

"A Practical Solution to Real Time Path Control of a Robot" was the subject of a paper presented by P. Sholl (UK). He described the real-time path control capability, called ALTER, of the UNIMATION robot-control language VAL II. He presented the language, discussed the communications and implementation aspects of ALTER, and gave examples of internal and external path control. One specific example for real-time path control was included.

A. Casals (Spain) described a specialized image processor that detects an object's appearance in complex scenes and obtains the object's coordinates and orientation in a very short time (100 ms). A low-cost microcomputer processes the information about the object obtained by isolating it from its background and processes the data needed for guiding the robot. The image processor detects the object's appearance on the scene by comparing the image obtained,

128x128 pixels, with a scene-reference image. This image is continuously updated to adapt it to lighting fluctuations or variations in the environment. The detected difference between images is filtered to avoid false detections.

C. Meier (West Germany) discussed sensor technology with robot-mounted sensors. The extension of the field of application of industrial robots depends on the provision within the robot control of freely adaptable techniques for processing sensor signals. Meier described how these sensor functions can be used to provide speed regulation, on-line path correction, and adaptable signal processing in a manner which is easy for the user to implement. The on-line sensor functions are part of a closed-position control loop or other general-process control loop. The loop is formed by the sensors, the control, the sensors with the drives, and the robot. The use of sensors mounted on the robot grippers adds another dimension to the subject. These sensors are expected to work anywhere within the working space of the gripper, and the resulting geometrical factors must be considered. Meier gave three examples of gripper-mounted sensors used to tackle problems: recognition and location of parts, 3-D search, and path control.

An experimental, very-high-resolution, tactile-sensor array was described by D.H. Mott (UK). A pressure-intensity transduction principle was presented to construct a tactile sensor that is small and that offers very high resolution. Two robot-gripper-mounted sensors linked to a tactile-processing module and a tactile work surface have been designed and built, and are being evaluated. They use the pressure-intensity transduction principle.

#### Knowledge-Based Sensory Systems

J. Foster (UK) discussed the development of an expert system for automatic industrial inspection. The Joyce-Loebl Magiscan system has been used for inspecting complex industrial assemblies for many years. The knowledge base and experience so obtained are now being

used to develop an expert system for the automatic inspection of surface texture and finish of industrial components. Foster gave two examples of the application of these techniques--the inspection of explosive detonator material and the classification of wooden staves. The system makes automatic measurements of a number of key parameters and by intelligent assessment decides upon the quality or grade of the component. Self-learning is used to allow the system to accommodate different components and ranges of materials from which the components can be manufactured.

A pragmatic approach to the bin-picking problem was discussed by O. Ledoux (Belgium). He proposed a pragmatic visual method to grasp parts from a bin. The locating and recognition of an object is done in two steps. First, the system looks for a grasping site. The image processing is based on an edge operator, computed on a 64-grey-levels image, to find some parts of the object's outline. Second, the vision system models two opposite parts of the object's outline and tries to find a grasping site when the fingers of the gripper fit this modeled outline. In the second step, the part is on a flat surface below another camera where lighting conditions are easily controlled and where the part is isolated. This simplified scene is then analyzed by conventional means.

P.J. Gregory (UK) described knowledge-based models for computer vision. Vision systems capable of analysis of grey-scale images are now becoming available and offer the potential to handle the complex inspection requirements of today's manufacturing industry. Their widespread use is likely to be limited by the cost of developing applications-specific software that is sufficiently robust to achieve acceptable inspection performance. By using a "knowledge-based model" to direct the analysis, one can improve performance while allowing programming to be performed by nonexpert users in a graphical manner. An example from the automobile industry was discussed.

A conceptual approach to artificial vision was described by G. Adorni (Italy). Object descriptions based on geometrical features are not very satisfactory because of wide variations in structure and shape often due only to style. A more functional description is needed, which in turn requires some knowledge about the everyday experienced physical processes in order to be linked to the observed shapes. For example, knowledge of the function of a chair, if stored in the knowledge base, can be of help in the process of recognizing a shape as a chair. Some preliminary geometrical operations on visual data were also discussed, and a method for integrating structural and functional information was proposed.

#### Advanced Vision Techniques

R.B. Kelley (US) described a heuristic-vision hole finder. In the usual methods, the holes must be of known shape, and corrections are needed to account for perspective distortion or hole surface orientation. Heuristic-vision algorithms are based on the notion of locating good hold-sites on some part of the objects seen by the camera. The algorithms can be uninformed about the nature of the object itself. The heuristic-vision hole finder seeks edge patterns which correspond to holes. By using neighborhood operators applied in both horizontal and vertical stripes across the image, the hole centers are located directly. The algorithm requires modest computation and is designed to minimize execution times.

Local ordered grey levels as an aid to corner detection was the topic of a paper by K. Paler (UK). He presented a novel method for detecting corner points in a scene. The method is based on features extracted from the distribution of ordered grey level values within a local window. The algorithm is independent of the orientation of the objects in the scene. Paler presented results for an image containing corners of different angles and orientations. A comparison was made between the positions obtained for the corners detected

using this method and those obtained by direct measurement. The signal strengths of similar corners at different orientations were also compared. These comparisons show that the proposed algorithm can provide useful corner-point information without the need for preprocessing of the image.

D. Juvin (France) presented a paper on a heuristic method of classification and automatic inspection of parts. The recognition system, ANIMA, does part recognition of objects with a limited number of stable positions in an industrial environment. He first described a contour encoding of the pattern to be recognized, which is invariant in translational and rotational modes. This encoding keeps the geometric aspect of the contour. The algorithm then carries out the identification of the shapes to be recognized by using a Euclidean distance specified in terms of the invariant encoding. Through this distance an estimate of the shape distortion and the recorded selected reference is obtained. A dynamic acceleration heuristic using a preclassification technique has been implemented on an INTEL 8086 microprocessor. It carries out the object recognition and location of pre-recorded points by reference to 10 recorded shapes in less than one second.

A.P. Ambler (UK) described the use of vision verification in the RAPT system. RAPT is an off-line robot-programming language which uses descriptions of spatial constraints between features of objects to determine the planned positions of objects. "Vision verification" is the use of vision information to determine the difference between the planned positions and the actual positions taken up at run time. Ambler showed how vision commands can be used to allow the combination of run-time and compile-time information in a general way so that all ramifications of the effect of the changed position are taken into account. This involves symbolic reasoning about spatial constraints at compile time and the construction of a framework indicating the dependence of object positions on each other.

W.H. Tsai (Taiwan) described a 3-D object recognition system capable of measuring 3-D object surfaces. The system is simple, efficient, and relatively inexpensive. It relies on parallel-stripe projections for 3-D surface measurement. Data from four camera views are collected to form reference models which consist of horizontal cross-section boundaries. The recognition scheme engages 3-D object registration followed by 3-D similarity measurement. The 3-D registration is accomplished by multiple 2-D registrations on the cross-section planes using the generalized 2-D Hough transform. The 3-D similarity measure uses the average of all the 2-D cross-sectional similarity measures, which are based on the "distance-weight correlation." Since the recognition scheme involves only pixel-level operations, it is amenable to parallel processing.

"Techniques of Multisensor Signal Processing and Their Application to the Combining of Vision and Acoustical Data" was the subject of a paper by J.M. Richardson (US). He considered first the general problem of single-time state estimation when the measured data are produced by sensors of different types. He discussed the kind of signal processing involved in the merging of the sensor outputs. Other questions pertinent to the later stages of the total state-estimation problem were discussed. He gave as an illustration the problem of estimating the 3-D geometry of an object using a combination of data from an acoustical-scattering measurement system and an optical system. The treatment was limited to conventional monocular optical systems involving a variety of illumination directions. Results based on synthetic data were presented and evaluated.

### Conclusion

The conference represented a good state-of-the-art sample of research in robot sensing. Vision sensing was predominant, but there were several good papers on tactile sensing as well. The papers show convincingly that the present state of development permits

sensor-based manufacturing. It is now possible to move from fixed automation in which a robot follows a prescribed set of motions which have been "taught" to a flexible automation in which visual and tactile feedback permit adaptation of the robot's motion to unforeseen changes in the workpiece or the environment.

This capability is responsible for a great increase in the use of robots and machine vision in computer-integrated manufacturing. Spot welding and spray painting have been predominant in the use of robots in the automobile manufacturing industry. Now due to

visual and tactile sensing, feedback seam tracking is practical and the use of robots for arc welding is greatly increasing. It has also become possible to use robots in assembly with the use of parts recognition through visual sensing and bin picking of parts and assembly of products by robots.

#### Reference

*Proceedings of the 4th International Conference on Robot Vision and Sensory Controls, 9-11 October 1984, London* (IFS Publications Ltd. and North-Holland, 1984).

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