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Machine Vision Architectures, Integration, and Applications

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Machine Vision Architectures, Integration, and Applications

Bruce G. Batchelor
Michael J. W. Chen
Frederick M. Waltz
Chairs/Editors

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MACHINE VISION ARCHITECTURES,
INTEGRATION, AND APPLICATIONS

Volume 1615

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MACHINE VISION ARCHITECTURES,
INTEGRATION, AND APPLICATIONS

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Conference 1615, *Machine Vision Architectures, Integration, and Applications,* was part of a two-conference program on Machine Vision held at SPIE's Symposium on Advances in Intelligent Robotic Systems, 10–15 November 1991, in Boston, Massachusetts. The other conference was:

Conference 1614, *Optics, Illumination, and Image Sensing for Machine Vision VI*

MACHINE VISION ARCHITECTURES,
INTEGRATION, AND APPLICATIONS

Volume 1615

INTRODUCTION

Part A
Machine Vision Systems: Integration and Applications

Machine vision technology has been advancing across a broad front, but the number of systems actually installed in industry is significantly smaller than the number that could be justified technically. This difference is due in part to the difficulty of *integrating* the many aspects of this technology into robust cost-effective systems. This was the second meeting in a series intended to stimulate discussion of the interdisciplinary problems involved in systems integration. Papers covering many aspects of systems integration were presented in four sessions over a two-day period. The sessions were well-attended, and lively discussion followed many of the papers.

The opening session involved papers relating to the acquisition of good-quality images: cameras, lighting, and a very important but inadequately addressed issue, camera calibration. The second session covered image processing architectures, as well as advanced algorithms. Papers ranged from the dedicated architectures for pattern recognition applications, to the use of high-speed linear hardware for binary morphology, to analysis of colored images and Hough transforms using Prolog.

The focus of the third session was the design of the vision systems themselves, and particularly the user interfaces. Of particular interest was a system that allows many cameras (up to 32, including color cameras) to work together in a coordinated and "intelligent" way to carry out complex inspection tasks. The final session was devoted to successful applications of machine vision to diverse problems, such as analysis of corn color, determination of the uniformity of a wheat-crushing process, and traffic monitoring.

We wish to thank the members of our program committee, who helped arrange for many of these papers. We especially wish to thank the authors who responded to our call with excellent papers. We look forward to the same kind of support and interest in future sessions on systems integration, the "last frontier" in the application of machine vision to real-world quality and production improvements in industry and elsewhere.

Bruce G. Batchelor
University of Wales College of Cardiff

Frederick M. Waltz
3M Company

INTRODUCTION
Part B
High-Speed Architectures and Systems in Machine Vision

The necessity for increased production rate and tighter quality control in manufacturing demands inspection at higher speed and finer resolution, with more accuracy and intelligence. Automated inspection and measurement requires multidisciplinary cooperation and effort in image processing, pattern recognition, and artificial intelligence. Real-time, on-line system implementation requires advances in high-speed parallel computer architectures and concurrent processing algorithms.

This conference, the seventh in a series, provided an international forum for the exchange of information among research and development workers in this area. Since 1987, the conference name has changed from the original Automated Inspection and Measurement, to High-Speed Inspection Architectures, Barcoding, and Character Recognition, to the current High-Speed Architectures and Systems in Machine Vision, reflecting our changing focus. Seventeen papers from diverse countries are included in this proceedings and reflect the trend in artificial inspection systems toward ever-increasing technical sophistication.

Emphasis this year was placed on the following areas:

- High-speed system architectures
- Application-specific architectures
- Algorithms and methodologies

I wish to thank the cochairs and the program committee for their assistance in selecting excellent technical papers. I hope that readers will find the papers a valuable resource and will share our enthusiasm in providing this information exchange.

Michael J. W. Chen
AITech International Corporation

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MACHINE VISION ARCHITECTURES,
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Part A

MACHINE VISION SYSTEMS: INTEGRATION AND APPLICATIONS

SESSION 1A

Sensors and Image Acquisition

Chair

Michael A. Snyder

3M Company

Application aspects of new video camera technology

Dennis N. Harvey

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ABSTRACT

Some of the new state-of-the-art video cameras offer features which enhance vision-based sensor performance and simplify the task of integrating the cameras into a manufacturing environment. Other new features make some applications possible which previously were not. One of these new features, video frame rates greater than 30 hz, will be described in the context of an application of a six-D.O.F. (Degree Of Freedom) sensor. Some new video cameras, such as the EG&G Reticon MC4256 and MC6464, offer very high video frame rates, which make the proposed sensor system appropriate for an application in a suspension Kinematic and Compliance measurement machine.

1. STATE-OF-THE-ART CAMERAS

Many engineers and managers have become disillusioned with machine vision technology, especially in industrial applications. In theory, the technology seemed to be an answer to a specific sensing requirement, but subtle problems encountered during implementation led to disappointment. Recent developments in video camera technology, however, can potentially overcome some of these difficulties. Features of significance include the following:

- Remote camera heads with ultra-compact geometries (e.g., 0.65" dia. x 2" long)
- High resolution B&W and color sensors (1k x 1k pixels)
- Multi-level electronic shuttering (eight or more discrete levels)
- Asynchronous reset (for synchronizing an image with a specific event)
- Integral image enhancement (improves contrast in an image)
- Improved resistance to streaking and blooming (critical when dealing with spurious, spectral reflections, or an image with a bright light source such as in welding)
- Good spectral response (for accurate colorimetry, or use with short-wavelength lasers)
- High frame rates (up to 7,500 hz.)

Creative utilization of these features can reduce or eliminate a number of the often-encountered barriers to the successful implementation of machine vision sensors (e.g., lighting, image contrast, and physical size). The following case study is one example of how special camera features, some only recently becoming commercially available, can open the door to new and successful industrial applications for machine vision.

2. A 6-D.O.F. SENSOR FOR K&C TESTING - BACKGROUND

MTS Systems has recently identified a sensing requirement in an area termed vehicle performance test systems. Vehicle performance test systems are used to measure vehicle and vehicle subsystem performance. Generally the measured properties relate to how the vehicle will ride or handle on the road. One of these systems is specifically called a suspension Kinematic and Compliance (K&C) measurement machine. This system may be used to determine the understeer/oversteer characteristics of an automobile or truck. Data from this system is also a key input in most handling computer models.

Using servohydraulics and computer controls, this machine will exercise the vehicle suspension using a multiple-input, tire-coupled platen. In the Kinematics mode the spindle displacement is measured in 6

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D.O.F.s as the unloaded suspension is moved through it's design trajectory. In the Compliance test mode one measures the deflection of the suspension under different combinations of loading at the tire patch, and at different suspension positions; in this case both force and displacement are measured. The ability to measure the vehicle spindle motion both quickly and accurately is crucial to the use of this system. High bandwidth is required to maintain good correlation between system inputs and the resulting spindle responses. Very small changes in tire slip angle greatly affect the vehicle's handling response. It is also desirable to perform these measurements without making contact with the vehicle spindle. A non contact sensor system would be more robust, more easily maintained, and would require less setup time for each vehicle. Targets can be attached to the spindle prior to its entering the Kinematic and Compliance measurement machine and still meet these requirements. With these criteria in hand, the following sensor system has been proposed.

3. SENSOR DESIGN

The six-D.O.F. wheel motion sensor is a laser-based, machine vision system. It comprises the following hardware:

- A high resolution, black & white, CCD video camera,
- A controlled light source for target illumination,
- Two, eye-safe, laser stripe projectors,
- A robust, compact enclosure for the above three items,
- A camera-to-computer interface card and image preprocessor,
- A personal computer,
- A target which is attached to the wheel, or wheel hub, of the vehicle.

The software will provide the following capabilities:

- Facilitate sensor set-up and calibration,
- Perform image analysis algorithms,
- Decouple the six motion parameters,
- Log all data and/or upload data to a host computer,
- Optionally, can perform SPC-type data analysis.

Two basic sensing techniques are employed to simultaneously measure all three translations and all three rotations: 1) passive target tracking is used to measure longitudinal shift, vertical shift, and spin angle, and 2) laser-stripe triangulation is used to measure lateral shift, steer angle, and camber angle. Figure 1 shows schematic representations of the image that will be acquired by the camera/computer for analysis. The image consists of two dots that are fixed to the target on the vehicle wheel, and two lines that result from the laser stripe projectors. The laser stripes are projected onto the target surface at an oblique angle with respect to the optical axis of the video camera. The size of this angle is a function of measurement range and resolution.

Figure 1a represents an image of the target which corresponds to a reference position of the vehicle wheel. Figure 1b represents an image that would result from a longitudinal shift of the target with respect to the reference position. Note that the image of the two laser stripes remains unchanged, but the image of the two dots has shifted to the right. The magnitude of the change in the apparent position of the two dots is directly proportional to the longitudinal shift in the location of the vehicle wheel and its corresponding target.

Figure 1c represents an image resulting from a vertical shift of the target. The image of the laser stripes again remains unchanged, but the image of the two dots has now shifted up. This shift is directly proportional to the vertical motion of the wheel.

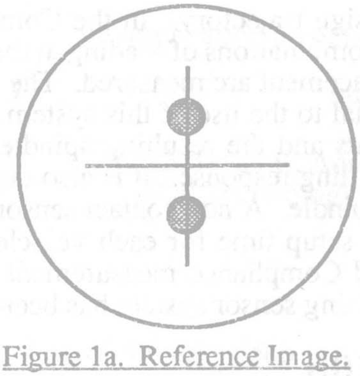

Figure 1a. Reference Image.

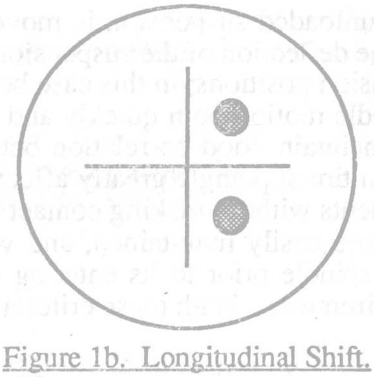

Figure 1b. Longitudinal Shift.

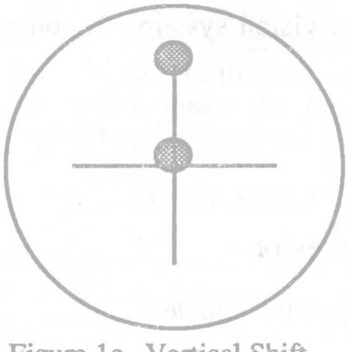

Figure 1c. Vertical Shift.

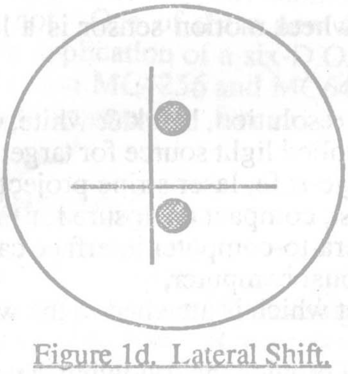

Figure 1d. Lateral Shift.

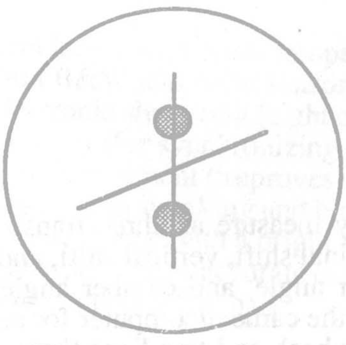

Figure 1e. Steer Angle.

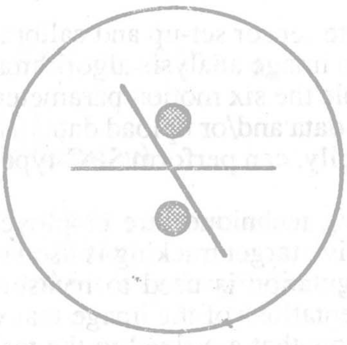

Figure 1f. Camber Angle.

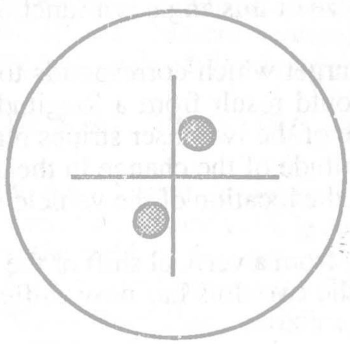

Figure 1g. Spin Angle.

Figure 1. Schematic Target Images for Various Motions.

Lateral motion of the target will result in an image similar to that shown in Figure 1d. There will be a small change in the image of the two dots (due to range), but this change is not of sufficient magnitude for use as a direct measurement of lateral shift. The image of the two laser stripes, however, has also changed (due to triangulation of the optical paths between the lasers and the camera), and this change is of sufficient magnitude to permit measurement of the lateral motion.

Figure 1e represents a target image corresponding to a given degree of steer angle. The image of the two dots will change slightly due to perspective and the image of the vertical laser stripe remains unchanged. The image of the horizontal laser stripe, however, rotates in a direction and magnitude that is proportional to the steer angle. In a similar fashion, the image of the vertical laser stripe is directly proportional to the camber angle. See Figure 1f.

Wheel spin will result in the image shown schematically in Figure 1g. The image of the two laser stripes will remain unchanged, but the image of the two dots will rotate about the center of the spin axis. The magnitude of the image rotation will be directly proportional to the spin angle of the target.

The actual images will differ from the schematic images described in the previous paragraphs. There is a certain degree of cross-coupling between the individual motions and the corresponding images, primarily due to the fact that the target cannot be located on the axis of rotation for the steer and camber motions. Fortunately, one can quantify the nature of the cross-coupling, and compensatory calculations can be performed.

The 'smart' algorithms used to extract the wheel motions from the images of the target will make use of known image constraints and certain data smoothing techniques to obtain sub-pixel resolution. These methods will permit a higher ratio of measurement range to resolution than is typical in most machine vision systems.

Relative motions of the wheel are obtained by subtracting the position data for one reading from the position data of a second reading. This means that any position of the target pattern can serve as a reference, and auto-calibration techniques can be employed to save time and reduce the chances for error.

Figure 2 shows a schematic representation of the sensor hardware and the target that is to be secured to the vehicle's wheel.

4. PERFORMANCE REQUIREMENTS

There are two elements critical to the satisfactory performance of the spindle motion sensor: accuracy and frequency response.

The centroids of the two dots and the locations and angles of the two laser stripes can be easily determined to sub-pixel resolution using standard SRI algorithms (blob analysis). The optical target is cooperative (clean and of high contrast) and will not significantly vary over the course of a test. Some of the noise in the system will be random, and given an adequate sensor bandwidth, this noise can be dealt with through frame averaging. Accuracy should not be a problem.

Sensor bandwidth (frequency response) is the other critical element. If one is limited to the conventional video frame rate of 30 hz, the bandwidth of the proposed sensor system may be inadequate. But some of the new video cameras, such as the EG&G Reticon model MC4256 and model MC6464, offer frame rates that are significantly greater (480 and 7,500 hz respectively). The trade-off that one must make with these cameras is resolution (256x256 and 64x64 pixels respectively) and price. With these and other high-frame-rate camera options, however, the engineer can consider what tradeoffs are permissible such that overall sensor performance is optimized.