A RANDOM ACCESS PICTURE DIGITIZER, DISPLAY, AND MEMORY SYSTEM*

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The JPL Robotics Research Program is developing techniques that might be applicable in the future to planetary missions, to the assembly of large structures in Earth orbit, or to free-swimming underwater vehicles where there is a need for the integration of a computer vision system with mechanical effectors. In each of these applications there Is a necessity for real-time processing and a size limit on the on-board processor. To meet these objectives, a random access picture digitizer and memory system (RAPID) has been developed which provides, in effect, real-time random access television cameras to the computer. This short report describes the impact of RAPID on the Robotics Program, both in terms of the hardware design and software organization.

ROBOT VISION SYSTEM

The robot vision system (Ref. 1) consists of two solid-state CID television cameras mounted on the robot, a random access video memory, the scene analysis algorithms, and the image displays. The software also has access to data from the laser ranger. The vision system shares the General Automation SPC-16/85 minicomputer with the other robot subsystems.

The General Electric CID television cameras, 'providing a resolution of 188 pixels by 244 lines, were selected to solve the problem of image linearity and stability. Also, the GE cameras could be easily locked to the digitizer sampling window assuring that each stored pixel was from only the center of an active detector on the CID chip. While resolution was lost from previous silicon target vidicons, necessitating more frequent camera motion, a major problem of scene constancy was eliminated. RCA, GE, Fairchild, and Texas Instruments now offer devices with equal or higher resolution.

RAPID (Ref. 2) was developed to increase the image-processing speed and permit such real-time functions' as object tracking. This was accomplished by eliminating unproductive computer bus traffic, providing fast access to any pixel (5 us) and updating the image memory at video rates (a new image every 1/30 s). Through a unique buffering scheme, RAPID provides concurrent digitization and display at video rates as well as random word or byte access from the computer.

The algorithms for object detection, object tracking (Ref. 3), region growing (Ref. 4), scene segmentation (Ref. 5) and stereo measurement (Ref. 6), originally developed for the robot, have been used for studying Viking (Mars) imagery, maze puzzles, facial changes following surgery (Ref. 7), and changes in astronaut body volume.

VIDEO DISPLAY AND MEMORY

RAPID (Fig. 1) combined with the television cameras provides, in effect, live random access television images. Any byte or word in RAPID memory can be accessed (read or write) by the computer without interfering with the sequential storage and retrieval of EIA RS-170 standard video. RAPID Is organized as a 256 pixel by 256 line byte memory using eight byte buffers and high-speed TTL logic in order to operate at video rates without interference. Similar units (Ref. 8) are now available but at a cost higher than the JPL development cost and lacking capabilities believed to be important. Some additional features of RAPID are: six computer selectable input channels, stereo mode that interleaves two images in memory, freeze mode that inhibits video input, interrupt at the end of the video frame, automatic compensation of known camera blemishes, and computer-controlled cursor.

Incoming video is digitized continuously at 280 ns/pixel to a resolution of eight bits and stored sequentially In one of two eight-byte input buffers. Using a double buffer scheme, the eight bytes of the input buffer are written into memory at one time, alternating between the two input buffers. The same double buffer technique is used in reverse for video output. The memory cycle time for reading or writing the 64 bit buffers is 700 ns. Since 2.24 us (280 ns X 8) elapses between reading or writing a buffer, 1.54 us is available for handling a computer request for access to the video memory. The minimum time between computer requests for access to RAPID is 5 us. Since the video memory is continuously accessed for video output even when video input is inhibited, no separate circuitry or time is needed to refresh the dynamic memory.

REAL-TIME IMAGE ANALYSIS

An example of scene analysis is the object location sequence for manipulation. The first step is image transformation which provides the edge enhancement and image reduction to one sixteenth the original size. The image is sampled at one-quarter resolution and partitioned into two by two cells. For each cell, all six differences are computed, and the absolute values are averaged to obtain an eight-bit value, which is then stored in RAPID as one pixel, producing the second one-quarter reduction. Small values in the tranformed image correspond to areas of uniform intensity, while large values indicate a sudden change in intensity, which is usually the edge of an object. The transformed image is scanned line by line in the second step to obtain a list of regions that

This paper presents one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract NAS 7-100, sponsored by the National Aeronautics and Space Administration.

correspond to possible objects of interest. The regions are connected clusters of pixels that exceed an edge confidence threshold. The third step is to select one region from the list, read the full digitized image into RAPID again from the cameras, and obtain the outline of the object in full resolution using a region growing algorithm. The shape of the object is determined at this point, and the short axis is computed to determine the orientation for the manipulator hand in grasping the object. The fourth step is to obtain a 3-D measurement at the image centroid. This location and the orientation are sent to the manipulator, which is then commanded to fetch the object. The entire scene analysis sequence runs in about 5 s and requires no operator intervention other than the command to begin. This represents an increase in speed of ten to twenty times over similar schemes in use before the advent of RAPID.

3-D measurements are necessary for manipulation (object location) and navigation (terrain mapping). A correlation algorithm matches conjugate image points in the left and right images. The pair of points thus obtained corresponds to a unique point in three-space that is determined as the intersection of two rays. A typical correlation time (100 correlations, 70 points per correlation) is approximately 0.8 s, with grey level acquisition from RAPID accounting for approximately 0.035 s, or about 4% of the total time. This is opposed to 5 s for the same images accessed from disc files.

An object tracking algorithm has been implemented using correlation techniques similar to the 3-D program to track arbitrary objects moving in a single television image. The tracking speed ranges from 50 to 75 pixels/s, depending on the number of points used to define the feature being tracked (9 to 25 points). The capability is directly attributable to RAPID for two reasons: (1) the gray level data are accessed rapidly and (2) fast digitization (1/30 s/frame) gives the next position in the shortest possible time at standard video rates.

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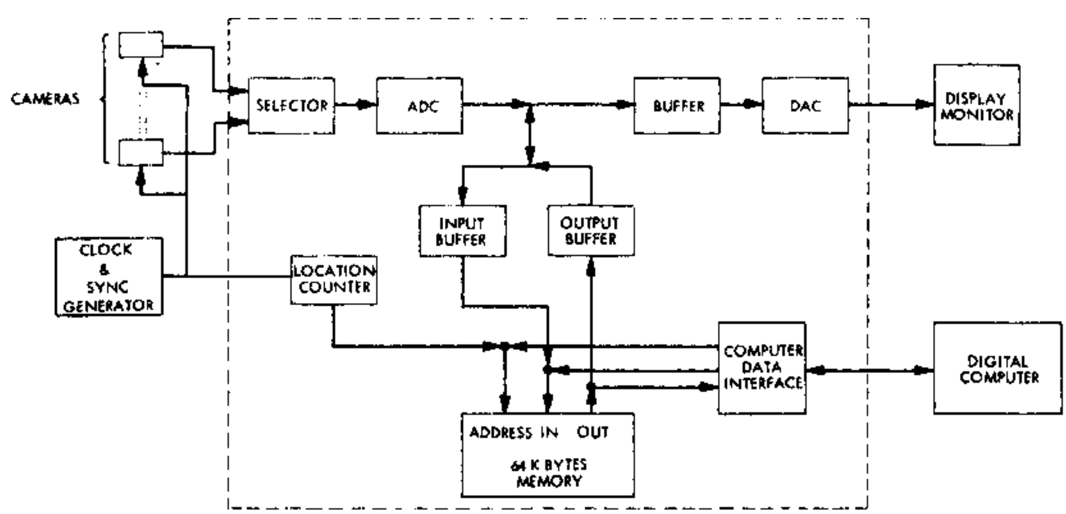

Fig. 1. Block diagram of RAPID