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MEASURING AND UPDATE OF SHAPE OF PILE FOR LOADING OPERATION BY WHEEL LOADER

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ABSTRACT

Authors have been conducting research on an unmanned loading system by wheel loader. The system has function of sensing, decision making and control of motion. The operation of the system is autonomous completely without any assist of human operator. As a part of the research, the detection method of location and shape of the pile will be described in this paper. At the beginning of the loading operation, scooping positions should be decided based on the location and shape of the pile. Stereo vision system with two CCD cameras is attached on the loader. For obtaining three dimensional data of the shape of the pile, a correlation method is applied on the images. The 3D data is converted into the column model by quantization. The scooping positions are decided based on the data of the pile and the location and direction of the dump truck for effective operation at the beginning state of the operation.

Because the shape of the pile is changed by scooping with advancing the loading operation, the measured shape has to be updated during operation. After several scooping, the images of the pile are captured during travelling between the scooping position and the loading position. It is not necessary to slow down of velocity of the loader up to 8km/h for capturing. 3D shape and column model of the pile is obtained in the same manner.

The proposed method is applied on the experimental system for autonomous loading operation and shows good results in the test field trial.

KEYWORDS

Wheel loader, Loading operation, Autonomous system, Stereo-vision

1. INTRODUCTION

Wheel loader is one of the major loading machines used in construction, surface mining and so on. The authors have been conducting a development of autonomous loading system by wheel loader [1]-[4]. The developing system is completely unmanned system and self-contained. Working environment at construction site consists of irregular shape objects such as pile of gravel, which change their shape or volume with advancing of the operation. Loading operation by wheel loader involves relational movement with dump trucks. Detection and localization of other object such as the pile and the truck are essential function for an autonomous system for loading operation.

The essential functions for an autonomous system are (1) recognition of environment, (2) planning and (3) motion control. The pile is the main object of the task. A stereo-vision system is employed for detection of location and shape of the pile in the developing system. The outline of the developing system and the detection of pile by stereo-vision system with experimental results are described in following sections.

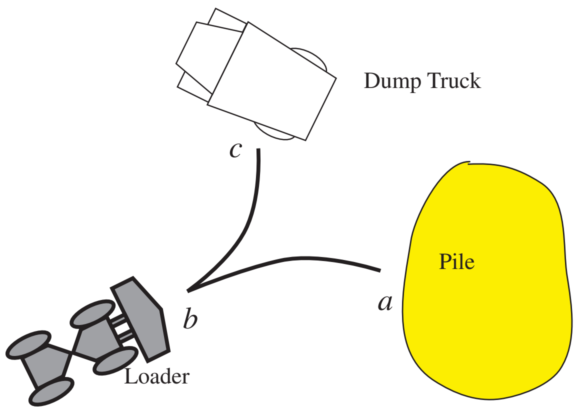

Figure 1. V-Shape loading method

2. TARGET TASK

The target task of the developing system is loading by V-shape method as in Fig.1. The loading operation is carried out by repetition of the cycle of phases:

(1) scooping from the pile (a),
(2) traveling to the dump truck (a - b - c),
(3) loading to the truck (c) and
(4) traveling to the pile (c – b - a).

Wheel loader (loader hereinafter) moves on V-shape path which includes switch back in the middle of the path between scooping point and loading point.

Because the developing system is autonomous or unmanned system, every motion of the operation is determined by the system itself based on the environment measured by sensors installed on the system. The developing system is tested on an experimental loader: Yamazumi-4 (YZ4 hereinafter: Fig.2). The base machine of YZ4 is a middle size wheel loader with about 7m in length, 6t in weight and bucket capacity is 1.3 m^3. Hydraulic system is arranged for computer control with pilot valves. PCs and sensors are mounted for following functions. The autonomous system consists of the planning sub-system, the motion control sub-system and sensor system. The planning sub-system makes decision for scooping point, V-shape path and loading point to the dump truck. The planning sub-system for scooping point issues the scooping position and direction on the edge of the pile based on the position and shape of the pile. The planning sub-system for loading point issues the loading position and direction on the vessel of the truck. The path planning sub-system generates a path between the scooping point and the loading point. Because the Scooping points and the loading point are changed with advancing of the operation cycle by cycle, the planning procedure is executed for each cycle of the operation.

3. MEASURING BY STEREO-VISION SYSTEM

3.1. Stereo-vision System

Stereo-vision system with two CCD cameras is fixed on the top of canopy of YZ4 (Fig.3). Cameras are put in sealed boxes for outdoor use. The cameras are black and white type and have resolution of 640x480 pixels. The length of the base line of the system is about 1.2m. The cameras are connected to PC for the planning sub-system. All of operation of the cameras including shooting and shutter arrange are controlled by the PC.

Figure 2. Experimental loader: Yamazumi-4

Figure 3. Stereo-vision system

A stereo-vision system is a method of measuring three dimensional shape of the object with two cameras. Measuring is based on the principal of trigonometry. Let $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$ be vectors to target point p from observational coordinates Σc_1 and Σc_2 respectively. Let $\boldsymbol{d}$ be a vector between origins of Σc_1 and Σc_2. Because the target point p is on extension lines of p_1 and p_2,

$$\boldsymbol{p} = \mu \boldsymbol{p}_1$$

$$\boldsymbol{p} = \lambda \boldsymbol{p}_2$$

where μ and λ are arbitrary coefficients. Following equation is relation among them.

$$\lambda \boldsymbol{p}_1 = \mu \boldsymbol{p}_2 + \boldsymbol{d} \tag{1}$$

$\boldsymbol{d}$ is known. $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$ are obtained by measurement. Coefficients μ and λ can be eliminated based on elements of these vectors. Therefore position of point p is obtained. (Fig.4)

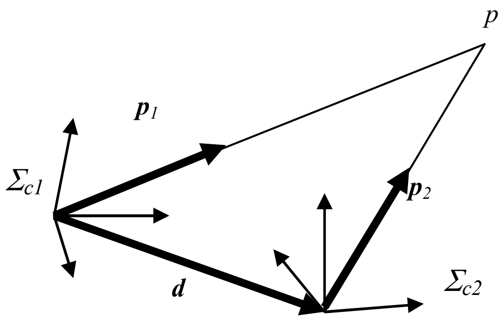

Figure 4. Trigonometry

Two cameras of stereo-vision system are modelled as pin-hole camera model. In the pin-hole camera model, all of light pass through the pin-hole instead of the optical centre of lenses system. As shown in Fig.5, Camera coordinate system Σ_c is fixed on the camera. The origin and z-axis are coincided to the pin-hole and the light axis respectively. The focal plane is normal to z-axis and located at focal length f from the pin-hole. Focal plane coordinate system is fixed on the focal plane to represent position of pixels on the focal plane. let p' be image on the focal plane of a point p in measuring space, (u,v) be position of pixel corresponding to p' on the focal plane and (x,y,z) be elements of position vector of point p in measuring space. Relation is represented by following equations.

$$u = fk_u(x/z)+u_0 \tag{2}$$

$$v = fk_v(y/z)+v_0 \tag{3}$$

where u_0 and v_0 are corresponding pixel of crossing point of the focal axis on the focal plane and k_u and k_v are coefficients of translation between the focal plane coordinate system and CCD element. The vector to the point p in the camera coordinate system is obtained from measurement of (u,v) by equations (2) and(3).

To identify three dimensional position of a point in measuring space from images of right and left camera, principal of trigonometry is adopted. For effective corresponding, the camera model is modified into parallel camera model by rectification. In parallel camera model, two focal planes of each camera are parallel and on the same plane.

The camera parameters including the geometrical relationships between the two cameras and the parameters related inner structure of the cameras such as focus length are calibrated using images of calibration pattern before experiments.

To obtain 3D data set of the pile, the minimizing of the sum of absolute difference (SAD) is adopted as the stereo corresponding method. SAD is defined as equation (4) for an area including *m* x *n* pixels on the focal plane.

$$SAD = \sum \left| I_1(x,y) - I_2(x+i, y+j) \right| \quad (4)$$

where I_1 and I_2 are brightness of pixel(*,*) at camera 1 and 2 respectively. SAD is calculated over search area by changing *i* and *j* in the image of camera 2. The pixel which gives the least SAD is the corresponding pixel to *(x,y)* in image of camera 1. In the parallel camera model, *j* can be fixed as a constant. This makes the procedure of corresponding simple and fast. As the pile of fragmented rock has random texture on the surface, SAD method is adequate method for stereo corresponding.

3.2. Measuring Results

Accuracy of the stereo-vision system on YZ4 is tested by using the test pattern. The distance between the test pattern and the stereo-vision system on YZ4 are 10, 15, 20, 25 and 30m as shown in Fig.6. From the result of the test (Fig.7), the accuracy of measuring is very high. The errors are less than 5% of the measuring distance. Practical measuring range is about 5 to 35m.

Fig.8 shows raw images of each camera; fig.(a) and (b) are images by left and right camera respectively. Obtained 3D data set is shown in Fig.9. It is obvious that the obtained three dimensional points cover the measuring area including the pile and the ground. The detail of the surface of the pile is measured clearly.

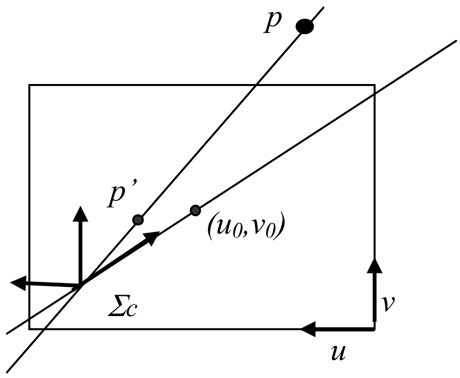

Figure 5. Pin hole camera model

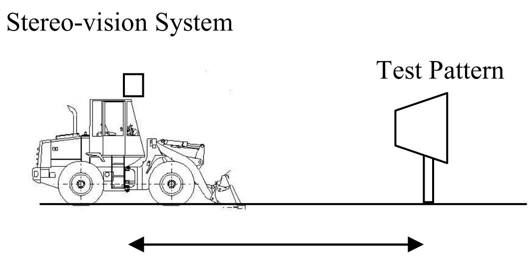

Figure 6. Test for accuracy

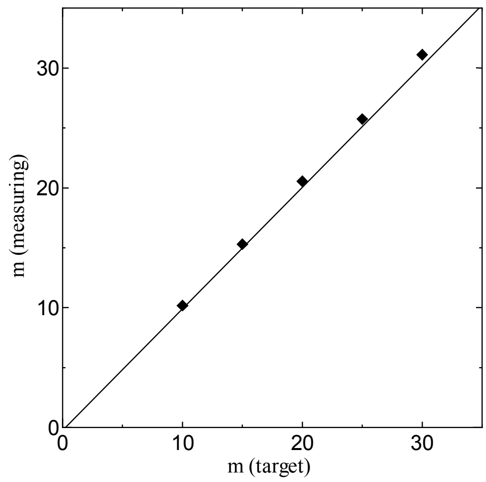

Figure 7. Result of accuracy test

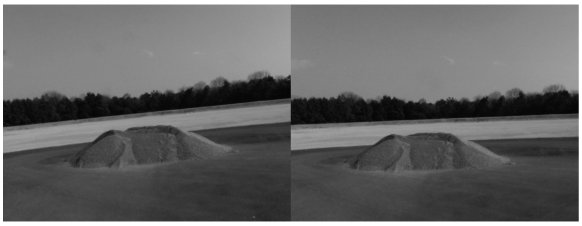
a b

Figure 8. Image of pile: (a) left camera (b) right camera

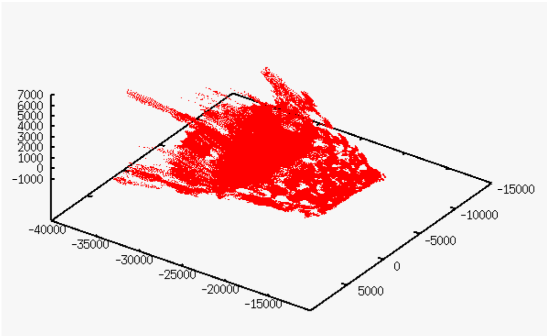

Figure 9. Three dimensional shape of pile

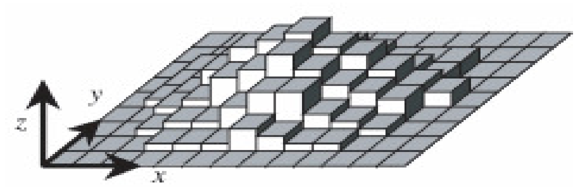

Figure 10. Column model

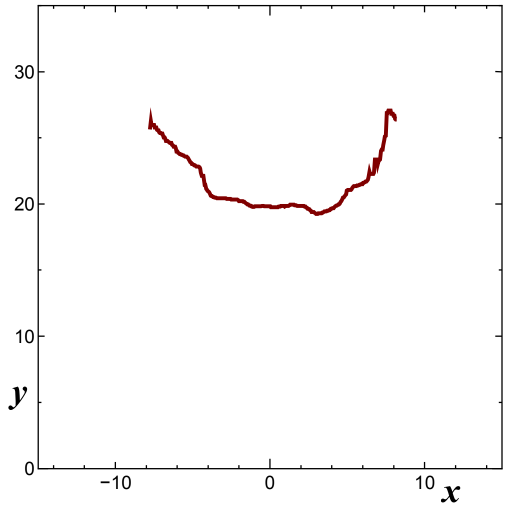

Figure 11. Edge of the pile

3.3. Modelling of Pile

Usually, a number of the points including the 3D data set are tens of thousands. The density of these points changes and is not monotonous distributed. The 3D data is converted into the column model by quantization for effective processing. Though simple in structure, the model can represent the shape of the pile, as well as changes in both shape and volume. Fig. 10 shows the structure of the column model. The working area is tessellated into sections, each forming the base of a column. The height of each column represents the height of the pile at that position. The sizes of the sections and unit of height have no relation to the particle or fragment diameter of the material making up the pile. The column model provides easy and fast processing of the pile model. The column model is a useful system for estimating the interaction between the bucket and piled material.

In the experiments by YZ4, number of column is 500 x 500 and the size of column is 50 x 50 mm. This model can represent area of 25 x 25m in the working place.

For effective scooping, scooping motion of the bucket should be started at the edge of the pile not at the middle of slope of the pile. The edge of the pile can be extracted through processing of the column model. Fig.11 shows the edge part of the pile. The threshold for extraction is 150-200mm above the ground. The columns which have height within the threshold range are extracted as the edge. 3D shape and column model of the pile is described in the camera coordinate system fixed on the stereo-vision system however it is easy to transform to the global coordinate system based on data from GPS positioning system which provides the position and direction of YZ4 in the global coordinate system (Fig.12).

4. UPDATE OF PILE MODEL

The shape and volume of the pile change by scooping during operation, the scooping points are determined based on the shape of the pile, the model of the pile should be updated during operation for the task planning of the next cycles of scooping.

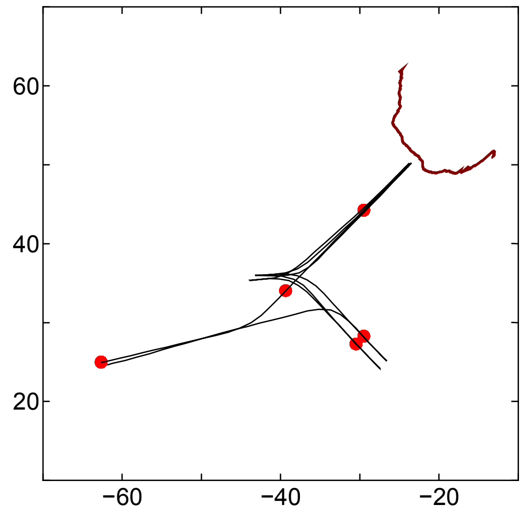

Figure 12. Pile edge in the global coordinate system (with path of the loader in operation)

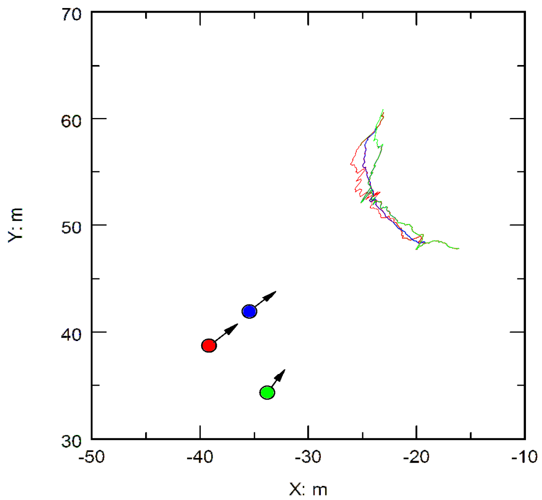

Figure 13. Results for update of the edge of pile

The results of experimental measurement are shown in Fig.13. The lines represent the edge of pile. The dots with arrow represent the capturing position and direction of the loader. Each line is described in the coordinate system fixed on the camera system during processing of extraction of the edge from 3D shape of the pile. Then the lines are transformed into the coordinate system fixed on the working place based on the position and direction of the loader provided by GPS positioning system. Every edge are coincide each other very well.

3D shape of the pile can be constructed from images taken during travelling at velocity up to 8km/h. This velocity is the maximum one at the experiments of the target task.

5. CONCLUSIONS

As a part of development of the autonomous system for loading operation by wheel loader, detection method for the pile by stereo-vision system has been developed. Stereo-vision system with two CCD cameras is equipped on experimental loader. From images of the pile, 3D shape is formed and converted to the column model. The shape and location of edge of the pile is obtained trough processing column model. As a part of planning of the operation, scooping position is decided based on the detected edge.

3D shape can be obtained from images taken at travelling with velocity up to 8km/h. The model of the pile can be updated during travelling for continuous operation.

The developing method is applied on the experimental system for autonomous loading operation and shows good results in the test field trial.

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