Apr 1st, 8:00 AM

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Scholarly Commons Citation

Shawaga, Lawrence M., "Understanding Of And Applications For Robot Vision Guidance At KSC" (1988). *The Space Congress® Proceedings*. 7.
https://commons.erau.edu/space-congress-proceedings/proceedings-1988-25th/session-3/7

UNDERSTANDING OF AND APPLICATIONS FOR ROBOT VISION GUIDANCE AT KSC

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ABSTRACT

The primary thrust of robotics at KSC is for the servicing of Space Shuttle remote umbilical docking functions. In order for this to occur, robots performing servicing operations must be capable of tracking a swaying Orbiter in Six Degrees of Freedom (6-DOF). Currently, in NASA KSC's Robotic Applications Development Laboratory (RADL), an ASEA IRB-90 industrial robot is being equipped with a real-time computer vision (hardware and software) system to allow it to track a simulated Orbiter interface (target) in 6-DOF. The real-time computer vision system effectively becomes the eyes for the lab robot, guiding it through a closed loop visual feedback system to move with the simulated Orbiter interface. This paper will address an understanding of this vision guidance system and how it will be applied to remote umbilical servicing at KSC. In addition, other current and future applications will be addressed.

INTRODUCTION

Currently, in NASA KSC's RADL (Fig. 1 and 2) is a Robot Vision Guidance Subsystem which controls the lab robot (ASEA IRB-90) to track a target consisting of a black dot on a white surface (Fig. 3) in three degrees of freedom (x, y, z). A future hardware/software upgrade to the subsystem will allow the lab robot to track a target consisting of three black dots on a white surface in Six Degrees of Freedom (6-DOF) consisting of x, y, z plus three relative orientation angular coordinates. This paper will discuss an understanding of the hardware and software components comprising this subsystem currently and in the near future.

In addition, this paper will address four applications to be developed (two current and two future) utilizing the above subsystem at KSC.

COMPONENTS OF THE RADL ROBOT VISION GUIDANCE SUBSYSTEM (FIG. 4)

Solid State Camera

- The camera used with the vision system in the RADL is a Charged Coupled Device (CCD) Sony video camera with a 16 mm, auto-iris, C mount lens. This lens provides compensation for variations in lighting. Currently, target information viewed by the camera for tracking purposes is a 2 inch diameter black circle with a white surrounding for distinct region contrast. Coordinate information supplied by the camera to the vision system is from a plane perpendicular to the line of sight of the camera. The camera scan rate is 30 images per second.

Vision System Computer

- The Motorola System 1000 is the vision system computer in the RADL. It is interfaced with a DATACUBE Company image processing board set through a VME bus. The System 1000 is configured with a Motorola 68010 10 MHz processor (replaced by the Motorola 68020 processor in March, 1988 to support the OS-9 installation, below), a 15 Mb hard disk, a 512 Kb RAM memory, a 655 Kb floppy diskette, 3 serial ports, and 1 parallel port. The vision system is supported by the Motorola VERSAdos operating system: a real-time, multiuser, multitasking operating system with features necessary for the support of the image processing boards (Note: This operating system will be replaced in March, 1988 by the OS-9 operating system. OS-9 and the Motorola 68020 were not installed at the time this paper was written.). These features provide servicing of directly connected interrupts, intertask communication, system utilities, memory allocation and task management services.

Image Processing Hardware and Their Use in the RADL Vision System

- The RADL vision system uses six boards selected from the DATACUBE MaxVideo line of image processing products. They use a pipeline design approach providing a high performance image processing capability with the flexibility to accommodate more modules without impacting the capability to process images at the 30 images per second scan rate of the camera. The following describes the image processing performed by the six hardware/firmware boards and their use in the RADL.

  - DIGIMAX - The DIGIMAX board receives the standard RS-170 video signal from the camera. This analog input signal is then filtered from one of four software selectable filters, conditioned with programmable gain and offset circuitry, and converted to an 8 or 6 bit digital signal. This signal is then passed through one of eight banks of a look-up table (256 levels of gray), and output for storage or processing. The DIGIMAX board also drives a Panasonic video monitor with a converted D/A signal from a green LUT for the current black and white image (processed or non-processed) seen on the monitor. A centroid crosshair overlay (to be described later) also resides in DIGIMAX.

  - FRAMESTORE - The FRAMESTORE board contains 3 (384H x 512V pixels) frame storage buffers to hold digitized video images. It is used to provide a window (mask) which is gated with the data output from the VFIR board (below) to reduce the "area of interest" processed by the feature extraction board (FEATUREMAX, below). It also provides the centroid crosshair to the DIGIMAX board for output to the Panasonic video monitor to view what the vision system is calculating as the center of the target.

  - VFIR - The VFIR (Video Finite Impulse Response) board performs 3 x 3 two dimensional convolutions on a full frame (384H x 512V pixels) of video data in 1/30th of a second. Therefore, in 1/30th of a second , the complete edge information between the light and dark regions of the target being tracked in the RADL is enhanced. Note: The VFIR board operation has been superseded by the MAX-SIGMA board, below.

- FEATUREMAX - The FEATUREMAX board (feature list extraction board) receives the enhanced edge image data and stores the x, y coordinates in 16k of RAM of every point in the image that has a value higher than a preset threshold value (set by the vision system console operator in the RADL). The Motorola System 1000 vision software uses this data to calculate the centroid of the target to be tracked by vector summing the x, y coordinate pairs and dividing by the total number of pairs.

- MAX-SIGMA - The MAX-SIGMA board replaced the VFIR board in the RADL vision system for edge enhancement purposes. MAX-SIGMA allows variable (programmable) large kernel convolutions from 1 x 1 up to 63 x 63 pixels. By passing a larger kernel size over the 384H x 512V frame of video data, a higher degree of filtering occurs per center pixel in the kernel (in the determination of edge pixels) by comparing its value with more neighboring pixels for weighting purposes. As with VFIR, the value of the center pixel is computed by weighting each neighboring pixel's value by coefficients in the convolution kernel, and summing these values together to determine the weighted average. MAX-SIGMA utilizes a Difference of Gaussian (DOG) convolution operation for edge finding. To do this, a kernel of size 7 x 9 pixels and a kernel of size 9 x 11 pixels is passed over the digitized video frame of data. MAX-SIGMA actually simulates the DOG solution with DOG boxes through convolution, multiplier, and adder functions.

    - Problem - If the size of the kernels is set too large, extraneous information not edge related may actually cause obscuration of the center pixel weighting and thereby produce false edge information.

    - Note: A single two dimensional convolution operation over a single frame of video data is performed by MAX-SIGMA in 20 msec. (some 10 msec. faster than VFIR).

- MAX-SP - MAX-SP is a board added to the vision system image processing arsenal of boards to perform single point temporal and spatial filtering on the processed image information. Other functions it can perform are image merging, image subtraction and addition, and minimum/maximum processing.

Tracking System Software

- Firmware on the image processing boards has been integrated with the Motorola vision system computer based software modules developed to control and monitor target tracking tasks. Their modularity allows them to be used later in different combinations for future image processing tasks (i.e., when 6-DOF tracking becomes a reality). The tracking system modules provide the following functions:

    - System initiation modules allocate shared memory blocks for intertask communication, allocate system queues to allow transfer of messages between tasks and loads/starts the other vision system tasks.

    - Command processing modules examine commands received from the operator's terminal which can set vision system parameters and stop the target tracking task. They are essentially message processor modules invoking routines to initialize, request status, set/request parameters, start and stop target tracking and set the area of interest window.

- o Vision system communication modules implement system protocol with the MicroVAX supervisory control system computer (see Fig. 4). A protocol has been developed in which one MicroVAX command generates continuous vision system responses. This mode transfers target tracking coordinate information from the vision system computer to the supervisory computer. Termination can be by either the MicroVAX, the operator or a vision system error. An additional "window" command allows the MicroVAX to dynamically control the size of the camera view, as the distance from the camera to the target changes.

- o Target tracking modules compute the spatial derivatives of the image, determine the location of significant edges and determine the centroid of the edges.

o The software modules above are implemented as a series of three tasks in the Motorola vision system as follows:

- o STRTTASK (Start Task)

    - Allocates intertask shared memory
    - Allocates system queues
    - Loads/starts both the VISNTASK and COMMTASK (below)
    - Passes keyboard messages
    - Displays messages from the other tasks
    - Coordinates orderly shutdown of the vision program

- o VISNTASK (Vision Task)

    - Attaches to intertask shared memory
    - Allocates its queue
    - Opens/initializes data structures for all the vision boards
    - Maps logical to physical memory for the vision boards
    - Initializes vision board hardware
    - Parses vision commands received from the STRTTASK and COMMTASK as follows:

        - tracking()
        - send_status()
        - set_params()
        - get_params()
        - vwindow()

    - Deallocates its queue and waits for the shutdown command from STRTTASK

- o COMMTASK (Communication Task)

    - Attaches to intertask shared memory
    - Allocates its queue
    - Maintains communication with the MicroVAX supervisory control computer
    - Passes messages to VISNTASK
    - Receives messages from VISNTASK
    - Sends the shutdown request to STRTTASK when the MicroVAX requests shutdown
    - Deallocate its queue and waits for the shutdown command from STRTTASK

RADL Robot Tracking Motion Control

- The MicroVAX supervisory control computer in the RADL sends the coordinate motion information to the lab robot controller (see Fig 4) in order for the robot to track the target. The x, y coordinates of motion (centroid of the target) received by the MicroVAX from the vision system computer are input to MicroVAX x, y, z control loop application software (The z coordinate is computed as the proportion of one over the square root of the number of pixels contained in the black dot target seen by the vision system.). This software directs the motion of the lab robot and converts the motion data to the Quaternion coordinates of motion the robot controller understands.

  The near future (May, 1988) 6-DOF target tracking capability will be implemented in the Robot Vision Guidance Subsystem in the form of two new Vision Systems Company APA 512 VME hardware/firmware boards, new Motorola vision system computer software, and new MicroVAX supervisory control computer software. The APA 512 VME boards will be installed in the vision system computer to provide all six coordinates of motion (x, y, z, plus three orientation angles) and centroid calculations for the new three dot target. The boards presently installed in the vision system computer will perform some of their present capabilities, but not all. The new vision system computer software will provide 6-DOF target position information at a rate of 15 updates per second via a serial communications link to the MicroVAX computer. Target position information will consist of three relative position distances and three relative orientation angles between the CCD camera and the target. Also, limited target discrimination to counter the effect of noise and extraneous objects in the image will be implemented in the vision system computer. The MicroVAX supervisory control computer software will be modified to incorporate six individual closed loops for the control of robot position and orientation using the relative target information provided by the vision system. In addition, this software will include the conversion of three angles of relative target orientation to quaternion representation needed to control the robot tool center point.

APPLICATIONS FOR THE RADL ROBOT VISION GUIDANCE SUBSYSTEM AT KSC

Current Applications

- Remote umbilical plate docking
  - Remote umbilical plates are used in many places to mate with the Space Shuttle Vehicle at KSC. They provide the vehicle's requirements for fuel, communications, heating, ventilating, air conditioning, hydraulic power, electrical power, etc. Most of the umbilical plate connections are hazardous to worker safety (mainly the hypergolics and cryogenics), repetitive, and heavy/cumbersome to handle.

    NASA/KSC plans to replace some or all of these umbilical plates and their connections with new technology umbilical plates employing robotics and machine vision to automatically mate/de-mate with the Space Shuttle Vehicle interfaces.

    The current Space Shuttle Vehicle umbilical interfaces rock with the vehicle in six degrees of freedom. This situation makes the RADL the ideal test bed for the development of new umbilical plate technology utilizing the lab robot and the Robotic Vision Guidance Subsystem to perform simulated tracking and docking maneuvers in 6-DOF. Figure 5 illustrates how this might be performed in the RADL. A simulated Space Shuttle Vehicle interface with associated three dot target will be attached to a three degree of freedom motion simulator (currently in the lab - Note: Later deflection motion will have to be added to the simulator.). The Robotic Vision Guidance Subsystem will then guide the lab robot with new technology umbilical plate attached to dock with the interface.

- Plant growth chamber automation
  - The plant growth chamber, part of the Controlled Ecological Life Support System (CELSS) at KSC to support long duration space missions, is the second of the two current applications for robotics and machine vision which will utilize the robot and the Robotic Vision Guidance Subsystem in the RADL. Figure 6 illustrates how this might be performed in the RADL.

    Proper planting is cumbersome and time consuming to perform manually as the seeds (wheat seeds primarily) must be planted in a proper orientation with the groove of the seed up and its root bulb left and down. The lab robot with a specially designed end effector will be guided by the Robotic Vision Guidance Subsystem to pick up a seed and properly orientate it (after an object recognition system determines the seed is good, otherwise it will be discarded, and another seed retrieved). The seed will then be inserted in its proper plant growth unit.

Future Applications

- Orbiter tile/radiator damage inspection and repair
  - Upon return from space, the Orbiter is ferried to the KSC Orbiter Processing Facility (OPF) for among many tasks, the assessment of damage and repair to Orbiter tiles and radiators. The inspection and repair process involved is currently manhour intensive and operationally expensive.

    The RADL has been proposed as a facility to develop prototype hardware sensors and software imaging techniques using the lab robot and machine vision system, and mockups of Orbiter tiles and radiator sections for the assessment of damage to tiles and radiators.

- Payload inspection and closeout verification
  - Payload inspection and closeout verification in the Orbiter payload bay (when the Orbiter is integrated in the Shuttle configuration at the launch pad at KSC) is very involved, intricate, and time consuming (depending on the payload being processed) under current manual methods.

    Robotics and machine vision has been proposed for payload inspection and closeout verification for payloads at the launch pad in the Orbiter payload bay. A robot or robotic devices integrated with machine vision or a laser scanning system could be installed in the launch pad payload changeout room and utilized to inspect and verify closeout of payload components in hard to reach places. In this way, the danger of damage caused to the components would be greatly minimized in comparison to current manual operations.

CONCLUSION

The intention of this paper has been to provide an understanding of the state of robot vision guidance as it currently exists at KSC. Also, this paper has introduced four applications (two current and two future) for robot vision guidance at KSC.

The understanding has been concentrated on the Robotic Vision Guidance Subsystem in the RADL under both its current and near future configuration. This system is expected to provide the primary thrust of robot vision guidance at KSC. It will be adapted to change (and has been designed for that purpose) as current and future applications warrant. This should not be interpreted as the only location for robot vision guidance at KSC. The Engineering Development Laboratory (EDL) at KSC has been selected for the development of mobile robotics.

The four applications discussed are the predominate ones for robot vision guidance implementation at KSC. They should not be interpreted as the only ones as future requirements (i.e., Space Station module processing) will dictate further implementation. In addition, as mentioned above, mobile robotics will be developed at KSC for hazardous servicing and surveillance purposes. Their guidance systems will be dictated by their applications.

FIGURE 1

FIGURE 2

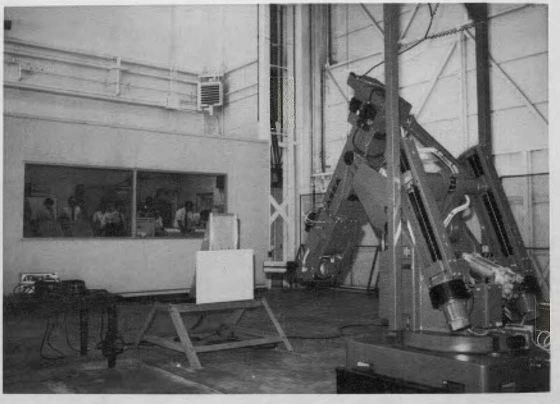
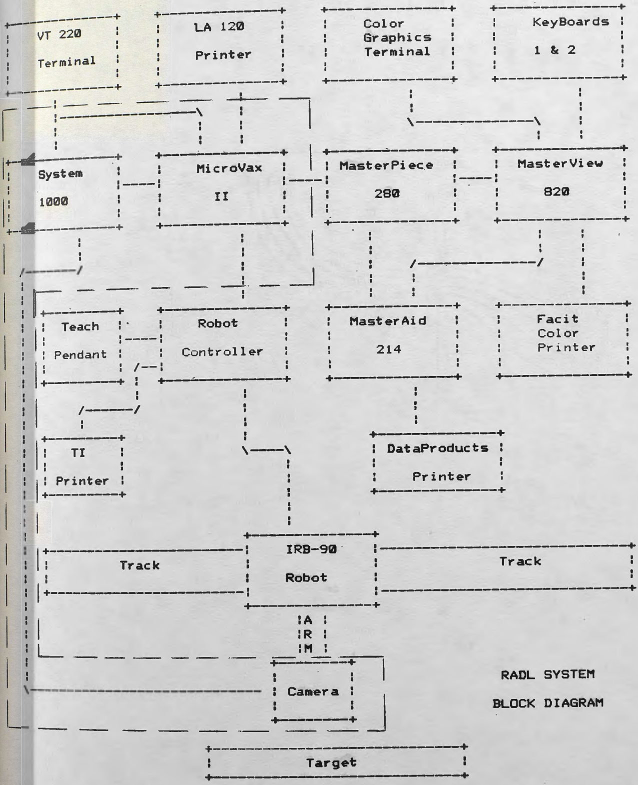


FIGURE 3

FIGURE 4 - ROBOT VISION GUIDANCE SUBSYSTEM (DASHED LINE ENCLOSURE)



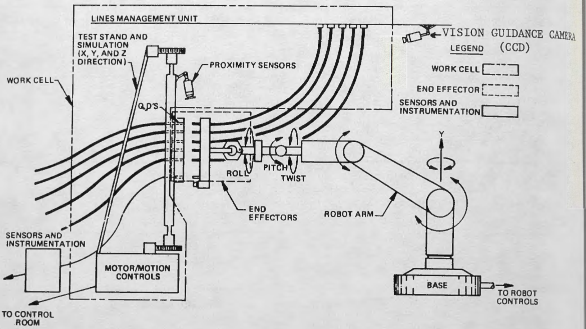


FIGURE 5 – *RADL Work Cell, Prototype System for Handling T-O Umbilicals*

PLANT GROWTH

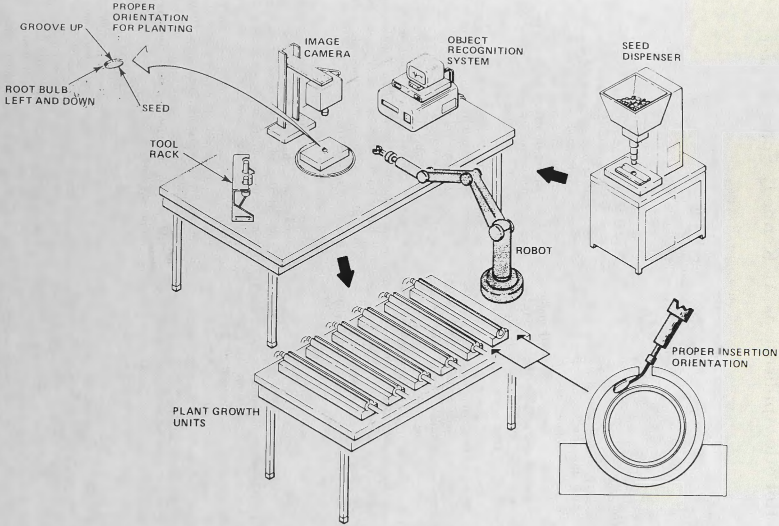


FIGURE 6