STEREO SOLID STATE CAMERA SYSTEMS

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ABSTRACT

Recent developments in machine vision systems, solid state cameras, and image processing are reviewed. Research directions for the development of real-time photogrammetric systems are proposed.

INTRODUCTION

Real-time machine vision is one of the most exciting and active fields of research and development in science and technology today. The potential impact of real-time machine vision in science and technology is practically unlimited. It has already found important applications in industrial manufacture, medicine, astronomy, and robotics. While systems of various degrees of sophistication are commercially available, the problems that remain to be solved are numerous and complex. Research and development efforts will require truly interdisciplinary efforts involving expertise in photogrammetry, optics, electronics, computers, communications, as well as bioengineering.

The purpose of this paper is to review the present state-of-the-art in real-time imaging systems, and to identify major directions of research within the field of photogrammetry.

TYPES OF SYSTEMS

Real-time imaging systems can be divided into the two general types.

1. Single-purpose systems

   These are systems that are designed to perform a specific function, such as identifying objects of specific shapes or dimensions, change detection in a stationary scene, and determination of the spatial coordinates of a specific type of target.

2. Multi-purpose Systems

   These systems can be program controlled to perform user directed functions.

A real-time imaging system typically includes one or two cameras, an analog to digital converter, an image processor, a control computer and output peripherals. The image processor is a special-purpose computer designed to perform at very high speed such basic image processing operations as image enhancement, edge detection, feature extraction and convolution.

Tutching (1984) presented an excellent overview of the market demands for vision systems during the 1984-1987 period. He estimated that the 1984 market for such systems was in the $70 to $80 million range. He projected that, by 1992, the annual sales will amount to about 15,000 units with a dollar value in excess of $150 million. Of the approximately 70 manufacturers of such instruments in 1984, he estimated that 49% of the firms manufactured general purpose systems, 27% dedicated systems, and 24% produced only system components.

Keil (1984) presented a general description of 27 off-the-shelf image systems. Sixteen of these systems were designed for pattern recognition with the 1984 costs ranging from $10,000 to $59,000. The remaining eleven systems were designed to perform dimension measurements, with the 1984 costs ranged between $19,700 and $120,000.

By far the largest group of current users of real-time imaging systems is in industrial manufacturing, where the systems are used to perform such tedious and exacting functions as inspection, part identification, guidance, and control. Mayer (1984) estimated that there were 1,000 imaging systems in use in the manufacturing plants in U.S. in 1984.

While real-time imaging systems have the tremendous potential of providing vision capability to robots, it is interesting to note that the vision market currently has 10 times the volumes (in number of units) of the robot market (Falkman and Murray, 1984).

SOLID STATE CAMERAS

Both conventional vidicon television cameras and solid state cameras may be used as image sensors for a real-time imaging system. However, because of the unavoidable presence of large geometric distortions in vidicon images (Wong, 1969), vidicon cameras are not expected to play an important role in imaging systems that are designed for making precise geometric measurements.

A solid state camera may use either a charge-injection device (CID) or a charge coupled device (CCD) as focal plane. Both types of focal planes consist of sensor elements arranged in rectangular arrays. The geometric fidelity of these focal planes is limited only by the accuracy with which the sensor elements can be placed in the array during the manufacturing process. As an optical image is focused by a lens system on the linear array, each sensor element in the array detects the intensity of the light incident upon it. Thus, each sensor element records a single gray value resulting in a picture element (pixel), and the linear array of individual pixels constitute the picture.

Commercially available CCD and CID cameras vary widely in the dimensions of the linear arrays (Gunn and Westphal, 1981; Keil, 1984). Arrays consisting of about 250 x 250 elements are in common use, and arrays of 800 x 800 have been used in astronomical applications (Blouke, et al., 1981). The pixel size may range from about 15 x 15 μm to about 45 x 45 μm.

Mosaic focal planes consisting of millions of picture elements are presently feasible (Chan, 1981; Schlessinger and Chan, 1981). A mosaic focal plane is formed by arranging into a linear array of individual chips, each of which is a smaller subarray of say 100 x 100 pixels. Such mosaic focal planes have been developed for use in space telescope for the real-time detection of subsonic strategic aircrafts (Birtley, et al., 1981), and in earth-based telescope for the tracking of earth-orbiting satellites (Johnson and Burczewski, 1981).

A major advantage of CCD and CID devices is the geometric stability of the picture elements. The position of the picture elements are fixed with respect to each other and do not change from picture to picture. Thus, for conducting precise photogrammetric measurements, there is no need for fiducial marks to define the interior geometry of the cameras.

IMAGE PROCESSING

Much of the basic image processing techniques in use today were initially developed for the processing of television images returned from space vehicles. These techniques were later refined and supplemented with new developments from the LANDSAT remote sensing program. But most of the techniques developed for these programs were confined to the processing and analysis of two-dimensional images. The full potential of real-time imaging systems can only be realized by extending image processing capability to the three-dimensional space. Papers presented at a recent conference on the processing and display of three dimensional data (Pearson, 1984) testified to the increased complexity of the image processing tasks as well as the wide spectrum of application needs. Since a large amount of knowledge has been developed in the field of photogrammetry for the precise processing of three dimensional data, it is in the application of their knowledge to real-time processing that the photogrammetrists can be expected to make their biggest contributions.

One of the fundamental problems associated with real-time imaging is the vast quantity of data and complexity of the image processing algorithms. General-purpose processors are unlikely to be able to meet the processing needs. Task-dedicated special array processors operating in parallel will be needed (Wolf, 1981; Wambacq, et al., 1981). Extensive off-the-shelf hardwares and softwares are presently available at reasonable cost.

Perhaps the biggest challenge associated with real-time imaging systems is the development of knowledge based algorithms (or commonly referred to as artificial intelligence) for the extraction and interpretation of data. Some interesting works in this area have been reported in the literature. McKeown, et al. (1986) developed an algorithm for stereo verification in aerial photographs. Wesley (1986) presented some interesting results on the use of imprecise, often inaccurate, (so called evidential information) for image interpretation.

PHOTOGRAMMETRIC RESEARCH

Briefly outlined below are some potential topics of research by the photogrammetry community.

1. Stereo solid state camera systems

Digital correlation of conjugate images remain to be a most time-consuming process in the generation of three-dimensional data. The process usually involves three steps: 1) determination of the orientation of the conjugate epipolar rays; 2) resampling of photo densities of picture elements along the epipolar directions; and 3) determination of conjugate image points. A stereo solid state camera system can be designed so that the need to perform the first two steps of the process is eliminated. The two focal planes can be precisely aligned so that the direction of the epipolar lines are in coincidence with that of the linear array of picture elements. The stereo imaging system will function as a pair of human eyes, and the computational load associated with digital correlation will be significantly reduced. Such a system can operate either in real-time or near real-time mode. However, it will be limited to the nominal case photography, and because of the small base-to-height ratio, will likely be limited to short range applications. Yet, such a system should find significant applications in areas where machine vision systems are required to provide low-accuracy dimensional measurements.

2. Targeting accuracy

Measurement of the image coordinates of a target is a fundamental operation in photogrammetric measurement. Considerable amount of effort had been devoted to studying the accuracy of this operation performed by human operators on stereo- and mono-comparators. It is unlikely that the results from these previous studies can be applied directly to digital image data. Human factors no longer enter into the measuring process. Instead, the accuracy of determining the center of a target is affected by the pixeling effect of a digital image. The size, shape, and contrast of the target directly affect the accuracy of the targeting operation. A better understanding of these factors will be needed to optimize the accuracy of digital measurement.

3. Image correlation

Digital image correlation has been a subject of intensive study in connection with the development of analytical plotters. Yet, present algorithms for digital image correlation can hardly match the capability of an experienced human operator. In close-range applications, digital correlation is further complicated by differences in view perspective as well as the complexity of a usual scene. A better understanding on the accuracy of digital correlation as well as more efficient correlation algorithms will be needed.

4. Self-calibration and self-orientation

Algorithms are needed for the automatic recognition of control targets, and self-determination of both the interior and exterior orientation parameters of a digital camera within an application environment.

5. A general algorithm for multi-station and multi-camera photography

In close-range photogrammetry, it is often necessary to photograph an object from three or more view points. Sometimes it is necessary also to employ more than one camera. Analytical solutions have been developed for the triangulation of such photographs. For digital imaging system, a more powerful algorithm will be needed. The algorithm should be able to perform the following tasks in real-time or near real-time: 1) identification of control targets; 2) identification of the best stereopair for the mapping of a particular part of the object; 3) perform digital correlation of conjugate stereo pairs; 4) merging of spatial data from the individual stereopairs to form a three-dimensional model of the object; 5) absolute orientation of the generated digital model; 6) accuracy and error analysis; and 7) generation of graphical and numerical outputs.

6. Artificial Photogrammetry

The ultimate goal must be the development of a system, which for all practical purposes, may be called an "artificial photogrammetrist". Such a system will be founded on knowledge based algorithms. It will possess the expert knowledge of a remote sensing specialist, an analytical photogrammetrist, and a stereoplotter operator, and will be able to make logical decisions in microseconds!

CONCLUSIONS

The machine vision industry is still in its early stages of evolution. Yet, exciting capabilities have already been demonstrated, and future potential is practically unlimited. Research and development efforts are accelerating at a rapid pace. The field of photogrammetry is in an excellent position to make major contributions to the development of real-time or near real-time vision systems for precise geometric measurements.

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