Overview of the computer vision and robotics programme at the University of Utah

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The computer vision and robotics research programme at the University of Utah, USA, is directed towards solving both practical and theoretical problems in robotics, vision and sensory control. The design and development of integrated robotic systems is of central concern, as well as individual components of such systems. In particular we are studying high-level control of a multi-fingered robot hand, contact sensors for the hand, together with the image processing and pattern recognition aspects of the problem: multisensor integration systems, three-dimensional (3D) sensing systems, representations and modelling of objects, grasping, computation of salient features, and manipulation strategies for industrial tasks.

Another major area of work is computer vision based on computer-aided geometric design (CAGD), for recognition and manipulation of 3D objects. Work on segmentation, classification and contextual cueing algorithms and the evaluation of various image processing and pattern recognition algorithms and expert systems is also in progress.

Long-range and short-range goals

The long-range goals of our research are to contribute to the understanding of human intelligence and to participate in the development of machine vision systems. Thus artificial intelligence is of central concern to us and, in particular, all aspects of image analysis and pattern recognition. Areas of special interest include robotics, both in the artificial intelligence sense of planning and in the hand–eye coordination genre, 2D and 3D shape analysis, 3D digital geometry, and parallel processing.

As for the short-range goals of the next year or so, several projects have been started or planned.

The major short-term goal is the development of a multisensor integration and data acquisition system. Such a system will be useful for a wide range of activities, including situation assessment and distributed sensory systems, and (in our particular application) for the integration of data from diverse sensors at a robot workstation (eg cameras, tactile sensors, sonar etc). Currently we are working on developing the notion of logical-sensor specifications, an approach which should provide most of the benefits of data abstraction to the user of the multisensor system.

Another major short-term goal is the development of a robotics laboratory. A Rhino XR-1 robot arm has been acquired and used in several courses. We also have an industrial-grade robot arm, the Unimation Puma arm; the Puma not only provides the capability for studying a multiarm system, but also comes with its own high-level robot programming language, VAL-II.

A medium-term project is just getting under way which deals with the specification of a global tasking environment in terms of a set of cooperating processes and a mechanism for specifying the constraints between those processes and maintaining their consistency. A system is composed of components which can be represented as abstract data types with both a data structure and operations based on this data structure. These abstract data types will be implemented as objects. If these objects are viewed as various resources in the robotic workstation environment, a dependence relation can be seen between these resources. This can also be viewed in terms of constraints between objects. Furthermore, special types of processes can represent these constraints. An area of major concern is the avoidance of constraint violation. For example, robot arms should not be allowed to collide with each other. This can be accomplished by constraining the arms to occupy different volumes of space. Another approach is to simulate the system concurrently, and to hypothesize the future location of the arms and take appropriate action before the constraint violation occurs.

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Another ongoing project is the development of dextrous hand-control systems. This work is being done in conjunction with Steve Jacobsen of the Mechanical Engineering Department. Several levels of hand control are being investigated, and our area of interest includes the integration of touch information from tactile sensors, object characterization and object reorientation. Expert systems dealing with physics and geometry are under development.

The use of CAGD in driving vision algorithms and systems is another area of study. Visual recognition is accomplished by the use of multiple, perhaps hierarchical, representations of an object to obtain orientation and position information.

An algorithm and sensor-performance evaluation system is another area of interest which allows the characterization of physical sensors, the specification of algorithms and the evaluation of algorithm–sensor combinations.

Specific areas of research include

- CAGD-based vision analysis
- low-level representations of sensor data
- logical-sensor specification and multisensor integration
- representation and models of 2D and 3D objects
- constraint-based analysis
- evaluation of pattern recognition and image analysis algorithms
- contextual cueing and expert systems
- multifinger hand control using vision and tactile sensors
- robot hand grasping and manipulation strategies
- distributed problem solving

Academic programme

The Department of Computer Science also teaches several sequences of courses related to these research areas, including

- computer graphics (three-quarter sequence)
- digital signal processing (three quarter sequence)
- CAGD (three-quarter sequence)
- computer vision (two-quarter sequence)
- robotics (two-quarter sequence)
- symbolic computation (three-quarter sequence)

Facilities

As well as a VAX/750 and graphics facilities, the machine vision and robotics group has a Rhino XR-1 robot arm with six degrees of freedom, a Unimate Puma 560 arm with six degrees of freedom, a Vicom image processing system, and a laser range finder (White scanner). In addition, we have an HP 9000 model 237 artificial intelligence development workstation; also available is a Symbolics 3600 for expert system development and symbolic processing. The graphics facilities provide a suitable environment for simulations, and the Mechanical Engineering Department's Center for Biomedical Design offers a strong complement to the research of the group by allowing first-hand experience with the latest in robotics technology such as the multifingered dextrous hand. Currently we are acquiring grippers and other laboratory accessories.

The major research computing facilities in the Department consist of six laboratories

- the software research laboratory
- the computer-aided design (CAD) and graphics laboratory
- the small-computer laboratory
- the video-computer instruction laboratory
- the robotics laboratory
- the digital signal processing laboratory

The software research laboratory contains a DECSystem 2060 computer and a VAX 11/750 which are used for general-purpose time-sharing. The DECSystem 20 is connected to the Arpanet, CSnet and Telenet networks.

The CAD and graphics laboratory contains a DEC VAX 11/785 and special hardware for the display of black and white and colour images, as well as a dedicated Computer-Vision system for integrated circuit design and a Symbolics 3600 LISP machine.

The small-computer laboratory is the focus for the Department's effort in the development of a professional workstation environment; it provides support for several different families of such systems, including a large Apollo Domain and Hewlett-Packard 9836 networks, and various other 16- and 32-bit microprocessor systems, as well as a DEC VAX 11/750 for LISP software development support.

The video-computer instruction laboratory provides an environment of various microprocessor systems and connections to the various host systems for use in developing tools for computer-aided instruction.

The digital signal processing laboratory contains a DEC VAX 11/750 supporting specialized D/A and A/D equipment for realtime signal processing.

A 10 Mbit s^{-1} Ethernet provides host-to-host services connecting the DECSystem 20, VAX 11/750, graphics laboratory VAX 11/750, signal processing VAX 11/750, SCL Vax 11/750, Sun workstations, and instructional VAX 11/780. A gateway between the Apollo token ring network and Ethernet is operational, and another gateway to the Hewlett-Packard 9836 network is under development. Gateways effectively give all systems direct access to the Arpanet, Usenet, CSnet and UUCP networks.

A Sytek LocalNet using broad-band coaxial-cable technology provides virtual terminal service to all systems in the Department. Terminals that need to access several machines are connected to specialized terminal interface nodes on the local network instead of hard wired to a particular machine. To minimize portability problems, all VAXs run under the Unix operating system, and a Unix-compatible compiler and environment for the C programming language exists on the DECSystem 20. The Department also makes extensive use of a highly efficient and portable version of LISP (Portable Standard LISP) that runs on all host systems and workstations.

The CAD and graphics laboratory houses a DEC VAX 11/785 as the host computer for many specialized pieces of computer graphics hardware. The VAX has 6 Mbyte of main memory and over 1 Gbyte of disc space. The specialized graphics hardware currently consists of an Evans and Sutherland Multi Picture System (MPS) and PS 300 for producing high-resolution black and white line drawings, a Grinnell 512×512 frame buffer and several high-resolution colour monitors for the production of colour pictures and computer-generated movies, a Megatek 7290 colour raster line-drawing system, and a Lexidata 3D image viewing system.

Recent additions in this laboratory include a very high-resolution (1580×1024×32 bit) Chromatics 1500CX colour frame buffer and Silicon Graphics Iris system. This system also drives a Monarch Cortland 45 direct numerical controlled machining centre.

The CAD and graphics laboratory also has a ComputerVision Designer CAD system with three interactive design stations and a Symbolics 3600 LISP machine. These systems are used for varied CAD activities, with emphasis on integrated circuit design and printed circuit board layout. Attached to this system is a very high-speed Calcomp 960 plotter for hard copy output.

The digital signal processing laboratory contains a DEC VAX 11/750 system dedicated to single-user realtime applications involving image and sound processing. The VAX has 6 Mbyte of main memory and several disc drives, as well as special analogue-to-digital and digital-to-analogue hardware and an array processor for realtime use.

Support

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Selected results

Some representative publications are the following.

Bhanu, B 'Representation and shape matching of 3-D objects' *IEEE Trans. Pattern Anal. Mach. Intell.* Vol 6 (May 1984) pp 340–351

Bhanu, B and Faugeras, O D 'Segmentation of images having unimodal distributions' *IEEE Trans. Pattern Anal. Mach. Intell.* Vol 4 (July 1982) pp 408–419

Bhanu, B and Faugeras, O D 'Shape matching of two-dimensional objects' *IEEE Trans. Pattern Anal. Mach. Intell.* Vol 6 (March 1984) pp 137–156

Bhanu, B and McClellan, J H 'On the computation of complex cepstrum' *IEEE Trans. Acoust., Speech Signal Process.* Vol 28 (October 1980) pp 583–585

Bhanu, B and Henderson, T C 'CAGD-based 3-D vision' *Proc. IEEE Int. Conf. on Robotics and Automation, March 1985* IEEE, New York, USA (1985) pp 411–417

Henderson, T C and Triendl, E 'Storing feature descriptions as 2-D trees' *IEEE Conf. on Pattern Recognition and Image Processing, June 1982*

Henderson, T C and Triendl, E 'MKS: a multisensor kernel system' *IEEE Trans. Syst. Man Cybern.* Vol 14 No 5 (September/October 1984) pp 784–791

Henderson, T C 'Efficient 3-D object representations for industrial vision systems' *IEEE Trans. Pattern Anal. Mach. Intell.* Vol 5 No 6 (November 1983) pp 609–618

Henderson, T C and Shilcrat, E 'Logical sensor systems' *J. Robotics Syst.* Vol 1 No 2 (1984) pp 169–193

Henderson, T C, Hansen, C and Bhanu, B 'The specification of distributed sensing and control' *9th Int. Joint Conf. on Artificial Intelligence, Los Angeles, CA, USA, August 1985*