Machine Vision, Robot Vision, Computer Vision, and Close-Range Photogrammetry

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ABSTRACT: Recent developments in machine vision, robot vision, and computer vision have made significant impact on the automation of manufacturing processes. Vision technology also provides the means and impetus to develop fully-automated, real-time photogrammetric systems for close-range applications.

INTRODUCTION

RESEARCH DURING THE LATE 1960s and early 1970s already showed that geometric distortions in television (TV) images were highly systematic, and that measurement accuracy better than ± 0.5 TV lines was possible (Wong, 1970; Wong *et al.*, 1973). However, outside of the space program, there was very limited interest on the use of television systems for performing metric measurements.

Today, a new generation of TV cameras has been developed, resulting in significant increase in geometric fidelity. At the same time, computer technology has developed to the extent that low-cost, high-power, desktop computers are commonly available, and duplication of human intelligence in the computer is considered a definite possibility. Fierce competition in the industrial sector has also spurred a relentless drive for efficiency and quality control. The convergence of these forces has resulted in the development of several new and closely related disciplines called machine vision, computer vision, and robot vision.

The purpose of this paper is to review the current status of developments in these disciplines, and to discuss their potential impact on close-range photogrammetry.

MACHINE VISION

Machine vision has been defined as "the automatic acquisition and analysis of images to obtain data for interpreting a scene or controlling an activity" (Schaffer, 1984). The primary driving force behind the development of machine vision has been the manufacturing industry. Machine vision provides a cost-effective means for performing automated inspection, gauging, recognition, and process control in real-time, resulting in significant improvement in product quality as well as reduction in manufacturing cost (Zuech, 1987). The Machine Vision Association of the Society of Manufacturing Engineers was founded in 1984, and has sponsored annual conferences on machine vision.

A typical machine vision system consists of four components: one or more CCD (charge coupled device) cameras, a frame grabber, a computer, and an image analysis software package. The output analog signal from the cameras conforms to the standard RS170 video format of 525 scan lines per frame, 30 frames per second, two fields per frame, and an image aspect ratio of 4:3. A frame grabber, in the form of a circuit board that can be easily installed in a computer, is used to capture an image on command, convert the analog signal to digital form, and then forward it to the computer for either immediate processing or storage. The resulting digital image usually consists of 256 by 256 or 512 by 512 picture elements.

A CCD focal plane consists of a linear array of photo-sensitive cells. There is a wide selection of CCD cameras available in the market with different array dimensions and cell sizes. For vision systems using the RS170 signal format, there is usually no one-to-one correspondence between the photo sensitive cell in the focal plane and the picture elements in the final digital image. For example, a digital image consisting of 512 by 512 pixels may be generated from a CCD camera that has a focal plane array of 490 by 800 cells. The CCD cameras can be classified into two groups according to the method used in transferring the analog image out of the focal plane. These are line-transfer CCD cameras and frame-transfer CCD cameras. From a user standpoint, the most important difference between them is that, in a line-transfer camera, less than 50 percent of the actual surface area of a focal plane is photo sensitive, while more than 90 percent of that of a frame-transfer camera is photo sensitive. Thus, there are large physical gaps between the photo sensitive cells of a line-transfer CCD camera that can significantly affect its resolution as well as measurement accuracy.

Fully digital vision systems uses CID (charge injection device) cameras. In this type of system, every pixel in the final digital image corresponds to a physical photo sensitive cell in the CID focal plane. Each cell in a focal plane is directly addressable through software. A CID vision system, however, typically costs two or more times that of a CCD system. In the manufacturing industry, machine vision systems are usually integrated into the manufacturing process to provide real-time feedback and control. The systems must be fully automated, fast, and cost effective. The basic strategy to meet these criteria are (1) simplify the vision task, (2) tightly control the application environment, and (3) make full use of low-cost personal computers. For example, in machine gauging, a piece of flat machine part can be placed on a light table. A camera is used to capture the silhouette image from above the table. The image analysis task is thus reduced to finding the edges where transition from dark to bright intensity level occurs. It is clear from this example that lighting plays a major role in machine vision.

For image analysis and interpretation, to-day's machine vision systems depend largely on algorithms that have been developed over the last 20 years in such fields as pattern recognition, remote sensing, image processing, and photogrammetry. Some of the basic image analysis operations are image segmentation, convolution, edge enhancement, edge detection, filtering, correlation, connectivity analysis, blob labeling and centroiding, template matching, and optical triangulation.

ROBOT VISION

Robot vision may be defined as the automatic acquisition and analysis of images for the control, manipulation, and guidance of robots. Examples of application of robot vision include autonomous vehicles, arc welding, and mail sorting (Casasent, 1986; Wolfe and Marquina, 1986). The image processing tasks

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associated with robot vision are considerably more complex. The application environment is such that both lighting and scene contents are less controllable, and the interpretive algorithms must possess intelligent decision-making skill. Three-dimensional scene reconstruction and feature recognition are essential elements of a robot vision system. One current approach to simplify the image processing task is to supplement the vision systems with other types of sensors such as sonar for obstacle avoidance in mobile robots, laser imaging radar for generating 3D scene information, and infrared cameras for location of heat sources.

Robot vision, as well as the field of robotics itself, is still in an early stage of research and development. Commercial applications of robots equipped with vision capability approaching anywhere near that of human vision is still in the distant future.

COMPUTER VISION

Computer vision, also sometimes referred to as computational vision, has been defined as "visual perception employing computers" (Gevarter, 1983). Visual perception includes the ability to look at a street scene, for example, and be able to recognize the trees, buildings, cars, pedestrians, and other features. At a higher level, for example, it is able to recognize people by their facial features, physical characteristics, and mannerisms. Recent research has developed significant understandings about the process of human perception. Algorithms have also been developed for such tasks as motion estimation, shape from shading, and integration of multiple 3D cues. Yet computer vision is generally considered to be still in a very early stage of development. After more than a decade of research, it is still one of the most challenging problems in artificial intelligence.

CLOSE-RANGE PHOTOGRAMMETRY

One of the major limitations of close-range photogrammetry using conventional film cameras has been the time lapse required between photo acquisition and the availability of measurement results. The development of vision technology, in both hardware and computational algorithms, has provided the means, as well as impetus, to develop fully automated real-time photogrammetric systems (El-Hakim *et al.*, 1989). Commission V of the International Society for Photogrammetry and Remote Sensing has taken a leadership role in the promotion of development in this area, and has sponsored several successful conferences in the last few years (Gruen *et al.*, 1987; Gruen and Baltsavias, 1990; El-Hakim, 1991).

Recent research has shown that digital targeting accuracy on the order of $\pm$ 0.1 pixel (equivalent to $\pm$ 2 μm for a pixel dimension of 20 μm) in the focal plane is feasible; and that a high degree of automation can be achieved for measurement problems that would have been difficult even by manual methods of the past (El-Hakim, 1991; Mass, 1991). Yet the limited resolution capability of CCD and CID cameras post major problems in photogrammetric applications. Although focal planes with array sizes of 1,000 by 1,000 or larger are now available, the increase in cost and computational burden make such systems feasible only for highly specialized applications, such as space telescopes and military surveillance.

Full automation of the photogrammetric measurement process will require the development of algorithms to perform decision-making functions such as blunder detection, accuracy analysis, and identification of relevant point features.

CONCLUSION

Machine vision, robot vision, and computer vision have been discussed above as though they are three distinct disciplines. It is clear, however, that there are large areas of overlaps. Both machine vision and robot vision may be considered as parts of computer vision, while robot vision may be considered as part of machine vision. On the other hand, arguments can be presented that machine vision encompasses all three. In fact, the three terms are commonly used interchangeably in the literature. In spite of the obvious limitations of current vision technology, the vision industry is well established and has already made significant impact on the automation of the manufacturing industry. Because 3D perception is the ultimate goal of computer vision, close-range photogrammetry can both benefit from, and contribute to, the future development of vision technology.

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