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TRC RESEARCH PRODUCTS: COMPONENTS FOR SERVICE ROBOTS

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p. 6

Abstract

Transitions Research Corporation has developed a variety of technologies to accomplish its central mission: the creation of commercially viable robots for the service industry. Collectively, these technologies comprise the TRC "robot tool kit."

The company started by developing a robot base that serves as a foundation for mobile robot research and development, both within TRC and at customer sites around the world. A diverse collection of sensing techniques evolved more recently, many of which have been made available to the international mobile robot research community as commercial products. These "tool-kit" research products are described in this paper.

The largest component of TRC's commercial operation is a product called HelpMate for materiel transport and delivery in health care institutions.

Operation in a Service Environment

Manufacturing operations require precision that is not necessary for mobile robot navigation in most service applications. Service robots generally face situations with less structure and intensity than their counterparts on the assembly line. In a service application, performance is not measured in numbers of rejected parts but in the accomplishment of completed tasks.

In an industrial environment, the robot usually becomes a tightly integrated piece of equipment in the overall manufacturing process. Service tasks such as fetch-and-carry distract and diminish the effectiveness of highly trained personnel. In the service environment, most of the integration is with humans rather than other automated machines. Behavior and interface are important factors in the success or failure of machines working in the service arena.

TRC Technology for Service Applications

LabMate® Mobile Robot Base

The LabMate mobile robot test bed, developed with DARPA support, is now in service at over 100 sites around the world. LabMate is a low cost, mobile robot base designed for use as a component in the development of transport systems and to support research in artificial intelligence, computer science, and robot engineering.

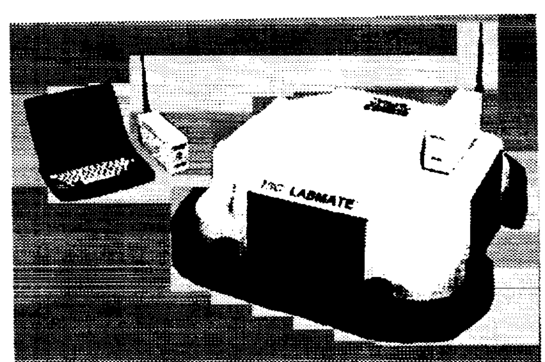

Figure 1 LabMate Mobile Robot Base

The vehicle has a square footprint designed to fit through a standard door opening. Six wheels support LabMate: one passive caster at each corner, and two driven wheels centered longitudinally along either side. Each drive wheel is under individual servo control. The only moving parts on the vehicle are the fixed drive wheels. Differential variation of wheel velocities steers the vehicle. When each wheel is driven at identical velocities in opposite directions, the LabMate spins in place. This capability to change orientation without translating position is important for sensor systems with a limited field of view. The differential steering architecture eliminates the need for an additional rotating turret.

The drive motors are servo controlled by a microcomputer controller based on the Motorola 68HC11 microprocessor. The computer monitors and controls wheel position and converts the rotational displacements of the wheels to a position and angle in a two-dimensional Cartesian space, i.e. X, Y, and Θ expressed in millimeters and degrees/100.

Through the RS-232 interface, the host application can query the LabMate at any time to determine position and orientation and issue motion commands.

Payloads as large as 200 pounds can be mounted on board. Payloads typically include computers, manipulator arms, communications gear, cameras, and sensors.

The low profile of the LabMate base provides an important advantage. Active, awkward payloads with high moments of inertia affect vehicle stability. To minimize these effects, the LabMate drive hardware and batteries are located within a few centimeters of the floor.

LabMate serves as the foundation for the TRC HelpMate® autonomous service robot and several similar systems developed by TRC customers.

LightRanger™

The TRC LightRanger Light Direction and Ranging (LIDAR) system delivers fast low noise range information from an actively scanning eye-safe infrared beam. LightRanger locates oblique surfaces missed by acoustic techniques; specular reflectivity is not required.

The LightRanger projects the beam from an infrared LED and continuously sweeps the beam 360° through a volume of rotation 45° across the cross section. A large area lens gathers reflected light from objects, and on-board circuitry then compares the phase of the modulation of the returned signal with that of the transmitted light. A built-in 68HC11 microprocessor converts this information into true range units and transmits it to the host computer via an RS232 serial link or Ethernet.

The sweeping and nodding mechanism is driven at up to 600 rpm by one servo motor. This translates into a 10 Hz refresh rate for the entire circumference of the observed volume. In operation, LightRanger can locate white objects out to 10 m and darker objects (such as blue denim) to 7 m.

The light-based direction and ranging system differs significantly from traditional vision systems. A vision system acquires an entire frame of data represented by the image sensor plane. The image must then be analyzed to extract feature information and indirectly compute the distance to obstacles within the image field. The LightRanger generates its three-dimensional map with a scalar measurement under active, mechanical servo control. The scalar reading from each optical sample is combined with the instantaneous heading and elevation of the scanning mechanism to yield a position in three-dimensional space.

The vertical nodding action of the scanner is deliberately set to a fraction of the rate of the horizontal scan. The sensing beam traces a series of flat spirals that approximate horizontal planes. The effect is to produce two dimensional maps of the environment at several elevations. This provides fine resolution data on the planar location of obstacles and targets, and course resolution data on elevation, which is optimal for a mobile robot navigating in a two-dimensional horizontal plane.

LightRanger Beacon Navigation System

The Beacon Navigation System (BNS) automatically senses and reports $[X,Y,\Theta]$ position and heading at ranges up to 25 meters within a quadrilateral area defined by four retroreflective beacons. BNS, which is based on the TRC LightRanger, acquires and locks on to the four beacons during a stationary initialization sequence lasting a few seconds. From that moment on, BNS sends a continuously updated stream of $[X,Y,\Theta]$ information that a host computer or track following mechanism can use to control the vehicle trajectory.

BNS will continue to operate even if two of the beacons are completely obscured. If a beacon is moved after initialization, BNS software will automatically adjust the bounding quadrilateral to compensate.

The sweeping motion is driven at up to 60 rpm by one servo motor. This translates into a 1 Hz refresh rate for the entire circumference of the observed plane.

BNS was developed for commercial floor sweeping operations in large, open areas. The BNS light direction and ranging unit operates at a lower wavelength than the stand-alone LightRanger. This increases the range but reduces the precision of the data. This is an appropriate trade-off: the LightRanger is designed for navigation in comparatively crowded corridors where clearances for passage are measured in centimeters, while the BNS is designed to control cleaning machines wide paths in open spaces up to 30 meters per side.

SonaRanger™

The SonaRanger senses its environment by bouncing ultrasonic pulses off objects and timing the delay before the reflection is detected. The system consists of a small microprocessor that controls sonic actuation and detection of up to 24 ultrasonic transducers.

The ultrasonic transducers transmit signals covering a 15° cone out as far as 10 meters. On a mobile robot vehicle, the sensors are aimed forward for obstacle detection and landmark identification, to the sides for detecting wall surfaces, and along vertical axes for detection of obstacles with suspended horizontal surfaces such as tabletops and desks with overhanging ledges. The sensor data are continually monitored and verified through a number of filtering techniques, such as comparing successive readings from the same sensor and summation of readings.

Logarithmic-Polar Vision

Image analysis and compression techniques based on logarithmic-polar mapping were introduced in the 1970's. In the past five years, functioning prototype logarithmic-polar vision guidance and control systems have been demonstrated by researchers at TRC and a number of universities around the world.

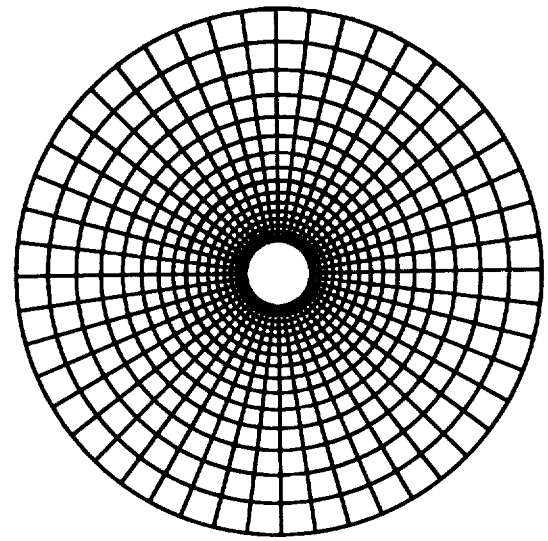

Figure 2 The Logarithmic Polar Coordinate Space

In logarithmic-polar representation, image plane pixels are arranged in a polar coordinate system where the distance between the concentric circular pixel boundaries grows exponentially.

In the logarithmic-polar representation, pixel count drops by nearly two orders of magnitude. The image has high resolution in the center and low resolution at the periphery. Images in this coordinate system are invariant in rotation and zoom. In the Cartesian space, a matrix transformation on each of the thousands of individual pixels is required for rotation and zoom. These operations in the logarithmic-polar space are accomplished by merely shifting the image data. This dramatically reduces the computational requirements for image transformation. In logarithmic-polar representation, the computer processor accomplishes these transformations quickly by shifting a single block of memory across the address space. In a frame buffer, this can be achieved by indexing all addresses by the shift vector.

The application of a Hough transform to the logarithmic-polar image yields edge and line information that can be used for identification of objects in the environment.

There is a growing body of evidence that human and higher mammalian vision processes images in the logarithmic-polar space. Indeed, the arrangement of cones on the retina of human eyes provided the original inspiration for using the logarithmic-polar space.

The highest resolution and detail in a logarithmic-polar image are always at the center of the image. A shift of attention or displacement of the imaging device requires rapid and accurate repositioning of the direction of gaze. This is a highly refined capability in even the most primitive animals.

The bulk of research in vision to date has concentrated on image analysis techniques where the camera position is fixed or rigidly attached to a moving vehicle. More recently, vision systems where the camera is actively controlled as part of the imaging process have appeared in research laboratories. Instead of intensively processing the entire image delivered by a camera at an arbitrary position, these new active vision techniques use the direction of gaze as an integral part of the algorithm.

A vision system based on the principles of logarithmic-polar space and a single camera requires active camera servo control to keep the image centered on the object of interest. With two cameras, the differences between each image can be used to extract depth information. Binocular active vision is rapidly emerging as a premier sensory modality for robot navigation and obstacle avoidance. Pioneering work by researchers at NIST, University of Genoa, Florida Atlantic University and others have shown optic flow and binocular vision can provide rich, 3-D perception at high speeds. For robot vehicles, the vision sensor mount must be steerable to compensate for vehicle motion, lock on to targets of interest, and converge for binocular stereo.

TRC has developed a high performance light-weight binocular vision head for robot vision. Both speed and precision are important. Trademarked the "BiSight," this system mimics the articulation, speed, and precision of human vision. Two CCD cameras are mounted on direct-drive brushless DC motors to provide saccadic (fast motion to new point of interest) motions at speeds of up to 1,000° per second, and binocular vergence motions at precisions of a fraction of a degree. Vergence and tilt axes pass through camera nodal points, assuring a constant binocular baseline throughout the range of motion, and complete separation of camera rotation and translation.

TRC is developing advanced image processing algorithms for NASA based on Gabor functions, to give mobile robots high precision 3-D perception of moving environments.

The Opportunities in Health Care

Several years ago, TRC identified a need in health care institutions for improved transport systems. As hospitals, clinics, and other health care institutions have grown, single buildings have expanded into sprawling campuses. In a typical expansion project, many departments are relocated to increasingly remote locations. Trips to a department formerly a couple of doors down the corridor become half-hour excursions.

Trained specialists such as pharmacists and nurses achieve zero productivity in their respective fields when they are walking across the campus to retrieve a sample or deliver paperwork.

Fixed, "hard-wired" transport systems such as pneumatic tubes were developed as an early solution. These systems were expensive to install, difficult to maintain, and costly to modify as the institution grew. Reprogramming meant ripping through walls, tearing up floors, and rewiring switch panels. TRC has seized the opportunity to develop a low cost robot that requires minimal facility modification, is easily maintained or replaced, and can be reprogrammed with a simple CAD drawing.

HelpMate ®

The HelpMate trackless robotic courier is TRC's principal product. HelpMate transports supplies between remote locations in office and institutional environments without a dedicated guidance system. It reduces or eliminates courier trips by skilled hospital staff.

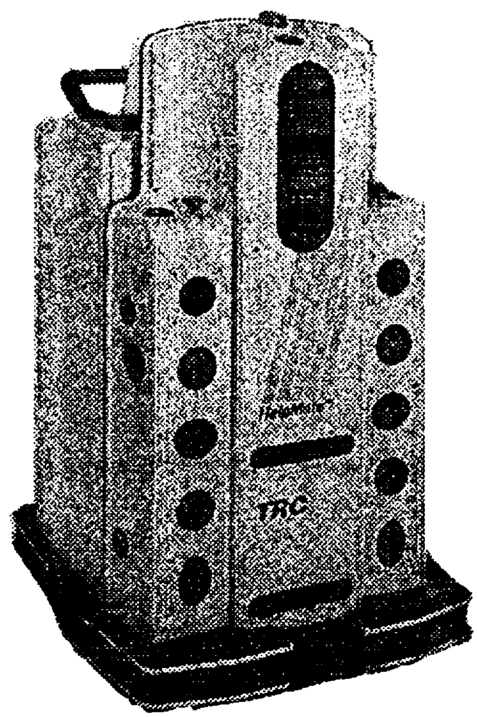

Figure 3 HelpMate Autonomous Robot

HelpMate navigates fully autonomously using passive data from its environment. This eliminates expensive facility modifications to install guidance aids, such as a network of beacons or embedded wiring in the floor or ceiling.

The HelpMate is the ultimate application for most of the technology developed at TRC. HelpMate is controlled by a main on-board processor with smaller peripheral processors for each sensor system and the drive carriage. As it moves down a corridor, HelpMate uses an ultrasonic sonar ranging system to measure distances to walls and potential obstacles. A vision system that uses twin, parallel planes of infrared light locates obstacles to the front of the vehicle. The data from all the sensors is collected by the central processor and placed into a stored map of the local environment. The central processor analyzes the map and calculates the path, avoiding obstacles as needed. Other processors handle the user control interface, indicator lights, compartment latches, and communications with the central fleet manager computer, elevator controls, and delivery enunciators.

An advanced prototype of the HelpMate equipped with a LightRanger is now being used to develop improved obstacle avoidance and navigation algorithms. Walls, stationary objects, and moving obstacles can be detected and tracked with greater resolution.

TRC is working with NASA to produce a demonstration vehicle consisting of a LabMate mobile robot base integrated with a binocular logarithmic polar vision system. This vehicle will be used to develop new techniques for guidance, obstacle avoidance, and object detection and recognition.

Bibliography

1. Engelberger, J. F. Robotics in Service, MIT Press, Cambridge, 1989.

2. Evans, J. M., Krishnamurthy, B., Pong, W., Skewis, T., Barrows, B., King, S., Weiman, C. and Engelberger, G., "Creating Smart Robots for Hospitals", *Proc Robots 13 Conf*, Wash. D.C., May 1989.

3. Krishnamurthy, B. et. al., "HelpMate: A Mobile Robot for Transport Applications", *SPIE Vol. 1007 - Mobile Robots III*, 1988.

4. Miller, G. L. and Wagner, E. R., "An Optical Rangefinder for Autonomous Robot Cart Navigation", *SPIE Vol. 852 - Mobile Robots II*, pp. 132-144, 1987.

5. Skewis, T., Evans, J., Lumelsky, V., et. al., "Motion Planning for a Hospital Transport Robot", *IEEE International Conference on Robotics and Automation*, April 1991.

6. King, S. J. and Weiman, C.F.R., "HelpMate Autonomous Mobile Robot Navigation System", *SPIE Vol. 1388 - Mobile Robots V*, 1990a.

7. Sandini, G., and P. Dario, "Retina-Like CCD Sensor for Active Vision", *NATO Advanced Research Workshop on Robots and Biological Systems*, Il Ciocco, Tuscany, Italy, June 1989.

8. Schwartz, E. L., "On the Mathematical Structure of the Retinotopic Mapping of

Primate Striate Cortex", *Science*, Vol 277, page 1066, 1985.

9. Weiman, C. F. R. and G. Chaikin, "Logarithmic Spiral Grids for Image Processing and Display", *Computer Graphics and Image Processing*, (11), pp. 197-226, 1979.