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Development of a Height Measurement System based on 2D Laser Scan

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***Abstract*— A novel system to measure the height of an object was developed for application to logistics in this paper. 2D laser scanner is employed as a main sensor for the system. A new method based on 2D scan was proposed for that. The system was developed as portable device. And its software was designed for effective measuring task in logistics site. Some experimental results to show the effectiveness of the developed system are also given.**

***Index Terms*—laser scan, height measurement, logistics**

I. Introduction

LASER scanner is a well-known sensing device, which has been increasingly used in recent robotic applications especially [1-6]. Different from conventional sensors such as image and ultrasonic sensor that are generally sensitive to environmental conditions and have relatively large error range, a measuring device using laser ray shows excellent performances in responding speed and accuracy.

In robotics research, laser scanners with both good measuring performance and compact design have been developed and employed for the recognition of object and environmental situation [1, 2]. For example, it has been utilized for the navigation of mobile robot as a basic sensor to make map [3], estimate the position of robot itself [4], and detect moving and static obstacles near the robot for collision avoidance [5]. Nowadays, advanced mapping algorithms to make 3D map using laser scanner with pan-tilt device have been also investigated [6].

On the other hand, logistics as well as industry automation is one of potential areas that the robotics technology could be applied. Therefore, as an application of robotics technique to logistics, this paper investigates a method to utilize the laser scanner as a measuring device to estimate the height of an object to transport.

The paper is organized as follows. The motivation of this work and the fundamental concept of the proposed algorithm are given in Section II. The developed measurement system is explained in Section III. After the discussion about the experimental results in Section VI, conclusion and future work are addressed finally.

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II. Motivation: Height Measurement in Logistics

In the case of transporting a big object by using public road, we have to check the size of whole vehicle including the object loaded on it for safety. It has been known that most countries have specified their traffic laws including the size of a vehicle that can pass through their public road. For example, in Japan, the limitation of the vehicle size passing on the public road has been defined as 3.8 meters in height (4.1 meters in special road), 2.5m in with, 12m in length, respectively. Therefore, before shipping an object from a warehouse or a factory, the whole size of a loaded truck should be measured in the site of logistics. Actually, height is the most important factor than the other dimensions because it is not easy to measure it.

Currently, a measuring rod has been being utilized as a traditional method. However, it has some difficulties in safety because the worker sometimes needs to step on the high place for accurate measurement. Besides, the accuracy is dependent to the measuring conditions such as the shape of target object and personal difference among workers and so on.

An alternative way is to use a laser distance measure. It measures the linear distance from the device and a certain point on a target object reflecting its laser ray, and generally shows very good performance in accuracy. However, when we measure the highest part of an object, it is difficult to check whether the target point is exactly detected or not.

Therefore, a more effective instrument to measure the height of an object is required.

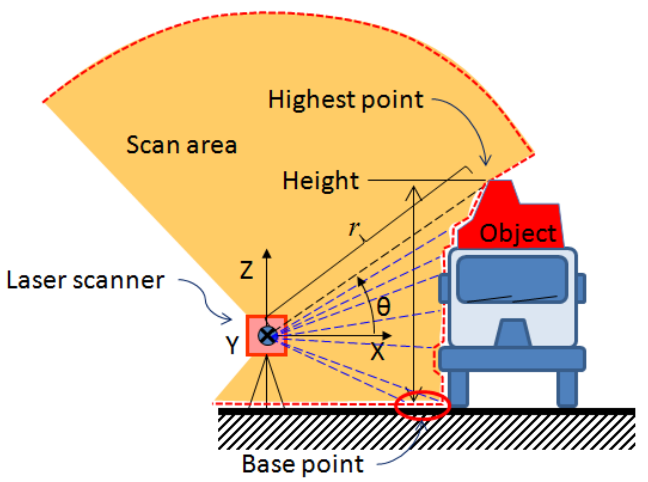

Fig. 1. Conceptual diagram of measuring object's height based on 2D laser scanning

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TABLE I
SPECIFICATION OF LASER SCANNER

Model No.	UTM-30LX
Light source	Semiconductor laser diode (905nm)
Detect range	0.1 to 30m, 270 °
Accuracy	0.1 to 10m: ±30mm, 10 to 30m: 50mm
Angular resolution	0.25°
Scan time	25msec/scan
Interface	USB2.0 (Full Speed)
Power source	12VDC (Max. 1A Current consumption)
Weight	Approx. 370g
Size	60mm x 60mm x 87mm
Manufacturer	Hokuyo Co. (Japan)

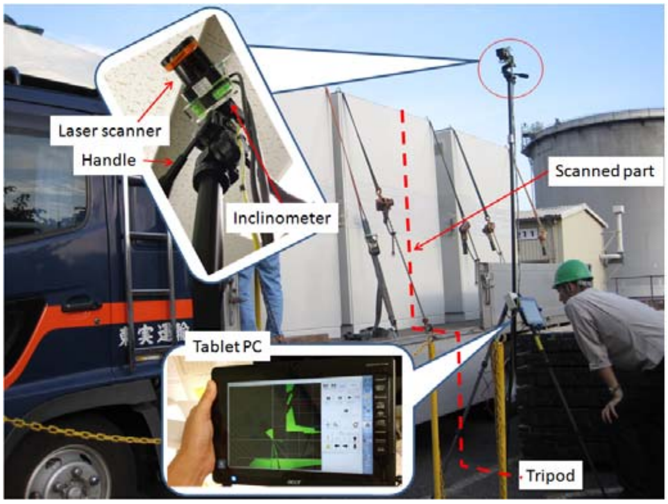

Fig. 2. The measurement system developed in this research

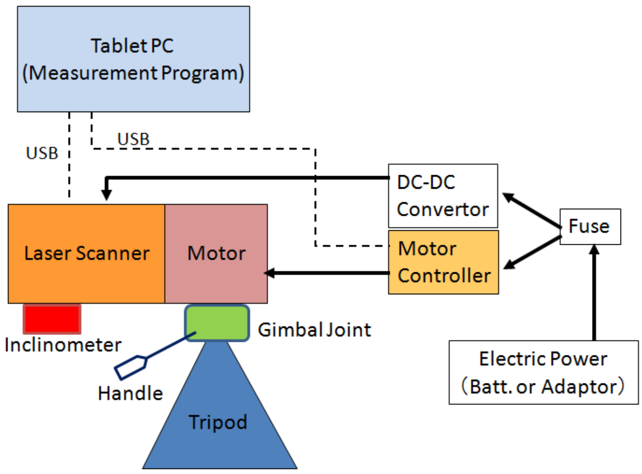

Fig. 3. Block diagram of the measurement system

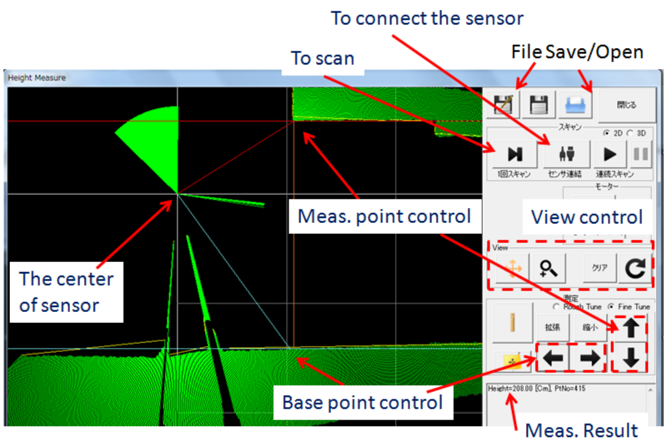

Fig. 4. The software developed for the measurement system

III. Development of the Measurement System

A. Height Measurement based on Planar Laser Scan

Based on the above requirements in logistics site, we have developed a new measurement system based on 2D planar laser scanning. Figure 1 shows the basic concept of the proposed method to measure object's height. When the vertical section including both the highest part of the target object and the base point on the ground is given, the height is computed from the vertical distance between them. In this work, we employed a laser scanner to achieve the planar section of a target object. The geometry of scan section is given as the set of data pairs that include θ_i, the angle of *i-th* laser ray and r_i, the distance from sensor to the object. Where, each scan has *N* number of data pairs, and '*i*' denotes the index of them. So it is transformed to the position information on the rectangular coordinate system according to the following equation.

$$x_i = r_i \cos \theta_i \quad (1)$$

$$z_i = r_i \sin \theta_i \quad (2)$$

The specifications of the laser scanner used in the system are given in Table 1.

B. Configuration of the Height Measurement System

Figure 2 shows an example of measuring task with the measurement system developed in this research. The block diagram of the system is given in Fig. 3. It consists of a 2D laser scanner, a tripod to support whole system, an extension bar to make the sensor higher, a 2-DOF gimbal joint with handle to adjust the pose of the scanner, an inclinometer to check the tilt angle of the scanner, a Tablet PC as a main computer to interface with the scanner and manipulate the data, a power electric module with battery and adaptor. And a motor and a controller are also installed for 3D scanning in future tasks.

As conditions for correct measurement, firstly, we have to check whether the target point was detected or not. So we utilize a special device to check whether the target point was detected correctly or not. The device indicates with its LED lamp while it is detected by laser scan. It can be also confirmed through the geometry of the scanned section. Secondly, the scan plane should be vertical. The inclinometer and the gimbal joint with handle to adjust the pose angle of the sensor were employed for that.

C. Development of Measurement Software

For effective measuring tasks, we developed a software program to control the system and manipulate its sensing data. We used Visual C++ language and Windows 7 operating system as development environment. The main window with an example of scanned data is given in Fig. 4. The geometry of the scanned section is displayed in the left part of the program. It can be enlarged or reduced by simple operation of arrow icons in the touch screen. And the viewpoint also can be moved by manipulating the view control icons in the right part of the program. The target point to measure and the base point can be selected easily by user's operation. The measurement result is computed according to each selection of both points immediately. The scanned data can be saved

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and possible to be opened again for the future off-line replay or analysis.

For easy indicating both target and base points, we prepared the function for rough movement of the points of interest. Most target and base points for height measurement exist near a corner or an edge of the scanned section in general. For that the scan data is divided to certain elements by an algorithm of line extraction [7, 8].

D. *Procedure of Measurement Task*

The procedure to measure the height of an object with the developed system is as follows. Firstly, after setting up the tripod and the laser scanner, the main power is supplied by turning on the switch. Secondly, the direction of the laser scanner needs to be tuned roughly so that the target point is detected. Here, the laser ray detector is used as shown in Fig. 5 (b). Third step is to adjust the scanner so that its scan plane becomes vertical. We operate the two angles of gimbal joint with handles according to the level of the inclinometer which is attached to the laser scanner. The main task to achieve the scan data is followed as forth step. It includes several operations of manipulating Tablet PC with touch screen such as connecting the sensor to the program, taking data by scanning the object, selecting the target and base point, saving the scan data, and so on. Then, the result of measurement is given according to the selection of target and base point immediately. The whole procedures are so simple and plain thus they can be completed in a couple of minutes.

IV. Experiments

Experiments to investigate the effectiveness of the proposed method and the usefulness of the developed system were carried out. The results are discussed in this section.

A. *Case 1*

In the first experiment, we investigated the influence of the positional relation between the measuring part of an object and the sensor on the measurement error. The outer wall of a building including the entrance and the window on the 2^{nd} floor was employed as the subject for measuring experiment as shown in Fig. 5. The scanned part detected by the sensor is displayed with the red dashed line. An example of the measurement result is shown in Fig. 6, which displays the geometry of the section scanned by the sensor system.

Five representative points were measured by the sensor and a typical tapeline, which were compared with each other. The experiment had been performed for the 13 cases of sensor positions being different in height and distance. The resultant data was given in Table II. It can be seen that the overall error of the three points P1, P3 and P5 whose planes are horizontal is relatively smaller than that of the other two points P2 and P4 whose planes are vertical.

B. *Case 2*

In the second experiment with the developed system, we have measured the height of storehouse in the campus of Ehime University. Figure 7 (a) and (b) show the scene of the measuring tasks. Figure 8 (a) and (b) show the resultant data achieved by scanning with the system. In this case, the height of the object is the distance between the ground and the highest part that stuck out from the roof of the storehouse.

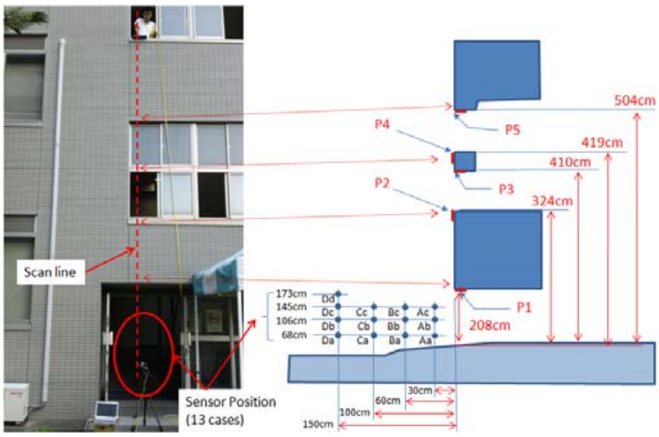


Fig. 5. The measurement experiment: case 1

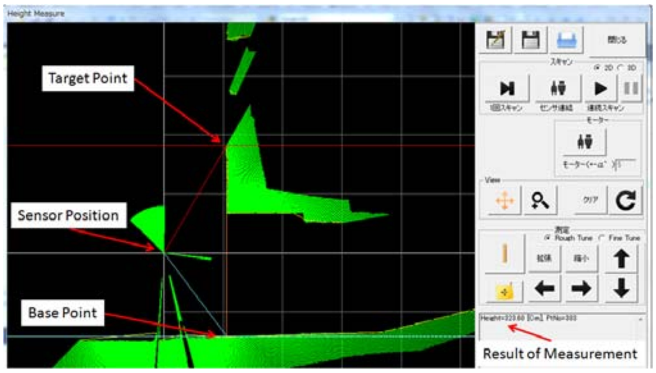
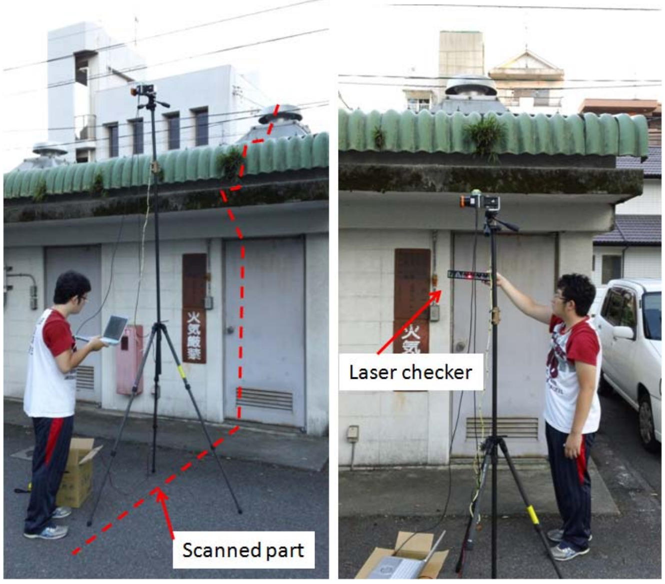


Fig. 6. An example of measurement results of case 1

TABLE II
MEASUREMENT RESULTS OF CASE 1

Sensor Position	P1	P2	P3	P4	P5
Aa	209.1	318.5	405.2	413.3	502.4
Ab	208.6	308.6	410.2	424.0	500.7
Ac	208.9	313.9	410.9	416.7	501.3
Ba	208.8	316.7	410.3	412.4	501.6
Bb	208.5	318.2	409.8	414.4	501.0
Bc	208.4	322.0	409.4	413.6	501.7
Ca	208.1	324.8	409.9	411.7	501.0
Cb	208.2	322.8	410.7	415.3	501.0
Cc	208.3	323.0	409.2	416.6	500.8
Da	208.2	322.3	410.1	414.4	501.0
Db	208.3	325.6	408.9	412.2	500.8
Dc	208.3	323.0	409.2	416.6	500.8
Dd	208.4	328.2	410.3	417.8	501.0
Measurement with Tapeline	*208.5*	*324.0*	*410.0*	*419.0*	*502.0*



(a) The isometric view (b) The front view
Fig. 7. The measurement experiment: case 2

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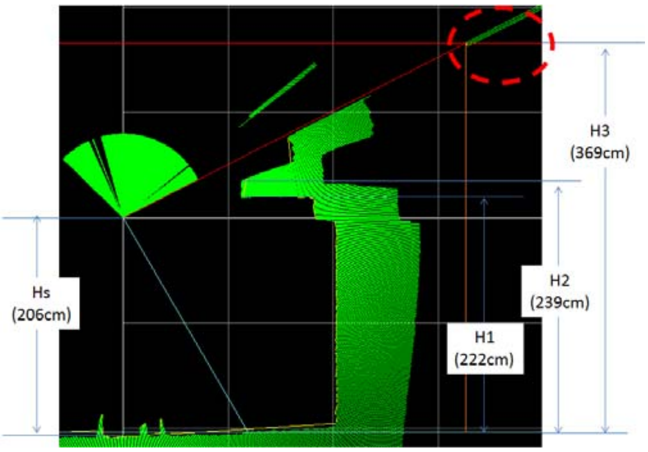
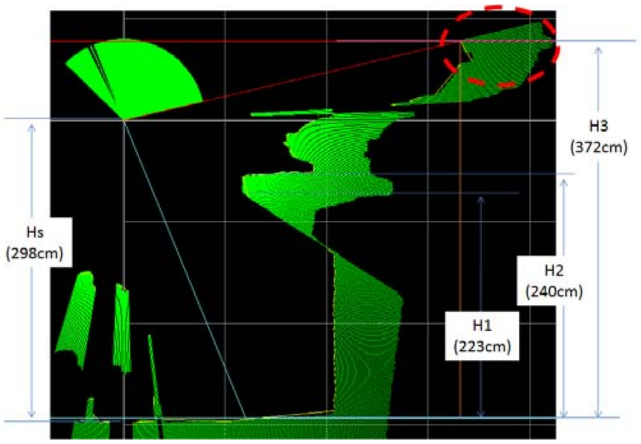
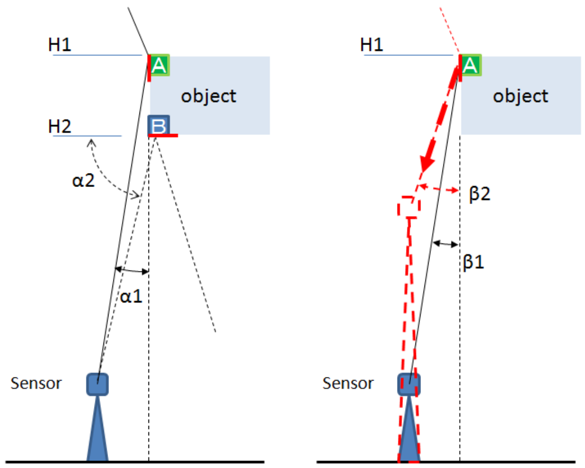
The relationship between the height of sensor and the measuring performance has been investigated here. For that, two times of scanning at the different sensor heights were carried out. Figure 8 (a) and (b) are the scan data when the sensor's heights are 206cm and 298cm, respectively. In the case when the sensor is lower position, the target point indicated with dashed line in Fig. 8 (a) is not detected well. On the other hand, when the sensor is located in the higher position as shown in Fig. 8 (b), the geometry of the targeting part could be achieved more completely. It can be known that the height of the target point is estimated in the case when the sensor's position is high.



(a) First measurement when the height of the sensor is 206cm.



(b) Second measurement when the height of the sensor is 298cm.
Fig. 8. The experimental results of case 2



(a) The direction of object's surface (b) The change of sensor height
Fig. 9 The influence of the relationship between the sensor position and the condition of object's surface on the reflection angle of the laser ray

C. Consideration of Measurement Error

From the experiments, it had been known that the performance of measurement especially related to error is dependent to the reflecting condition of the laser ray on the object's surface. It is very sensitive to the angle between the object's surface and the laser ray. It was shown that the error is small when the direction of laser ray is near vertical to the object's surface. It is like as the case that the horizontal surface of 'B' in Fig. 9 (a) is detected by the sensor, where the angle is denoted by 'α_2.' Reversely, when the vertical surface 'A' in Fig. 9 (a) is detected and the angle 'α_1' is small, the system showed worse performance in general. To cope with the weak point, we have employed the extension bar to achieve the higher sensor position. Figure 9 (b) shows the effect of higher sensor position on the reflection angle between the surface and the laser ray. It can be known that the higher sensor get the bigger angle. Besides, the sensor is located at the higher position, the better and more complete geometry of the scan section can be achieved as shown in the experiment 'case 2,' which is also related to the measurement performance.

V. Conclusions and Future Work

For a logistics application, a system to measure the height of an object has been developed. For that, laser scan technology has been applied. Besides, software for its efficient management was also developed. Through several experiments, some optimal conditions for more correct measurement have been investigated. It has been known that the developed system with the proposed method shows more efficient performance and convenience in the real task than the traditional one. For more advanced measurement, a method based on 3D scan will be carried out as a future work.

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