Visual Information Assist System Using 3D SOKUIKI Sensor for Blind People

– System Concept and Object Detecting Experiments –

Tatsuro UEDA[1], Hirohiko KAWATA[1], Tetsuo TOMIZAWA[2],
Akihisa OHYA[1] and Shin'ich YUTA[1]

[1]Inteligent Robot Laboratory, University of Tsukuba
{t_ueda,kwt,ohya,yuta}@roboken.esys.tsukuba.ac.jp
http://www.roboken.esys.tsukuba.ac.jp
[2]National Institute of Advanced Industrial Science and Technology (AIST)
t.tomizawa@aist.go.jp

Abstract— **The purpose of this research is to develop a system which gives blind people information of the environment around them. A person is equipped with a 3D scanner and a small sized PC while walking. The scanner scans and acquires 3D range data map of the environment. The PC analizes the range data map and detects objects which are useful for blind people in orde to walk. The PC gives environmental information to them by synthesized sound. This paper first introduces the concept of the whole system and clarify the tasks for realizing the system. Secondly the method for acquisition of 3D range data and detecting objects and obstacles are described. Then the usefulness of our proposed system is examined by an experiment in which our trial system detects bumps and trenches in the experimental environment.**

I. Introduction

In recent years accessibility of everyday-life environments for disabled and aged people attracts public interest. Actually there are a lot of improvements for it, such as textured paving blocks, slopes instead of steps, handrails, elevators, etc. The movement of universal design proposed by Ronald L. Mace has been more and more prosperous. However, these improvements are limited to specific places and it is still hard for the disabled to live in most of places at present. Especially for blind people who have no visual information, there are a lot of dangers in everyday-life environments. These people have a lot of difficulties to acquire environemental information. Moreover, obstacles which are not dangerous to ordinary people are able to become dangerous to them. Though they use blind stick to acquire these information, it is still hard for them to walk around in most of the places.

A lot of studies have been done to develop a system which assists blind people and these studies are roughly classified into two groups. In one group, a blind person walks with a guide robot and the robot guides him to a destination avoiding obstacles [1], [2]. However these guide robots limit the person's field of activities, because the robots have difficulty in walking on a crowded street or going through irregular ground. Another approach is to develop an intelligent blind stick which has sensors to help finding objects [3]. With this kind of blind stick, a blind person is able to find objects even if the stick does not touch them. The weak point of these intelligent sticks is that they can not cover the whole environment around the person.

On the basis of these problems above, we propose a visual information assist system using a 3D scanner. In this system, a blind person is equipped with a 3D scanner and a small sized PC. While walking, the 3D scanner scans the environment in front of the user and then the PC analyzes environmental data to acquire these information. The PC tells the information of environment to the person by synthesized sound. Using this system, blind people will be able to obtain visual information of the environment around them by sound.

This paper first describes the concept of the whole system (section II). Secondly, the method for constructing 3D range data map and detecting objects are described (section III, IV). Potential usefulness of our proposed system is examined by an experiment in which proposed system which is experimentally implemented is fastened to the environment, constructs environmental data map and detect obstacles (section V, VI).

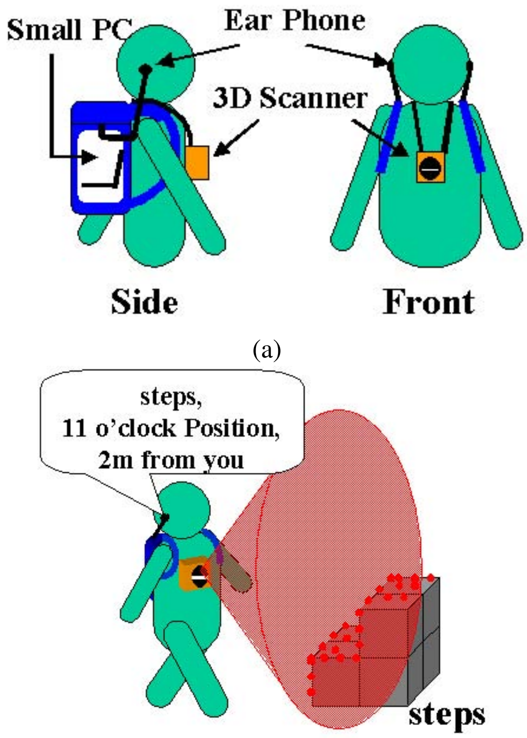
II. Concept of the System

Images of the concept of our proposed system are shown in Fig.1 (a) and (b). As shown in Fig. 1 (a), a person is equipped with a 3D scanner on his chest and has a small sized PC in his bag. The scanner and the PC are connected to each other. The scanner scans the environment in front of the person and then the PC analyzes the 3D range data continuously. In data analyzing, the PC first constructs 3D environmental map and then detects objects and obstacles which seem to be useful to the blind person, such as steps, doors, walls, bumps etc. As soon as any objects or obstacles are found, the PC tells the user these information by synthesized sound (see Fig.1 (b)). The system gives them the relative position, configuration and the name of the objects or obstacles so that they can easily recognize what and where it is located in the environment.

Considering that a human generally walks 1m in a second and that it takes some time to give these kind of information by sound, the maximum scanning range of the 3D scanner should be 5m at least, otherwise, the PC might tell him information of objects or obstacles, after they have passed these objects or collided with these obstacles. The function of the system is roughly classified into two parts shown below.

1. Acquisition of 3D environmental data.
2. Detecting objects and obstacles from the 3D environmental data.

The basic methods for these two subfunctions are described in the next two sections.



(a)

(b)

Fig. 1. Concept of the system : (a) A person equipped with a 3D scanner and a PC, (b) A person walking with the system

III. Acquisition of 3D Environmental Data

This section describes the method for acquisition of 3D environmental data.

A. Consideration of the Sensor

As it is described in the previous section, the information which is given to a blind person is position, configuration, names of objects and obstacles. To get such information, range data of the environment is important. In acquisition of 3D environmental data, cameras and laser range finders are commonly used. Using cameras for getting 3D information has some advantages. There is a lot of information in a camera image and it requires little time to be taken. However camera images are affected by light condition and also it has difficulty to capture 3D configuration data of the environment, so it is not appropriate for our system. On the other hand, laser range finders can get accurate range data and it is not affected by light condition. Therefore we use laser range finder for our 3D scanner.

A SOKUIKI sensor URG-04LX[4], which is a super small sized 2D Laser Range Finder (LRF) made by HOKUYO AUTOMATIC, is the most compact commercial LRF. Fig.2 shows the appearance of the sensor and tableI shows the main specifications of it. This LRF is light, compact and accurate, so it does not place any significant burden on the person equipped with the scanner. We use this LRF for our 3D scanner.

Fig. 2. SOKUIKI sensor URG-04LX

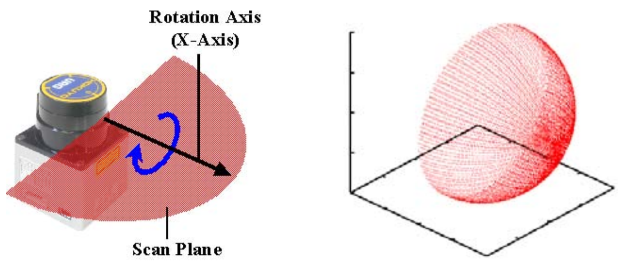
Detectable distance	0.02 to 4[m]
Accuracy	0.02 to 1[m]:±10[mm] 1 to 4[m]: ±1% of distance
Resolution	1[mm]
Scanning angle	240[degrees]
Angle resolution	Apporox. 0.36[degrees]
Scanning time	100[ms]
Weight	Apporox. 160[g]
External dimension	50×50×70[mm]

TABLE I

Specification of URG-04LX

B. Method for Acquisition of Data Set for 3D Range Data map

A 2D LRF measures only 2D range data. Changing sensor's posture is a common technique to make 3D scanning feasible. There are different ways to change its posture[6]. Our rotating method, shown in Fig.3(a), has horizontal scan plane and rotates its plane around x-axis. With this method, measurement points focuses on x-axis (see Fig.3(b)). To represent 2D range data in Cartesian coordinates, the position and posture of 2D LRF is needed. The angle of the sensor is determined by counting pulses from motor encoder which rotates the sensor.



(a) (b)

Fig. 3. Scanning Method : (a) Rotating Method, (b) Measurement Density Distribution

As shown in tableI, it takes 100ms for the sensor to make a 2D plane scan. It means that acquisition of enough 3D range data for recognizing environment takes some seconds. The 3D scanner is attached to a blind person's body, so the scanner changes its position and posture dynamically, the position and posture of the scanner also needs to be estimated for constructing 3D range data map. We use an inertial measurement unit (IMU), which consists of three gyroscopes and three accelerometer, for estimation of scanner's position and posture. 3D range data map is calculated using LRF sensor, angle estimation module and gyroscopes and acceleration sensors as shown in Fig.4.

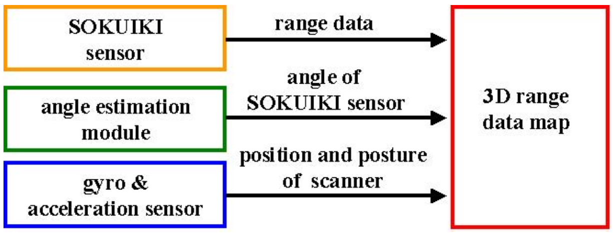


Fig. 4. Structure of the 3D scanner

C. Timing Consistency

As it was described already that the position and posture of the scanner and the rotating angle of the sensor at the moment when each measurement point is measured, is needed to construct 3D range data map. However, these devices are not synchronized with each other, which makes it difficult to capture the position, the posture and the angle. The SOKUIKI sensor URG-04LX transmits a synchronous signal right after it finishes scanning. Also the range data of the sensor has accurate time stamp. We have already developped the method to consistent data of the SOKUIKI sensor and other data [9]. Synchronous signals consistent range data and angles of the sensor and time stamps do range data and position and posture of the scanner.

IV. Recognition of Environmental Information

This section describes preparation of 3D range data map and the method for detecting objects and obstacles. A 3D range data is constructed and divided by voxels. Then objects and obstacles are detected by using template matching algorithm.

A. Preparation of 3D Range Data Map

Environment object information, especially information of obstacles, should be informed to the person as soon as possible. For this reason, 3D range data map should be constructed each time the LRF scans the environment. The purpose of our reaserch is to give the information of the environment around a blind person, so the map does not need to include all the range data which has been scanned. When the range data scanned in α seconds are enough to construct 3D range data map, the latest range data scanned in α second are used to construct the map after every scan finishes (Fig.5).

Though the range data map is constructed with millimeter accuracy, we can not recognize millimeter difference. Therefore 3D range data map is divided by voxels of 50×50×50[mm]. The size of each voxel is determined on the basis of the accuracy of the LRF. The voxels have only a single volume. If a measurement point is included in a voxel, that voxel has volume.

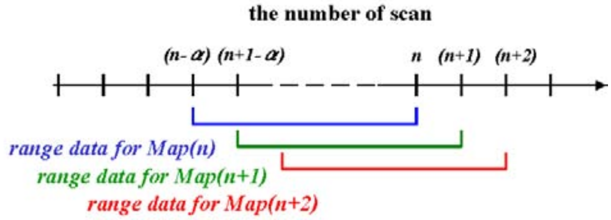


Fig. 5. SOKUIKI sensor URG-04LX

B. Detecting Method

We use 3D template matching algorithm to detect objects and obstacles. Firstly templates of the objects and obstacles, such as steps, doors, a bump etc. are prepared beforehand. When the voxel map is constructed, the map is scanned by each template. If the correlation between a template and an area of the map is lower than threshold, an object locates in this area. The correlation $C(u,v,w)$ is evaluated by the equation shown below in the standard 3D template matching algorithm.

$$C(u,v,w) = \sum_{z=0}^{d}\sum_{y=0}^{h}\sum_{x=0}^{w} |T(x,y,z) - M(u+x, v+y, w+z)| \quad (1)$$

Variables u, v and w are represent a position of a voxel in the map and x, y, z represent that of the template. Constant numbers d, h and w each represents depth, height and width of a template.

The problem of 3D template matching algorithm is the cost of processing. In 3D space, objects have 6 degrees of freedom, 3 for its position and the others for its posture. The equation shown above covers only position. It means that we prepare a number of templates for all postures and the calculation processes for each template. Though objects have 6 degrees of freedom, each object has different constraints. For example, the door is attached to the wall and vertical to the ground. The steps are along walls and on the ground. These constraint conditions decrease the cost of processing drastically. Specific method for detecting objects and obstacles depend on them.

V. Experimental Implementation

This section describes an experimental implementation which is setup in order to examine potential effectiveness of our proposed system. As it was stated in introduction, the usage of this experimental system is to be fastened in the environment and detect bumps and trenches which are common obstacles for blind people

A. Rotating Device and Angle Estimation Module

A rotating device is shown in Fig.6(a). A DC motor manufactured by Maxon Motor rotates the sensor. A slip ring manufactured by TSUBAME Radio Co.,Ltd is attached to the rotating shaft and all the cables from the sensor are through it so that the sensor rotates unlimitedly (see Fig.6(b)). Note that the maximum rotating velocity of the slip ring is 60 rpm. The angle of the sensor is estimated by an angle estimation module which we have developed in our previous research. The module estimates the angle of the sensor every 5 ms by counting pulses from the motor encoder. The module also receives synchronous signals from the sensor and put a time stamp to the angle data. This time stamp makes consistent of range data and angle data possible.


(a) (b)

Fig. 6. Rotating device : (a) overall view, (b) slip ring

B. *Rotating Velocity*

In constructional 3D scanning methods with a SOKUIKI sensor, the scan plane of the sensor is usually rotated slowly at 10 rpm or less. The increase of the measurement points with this method is shown in Fig.7(a) and the view from x-axis is shown in Fig.7(b). The numbers in Fig.7(b) represent the order of scanning. We see it from Fig.7 that the measurement points increase in two directions. However the 3D range data map has two big holes which have no measurement point until the sensor rotates 180 degree. The scanner cannot detect objects and obstacles in these holes and human might bump against it.

To solve this problem, we rotate the sensor fast, around 30 rpm. Fig.8(a) and (b) show the increase of the measurement points. If we see Fig.8 we will see that the measurement points increase from many directions. This rotating method disperses holes in the range map. When rotating the sensor fast, it should be noted that the sensor scans at a same angles after certain period of time, depending on rotation velocity. The rotation velocity should be determined carefully.

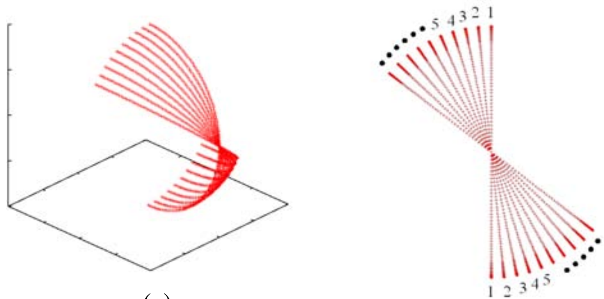

(a) (b)

Fig. 7. Change of measurement points with the sensor rotating slowly : (a) Bird view, (b) View from x-axis

C. *Templates for Detecting Bumps and Trenches*

The purpose of the experimental system is to detect bumps and trenches around a person. Fig.9 and Fig.10 each shows a template for a bump and parts of template for trenches. The template for bumps consists of 3 voxels which are attached to each other vertically. The detecting area for bumps are above the ground. 8 templates which are combination of a voxel with volume and 2 voxels without voxels are used for detecting edges

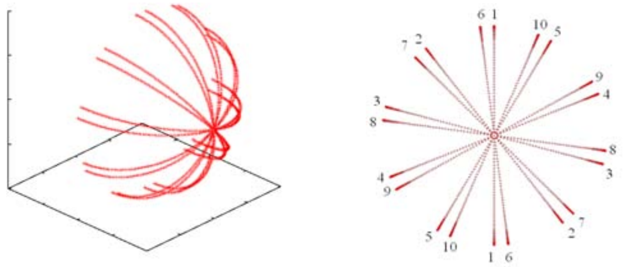

(a) (b)

Fig. 8. Change of measurement points with the sensor rotating fast: (a) Bird view, (b) View from x-axis

of trenches. Fig.10 shows only 4 templates. The point symmetries of these are the others. Detecting area of trenches are on the ground.

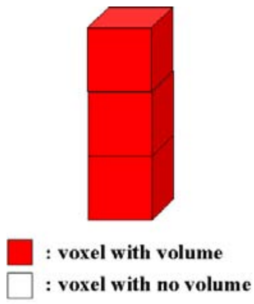


Fig. 9. Template for detecting bumps

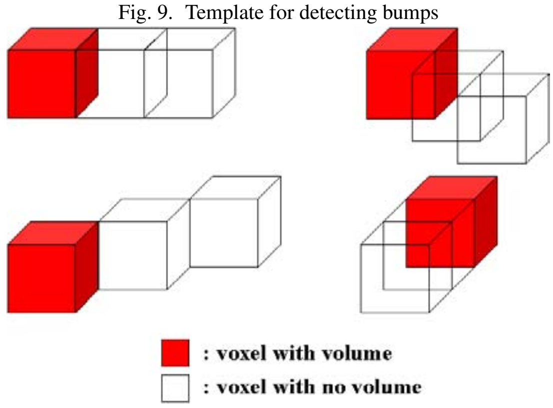


Fig. 10. Parts of templates for detecting trenches

VI. SCANNING AND DETECTING EXPERIMENT

An experiment is performed to evaluate potential of our proposed system. The environment for the experiment is shown in Fig.11(a). The 3D SOKUIKI sensor is fastened in the environment at a height of 1150 mm and scans environment. The velocity of rotation is 30.21 rpm. Fig.11(a), (b) and (c) show 3D range data map scanned in 2s, in 5s and in 10s. Measurement points which are higher than 2 m are not displayed to facilitate clear view of the data map. Fig.11(b), (c) and (d) shows that the measurement points increases relatively uniformly. Though the sensor rotates fairly fast, the scanning results are accurate.

Fig.12 shows detecting results. The green points in Fig.12 (a) represents bumps in the environment. We see from Fig.12 (a) that a lot of green points are found along the walls, in front of steps and in the middle of steps. The blue points in Fig.12

(b) which is viewed from the top show edges of trenches. The results show that the experimental system is able to detect bumps and trenches.

VII. Conclusion

In this paper, we proposed and described a visual assist system for blind people. The system which is implemented experimentally showed the effectiveness in constructing 3D range data map and detecting obstacles in the experiments. The experimental system cannot estimate its own position and posture at present. An IMU is going to be implemented for calculating its position and posture. The experiment showed that bumps and trenches were localized and recognized. The next step on this research is to detect walls, stairs and many other objects which are found in common environment.

VIII. Acknowledgement

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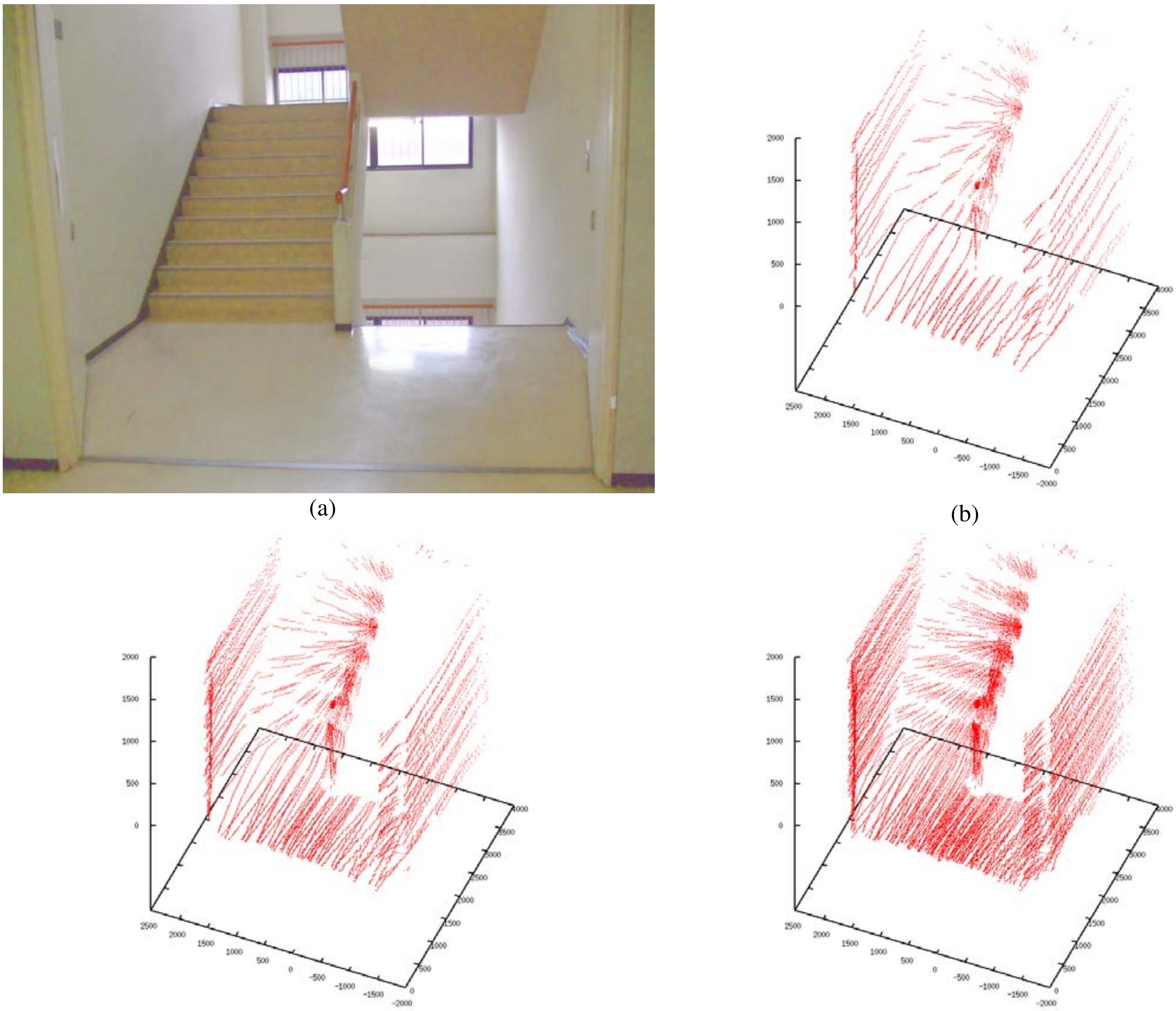
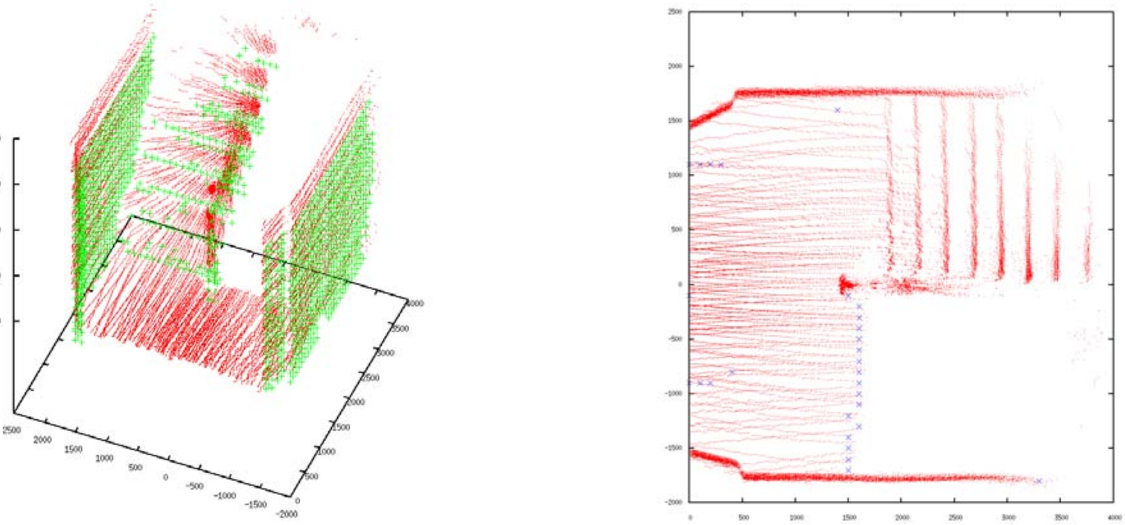


(a) (b) (c) (d)

Fig. 11. 3D range data map : (a) Experimental environment, (b) Scanning in 2 sec, (c) Scanning in 5 sec, (d) Scanning in 10 sec



(a) (b)

Fig. 12. Detecting obstacles : (a) Result of detecting bumps, (b) Result of detecting trenches