Three-Dimensional Visual Reconstruction of Path Shape Using a Cart with a Laser Scanner

Kikuhito Kawasue[1], Ryunosuke Futami[1] and Hajime Kobayashi[2]
[1]Faculty of Engineering, University of Miyazaki, 1-1 Gakuen Kibanadai Nishi, Miyazaki, Japan
[2]Mog Consultant, 20-20 Miyamae Kishiwada, Osaka, Japan

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Abstract: A movable three-dimensional measurement system of the shape of a path (road) surface has been developed. The measurement can be taken by rolling the proposed measurement cart along the path. The measurement system is composed of a laser scanner, CCD camera, omni-directional camera and a computer. The laser scanner measures the cross-sectional shape of the path at a rate of 40 Hz. The direction of the CCD view is downward to observe the texture of the path surface. The relative movement of the measurement cart to the path is detected by analysing the optical flow of the texture movement. Cross-sectional shapes of the path are accumulated, and the three-dimensional path shape is reconstructed on the basis of the movement of the measurement cart. The image data recorded by the omni-directional camera are allocated to the three-dimensional shape data, and the three-dimensional path is visualized in color on the computer. The reconstructed path data can be used for repair and design of a path in the field of civil engineering. The experimental results show the feasibility of our system.

1 INTRODUCTION

In recent years, measurement systems that measure the shape of large structures, such as bridges, tunnels or roads, have been developed for the maintenance of such structures. For example, mobile mapping systems (MMSs) have been utilized to measure the shape of large structures (Gandolfi 2008, EI 2002, Murai 2001, Haala 1995). In a typical MMS, an automobile equipped with a laser scanner runs on a road and the 3D reconstruction of the road is established by accumulating the shape data from the laser scanner. The position of the automobile is detected by GPS. However, the position cannot be detected inside a structure or on a small path between buildings since the GPS signal from a satellite cannot be obtained. MMS also has problems in accuracy, cost, system size, etc. Therefore, development of a new MMS without GPS is desirable.

In this study, we developed a movable three-dimensional measurement system for a path (road) surface. The measurement system is composed of the following: laser scanner, CCD camera, omni-directional camera, computer, and cart. The laser scanner measures the cross-sectional shape of the path at a rate of 40 Hz. The direction of the CCD view is downward to observe the texture of the path surface. The relative movement of the measurement cart to the path is detected by analysing the optical flow of the texture movement (Bigun 1987, 1990). The cross-sectional shapes of the path perpendicular to the moving direction are accumulated, and the three-dimensional path condition is reconstructed on the computer based on the movement of the measurement cart. The proposed localization method of the system enables us to measure a target space with high accuracy without GPS. Since the measurement cart is small, it can be used in a path too narrow for an automobile to pass. The image data recorded by the omni-directional camera are allocated to the three-dimensional shape data, and the three-dimensional path is visualized in color on the computer. In addition, the system enables us to measure a path having tilt or torsion by adopting a tilt sensor in the system. The reconstructed path data can be used for repair and design of a path in the field of civil engineering. The experimental results show the feasibility of our system.

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2 MEASUREMENT SYSTEM

2.1 System Setup

Figure 1 shows a photograph of the measurement cart. The cart is composed of a computer, a laser scanner (UTM-30LX:Hokuyo Automatic Co. Ltd.), an omni-directional camera with a tilt sensor, and a CCD camera to detect the movement of the system. The target space is measured three-dimensionally by rolling the cart on the path. The scanning (projection) direction of the laser is perpendicular to the moving direction of the cart. The view of the omni-directional camera is aligned to include the laser path. Another CCD camera is attached at the lower position of the cart. The direction of the CCD camera view is downward so that the CCD camera observes the texture of the path surface.

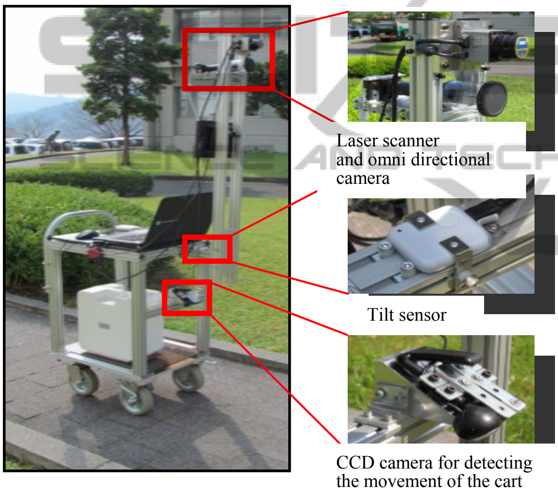

Figure 1: System setup.

2.2 Measurement Procedure of the System

The measurement (reconstruction) is established by arranging the cross-sectional shapes of the path perpendicular to the moving direction of the cart. The arrangement of the cross sections is executed by considering the direction and the magnitude of the displacement of the cart. The direction and the magnitude are detected by the CCD attached at the lower position of the cart. The optical flow of the texture movement of the path surface is analysed to detect the movement. By using this method, the movement of the cart can be detected accurately regardless of the path surface condition.

The laser scanner projects and scans the beam in a radial direction and the cross section of the space is measured at a rate of 40 Hz. Figure 2 shows the projection image of the laser scanner.

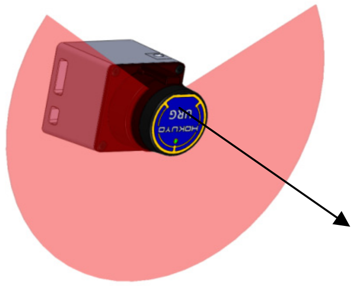

Figure 2: Projection image of the laser.

(Direction of scanning is perpendicular to the moving direction of the cart)

3 IMAGE PROCESSING FOR THE MEASUREMENT

3.1 Detection of Movement of the Cart

The direction and the magnitude of the displacement of the cart are detected by the CCD attached at the lower position of the cart. The image correlation method is used to estimate the optical flow. Small interrogation regions are selected in the images recorded by the CCD. An example of the interrogation regions is shown by the rectangular regions in Figure 3. The intensity of pixels is used to find the matching interrogation regions in consecutive different images. The following equation is used as the correlation function.

$$R(a,b) = \frac{\sum_{i=0}^{Ht-1}\sum_{j=0}^{Wt-1}\left|I(a+u,b+v)-O(u,v)\right|}{\sqrt{\sum_{i=0}^{Ht-1}\sum_{j=0}^{Wt-1} I(a+u,b+v)^2 \times \sum_{i=0}^{Ht-1}\sum_{j=0}^{Wt-1} O(u,v)^2}} \tag{1}$$

H_t *and* W_t are sizes of the interrogation region. I is the intensity of pixels in the input image and O is the intensity of pixels at (u, v) in the original interrogation region. R is a correlation value and (a, b), which has the smallest R, is the movement of the cart in the interval. The vectors in Figure 3 represent the optical flow vectors in the interval. The direction and the displacement of the cart are estimated by the optical flow vectors.

3.2 Calibration

Since the coordinate system of optical flow obtained in 3.1 is based on the camera coordinate system, the coordinate system has to be transformed to the

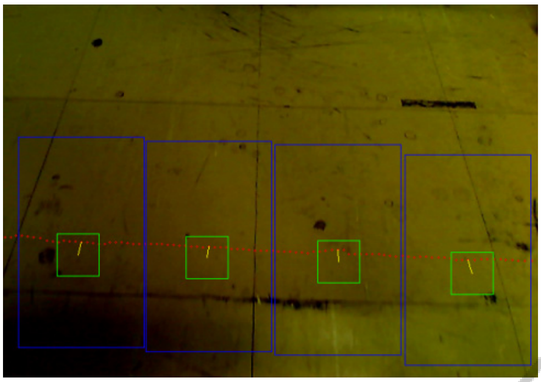

Figure 3: Detection of the movement of the cart by using optical flow.

global coordinate system for quantitative measurement. The relation between the camera coordinate system (u, v) and the global coordinate system (x, y, z) is as follows. In (2), $h_{i,j}$ is the transformation matrix (Wei 1993, 1994).

$$s\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{2}$$

This equation is transformed as follows.

$$\begin{aligned} h_{11}x + h_{12}y + h_{13}z + h_{14} - h_{31}ux - h_{32}uy - h_{33}uz = u \\ h_{21}x + h_{22}y + h_{23}z + h_{24} - h_{31}vx - h_{32}vy - h_{33}vz = v \end{aligned} \tag{3}$$

A scale board is set as shown in Figure 4 and the CCD camera records the scale on the board. The laser scanner is set on the upper position of the cart and detects the z position of the scale board. At least six non-coplanar points are selected by changing the z-position of the scale board. The camera coordinate (u, v) is read by using the mouse device on the computer. The global coordinate (x, y) is read by the scale on the board and z is detected by the laser scanner. The pairs of six coordinates between camera coordinate system (u, v) and global coordinate system (x, y, z) are assigned in (3), and the parameters ($h_{i,j}$) of the transformation matrix are determined.

Therefore, the conversion matrix from the camera coordinate system (u, v) to the global coordinate system (x, y) is as follows.

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} h_{11} - h_{31}u & h_{12} - h_{32}u \\ h_{21} - h_{31}v & h_{22} - h_{32}v \end{bmatrix}^{-1} \begin{bmatrix} u - h_{14} + (h_{33}u - h_{13})z \\ v - h_{24} + (h_{33}v - h_{23})z \end{bmatrix} \tag{4}$$

where z is detected by the laser scanner.

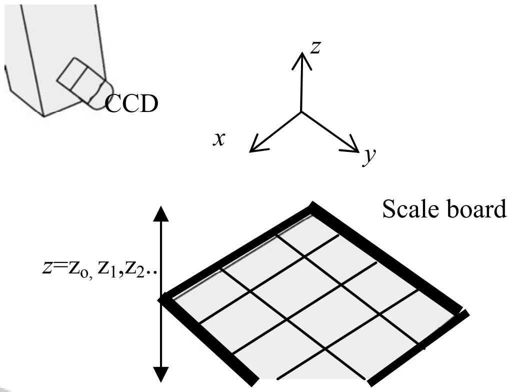

Figure 4: Calibration setup.

3.3 Allocation of Color Information to Shape Data

The omni-directional camera is attached near the laser scanner, and the view of the camera is aligned to include the scan area of the laser scanner (Park 2013). Three-dimensional point cloud data of the cross section of the path are obtained by the laser scanner and the color information obtained by the omni-directional camera is allocated to each point cloud data. The arrangement of the omni-directional camera and the laser scanner is shown in Figure 5. This figure is a view from the moving direction of the cart. In this figure, $\angle P_1P_2P_3(\alpha)$ is calculated by the inner product formula as follows.

$$\alpha(\mathrm{deg}) = \cos^{-1}\left(\frac{(y+H)}{\sqrt{x^2+(y+H)^2}}\right) \times \frac{180}{\pi} \tag{5}$$

As the laser is scanned from the first quadrant to the fourth quadrant, the value of θ is modified for each quadrant area.

$$\begin{aligned} &\textit{First quadrant } \theta = 90\,\mathrm{deg} - \alpha \\ &\textit{Second quadrant } \theta = 90\,\mathrm{deg} + \alpha \\ &\textit{Third quadrant } \theta = 90\,\mathrm{deg} + \alpha \\ &\textit{Fourth quadrant } \theta = 450\,\mathrm{deg} - \alpha \end{aligned} \tag{6}$$

The color information is allocated to each point data by (5) and (6).

4 SLOPE DETECTION

In our system, the tilt of the cart is detected by the tilt sensor. This sensor detects the direction of the gravitational acceleration (Gx, Gy). The range of the value is -1000 to 1000 mG. The slope of the cart is

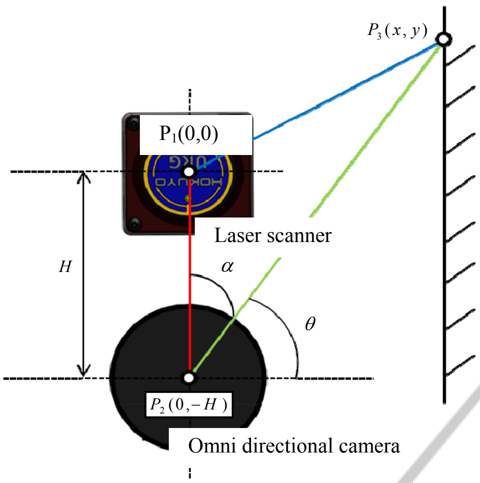

Figure 5: Relationship between omni-directional camera and laser scanner.

defined as follows.

$$\theta_x(\deg) = \sin^{-1}\left(\frac{G_y}{1000}\right) \times \frac{180}{\pi}$$
$$\theta_y(\deg) = \sin^{-1}\left(\frac{G_x}{1000}\right) \times \frac{180}{\pi} \tag{7}$$

As the data obtained by tilt sensor are not stable, as shown in Figure 6, 300–500 data from the tilt sensor are selected and mean data are calculated. The tilt data from the sensor are smoothed, as shown in Figure 6.

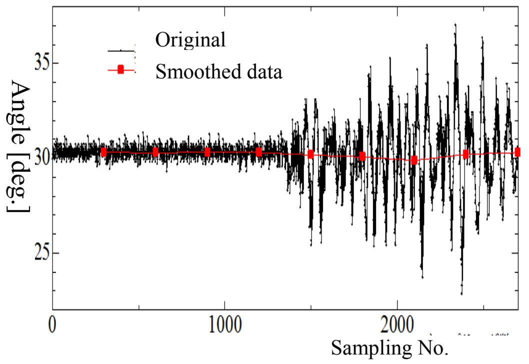

Figure 6: Result of the smoothing process.

5 EXPERIMENT

5.1 Detection Accuracy of the Cart Movement

The cross section of the path is arranged considering the movement of the cart. The accuracy of the reconstruction is dependent on accurate detection of the movement. The measurement accuracy of the cart displacement is evaluated on the basis of the cart speed. The average speed of the cart is estimated from images of the CCD camera. The line scale shown in Figure 7 is used to measure the actual displacement of the cart. The cart was rolled along the line scale and the result of the computation was compared with the actual displacement. The experimental result is shown in Figure 8.

Figure 7: Line scale used for the experiment.

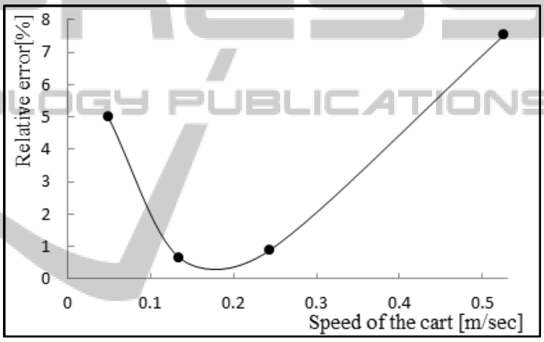

Figure 8: Accuracy of the movement detection of the cart.

The result shows that the percentage of measurement error is relatively large under 0.1 m/s and over 0.3 m/s. This error occurs for the following reasons.

Under 0.1 m/s: The difference between two images is too small to detect the optical vector under the digital image. For quantization, the optical flow vector cannot be calculated under movement of 1 pixel.

Over 0.3 m/s: The difference is too big between two images for estimating the correlation value. So, the error is caused by the corresponding error. Therefore, the best performance is realized at approximately 0.2 m/s.

The error of the laser scanner used in our system is 10–30 mm and the reconstruction accuracy is dependent on the laser scanner accuracy.

5.2 Reconstruction of the Path on the Computer

The path in our university campus is measured to check the feasibility of the system. A photograph of the path is shown in Figure 9. The cart was rolled on this path. The reconstructed path is shown in Figure 10. The distance of the measured data is approximately 10 m and the number of measured points is approximately 1 million. Once the data are set in the computer, the path can be seen from any view.

Figure 9: Photograph of the path in the campus.

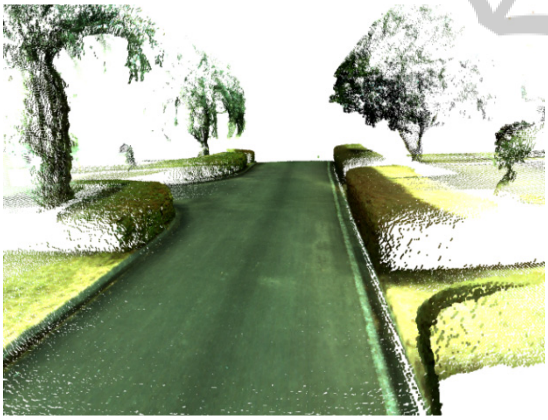

Figure 10: Reconstructed path on the computer.

6 CONCLUSIONS

In this study, a movable three-dimensional measurement system without GPS was developed. The system is composed of a cart with a laser scanner, omni-directional camera, and CCD camera. The laser scanner detects the cross section of the path. The detected cross section is arranged on the computer on the basis of the movement of the cart. The movement of the cart is calculated by the optical flow vector of the texture image on the path surface. Since it does not use GPS, the proposed measurement system can be used indoors. Therefore, applications to various situations in civil engineering are expected.

REFERENCES

Gandolfi, S., Barbarella, M., Ronci, E., Burchi, A., 2008. Close photogrammetry and laser scanning using a mobile mapping system for the high detailed survey of a height density urban area., *ISPR08* , B5: 909–914.

El Hakim, S., Beraldin, J., Picard, M., Vettore, A.,2003. Effective 3d modeling of heritage sites. In: *3DIM03*. , 302–309.

El Hakim, S., Beraldin, J., Lapointe, J., 2002. Towards automatic modeling of monuments and towers. In: *3DPVT02*. , 526–531.

Murai, S., 2001. Generation of 3d city models in japan: An overview., *ASCONA01*, 59–64.

Haala, N., Hahn, M., 1995. Data fusion for the detection and reconstruction of buildings. *ASCONA95*, 211–220.

Bigun, J., Granlund, G., Wiklund, J., 1991. Multidimensional orientation estimation with applications to texture analysis and optical flow. *PAMI 13* , 775–790.

Bigun, J., Granlund, G.,1987. Optimal orientation detection of linear symmetry. ,*ICCV87*, 433–438.

Bigun, J. A structure feature for image processing applications based on spiral functions. *CVGIP 51* ,1990, 166–194.

Wei, G., Ma, S., 1994. Implicit and explicit camera calibration: Theory and experiments. *PAMI 16* , 469–480.

Wei, G., Ma, S., 1993. A complete two-plane camera calibration method and experimental comparisons., *ICCV93*, 439–446.

Park, S., Chung, M., 2013. 3d world modeling using 3d laser scanner and omni-direction camera., *FCV13*, 285–288.