3D Scanning Map Building for Mobile Robot Navigation

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ABSTRACT

In our daily life, we dump the waste everyday. The waste is transported to the landfill after processing. Over long time, when the wastes mix with water, the bacteria breaks down and release out harmful gas from underground. We have to collect gas information periodically for long term until production of the gas is almost terminated. Therefore there are requirements to develop a mobile robot to monitor the activity of microbial process. In this paper, we mainly elaborate development of 3D scanning device to build 3D map in landfill to be applied to the robot navigation.

Keywords: 3D mapping, mobile robot, LIDAR sensor, mathematic transformation

INTRODUCTION

In daily activity at private homes, business and industry we produce waste everyday. These wastes are sent to a municipal sanitary landfill. Over time, the bacteria in the soils will break down the organic wastes in the landfill. The by-products, such as gases, are produced of these bacteria breaking down the garbage.

Landfill gases are typically made up different types of gases. These gases have a potential health hazard on inflammability. We have to know the gas information based on periodic monitoring. Fig.1 shows scenery of a landfill by depth of around 30 meters, the gases produced under the ground escape through the pipes to the air. To monitor the gas information sensors are inserted from the opening at the side of pipe (Fig.1). This research is to investigate the gas information using the robot navigation. Robot has to known the environment information in navigation. This paper mainly elaborates 3D mapping methods using LIDAR (light detection and ranging) sensor.

In recent years, there are lots of researches on the 3D map building. These improvements of research can be used to obtain and process the better robot environment information in the field of mobile robotics (Weingarten et al., 2003; Schroter and Beetz, 2004; Kuo and Cheng, 2007). By now, methods for achieving tasks such as localization (Thrun et al., 2201), navigation (Tsalatsanis et al., 2006) or automatic map building (Mariottini and Prattichizzo 2008), were restricted to the environment investigation robot. Several established motion planning and obstacle avoidance techniques are formulated in planar domains, and frequently rely exclusively on two-dimensional sensory input (Thrun et. at., 2000; Guivant and Nebot, 2001), but in the outsides that contain many objects which cannot be appropriately sensed and represented to difficulties in environment robot obstacles (Jensen et. al., 2003; Wulf and Wagner, 2003; Ueda et. al., 2006.

Figure 1. Robot moves in a landfill.

SYSTEM COMPOSITION OF ROBOT

In the Fig.2, ATV has a good performance in bad environment, we choose SUZUKI Vision Automatic 500 4×4 ATV as the body of robot.

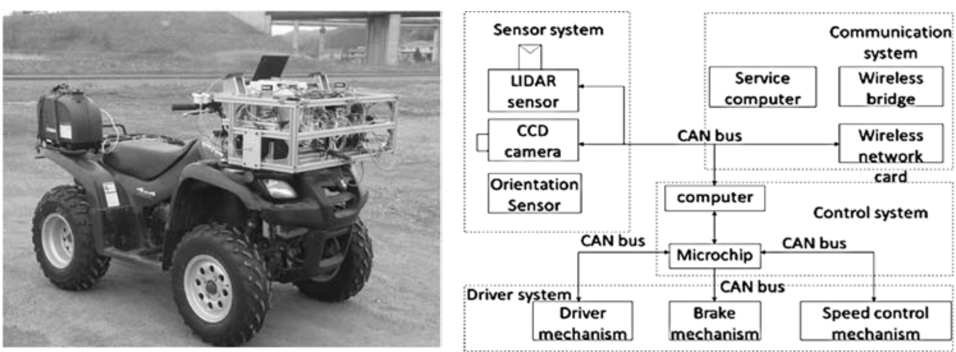

Figure 2. The overall structure of robot and system composition.

In the Fig.2, the robot system includes four parts, control system, sensor system, driving system and communication system. The control system consists of computer and microchip. The sensor system consists of LIDAR sensor, CCD camera, and orientation sensor. The driving system consists of steering mechanism, brake mechanism, and speed control mechanism. In this paper, we introduced the LIDAR sensor, CCD camera and orientation sensor to building 3D map.

THE 3D SCANNING DEVICE DESIGN

The idea of 3D scanning

Compare to 2D map that 3D map can provide direct geometric information of the environment. The environment investigation robot navigation in the outside, the LIDAR sensor has better performance than camera measurement system in high precision and without influence of light. An obvious optimization of the measurement system to take the scanning method most suitable for the application.

The LIDAR sensor can scan a planar domain. If the sensor rotates, we can scan 3D space. According to this method we can build 3D map. In the Fig.4, we use a step motor to drive the sensor rotation x2 is the rotational axis, this method can scan the 3D space in the front of robot. The right picture expresses the scan area and limit planes of scanning plane. The number 1, 2, 3…n is the scan plane.

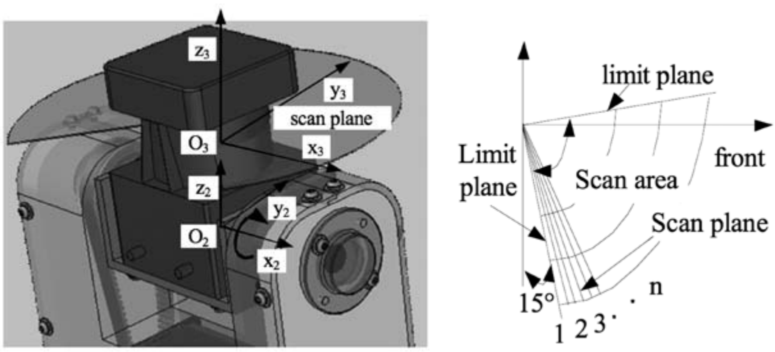

Figure 3. Rotational axis in the 2D scanning plane.

3D scanning device

When the robot moves in the landfill, it has to identify the obstacles and goals. We set the rotation sensor that can be rotated by 90 degrees range.

Fig.4 is the overall 3D scanning device structure. The device is drive by the step motor, and synchronous belt drives the LIDAR sensor by reciprocating rotation. The device is equipped with two mechanical limit switches. When the bar touches the limit switch, then the LIDAR sensor will change direction at the moment, in order to protect the limit switches. The addition of two stop bars prevents excessive rotation force.

The relation of step motor and LIDAR sensor

The scanning speed of UTM-30LX LIDAR sensor is 25ms. For example, if a 3D space includes 180 planes, it has to spend 4.5s. If 3D spaces have 90 planes, it will spent 2.25s. We assumed the rotate speed of step motor is N (rpm). We can conclude the relation of 2D scanning frequency s(x) with step motor rotate speed N as:

$s(N) = \frac{60}{N} \frac{1}{25\times10^{-3}}$, when N=60[rpm], the s(60)=40. We accord the parameter N to choose the step motor and setting the rotate speed.

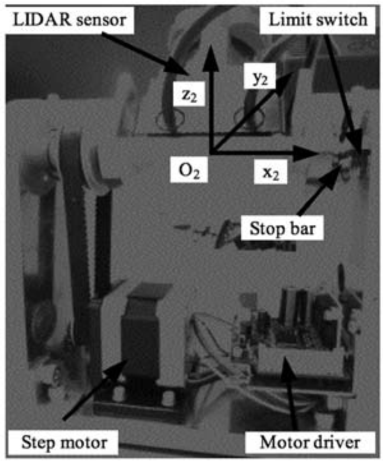

Figure 4. 3D laser scanning device.

SCANNING DATA COORDINATE SYSTEM TRANSFORMATION

Coordinate transformations include four steps:

Building coordinate system

In the Fig.5, O_0-$x_0y_0z_0$ is the world coordinates system. O_1-$x_1y_1z_1$ is ATV'S coordinate system, O_1 is located at the center of two rear wheels, x_1 is aligned to the right direction of robot, and y_1 is the front direction of robot. O_2-$x_2y_2z_2$ is 3D scanning device coordinate system, O_2 is the rotational center of LIDAR sensor, as shown in Fig.4. O_3-$x_3y_3z_3$ is LIDAR sensor coordinate system, O_3 is the laser point of LIDAR sensor, and the distance of O_2O_3 is L cm, as shown in Fig.5. 'P' is the scanning point, and O_3APH is LIDAR sensor scanning plane.

Scanned point expressed in LIDAR sensor coordinate system O_3-$x_3y_3z_3$

In the scanning plane O_3APH, $\rho_{m,n}$ is the distance of O_3P, $\lambda_{m,n}$ is the angle of AO_3P. $\rho_{m,n}$, and $\lambda_{m,n}$ can be obtained from the scanning data of LIDAR sensor.

We can express the point 'P' in the coordinate system O_3-$x_3y_3z_3$. The equation is shown as (4-1).

$$u\big|_{o_3} = \begin{pmatrix} x_3 \\ y_3 \\ z_3 \\ 1 \end{pmatrix} = \begin{pmatrix} \rho_{m,n} \cos\lambda_{m,n} \\ \rho_{m,n} \sin\lambda_{m,n} \\ 0 \\ 1 \end{pmatrix} \tag{4-1}$$

$O_0 - x_0y_0z_0$: world coordinate system

$O_1 - x_1y_1z_1$: ATV'S coordinate system

$O_2 - x_2y_2z_2$: 3D scanning coordinate system

$O_3 - x_3y_3z_3$: LIDAR sensor coordinate system

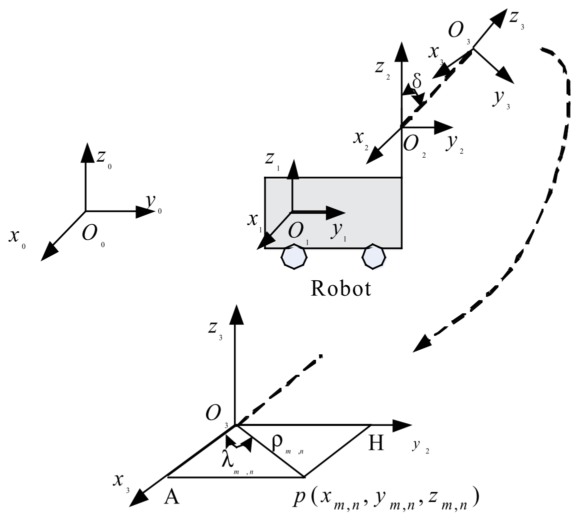

Figure 5. Coordinate system transformation.

Transformation matrix derivation

Transformation matrix derivations include three parts:

(1). Transformation matrix from O_3-$x_3y_3z_3$ to O_2-$x_2y_2z_2$.

The matrix not only includes translational transformation, but also rotation. It can be expressed as following equation:

$$^{o_2}_{o_3}T = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\delta & \sin\delta & L\sin\delta \\ 0 & -\sin\delta & \cos\delta & L\cos\delta \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{4-2}$$

(2). Transformation matrix from O_2-$x_2y_2z_2$ to O_1-$x_1y_1z_1$. This matrix only includes translational transformation and x-axis direction does not change.

So the matrix can be expressed as following equation (4-3):

$$ {}^{o_1}_{o_2}T = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & R_y \\ 0 & 0 & 1 & R_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{4-3} $$

(3). Transformation matrix from O_1-$x_1y_1z_1$ to O_0-$x_0y_0z_0$.

The matrix includes translational transformation and rotation transformation. Because the ground is not always flat when the robot moving, we use the orientation sensor (3DM-GX2 Micro Strain) to detect the angles in three coordinate axes direction.

$x_{m,n}$, $y_{m,n}$, and $z_{m,n}$ are robot relative locations to O_0-$x_0y_0z_0$ coordinate system. The transformation ${}^{o_0}_{o_1}T$ is calculated from multiplication of the translation and rotation matices matrix.

$$ {}^{o_0}_{o_1}T = Trans(x_{m,n}, y_{m,n}, z_{m,n})Rot(z,\theta_{m,n})Rot(y,\alpha_{m,n})Rot(x,\phi_{m,n}) $$

$$ = \begin{pmatrix} 1 & 0 & 0 & x_{m,n} \\ 0 & 1 & 0 & y_{m,n} \\ 0 & 0 & 1 & z_{m,n} \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{m,n} & \sin\theta_{m,n} & 0 & 0 \\ -\sin\theta_{m,n} & \cos\theta_{m,n} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\alpha_{m,n} & 0 & -\sin\alpha_{m,n} & 0 \\ 0 & 1 & 0 & 0 \\ \sin\alpha_{m,n} & 0 & \cos\alpha_{m,n} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi_{m,n} & \sin\phi_{m,n} & 0 \\ 0 & -\sin\phi_{m,n} & \cos\phi_{m,n} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{4-4} $$

Scanned point coordinate expression in world coordinate system O_0-$x_0y_0z_0$

According to the relation of coordinate transformation, the scanned point can be expressed in the world coordinate system as the equation (4-5).

$$ u\big|_{o_0} = {}^{o_0}_{o_3}T \cdot u\big|_{o_3} = \begin{pmatrix} 1 & 0 & 0 & x_{m,n} \\ 0 & 1 & 0 & y_{m,n} \\ 0 & 0 & 1 & z_{m,n} \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{m,n} & \sin\theta_{m,n} & 0 & 0 \\ -\sin\theta_{m,n} & \cos\theta_{m,n} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\alpha_{m,n} & 0 & -\sin\alpha_{m,n} & 0 \\ 0 & 1 & 0 & 0 \\ \sin\alpha_{m,n} & 0 & \cos\alpha_{m,n} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{4-5} $$

$$ \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi_{m,n} & \sin\phi_{m,n} & 0 \\ 0 & -\sin\phi_{m,n} & \cos\phi_{m,n} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & R_y \\ 0 & 0 & 1 & R_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\delta & \sin\delta & L\sin\delta \\ 0 & -\sin\delta & \cos\delta & L\cos\delta \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \rho_{m,n} \times \cos\lambda_{m,n} \\ \rho_{m,n} \times \sin\lambda_{m,n} \\ 0 \\ 1 \end{pmatrix} $$

Table 1. Parameters notation.

Symbol	Description	Symbol	Description
$\varphi_{m,n}$	roll angle	d_1	O2 displacement to O1 in x-axis
$\alpha_{m,n}$	pitch angle	d_2	O2 displacement to O1 in y-axis
$\theta_{m,n}$	yaw angle	d_3	O2 displacement to O1 in z-axis
$\rho_{m,n}$	distance information	x_m	robot location in x axis
$\lambda_{m,n}$	polar angle	y_m	robot location in y axis
$\sigma_{m,n}$	wound angle of sensor	z_m	robot location in z axis

EXPERIMENT

We performed the experiment using the 3D scanning device in an office. The angle range of LIDAR sensor rotation is 30 degree, and captured 33480 (31X1080) data. The Fig.6 is the real scene of the room. Fig.7-A is the 3D map observation in 'A' direction, Fig.7-B from 'B' direction, Fig.7-C is from 'C' direction. The 3D map can reflect the real scene. We can see and calculate the position of the book, wall, close hanger, and broad.

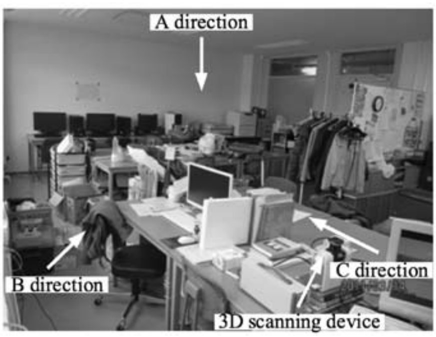

Figure 6. Real scene of experiment.

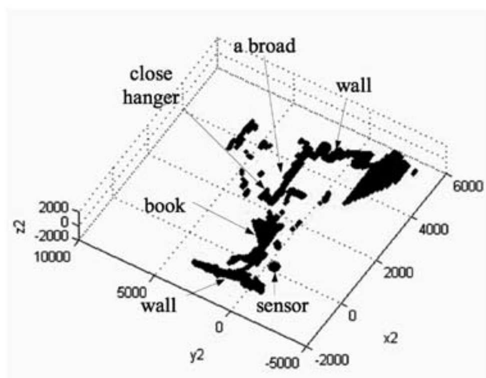

Figure 7A. 3D map in A direction.

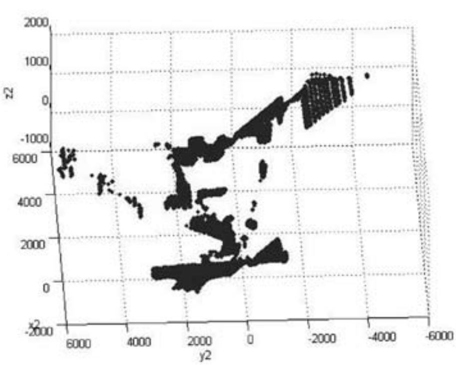

Figure 7B. 3D map in B direction.

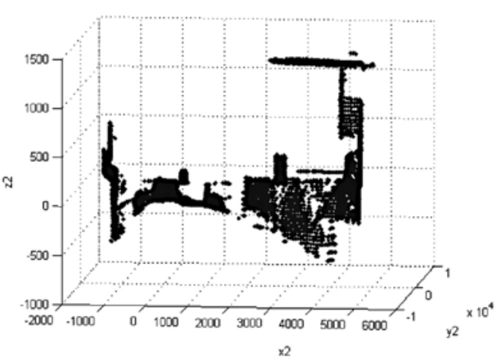

Figure 7C. 3D map in C direction.

CONCLUSION

This paper introduced an idea of 3D mapping, including the system components, mathematic model in coordinate system transformation. We performed the experiment in the room, and the map can express the real scene. In the next step, we will install the 3D scanning device on the robot, mapping in the outside, and choose proper SLAM (Simultaneous localization and mapping) algorithm for robot navigation.

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