STEREOSCOPIC VISION USING LINE-SCAN SENSORS

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ABSTRACT:

This paper describes the continuing research into the development of stereoscopic vision systems based on the line-scan camera. Results from earlier work in this area established the ability to use such devices in a stereoscopic arrangement to resolve three-dimensional co-ordinate information from a moving object volume. These early systems used lateral motion of the object to allow the line-scan camera to produce two-dimensional images.

At present the emphasis of the research has moved on and is now concentrating on using the line-scan device and rotational movement to produce both two- and three-dimensional images. Initial results indicate that these images are more difficult to understand but provide useful information from a potential 360 degree panoramic view.

KEY WORDS: Line-scan cameras, stereo, rotation, variable field of view.

1. INTRODUCTION

1.1 Line-scan cameras - The present position

The line-scan, or linear array, sensor has been widely used in industrial inspection and measurement applications for a number of years. These have included printed circuit board inspection[1,2], film registration[3], and the two-dimensional gauging of object dimensions[4,5]. In the majority of these applications movement is inherent in the manufacturing process, and this, when used in conjunction with a line-scan camera system, can produce two-dimensional images.

The main advantages of line-scan systems over standard television type camera arrangements can be identified as:

i. higher resolution sensors with up to 4096 picture elements are widely available;

ii. line-scan camera synchronisation can be determined by the application and not locked to any particular standard as with television type cameras, and;

iii. object motion, inherent in most manufacturing applications, can be used with line-scan sensors to generate two-dimensional images.

Disadvantages include:

i. additional hardware and software is needed to allow the operator to view a two-dimensional image;

ii. and the need for this hardware to be specially designed for the line-scan device.

Ultimately, the choice of sensor and technique used to generate and correspondingly display video images depends on the application for which they are intended.

1.2 Previous work

The 3-D Imaging Group at Nottingham (formerly Trent) Polytechnic has been involved in the development and application of three-dimensional visual techniques for a number of years[6,7,8,9,10]. Initial work included the construction of a stereo camera system, mounted on a teleoperated bomb disposal vehicle[11]. As a result of this work, it became apparent that the three-dimensional position of an object could be determined by the use of such a system[12].

At first this involved the introduction of measuring marks into the video signal and necessitated an operator to position the marks manually over the points of interest. These marks were then used to calculate the position of the object. The success of this technique prompted research into the use of such camera systems in robotic guidance applications. This has involved controlling a robot arm from information obtained from a stereo-camera system[13]. This arrangement has enabled the position of an object to be determined, and the robotic manipulator to be moved such that this object can be grasped. This was done without prior knowledge of the position of the object.

Concurrently, research has involved the production of a three-dimensional X-ray machine based on linear array sensors[14]. This machine is at present being used for work concerning the extraction of three-dimensional co-ordinate information from X-ray images[15].

1.3 Research Aim

The television type sensor, used in the majority of machine vision applications, was primarily designed to produce images that were suitable for humans to observe. However, these images may be far from ideal when the task of visual analysis is to be undertaken by a robot[16]. Hence, it is an objective of this research to demonstrate that there exists alternative methods of producing both two- and three-dimensional visual systems.

Initial research at Nottingham has demonstrated[17] that non-standard television type sensors, in this instance the line-scan camera, can be used to produce vision systems. Such systems have been calibrated and have subsequently returned a sub-millimetre degree of accuracy in all three co-ordinate axes. The current aim of the research leads on from this initial work and involves investigating the line-scan device further.

This paper gives brief details of the research conducted using the line-scan device to produce stereoscopic images and suggests possible uses for such systems.

2. BACKGROUND

2.1 Two-Dimensional Imaging Principles

2.1.1 Image Production The line-scan camera consists of a single line (or column) of contiguous picture elements or pixels (Fig. 2). It is often referred to as a one-dimensional array and the number of pixels in a typical device can range from less then 256 to over 6000. The principle of operation of these devices[18,19] is similar to the two-dimensional CCD sensors used in most modern television type cameras (Fig. 1).

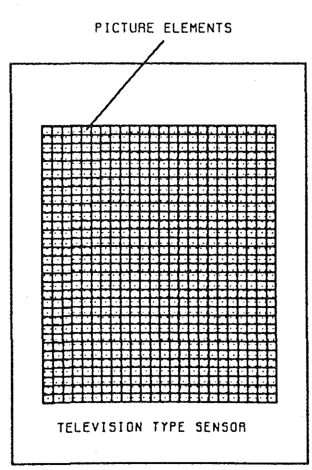

Figure 1 Photosensitive Area of Television Type Sensor

Two-dimensional images can be constructed from these sensors by producing relative motion between the object of interest and the camera (Fig. 3). Throughout this movement, the picture information is passed from the line-scan device to a storage medium after each line/column of information has been obtained. The collection and transferral of this line/column information is completed at a sufficient speed to allow continuous movement between camera and object. As long as there is strict correlation between the nth pixel in each line/column stored, ie: they appear alongside each other in the store, viewing the resulting data produces a two-dimensional image of the object.

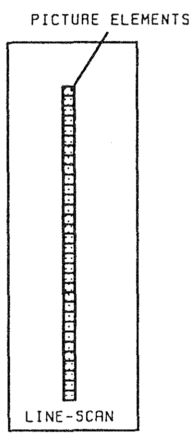

Figure 2 Photosensitive Area of Line-Scan Sensor

The extent of the field of view in the movement axis contained in these returned images is dependent on two parameters:-

a. the frequency at which the camera is driven, ie: the amount of time that each pixel has to collect incident photons;

b. the relative speed of movement between the camera and the object of interest.

By using the correct combination of these two parameters the field of view in the movement axis, and therefore the resolution in the object space in this axis, can be adjusted to suit a particular application.

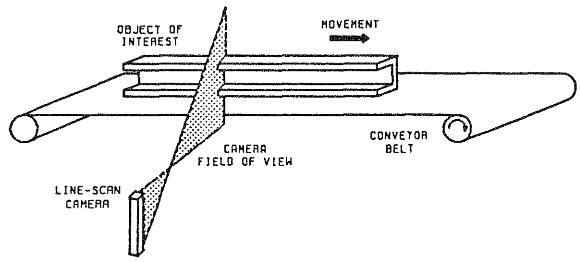

Figure 3

The axis of the line-scan image along the line of the sensor can be modelled on the principle of the pin-hole camera[20], ie: as in a two-dimensional CCD device. Thus, the field of view along the line of the sensor is dependent on the focal length of the lens used and the length of the line-scan device itself.

Figure 4 shows the perspective volume for the television type sensor. Figure 5 shows a similar volume obtained from the line-scan device after the object has passed in front of the camera (or the camera in front of the object).

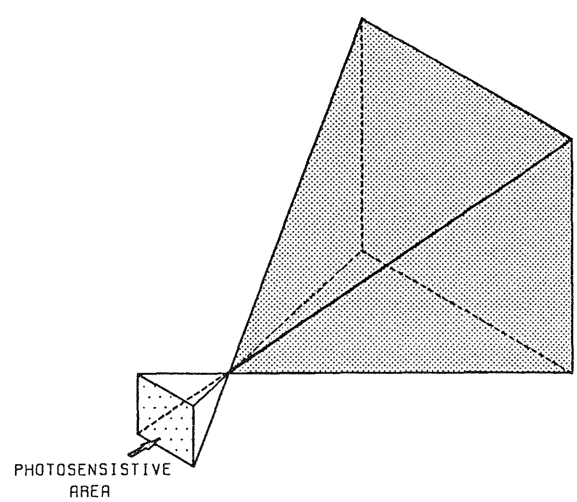

Figure 4 Volume of Space Viewed by Area Array Sensors

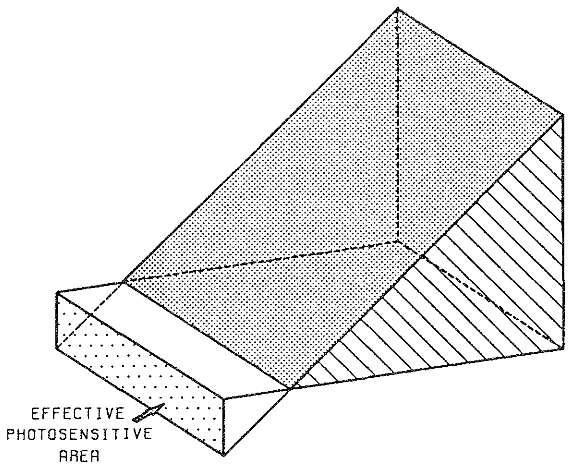

Figure 5 Volume of Space Viewed by Line-Scan Sensors

2.1.2 <u>Interaction of Scan Rate & Translation Speeds</u>

The previous section demonstrated the field of view that is obtained using a line-scan camera and movement. The extent of this viewing field is determined by the interaction between the scan rate of the camera and the translation speed of the movement stage. A representation of an image generated from a line-scan camera system is shown in Figure 6.

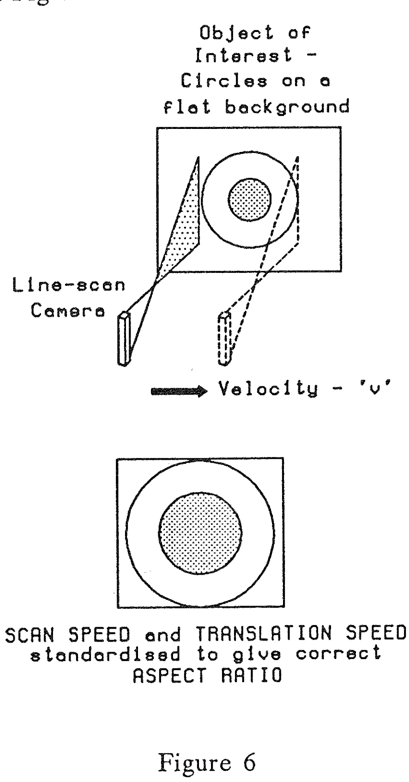

Figure 6

The scan rate of the camera can be considered as the speed in which an image is obtained from the line-scan device and retained in the framestore. The faster the scan rate the faster a full two-dimensional image is generated. If this parameter is altered while keeping the translation speed of the object/camera stationary, the field of view in the movement axis is altered accordingly. Increasing scan rate while maintaining the translation speed results in effectively 'stretching' the image axis in the direction of movement. Figure 7 demonstrates this principle. The effect is reversed if the scan speed is reduced: the resulting image in the movement axis is compressed or 'squashed' (Fig. 8).

A similar effect is achieved if the scan rate is kept constant while the translation speed is altered. However, the effects on the image are reversed: increasing movement speed produces a squashed image and vice versa.

Throughout this variation of scan and translation speeds, the field of view along the line of the sensor is not affected. This parameter is determined solely by the focal length of the lens fitted to the front of the camera.

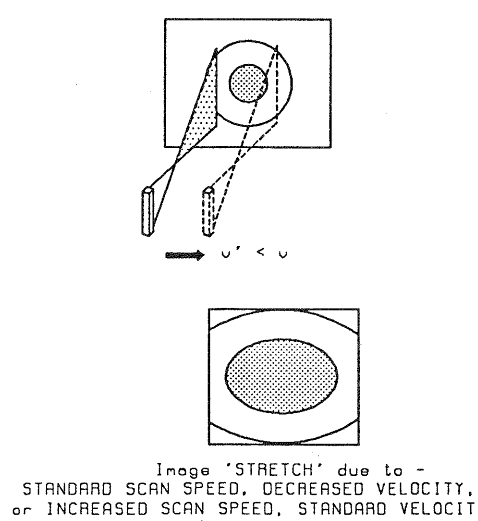

Figure 7

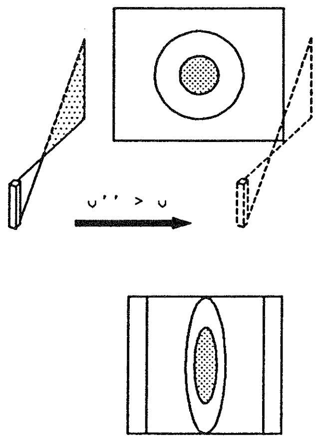

Figure 8

2.1.3 Creating Relative Motion

The method of creating relative movement between the line-scan camera and the object of interest has so far been considered to be lateral motion, parallel to the camera baseline. This does not have to be the case. Instead, the type of movement can be altered to suit a given application where lateral displacement may not be appropriate, ie: internal pipe inspection. To produce suitable images it is only required that correlation exists between the method of displaying the information and the technique used to obtain the picture information in the first instance. With this in mind, another obvious method of creating the required movement is by rotation of the line-scan camera in front of the stationary object of interest (or vice versa).

2.1.4 Rotational Movement

The field of view produced by the relative motion of the line-scan camera with respect to the object is determined by the interaction of the scan rate and the translation/rotation speed. This has already been discussed with respect to lateral movement in Section 2.1.2. If this aspect of the line-scan arrangement is now applied to rotational displacement the following points will apply:-

a. the field of view (and thus the resolution) of an image can be varied from any arc up to 360 degrees (Fig. 9);

b. if the field of view is less than 360 degrees, the area of the object space under consideration will depend on the start point of image capture (Fig. 10).

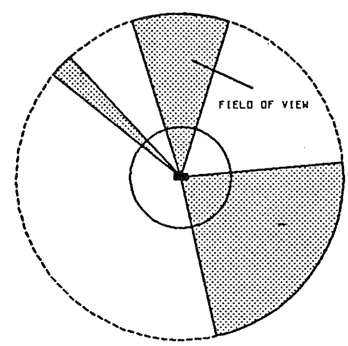

Figure 9 Variable Field of View

Taking each of these points in turn. If a 360 degree field of view is set up, the images produced will contain information from an area of the object space completely surrounding the line-scan camera. This field of view can then be subsequently adjusted to cover a smaller arc and this used interactively with the image start point. The resultant images can then display information at a given resolution from any part of the observed object space surrounding the camera.

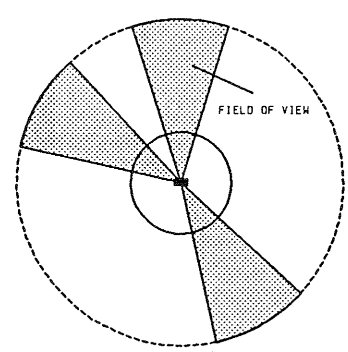

Figure 10 Variable Image Start Point

It is important to realise that the images produced using rotational movement between the line-scan cameras and the object of interest can be difficult to interpret. The complexity of the images is dependent on three parameters:–

- the camera–to–object distance varies as a function of the rotation;
- the field of view of the returned image can be arranged to cover up to 360 degrees of the intended rotation;
- the content of the observed field of view.

As the camera–to–object range decreases and dependent on the object of interest, the distortion caused by the rotational element of image generation becomes more apparent. However, if, under such circumstances, the field of view is kept as small as possible, suitable images may be produced. It can be seen from this that the parameters noted above are inter–dependent. Therefore, each should be considered before attempting to produce pictures that can be viewed by humans.

2.2 Stereoscopic Imaging Using Line–Scan Cameras

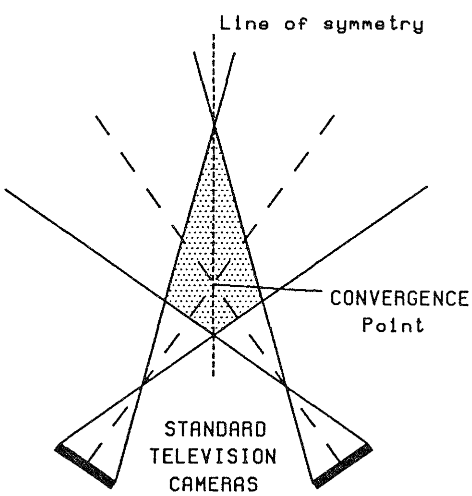

Figure 11 Stereo Region for Television Type Sensors

A simple two–dimensional line–scan camera system will allow co–ordinate information to be determined in only two axes. To resolve the third dimension, or depth, a further camera must be added. The two cameras can be arranged so that the field of view from each overlaps at a desired distance from the stereoscopic camera baseline. This overlapping area is termed the *stereoscopic region*, and is shown in Figure 11 for television type cameras and in Figures 12 and 13 for a line–scan stereo–cameras. If a point of interest lies within this region it will appear in the images from both cameras, however the horizontal position of this point will differ in each. It is this difference, commonly termed the *disparity*, that indicates the depth of the point in the stereo region.

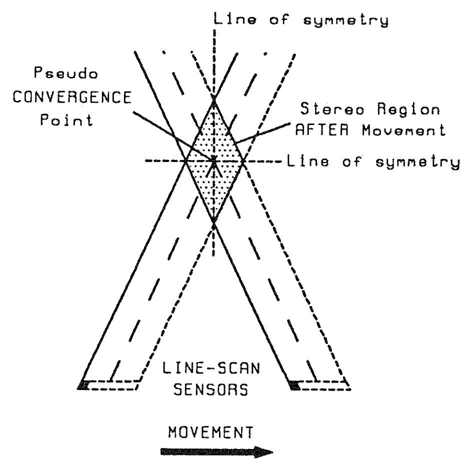

Figure 12 Stereo Region for Lateral Motion Line–Scan Sensors

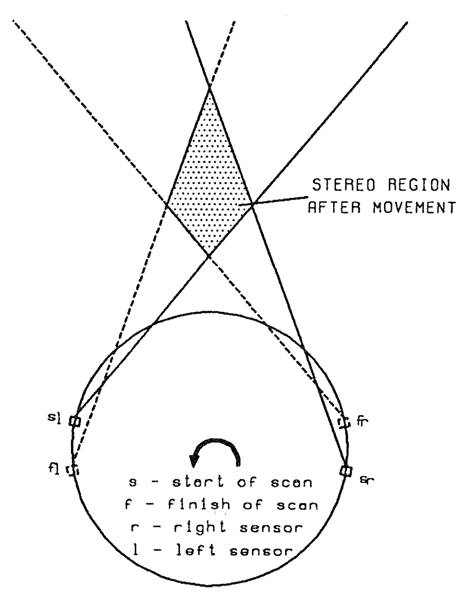

Figure 13 Stereo Region for Rotational Motion Line–Scan Sensors

3. PRESENT RESEARCH

3.1 Linear Displacement Vision System

Initial research at Nottingham Polytechnic has involved producing stereoscopic line-scan images from linear motion of the camera system relative to the object of interest and vice versa. A diagram of the system used is shown in Figure 14.

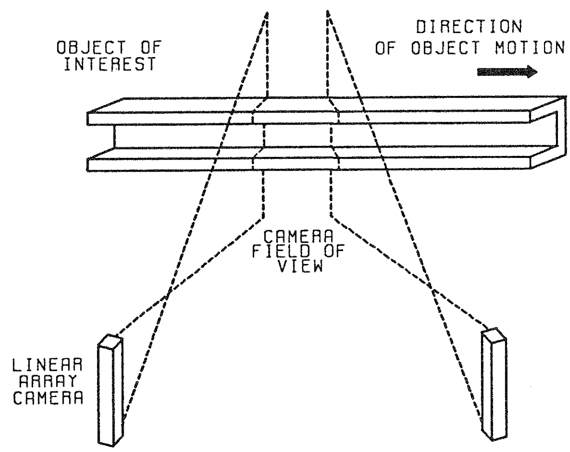

Figure 14

3.1.1 Experimental System The experimental arrangement consisted of:-

1. two 1024 element line-scan cameras;
2. a variable camera positional controller;
3. two 1024 pixel by 1024 line by 8 bits deep framestore;
4. an object translation stage.

The operation of the experimental system is described below.

With reference to Figure 14, an object is placed on the translation stage. The cameras separation and convergence is adjusted so that the field of view of each overlaps, and provides a stereo region within which the translation stage is to operate. The scan speed of the cameras is adjusted manually, along with the translation speed and the start point of image capture. The framestore is initialised and the relevant software executed to allow simultaneous image capture of the object as it passes through the stereo region. The object is subsequently moved in front of the cameras.

At a software controlled point in the movement, a hardware signal from the object motion controller starts image capture. When a full two-dimensional image from each camera has been generated, object motion is stopped at the opposite end of the translation stage.

This initial run allows certain parameters within the confines of the system to be monitored and adjusted accordingly, and therefore allow the most suitable images to be obtained of the object. These parameters include the focus for each camera, the image capture start point, the extent of the field of view (does the interaction of scan and motion speed achieve the required field of view?), and the necessary amount of object illumination. With these parameters adjusted to the optimum setting, images can be generated of a calibration frame and these used to calibrate the stereoscopic arrangement. Objects of arbitrary size and shape can then be placed on the translation stage and perspective views produced of them. These images are used to obtain three-dimensional co-ordinate information from the object space.

3.1.2 Results A series of experiments has been conducted with this arrangement of line-scan cameras[17]. This work has demonstrated that such an arrangement of these devices can be used to resolve three-dimensional co-ordinate information from an object workspace. Table 1 below provides a summary of the results obtained from this work.

TABLE 1

Range (m)	Camera Separate. (m)	Focal Length (mm)	Move-ment Speed (m/s)	rms Error in 3D Vector (mm)
1.5	0.45	50	0.12	0.981
1.85	0.45	25	0.06	1.935
1.85	0.45	25	0.12	2.809
1.85	0.45	50	0.12	0.974
1.85	0.45	50	0.18	3.096
1.85	0.75	25	0.06	1.354
2.5	0.45	50	0.06	3.537
2.5	0.45	50	0.12	3.094
2.5	0.75	50	0.12	2.509

3.2 <u>Rotating Head Vision System</u>

The present research focuses on producing line-scan images by introducing *rotation* of the camera head with respect to a stationary object. Details of the hardware used to accomplish this have been provided in the following sections and a block diagram is presented in Figure 15.

3.2.1 <u>Rotating Stage</u> The rotational movement of the line-scan cameras relative to the object of interest is achieved by using a rotary stage. A stepper motor provides the motion and a worm and wheel assembly transmits the primary drive to the rotary table top, via an 18:1 gearbox. A central aperture is provided through the centre of this table arrangement and this is used to pass control to and picture information from the cameras.

The stepping motor providing the camera motion is adjusted via a microprocessor based dedicated controller. This provides control over rotation speed, acceleration, etc..

It is necessary for this research to allow the cameras to rotate continuously. To achieve this, a 36-way slip-ring assembly has been used to electrically connect the cameras to the external electronic arrangement.

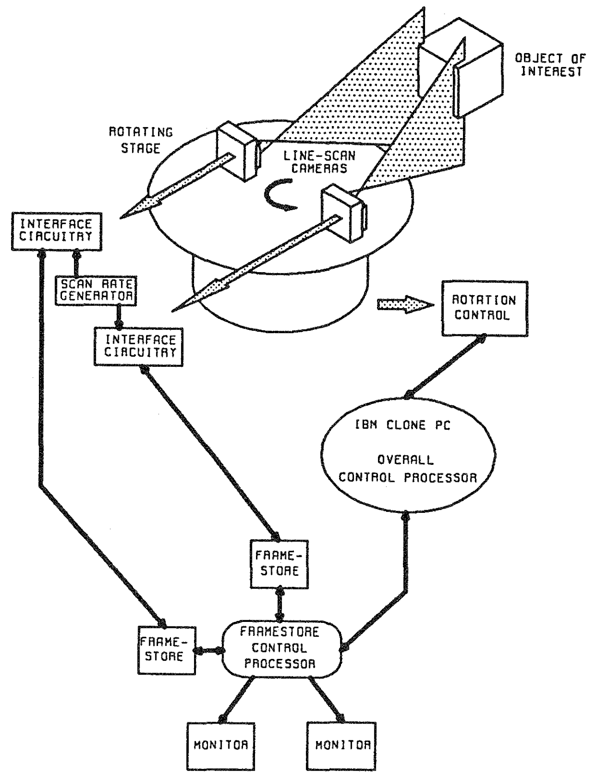

Figure 15

3.2.2 <u>Image Capture</u> The picture information returning from the cameras is controlled and stored in a stand-alone framestore. This provides sufficient storage memory to retain two 1024 pixels by 1024 lines by 8 bits deep images. The images are viewed using standard display technology, ie: a PAL signal providing a 512 pixel by 512 line picture of the original image. A roam facility can be used to move the 512 x 512 window to view any quadrant of the 1024 by 1024 image.

3.2.3 <u>Controlling Environment</u> The framestore and rotating stage controller are themselves linked to an IBM compatible PC. This principally provides the operator with direct control over the testing environment variables, eg: speed of rotation, start point for image capture, etc., and also allows dedicated software to be developed for specific tasks.

3.2.4 Scan Frequency Generator A frequency generator provides the scan rate for the two line-scan cameras. This allows the frequency of the scan rate to be adjusted, in combination with the rotation speed, to provide the required field of view. At present, this unit is manually controlled but it will eventually be linked to the IBM PC to allow computer control over this parameter. As a result, computer control will be achieved over the image generation start point, the speed of rotation and the scan rate of the cameras. The computer could then be used to adjust these variables to produce an optimum field of view for a particular application.

3.2.5 Experimental Methodology The aim of this research is to calibrate the images returned from the camera rotation. However, before this can be contemplated, the parameters controlling human vision have to be considered. Suitable images for human interpretation are required if correct calibration data is to be obtained from the images produced. A major aspect of this work will be an investigation into determining the extent of the potential field of view that can be practically used for human interpretation.

The next stage of the research will involve obtaining image data to develop photogrammetric algorithms. These will allow the system to be calibrated and the three-dimensional position of objects within the rotating field of view to be determined.

4. CONCLUSIONS & FUTURE WORK

4.1 Conclusions

The initial research into lateral movement line-scan systems established that such devices could be used in a stereoscopic configuration. This allowed three-dimensional co-ordinate information to be determined from a moving object volume to a sub-millimetre degree of accuracy.

The first pictures produced from the rotational movement of the line-scan camera have demonstrated the complexity of the image content. It has been established that this complexity is dependent on the relationship of the object space and camera, and the interaction of the scan rate and the rotational speed.

4.2 Future Work

The principle of generating the two-dimensional images with a rotational line-scan system is identical to that of the lateral movement arrangement. Accordingly, it is expected that a similar degree of accuracy can be produced from the rotational movement of the line-scan devices. However, this will require the development of specific photogrammetric algorithms due to the unique nature of this method of image production. The increased complexity of the returned images caused by the rotational movement may require automatic methods of image interpretation to be considered. Any future research will include an investigation into this aspect of the work.

5. APPLICATIONS

5.1 Production Line Inspection

Line-scan cameras have been used to produce two-dimensional images in a production line environment for some time. Consequently, the introduction of a stereoscopic line-scan system into such a manufacturing process should be possible. This will allow three-dimensional data to be obtained from a manufactured object passing in front of the camera system. The simplicity of the mathematical algorithms, developed as a part of the initial work, may allow the co-ordinate measurement to be conducted in 'real time', ie: without affecting the manufacturing throughput.

5.2 Security/Surveillance Applications

The variable field of view of the images produced by the rotational line-scan system discussed here would seem to provide an ideal solution to security and surveillance applications. In the first instance a 360 degree view could be used to provide an indication of the surrounding area. If an area of this arc proved to be of interest then the operator/computer could adjust the field of view to give maximum resolution for that particular area. These images could then be analysed to determine if a potential problem/threat existed at this point in the object space. The success of such a system would ultimately depend on the relationship of the surrounding object space to the camera system. The content of the object space would also need to be considered before suitable images could be produced.

5.3 Robot Control

An aim of this research is to produce mathematical algorithms that can be used to calibrate a volume of object space viewed by the rotational line-scan system. Once such a volume of space is calibrated this could then be moved to any point surrounding the camera and the returned images used to extract three-dimensional co-ordinate information from it. This principle could be used, for instance, to control multiple robot arms at different points around the camera. Once this has been achieved a rotational line-scan arrangement could be used for both 360 degree observation and for the manipulation of objects within the calibrated volume.

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