STEREO VISION BASED WORKER DETECTION SYSTEM FOR EXCAVATOR

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ABSTRACT

It always has been a serious issue to improve safety in mine sites, demolition work sites, and civil engineering work sites. Especially, collision accidents caused by construction equipment damage not only the productivity of operations but also the health and life of workers in those work sites.

To solve this problem, a variety of worker auto-detection means are developed so far, but they have not still become widely used in actual worksites. There have been two controversial points in the prior methods. One is that they were not enough in respect of the detection accuracy and certainty, and the other one is that the information of the detection results was not comprehensible to the operator of equipment.

In this paper, the functional requirements of the obstacle detection system in earth moving work site is redefined at first, and then, it is proposed to apply a stereo vision to the obstacle detection system for an excavator.

The system consists of horizontally arrayed two digital cameras with low distortion lens, an image processing controller, and a monitor for an operator in the cab. Stereo vision calculates the depth image from images of two cameras and detects the presence of obstacles, its distance, direction, and dimensions. Sensed obstacles are informed to the operator in the monitor image.

Preliminary experiments are conducted with a stereo vision system mounted on a real equipment in a demonstration site. The result shows that two controversial points of the conventional technologies are improved, and that the applicability of this system is validated.

KEYWORDS

Construction Equipment, Excavator, Safety, Proximity Detection, Stereo Vision, Camera

INTRODUCTION

Background

It always has been a serious issue to improve safety in mine sites, demolition work sites, and civil engineering work sites. Especially, collision accidents caused by construction equipment damage not only the productivity of operations but also the health and life of workers in those work sites.

Table 1 shows the relation between the type of construction equipment and the number of accidents occurred in public works ordered by the government in Japan from 2004 to 2009. The largest number of accidents is caused by hydraulic excavators. By type of accident, there is a large number of serious injury or fatal than property damage. Looking at the type of accidents caused by hydraulic excavators (Table 2), 80% of total seem to be contact accidents, such as "hit", "run-over", and "jammed."

Table 1 – Relation between the type of construction equipment and the number of accidents in public works ordered by Japanese government (2004-2009)

Type of Equipment	Fatal	Injury	Property Damage
Hydraulic Excavator	4	34	3
Mobile Crane	1	10	1
Haulage Equipment	5	2	0
Paving Roller	2	5	0
Misc.	5	14	0

Table 2 - Type of accidents caused by hydraulic excavators

Situations	Percentage
Hit	39%
Run-over	24%
Fallen	20%
Jammed	15%
Misc.	2%

Two problems have been pointed out as the cause of the accident, one is that there are many blind spots in the vicinity of the equipment, and the other one is that safety check by the operator can be difficult. The similar result has also been shown in an investigation on construction industry in the United States (Hinze & Teizer, 2011).

As a means to assist a safety check of the operator, several devices have been developed so far, those detect obstacles or workers around the equipment by acoustic/optical sensors or radars, and alarm to the operator. These sensors however have not yet been spread, because of the following three problems, (1) detection range is insufficient, (2) detection performance is insufficient, (3) information presentation for an operator other than the alarm is insufficient (e.g. information on location, and identification of obstacles). Further, as another means, there are methods of using active RFID tags or using GPS (Ruff, 2004; Teizer 2010). These are promising methods for correcting the above-mentioned problems (1) and (2), and are also expected to clear the problem (3) in further study.

Goal of This Research

Focusing on that the rear monitor cameras are being typically mounted already on recent excavators, we have investigated a method for detecting an obstacle by the image processing. By the stereo image processing, it is possible to obtain the three-dimensional position information (Ruff, 2004), and also false positives caused by the feature of background image seem less likely than monocular image processing. Further, it is more advantageous than conventional sensors in terms of three issues given above, (1) detection range, (2) detection performance, and (3) information presentation.

In this study, we aim to build a stereo vision based worker detection system, which detects the surrounding obstacles by stereo image processing, presents information on the obstacle to an operator accurately.

REQUIREMENTS DEFINITION

Type/Size/Operation of Equipment

Whilst there are a various kinds of construction equipment, this study is intended for the 20t weight class hydraulic excavators, often used in civil work sites.

Contact accidents caused by hydraulic excavators are classified into the following three operation patterns in general.

- Worker contacts with an excavator body when the excavator is traveling backward
- Worker contacts with an excavator body when the excavator is swinging
- Worker contacts with a bucket of the front arm when the excavator is working (e.g. digging, swinging, loading, etc.)

In this study, we consider the contact with the body when the excavator is traveling backward. One reason is because the highest percentage of accidents as those. The other reason is because the rear monitoring cameras for safety have already being standardized, and it is expected that applying stereo camera as substitute for them will be relatively easy.

Target Obstacle

In the work site, there are a variety of obstacles that can come into contact with excavators, for example, *personnel* such as workers, supervisors, and fitters, *other construction equipment and vehicles* such as dozers, rollers, and haulage vehicles, *structures* such as buildings and houses, *materials* such as iron frames and cement bags, etc.. These are also varied depending on each work site. In this study, our first target is to detect workers, because they are likely to result in the most serious damage.

Detection Range

Considering the defined conditions above, we set the range of detection as follows (Figure 1).

- Detection distance: max 6m from the rear end of the vehicle body
- Horizontal range: max 8m width, at 6m distance from the rear end of the vehicle body
- Vertical range: up to 2m from the ground (0m)

The maximum detection distance was derived in the following assumptions:

First, we assumed the scene the worker has come into the direction in which hydraulic excavator is traveling backward in 5.5km/h (approximately 1.5m/s) of its maximum travel speed. Next, we assumed that the system takes about 1 second as a processing time to detect a worker and issue a warning to an operator, and then the operator takes about 2 seconds since receiving the alert from the system until recognizing the worker and operate to stop excavator. Therefore, the total distance that the excavator can travel in 3 seconds is approximately up to 4.5m. We add 1.5m for the marginal distance between the excavator and the worker at the stop, and we have set the maximum detection distance 6m from the rear end of the vehicle body.

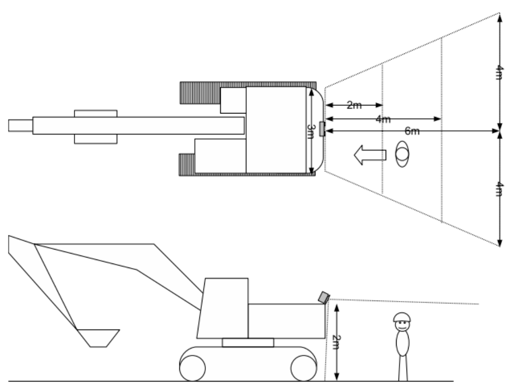

Figure 1 – Detection Range

EXPERIMENTAL PROTOTYPE

We developed an experimental prototype of stereo vision system which consists of two digital cameras horizontally arranged in parallel. Specifications of cameras and lens are shown in Table 3 and Table 4. The developed experimental prototype is shown in Figure 2. In this experiment, we set the camera image size 640x480[pixel]. Baseline of two cameras is 100[mm].

Table 3 – Specifications of Camera

Model	Point Grey Research Flea2-14S3M/C
Digital Interface	IEEE1394b(Maximum 800Mb/s)
Max Image Size	1280 x 960 (In this experiment, 640 x 480)

Image Data Format	24bit Color (In this experiment, Greyscale)
Frame Rate	15fps

Table 4 – Specifications of Lens

Model	Kowa LM3NC1M
Focal Length	3.5mm
Shooting Range	89 x 73.8 deg

Figure 2 - Experimental prototype of stereo vision camera

We developed the stereo calibration software and stereo matching software, using *OpenCV* library (being maintained by Willow Garage). While several kinds of stereo correlation algorithm are available, we adopted *Block Matching* (Konolige, 1997; Eveland & Konolige, 1998) which is superior in calculation speed on low performance processor.

RESULTS

Experimental Conditions

In the simulated civil work site environment, we installed the experimental prototype system on a 20t class hydraulic excavator (Hitachi ZX200, Figure 3). Stereo camera for this experiment was mounted on the top rear end of the counterweight.

Figure 3 – Hydraulic Excavator Hitachi ZX200 in the simulated civil work site environment

Figure 4 shows the camera position and field of view. Height of camera is approximately 2.1m, elevation angle is -40degree from the horizontal direction. Substantial vertical field of view after distortion correction and parallelize processing was about 65 degrees. In this setting, the camera can obtain an aspect of a worker in the range of up to 6m from 1m away from the rear end of the excavator.

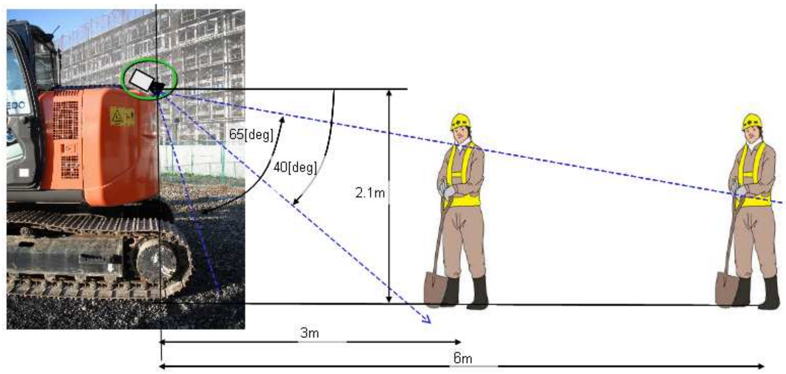

Figure 4 – Camera Position and Field of View

In this experiment, motion of the vehicle has been categorized into 3 patterns: Still, Swing, Travel.

Motion of the simulated worker has also been categorized into 4 patterns: Stand-Still, Squat-Still, Walk-Longitudinally (back and forth), Walk-Laterally (side to side). Table 5 shows a combination of these patterns, consisting of motions of the simulated worker and the excavator.

Table 5 – Patterns of Motions of Excavator and Worker

			Worker			
			Still		Walk	
			Stand	Squat	Longitudinal	Lateral
Excavator	Still		Scene1-a		Scene1-b	Scene1-c
	Swing		Scene2-a		Scene2-b	Scene2-c
	Travel	Longitudinal	Scene3-a	Scene3-b	Scene3-c	(Not done)

Figure 5 shows the overview of the arrangement of the experimental field. Camera coordinate is defined as the origin is set to the center of the rear end of excavator where stereo camera is mounted, Y-axis is set along with longitudinal direction, X-axis is set along with lateral direction. The simulated worker positioned with reference to these safety cones which were placed at intervals of 1m on this camera coordinate. The ground surface was flat gravel. The weather condition was occasionally cloudy, was no rain or fog.

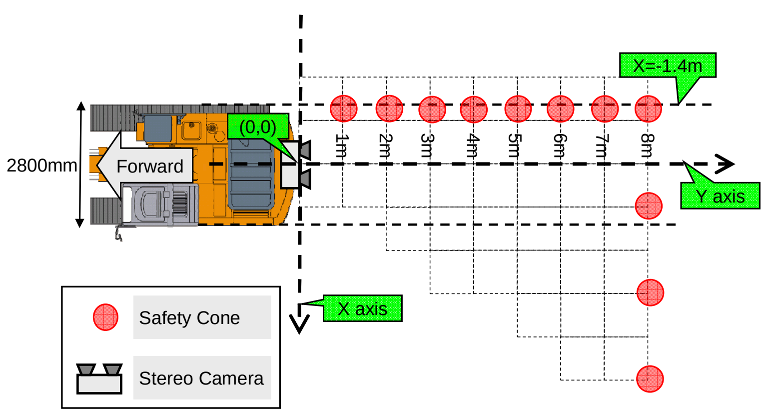

Figure 5 – Experimental Field

The following are examples of undistorted camera image and disparity image in some scenes. Figure 6 shows the images of Scene 1-a, when the worker was squatting at a distance of 1m, 6m from the stationary excavator. Figure 7 shows the images of Scene 3-a, when the excavator was travelling backward and the worker was standing still at a distance of about 6m from the excavator. Figure 8 shows the images of Scene 3-c, when the excavator was travelling forward and the worker was walking following the excavator at a distance of 1m.

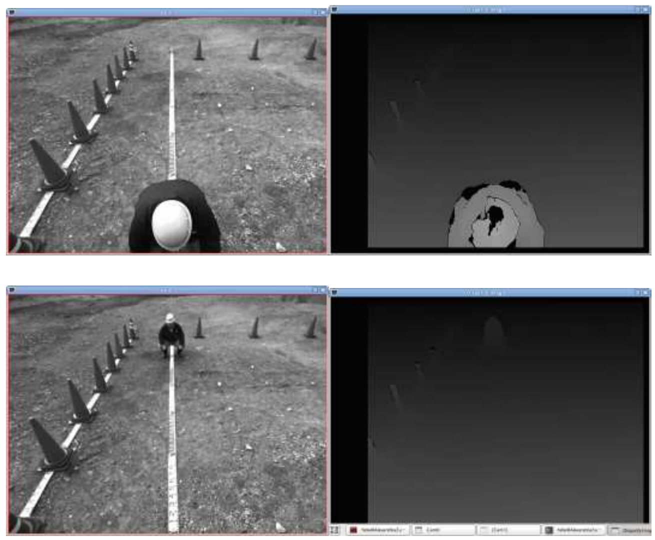

Figure 6 – Excavator: Standing Still, Worker: Squatting Still at a distance of 1m, 6m

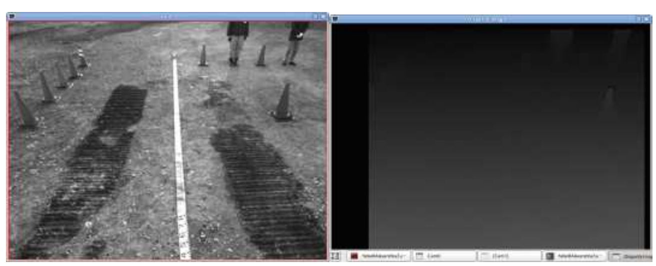

Figure 7 – Excavator: Travelling Backward, Workers: Standing Still at a distance of about 6m and 2m/4m away from the center of the Excavator

Figure 8 – Excavator: Travelling Forward, Worker: Walking Following the Excavator at a distance of 1m

DISCUSSION

The result of the correlation process was generally good. One of the factors is that to calculate correlation of two images was relatively easy because the background condition was the flat gravel where color unevenness has occurred randomly on the surface. This result indicates that the stereo vision system is suitable for the detection of workers in the civil engineering field. In all scenes, the correlation among 1-6m range is calculated successfully. This meets the defined requirements.

It is necessary to consider the effect on the detection performance due to the distance. Relation between the disparity and the distance of the depth direction is represented by the following formula: $d = fT/Z$, where f is the focal length [pixel], T is the camera baseline length [mm], d is the disparity [pixel], Z is distance to depth direction from the camera [mm]. In this experiment, the value of f is about 390, T is about 100. The relation between the disparity d and the depth distance Z is presented in Figure 9.

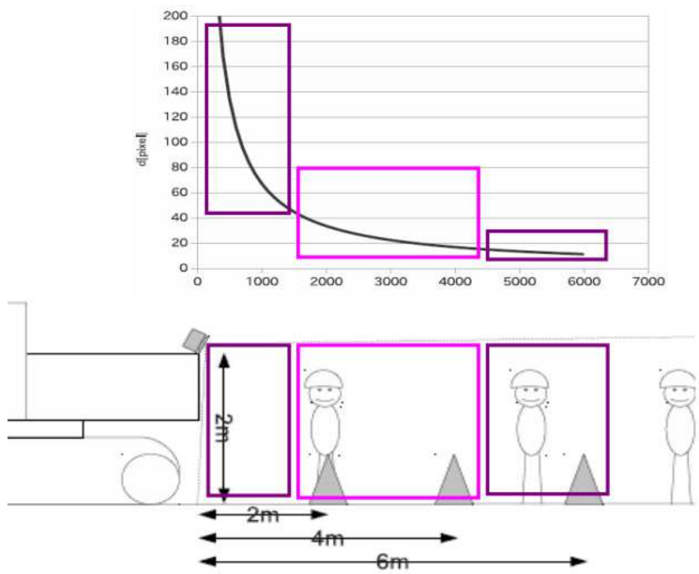

Figure 9 – Relation between Distance Z [mm] – Disparity d [pixel]

In the above case, at the distance of 5-6m, 1pixel of disparity may cause an error of about 500mm in distance. This means that there is a possibility that the distance to the obstacle is measured at a low accuracy depending on the result of the correlation. On the other hand, at 0-1m distance it is possible that the disparity become 60pixel or more. This causes another problem that the correlation may not be obtained by Block Matching in case the obstacle (worker) is too close to the camera (excavator).

Figure 10 shows a comparison of the relationship between distance Z and disparity d, when the baseline T is 100, 200, and 300, and the focal length and image size are same as of this experiment.

In case that the baseline is configured to T=200 or T=300, measurement accuracy at the distance of 5-6m is expected to be improved. However at the same time, it is expected that correlation at the distance of 1-2m will be difficult (i.e., disparity becomes 50pixel or more).

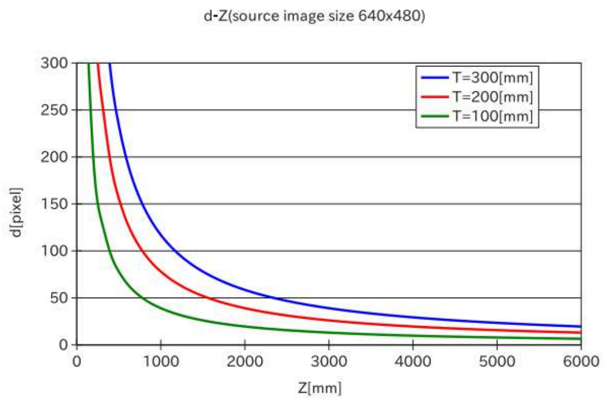

Figure 10 - Relation between Distance *Z* [mm] and Disparity *d* [pixel], (Baseline *T*=100,200,300[mm])

From the above discussion, in order to meet the target detection ranges of this research, it is important to arrange the baseline length of a stereo camera appropriately and to improve the correlation algorithm that can detect objects from close to distant range. Further, at the same time, it is necessary to also consider that too long baseline is inaptitude as for mounting on excavators.

CONCLUSIONS AND FUTURE WORKS

For the purpose of proposal of an obstacle detection method around the working machine using stereo vision, we developed an experimental prototype of stereo vision system, mounted it on a hydraulic excavator, and conducted preliminary experiments in a simulated civil work site environment. As a result, it is proved that stereo vision system have applicability to detect workers around the hydraulic excavator.

In this research, we are aiming at the realization of a system capable of detecting objects stable irrespective of the change in the distance of the obstacle. Therefore, the challenges of the next step are the coordination of appropriate baseline, and an improvement of correlation algorithm.

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REFERENCES

J. W. Hinze, J. Teizer, (2011). *Visibility-related fatalities related to construction equipment*, In Safety Science (49), (pp.709-718).

T. M. Ruff, (2004). *Advances in proximity detection technologies for surface mining equipment*, Proc. of 34th AIMHSR.

J. Teizer, (2010). *Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system, In Automation in Construction* (19), (pp.630-640).

K. Konolige, (1997). *Small vision system. Hardware and Implementa-tion*, In Proc. International Symposium on Robotics Research (pp. 111-116).

C. Eveland, K. Konolige, R. C. Bolles, (1998). *Background Modeling for Segmentation of Video-Rate Stereo Sequences*, In Proceedings IEEE Conf. on Computer Vision and Pattern Recognition, (pp. 266-271).