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A VISION SYSTEM FOR ROCK SURFACE USING ULTRASONIC RANGE FINDER AND IMAGE PROCESSING

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ABSTRACT

This paper deals with a simple vision system using an ultrasonic range finder and image processing. First, the image of the rock surface was taken by only one video camera. Then, the three dimensional shape measuring of rock surface was carried out by using the ultrasonic range finder. In this case, the scanning was conducted along only two lines, that is horizontal and vertical line of rocks. Therefore, the scanning period was much reduced compared to the previous method. The images were processed by image processor. Digital images consisted of 256×256 pixels with 256 gray levels for each pixel. By using the measuring data from ultrasonic range finder and pixel value profiles along the horizontal and vertical lines, the shape of rock surface was estimated in a short time.

1. INTRODUCTION

For the mechanization or automation in mining, the recognition of the shape of mined cavities might be essential functions. This means that the underground vehicles should have the vision system. For this purpose, some vision systems have already been proposed. For example, Takahashi et al.[1] and Sarata et al.[2] investigated the vision system using the ultrasonic range finder. Fuentes-Cantillana et al.[3], Terada et al.[4], and authors[5] have already presented the vision system using the image processing. Hurteau et al.[6] reported the potential application of vision system using the image processing to mining. Furthermore, St-Amant et al.[7] examined the vision system for underground vehicle guidance by the optical line network.

Each method has both merit and demerit. That is, if the vision system by the ultrasonic range finder is used, the three dimensional information for rock surface can be obtained. However, it takes a long period to measure the shape of rock surface even though the measuring area is narrow enough, because the scanning of the ultrasonic range finder is necessary. On the other hand, images by a video camera have a wide view in a few seconds, but the three dimensional information is not obtained unless we use two cameras. If two cameras are used to obtain the three dimensional information, the corresponding points in two images have to be found out. However, it is very difficult to find the corresponding points automatically because of the complexity of the shape of rock surface[8]. When the vision system is applied to the construction robots or underground vehicles, it is desirable to shorten the measuring period.

Recently, utilizing the plural sensors for three dimensional measuring have been received considerable attentions. This method integrates the merit of each sensor, and is called "Multi-sensor-integration" or "Sensor-fusion"[9].

In this paper, authors propose a simple vision system using the ultrasonic range finder and image processing for the three dimensional shape measuring. This is a kind of above mentioned "Sensor-fusion". In this method, the scanning of the ultrasonic range finder is conducted along only two lines, that is, the horizontal and vertical line. Therefore, this method has the merit to shorten the scanning time.

2. PRINCIPLE

2.1 Principle of vision system

The base coordinate frame(O;X-Y-Z) and the image coordinate frame(O";X"-Y"-Z") are defined as illustrated in Fig.1(a) and (b), respectively. The point O indicates the origin of the base coordinate frame. The image plane X'-Z' is a virtual plane and is normal to Y-axis of the base coordinate frame. The distance between the image plane and the origin is Y_0. The image area taken by the video camera is represented by the oblique lines on the image plane.

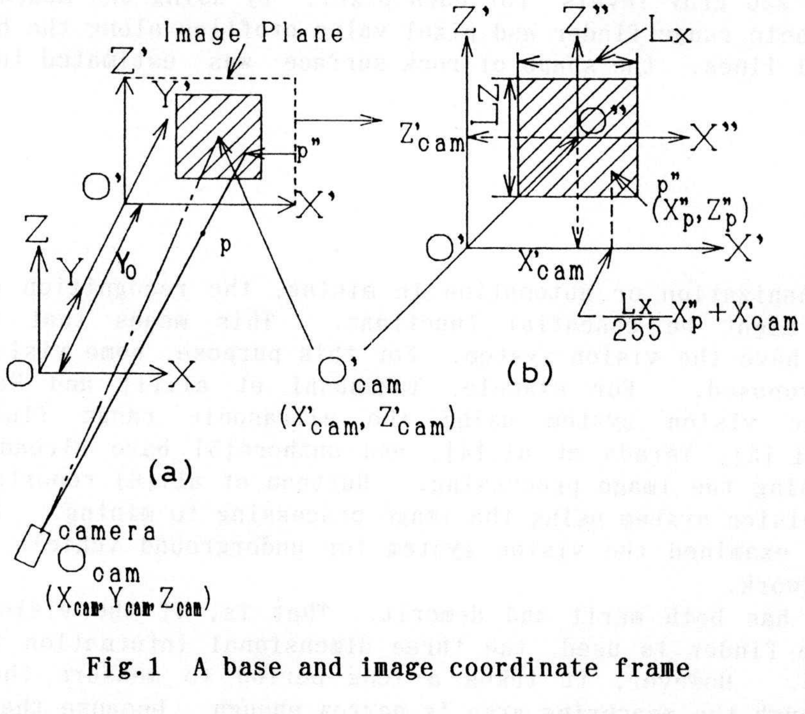


Fig.1 A base and image coordinate frame

First, the image of the object taken by the video camera is converted into digital image by the image processor. Figure 2(a) shows an example of the digital image. As described later, the digital image consists of 256×256 pixels, and the pixel value is given for each pixel according to the intensity of bright in the range of 0(black)-255(white). There are many factors affecting the pixel values. For example, the intensity of bright, the reflectance of the object surface, the length from the measuring point etc. affect the pixel values[10]. Therefore, the pixel value contains the three dimensional information in a sense. However, it is well-known that it is difficult to reconstruct the three dimensional shape of the object from the single two dimensional image[11].

In addition, the three dimensional profile is measured using the ultrasonic range finder. The scanning of this range finder is conducted along the horizontal and vertical line. Figure 2(b) shows the example of the measuring results. In this figure, the measurement is carried out along the lines of $X=X_i$ and $Z=Z_j$ in the base coordinate frame. As lines of $X=X_i$ and $Z=Z_j$ are corresponded to those of $X''=X''_i$ and $Z''=Z''_j$ in the image coordinate frame, the pixel value profiles along these two lines are easily obtained as shown in Fig.2(a). Although the three dimensional measuring is carried out along only two lines, the pixel values have already been obtained over the image area(256×256 pixels). Therefore, the shape of the object can be estimated from the pixel values of the digital image by correlating the measuring results from the range finder obtained along two lines of $X=X_i$ and $Z=Z_j$ with pixel value profiles along two lines of $X''=X''_i$ and $Z''=Z''_j$. In this study, these two lines are termed as the basic lines.

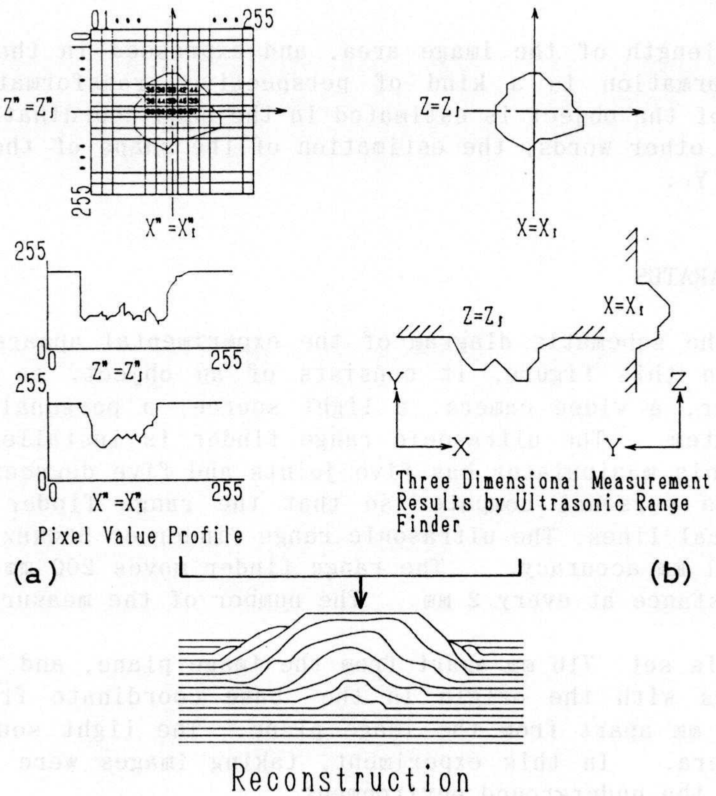


Fig.2 Principle to estimate the shape of the object

2.2 Algorithm to estimate the shape of objects

The algorithm to estimate the shape of the object from the three dimensional measuring results and pixel values is as follows : Each point $A=(X''_a, Z''_a)$ in the image area has the pixel value P_a. First, find out the all points on the basic lines which have the pixel value equal to P_a. Second, find out the nearest point to point A among those points. Then give Y coordinate value of the nearest point A from the three dimensional measuring results. Through the repetition of this procedure, Y coordinate value is assigned to every point in the image area.

X and Z coordinate value are determined as follows : there are two kinds of coordinates in this vision system, that is, the base coordinate frame and the image one. Therefore, the correlation equations to transform the image coordinates into the base one are necessary.

A point $p=[Xp,\ Yp,\ Zp]^T$ is projected to a point $p'=[X'p,\ Z'p]^T$ on the image plane. Let $p''=[X''p,\ Z''p]^T$ be the corresponding point on the image area taken by the camera. The point of the camera is $Ocam=[Xcam,\ Ycam,\ Zcam]^T$. In the case that Yp is Y_1, the transformation from p" to p is given by

$$\begin{bmatrix} Xp \\ Yp \\ Zp \end{bmatrix} = \begin{bmatrix} Lx/255\times Y_t & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & Lz/255\times Y_t \end{bmatrix} \begin{bmatrix} X''p \\ Y_1 \\ Z''p \end{bmatrix} + \begin{bmatrix} Xcam \\ 0 \\ Zcam \end{bmatrix} \qquad (1)$$

where

$$Y_t = \frac{Y_1 - Ycam}{Y_0 - Ycam} \qquad (2)$$

Lx and Lz are side length of the image area, and expressed in the base coordinate frame. This transformation is a kind of perspective transformation. If Y_1 is obtained, the shape of the object is estimated in the base coordinate frame using the above equations. In other words, the estimation of the shape of the object is equal to the estimation of Y_1.

3. EXPERIMENTAL APPARATUS

Figure 3 shows the schematic diagram of the experimental apparatus used in this study. As shown in this figure, it consists of an object, an ultrasonic range finder, a manipulator, a video camera, a light source, a personal computer and an image processing system. The ultrasonic range finder is installed at the tip of the manipulator. This manipulator has five joints and five degrees of freedom, and is controlled by the personal computer so that the range finder moves along the horizontal and vertical lines. The ultrasonic range finder of 500kHz can measure from 25 to 250 mm with 0.1 mm accuracy. The range finder moves 200 mm along each line, and measures the distance at every 2 mm. The number of the measuring points is 100 along each line.

The manipulator is set 710 mm apart from the image plane, and the center of the manipulator coincides with the origin in the base coordinate frame. The video camera was set 2000 mm apart from the image plane. The light source was set just above the video camera. In this experiment, taking images were carried out in a dark room to imitate the underground environment.

Analog images are converted into digital images by the image processing system. The digital image consists of 256×256 pixels with 256 gray levels. Since the experimental apparatus was set as shown in Fig.3, the image area is 190mm×190mm in the base coordinate frame, i.e., Lx and Lz are equal to 190 mm, respectively.

Figure 4 shows the block diagram of image processing. The image processor is LA-525 by PIAS Corp. in Japan. The sampling and smoothing of the digital image were conducted by this system.

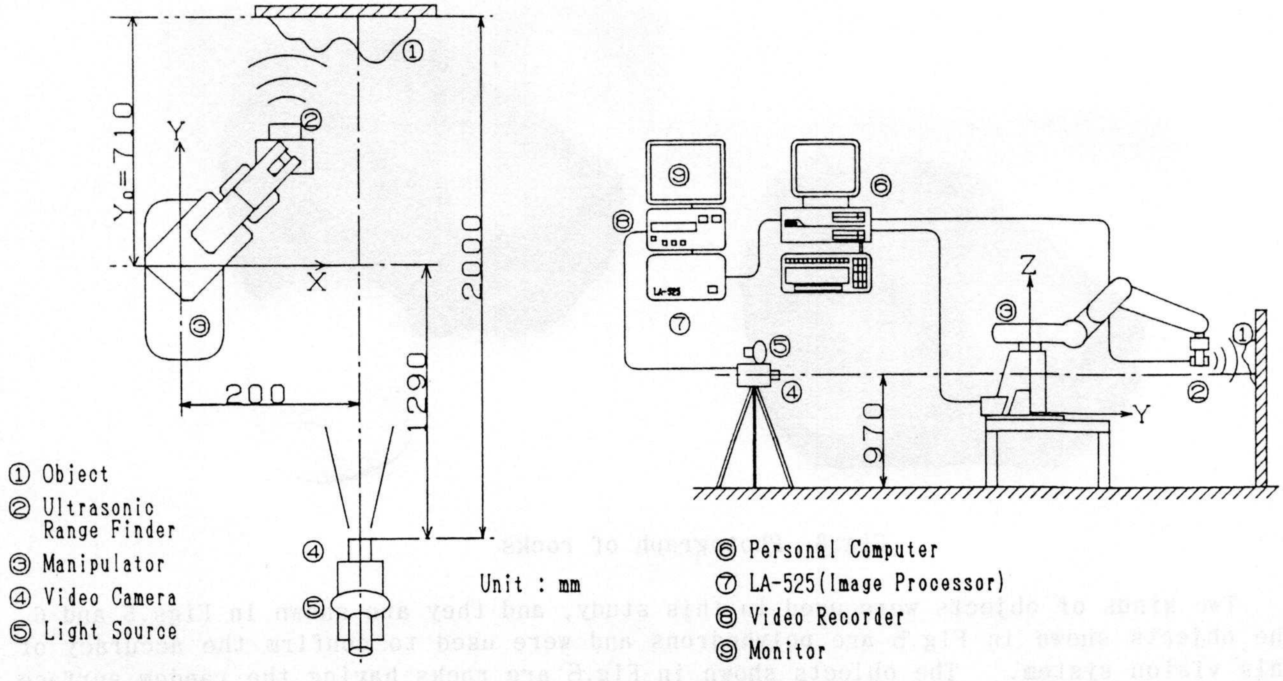


Fig.3 Schematic diagram of the experimental apparatus

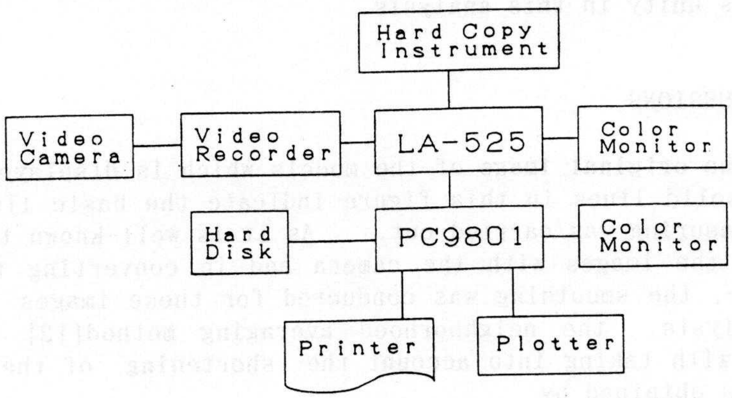


Fig.4 Block diagram of image processing

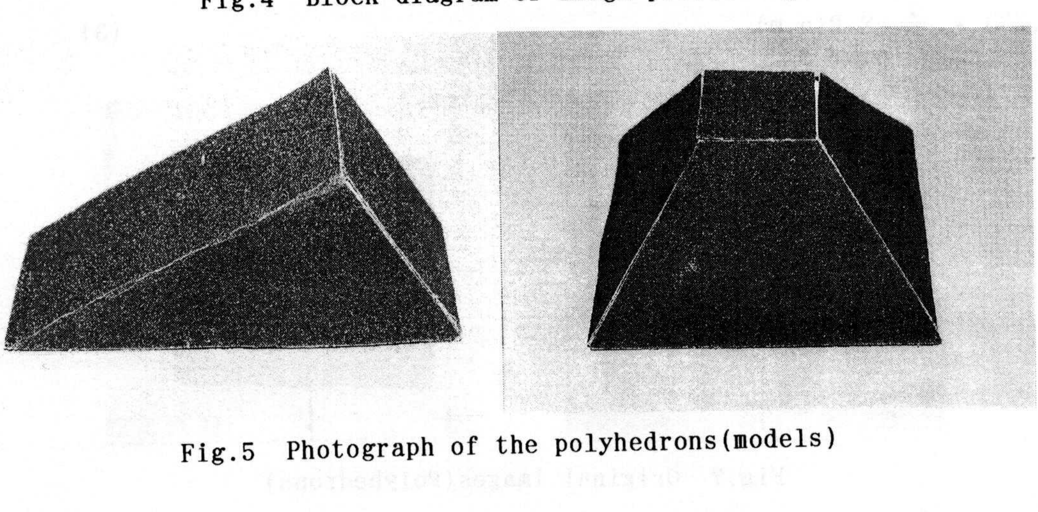


Fig.5 Photograph of the polyhedrons(models)

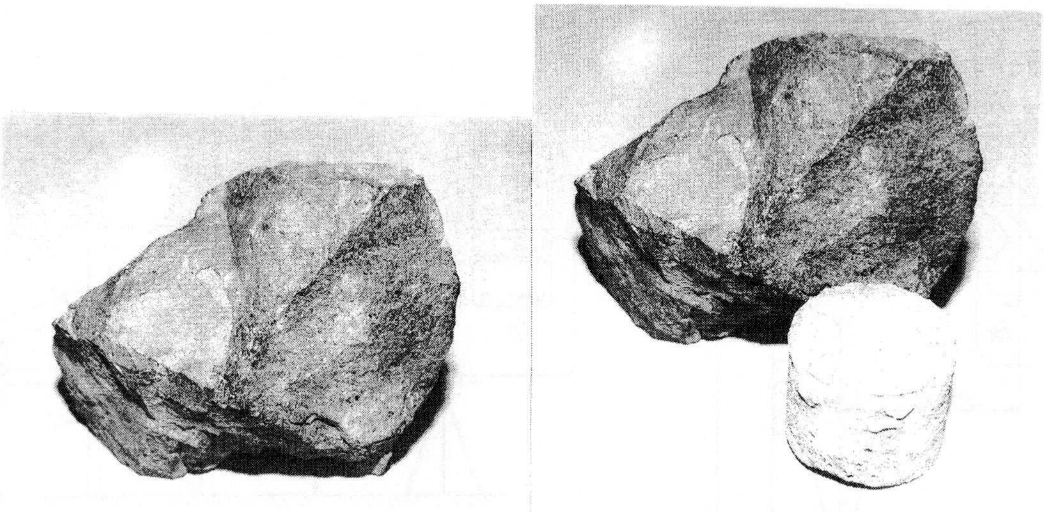


Fig.6 Photograph of rocks

Two kinds of objects were used in this study, and they are shown in Figs.5 and 6. The objects shown in Fig.5 are polyhedrons and were used to confirm the accuracy of this vision system. The objects shown in Fig.6 are rocks having the random surface roughness. Since these objects are rather small compared to Y_0 and the experimental apparatus is set as shown in Fig.3, Y_1-Ycam is approximately equal to Y_0-Ycam. That is, Y_t is regarded as unity in this analysis.

4. RESULTS AND DISCUSSIONS

Figure 7 shows the original image of the models which is displayed on CRT with 16 gray levels. The solid lines in this figure indicate the basic lines on which the three dimensional measuring was carried out. As it is well-known that the noise is generated in taking the images with the camera and in converting the analog image into the digital one, the smoothing was conducted for these images to eliminate the noise. In this analysis, the neighborhood averaging method[12] was adopted for smoothing operation with taking into account the shortening of the operating time. The smoothed image is obtained by

$$P'(X'',Z'') = \frac{1}{N} \sum_{n,m \in S} P(n,m) \qquad (3)$$

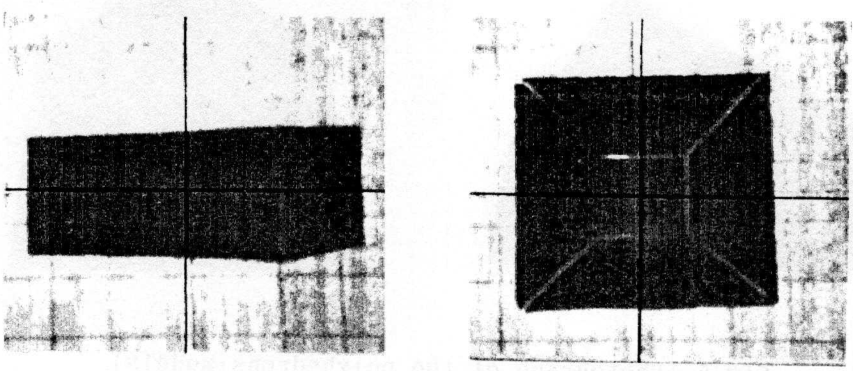


Fig.7 Original images(Polyhedrons)

where S is the set of coordinates of points in the neighborhood of (X", Z"), including (X", Z") itself, and N is the total number of points in the neighborhood. In this analysis, the filter size was set at 5×5(N=25).

Figure 8 and 9 show the results of three dimensional measuring using the ultrasonic range finder. The measuring was carried out along the lines shown in Fig.7. The solid and dashed lines in these figures represent the measuring results and the model shape, respectively. They agree closely with each other. These results prove the high accuracy of this range finder.

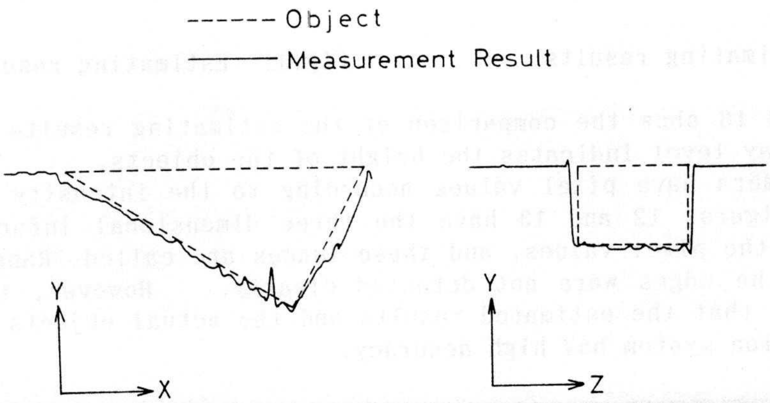


Fig.8 Results of three dimensional measuring

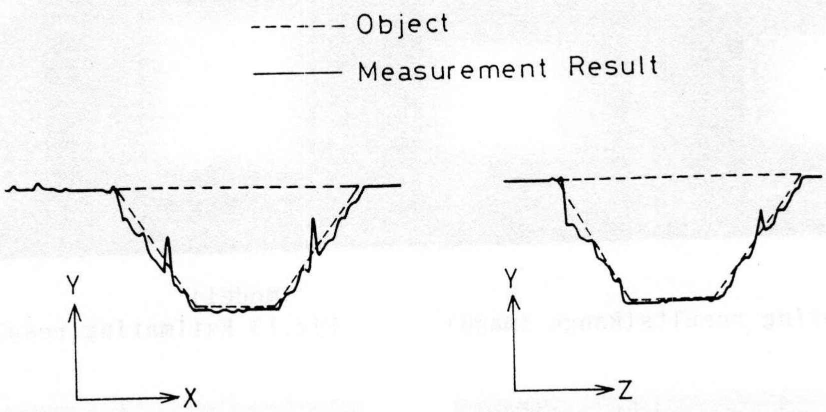


Fig.9 Results of three dimensional measuring

Figures 10 and 11 show the estimating results in three-dimensionally by the above mentioned algorithm. The edges of the objects are not detected clearly. However, the height of the objects are well estimated and the shape of the objects are well reconstructed. The time to estimate the objects is as follows : It needs about 30, 40 and 120 seconds for the three dimensional measuring, the sampling and smoothing of the image data, and the estimation of the object shape, respectively. Therefore, the total time to estimate the object shape is about 190 seconds. If 100×100 points were measured by using the ultrasonic range finder, it takes about 1500 seconds. So, this vision system can shorten the time to estimate the objects compared with the previous one. But, this estimation is far from the real-time processing. This is caused by the hardware of the system. That is, as described earlier, this estimation was carried out with the personal computer. If the high speed image processor and the work station are used, the real-time processing is possible using the above mentioned algorithm.

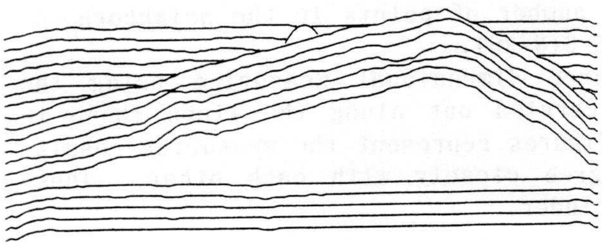


Fig.10 Estimating results

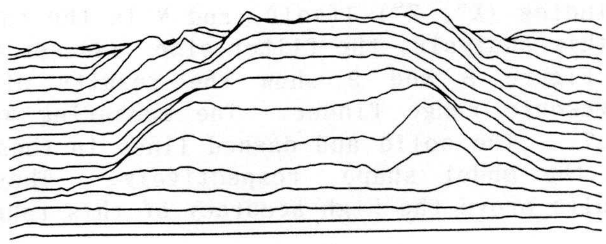
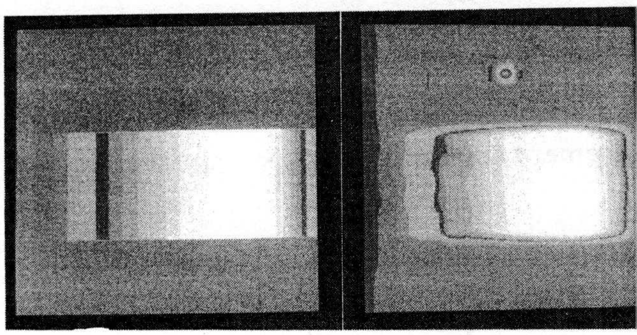
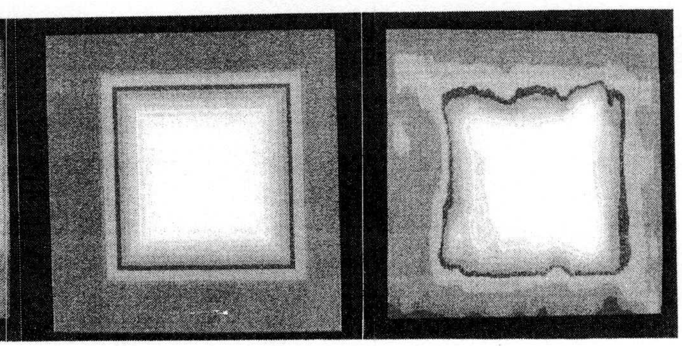


Fig.11 Estimating results

Figures 12 and 13 show the comparison of the estimating results with the actual objects. The gray level indicates the height of the objects. The images taken with the video camera have pixel values according to the intensity of bright. On the other hand, figures 12 and 13 have the three dimensional information for each pixel in stead of the pixel values, and these images are called "Range images". As mentioned above, the edges were not detected clearly. However, it was confirmed from these figures that the estimated results and the actual objects agree with each other and this vision system has high accuracy.



(model)
Fig.12 Estimating results(Range image)



(model)
Fig.13 Estimating results(Range image)

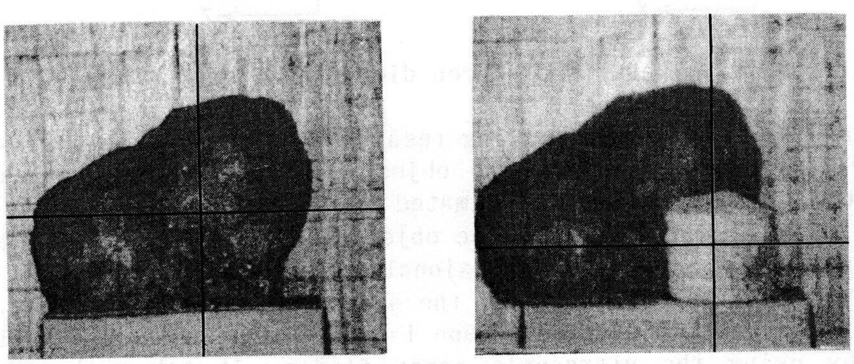


Fig. 14 Original images(rocks)

Figure 14 shows the original image of rocks which is displayed on CRT with 16 gray levels. The solid lines in this figure indicate the basic lines on which the ultrasonic measuring was carried out. Figures 15 and 16 show the results of three dimensional measuring using the ultrasonic range finder. As shown in these figures, it is recognized that the small rock is in front of the large rock.

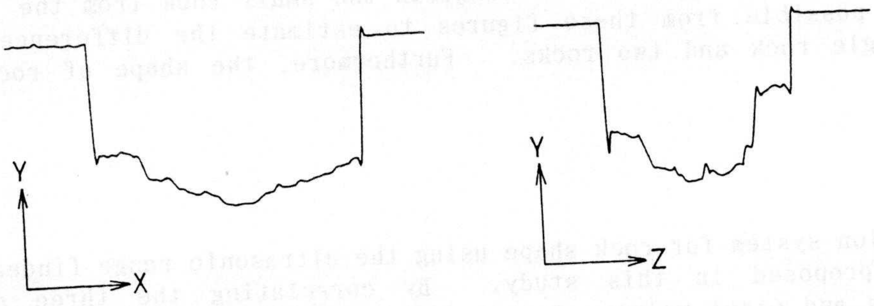


Fig.15 Results of three dimensional measuring

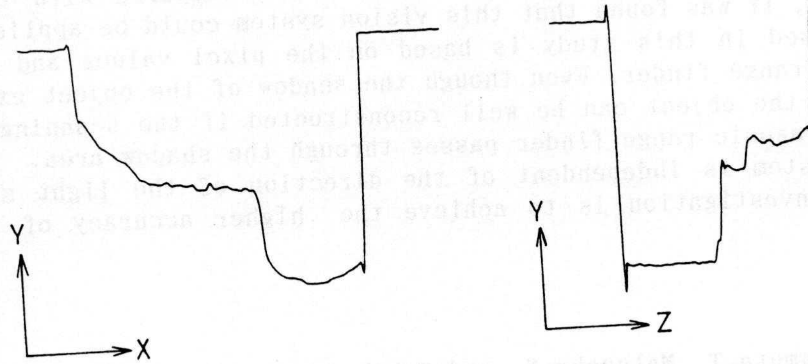


Fig.16 Results of three dimensional measuring

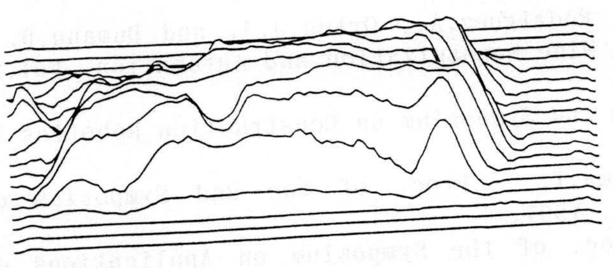


Fig.17 Estimating results

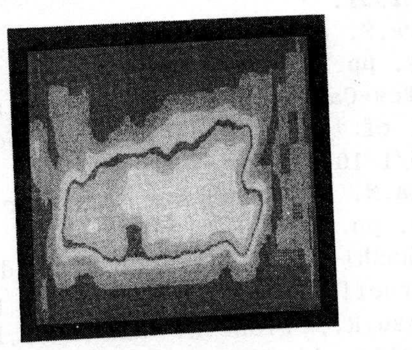


Fig.18 Estimating results(Range image)

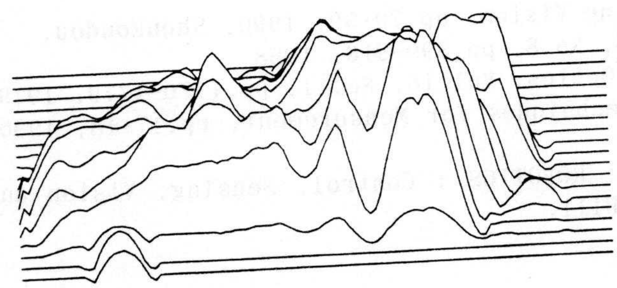


Fig.19 Estimating results

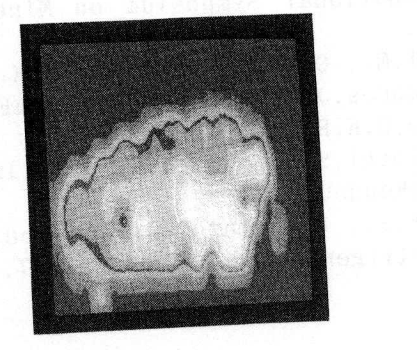


Fig.20 Estimating results(Range image)

Figures 17-20 show the estimated results. Figures 17 and 18 show the results for single rock, and figure 19 and 20 show the results for two rocks. As shown in Figs.19 and 20, it is not clear to distinguish the small rock from the large rock. However, it is possible from these figures to estimate the difference of height between the single rock and two rocks. Furthermore, the shape of rocks is well reconstructed.

5. CONCLUSIONS

A simple vision system for rock shape using the ultrasonic range finder and image processing was proposed in this study. By correlating the three dimensional measuring results and pixel values of the digital image, the height of the objects was estimated and the shape of the objects was well reconstructed. The total time to estimate the shape of the objects was much reduced compared with the previous method. Furthermore, it was found that this vision system could be applied to rocks. The algorithm proposed in this study is based on the pixel values and the results from the ultrasonic range finder. Even though the shadow of the object exists in the image, the shape of the object can be well reconstructed if the scanning is carried out so that the ultrasonic range finder passes through the shadow area. This means that this vision system is independent of the direction of the light source. A next step of this investigation is to achieve the higher accuracy of this vision system.

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