A TRANSPUTER BASED LASER SCANNING SYSTEM

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ABSTRACT: This paper presents a transputer-based laser scanner. This is to be integrated into an existing transputer-based manufacturing environment to allow rapid construction of 3-D models. The approach allows Z-gradient information to be obtained from a 2-D image by illuminating areas of interest with a form of structured light. An active scanning system is described. Simple algorithms are applied to the raw image data to extract concise information. This foveal analysis greatly reduces the data to be processed, allowing a simple and fast method for analysis. The system primarily consists of a video camera which obliquely views a scene being scanned by a laser. The principle, the procedure, and methods of scanning are described. An overview of the principles of foveal analysis, the prototype experimental system and initial results are presented.

Introduction

It is an important and difficult problem for a computer vision system to infer 3-D information and to recognise 3-D objects from 2-D images [1,2,3]. An image does not provide enough information, by itself, to recover a scene. The depth dimension is collapsed by the projection of a three-dimensional scene onto a two-dimensional picture. The appearance of an object is influenced by its surface material, the angle of the light source, the camera angle and characteristics, the ambient light, and so on. All of these factors contribute to a single measurement, usually the intensity of a pixel. It is difficult to determine the contribution of each of these factors to a pixel value. This problem is enhanced by the vast quantity of data that often needs to be processed, even for a simple task.

Traditionally, to resolve this situation and to regain the lost information, additional constraints have been applied. These constraints are based on reasonable assumptions, or on measurements. The way in which camera based systems analyze visual data can be broken down into a number of discrete processes:- digitization, smoothing, segmentation, labelling and analysis. With large amounts of data, the latter part of this processing chain becomes complex and costly in terms of processing time [2].

Illumination of an object is another important factor that affects the complexity of vision algorithms [1]. With camera systems a number of different approaches can be employed ranging from simple ambient lighting, to complex structured lighting [4].

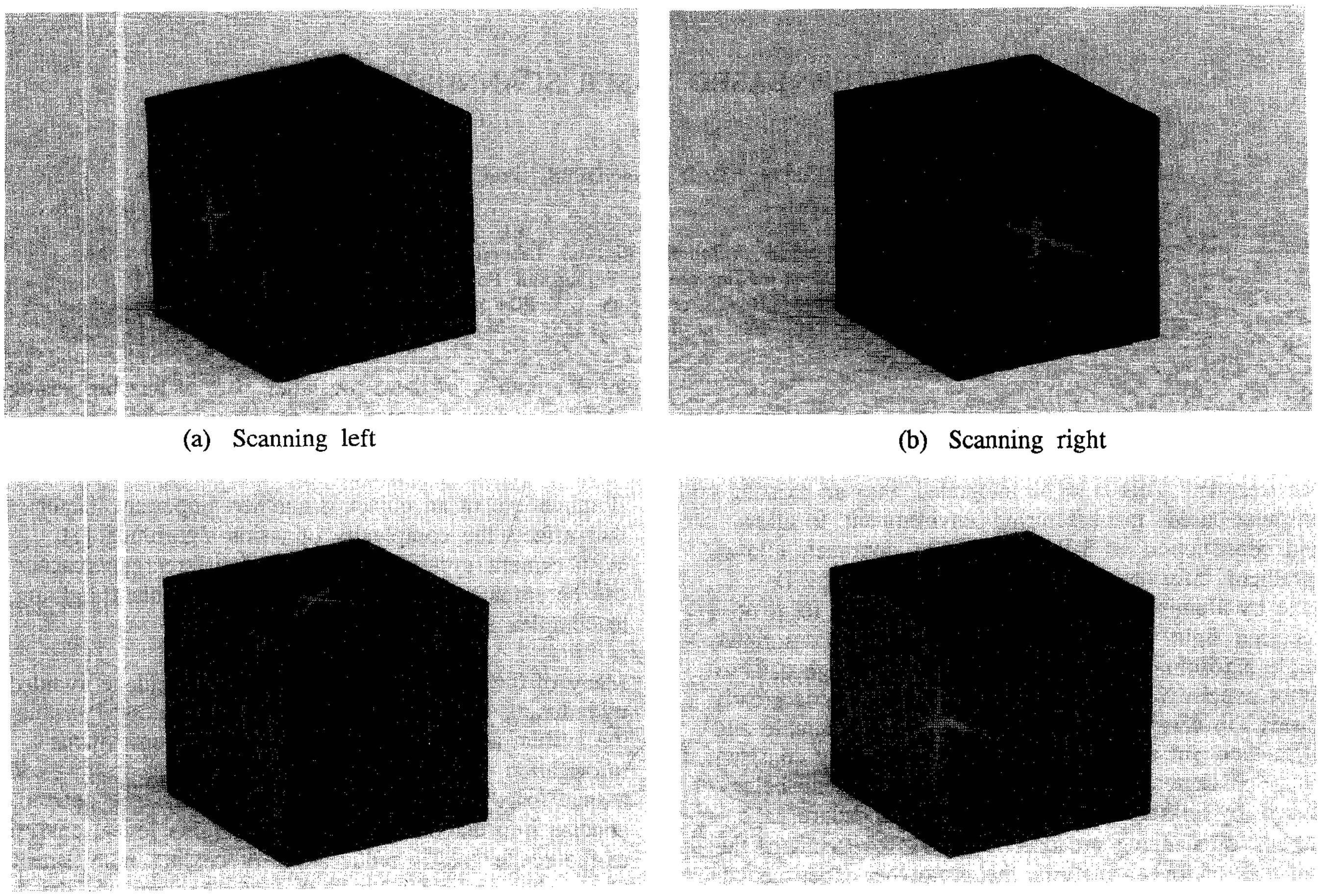
Many of the problems outlined above could be avoided by reducing the volume of data being processed within the system and restricting this to only un-ambiguous information. This can be achieved by concentrating on a small part of the field of view and extracting defined, concise information about this area. This foveal analysis of the scene greatly reduces the processing requirement. The technique is similar to that of a human eye; the eyeball moves to keep the point of interest of the scene centred on the most sensitive part of the eye, the fovea centralis. Similarly a camera can be focused on the centre of interest in a scene and moved around to interrogate it [5].

Using this method, the number of bytes processed in a frame can be reduced from tens of thousands to mere hundreds. The typical data explosion problem, often found in robotic systems can be avoided.

The method presented in this paper is to control the illumination of an object. A special form of structured lighting is used to interrogate the scene and to extract only the information required for the reconstruction of a 3-D model of the scene. By constraining the data entering the system, less processing is required, and specific edge and surface information can be gathered.

The laser scanning problem is inherently parallel. The laser is moved in both the x and y planes, requiring simultaneous analysis for each plane of motion. When following discontinuities, path predictions are made and therefore analysis, motion and image capture all occur simultaneously.

Transputer technology has been used. This will allow the system to develop for use in 'real time'



(a) Scanning left (b) Scanning right

(c) Scanning top (d) Edge detection

Fig. 2 Object under laser observation

manufacturing situations [6]. Typical situations are described later in the paper. Pre-filtering by constraining the data from the vision sensor reduces the processing time. By the application of transputer technology and parallel processing, system speed can be further increased, especially when fast CCD's are being utilised.

Methodology

A cross of Laser light is generated by using a Laser and a set of fixed optics. A CCD camera, slightly offset and inclined relative to the laser, retrieves visual information about the cross. The cross is used as a cursor to explore the object being scanned. Because of the positional difference between the camera and the laser, the camera has a slightly offset view of the scene and the projected cross is distorted by objects in the scene. By analyzing the distorted light pattern, it is possible to extract three dimensional characteristics of the object.

Two types of information can be extracted from the image. These are (a) discontinuity and (b) relative gradient.

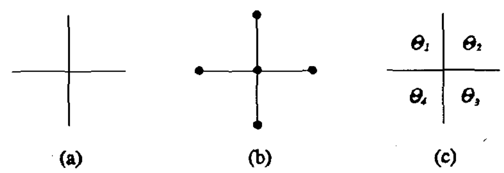


Fig. 1. (a) Line Fitting applied to captured image, (b) nodes detected, (c) angles calculated for gradient information.

Discontinuities occur when two or more faces with different gradients meet, or when the gradient of a face changes suddenly. By extracting the distorted cross from the camera's view of the scene, these discontinuities can be detected. The first stage is to

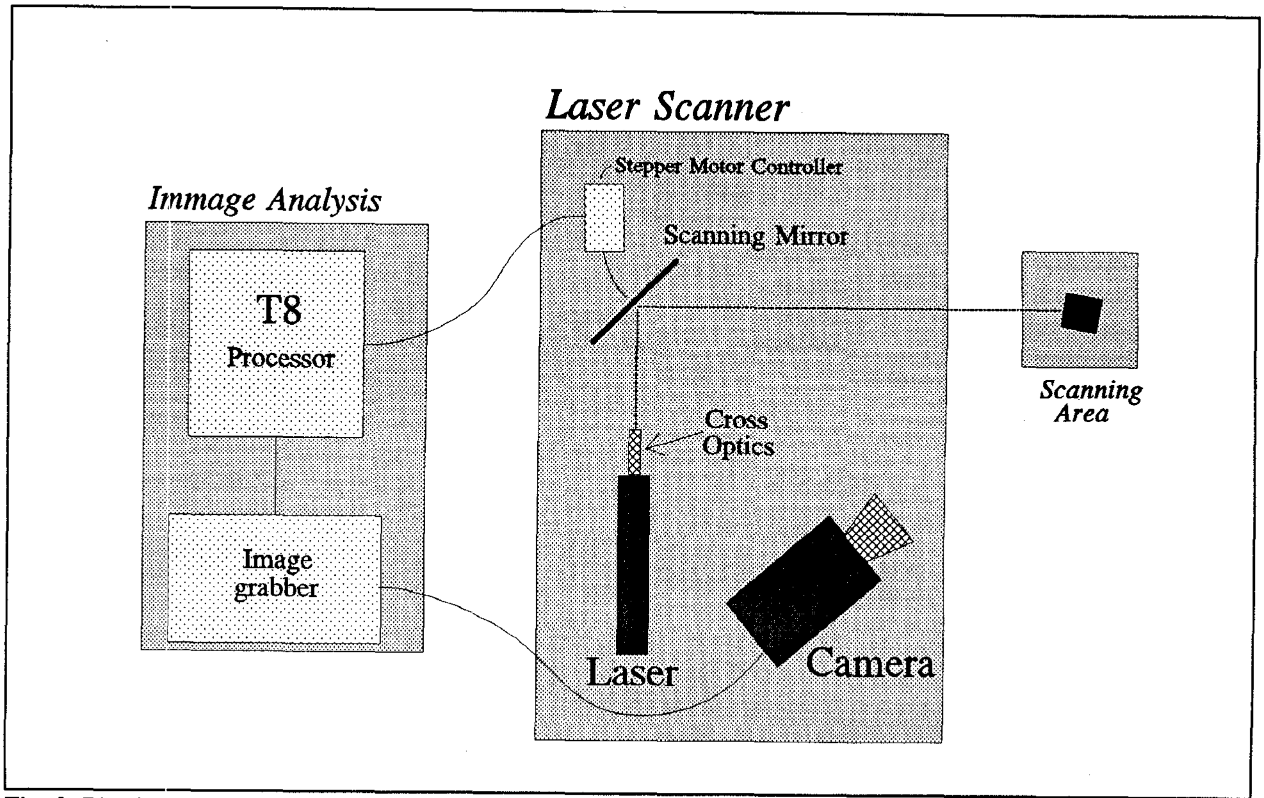


Fig. 3. The laser Scanning Apparatus

detect the lines which make up the cross. These lines can then be used to extract five or six nodes which contain discontinuity and gradient information.

The angles at which the distorted cross axis lie, determine the gradient of the surface at the point at which the cursor is positioned.

Using simple algebra it is possible to obtain the angle between the two lines, and therefore the angle of inclination of the surface with reference to the x-axis and y-axis of the 2-D image.

So from the retrieved image we can:

i. Deduce existence of discontinuities
ii. Follow edges (discontinuities)
iii. Determine relative gradients.

The information can be used to guide the laser to interrogate other areas of the scene. Simple rules can be deduced for the detection of an edge and the generation of a trajectory to follow the edge. The laser is fired at the centre of the scene, if no discontinuity is found, the gradient information is used to move the laser to an edge. Fig. 2 (a),(b) & (c) show the laser being fired onto different surfaces of a cube, the gradient information is contained in the angle of the reflected cross. Once the edge has been located (Fig. 2(d)), a scanning trajectory for the edge can be calculated. The cross can be 'locked' onto the edge by simply checking that extra nodes don't appear whilst scanning, if they do, a new trajectory can be determined.

The information from the vision system completes a feed back loop and directs exploration of the scene. The system follows discontinuities, edges and gradients. Models of the scene are made by recording the position of the laser stepper motors. The model created is therefore dependent on the accuracy of the laser scanning system and not the accurate positioning of the camera.

System Apparatus

The complete laser scanning system is illustrated in Fig. 3. It comprises two main elements:

Laser scanner which is used to actively scan the scene and retrieve an image of the cross for analysis. The scanner consists of a laser, an X - Y scanning mirror and a CCD camera (offset from the laser).

Image analysis system which, on acquiring an image from the CCD camera analyses the image, calculates the next position to interrogate and records information about the scene.

On acquisition of an image the computing system analyses it, by firstly segmenting the section of interest. A thinning algorithm [7] must next be applied, followed by line fitting and node detection algorithms. This data can then be used to determine the attributes of the surface under examination and so a new location can be deduced for the laser to interrogate.

Initial Results

A prototype system has been built in the Automation and Robotics Research Laboratory at Portsmouth Polytechnic. The control elements for moving the mirror were not sufficiently rigid, and this problem led to errors in positioning the laser. The images retrieved of the cross were distorted due to interference fringes caused by the laser light passing through a mask. This led to inaccuracies in the interpretation of relevant gradients.

All these problems concern the construction of the prototype system. A second improved system is now under construction at Portsmouth.

Discussion

The accuracy and the resolution of the system is dependant on the laser scanning mechanism, not on the resolution and accurate positioning of the camera. This would normally be the case in structured light applications. The only information which needs to be retrieved from a scene is the shape of the reflected cross. If the camera is focused on the whole of a scene then a high resolution camera is required to interpret the cross anywhere within that scene. If however the camera is focused purely on the reflected cross, then it is possible to greatly reduce the resolution of the camera. Decreasing the resolution of the camera, has the effect of reducing the volume of data entering the system. This in turn means it may be possible to grab frames at a much higher frequency. One solution is to have the camera focused onto the reflected cross through a mirror which will track the laser image. Using this method it is possible to have a very low resolution CCD camera, acquiring data very quickly, with a high scan rate.

This system differs from conventional vision systems in that only clearly defined, concise vision information is processed. This information is used to define the next piece of vision information captured. With the use of transputers to analyze and drive the scanner the system may be well suited to real time manufacturing environments.

The method is suited to situations which require relative measurements, for example, automated, mix and match assembly lines[6]. Consider a product which requires two components, a peg and a hole, to be manufactured and inserted to a specified tolerance. A tolerance would first be assigned to the size of the peg, and to the size of the hole, so that in a worst case situation the tolerance of the peg in hole would meet that required. Any machining operation will have a distribution associated with it, and obviously this distribution would have to fall inside the tolerance specified for the component being manufactured. If as the 'peg' components were manufactured they were measured, and matched to measurements of the 'holes' then the tolerances on both of these manufacturing processes can be relaxed to allow inexpensive machines with wider distributions to be used. The laser scanner could quickly identify the area of interest, locate and make the required measurements.

In this work, the scanned edge information is accurate. This, combined with the relative depth information, gives an accurate 3-D model of the object being scanned.

Conclusion

An accurate and efficient non contact method for scanning solid objects has been described. The approach offers a simple solution to the problem, and has suggested a number of new applications for vision systems. This system is currently being integrated into a distributed manufacturing cell developed at Portsmouth.

Acknowledgements

The authors wish to acknowledge the early project work completed by P. K. Tam and C. Y. Li, final-year degree students, in the interface and programming of the laser scanning system. The research has been supported by SERC.

References

[1] D. A. Sanders (PhD) Automatic Robot Path Planning with Constraints, Portsmouth, UK. 1990

[2] M. Brady, "Robot Science", Cambridge, MIT Press, 1989, Ch 2, pp 39 - 137.

[3] W. Lin, D. A. Fraser, "Identification of 3-D objects from 2-D Images", in the Proceedings of the 2nd International conference on Applications of transputers (southampton), IOS press, 1990.

[4] J. P. Moss, A. D. Linney, S. R. Grindrod and C. A. Mosse, "A laser scanning system for the measurement of facial surface morphology", Optics and lasers in engineering, No. 10, pp 179-190, 1989.

[5] J. Billingsley and A. A. Hosseinmardi, "A vision system for robots", in the Proceedings of British Association meeting,Brighton, UK, August 1983.

[6] J. Billingsley, F. Naghdy and D. Harrison, "The craftsman robot", IEE Journal Electronics and Power, pp 805-808, November 1983

[7] N. J. Naccache and R. Shinghal, "SPTA: A proposed algorithm for thinning binary patterns", IEEE Transactions on Systems, Man, and Cybernetics, Vol 14, No. 3, pp 409 - 423, 1983.