Obstacle Avoidance Control by Laser Range Finder for Six-Legged Robot

SLAM by Laser Range Finder for Six-Legged Robot

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When the robot walking in an environment to a targeted destination by using odometer, or in our case, we used Center of Body (COB) data, it might be can't reach to the destination precisely due to the errors of the sensor itself or due to mechanical problem of the robot. To reach the targeted destination precisely, higher accuracy of estimation data are needed. Therefore, we used laser range finder (LRF) 3D information with the application of Extended Kalman Filter (EKF). However, the location of the robot has to know it's coordinate in the environment simultaneously during its journey. For that purpose we apply Simultaneous Localization and Mapping (SLAM) method in this research. Furthermore, we also apply the Occupancy Grid Mapping algorithm for obstacle avoidance control besides implementing the SLAM.

Key Words: LRF, Obstacle Avoidance, SLAM

1. Introduction

Research and development of outdoor mobile robots for hazardous operation shows a remarkable growth over the world. However, most of the robots are wheeled and crawler type [1]. Generally, a legged robot is the most suitable for rough terrain due to its high stability and mobility. The authors group has developed a series of mine detection and clearance hexapod robots, like COMET-I, COMET-II and COMET-III [2]. Now, to advance the adaptability to the terrain and use in various hazardous operation, we developed a hydraulically actuated hexapod robot COMET-IV [3], [4]. This robot is designed to walk in all direction autonomously in outdoors. For further advancement of our robot, we are working toward applying "Simultaneous Localization and Mapping", or SLAM method to our robot. A method which the robot simultaneously updates new information of its location and landmarks information in an unknown environment and then navigate itself while avoiding obstacles [5]. However, simultaneously updating information is not an easy job. Therefore, we also applied Occupancy Grid Mapping algorithm for obstacle navigation to compensate the difficulty since each grid cell is stored with landmark features every time data is updated. On the other hand, inherent problem of sensors used, structures of the robot and computing capability always make the SLAM problem is very challenging. The inherent problem of the sensor could be limited scanning range, reading accuracy affected by reflected light and vibration caused by the engine used to move the robot, etc. While, the structure of the robot such as slippery due to foot design and its traveled distance estimated based on leg movement angle could produce big uncertainties. The EKF based SLAM algorithm is the most popular approach to solve those problem [6]. However, another filter such as particle filter [7], [8], Hx filter [9], etc. are also have been used.

Normally, the distance traveled by the robot is estimated based on odometer or GPS reading and the location of the obstacles are estimated using sonar sensor, infrared sensor, laser range finder (LRF), camera and etc. In our case, traveled distance is estimated based on the movement of COB of the robot while the locations of the obstacles are estimated using LRF that is perform scanning vertically instead of scanning horizontally as per normal. Then the EKF is applied to reduce uncertainties associated in the measured data.

2. Overview of COMET-IV Structure

Fig.1 shows the overview of the hydraulically actuated hexapod robot COMET-IV, and its specification is shown in Table 1. Two gasoline engines are used to drive two hydraulic pumps. Electric power is supplied from two batteries installed on this robot. Each leg has 4 degrees of freedom. Shoulder is actuated by hydraulic motor, thigh and shank and foot are actuated by hydraulic cylinders.

<table>
<thead>
<tr>
<th>Height</th>
<th>2.80 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>3.30 m</td>
</tr>
<tr>
<td>Length</td>
<td>2.50 m</td>
</tr>
<tr>
<td>Max. Walking Speed</td>
<td>1000 m/h</td>
</tr>
</tbody>
</table>
3. System Configuration of COMET-IV

Fig. 2 shows the sensors used and how they are inter-communicating each others. In this research, potentiometers, pressure sensors, attitude sensor, azimuth sensor, LRF and GPS are used. Potentiometers and pressure meters are used to control the leg movement and attitude sensor is used to acquire roll and pitch angle of robot's body. Whereby, the azimuth sensor is used to acquire yaw angle and LRF is functioning as an eye of the robot to detect the availability and the location of obstacles exist in its walking environment. Lastly, the RTK-GPS is used to verify the location of the robot on world coordinate. The important specifications of the sensors are listed in Table 2.

![Fig. 2 Structure of COMET-IV](image)

Table 2 Specification of the sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Azimuth</th>
<th>LRF</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>CANON HS-02-2</td>
<td>SICK LMS200</td>
<td>Trimble MS750</td>
</tr>
<tr>
<td>Range</td>
<td>-</td>
<td>0 - 8 m</td>
<td>-</td>
</tr>
<tr>
<td>Resolution</td>
<td>-</td>
<td>0.5°</td>
<td>-</td>
</tr>
<tr>
<td>Accuracy</td>
<td>1 V/G</td>
<td>15 mm</td>
<td>3 cm</td>
</tr>
</tbody>
</table>

4. Coordinate Estimation Using COB Data

Walking distance of the robot is estimated by calculating how many cycle the robot move. One cycle is the sum of small displacement of leg 1, 3, 5 and leg 6, 4, 2. The estimation is not done using acceleration data acquired from GPS sensor because in some environment condition, such as inside building or inside an area covered by many trees, it is impossible.

By the way, the small displacement \((\Delta X_i, \Delta Y_i)\) of the body movement of Leg 1, 3, 5 and Leg 2, 4, 6 are determined according to the following equations:

\[
(\Delta X_{135}, \Delta Y_{135}) = (\Delta P_1 + \Delta P_2 + 2\Delta P_3)/4 \quad (1)
\]

\[
(\Delta X_{642}, \Delta Y_{642}) = (\Delta P_6 + \Delta P_4 + 2\Delta P_5)/4 \quad (2)
\]

The body centre XY position \((X_{COB}, Y_{COB})\) on world coordinate system can be obtained by integrating the small displacement of body movement of the robot [10]. However, big uncertainties exist due to inherent mechanical limitations of each joint of its leg. The big uncertainties are also caused by slippery phenomenon during walking [11].

5. Coordinate Estimation Using LRF Data

The robot XY position \((X_{LRF}, Y_{LRF})\) on world coordinate system is estimated based on the data acquired by the LRF as shown in Fig. 3. On the other hand, Fig. 4 shows how to determine the vertical scanning angle \((\varphi)\) and horizontal scanning angle \((\theta)\) when the LRF is in operation.

![Fig. 3 LRF mounted on rotating stage](image)

![Fig. 4 Horizontal and vertical scanning angle](image)

By performing such style of scanning, 3D point cloud data could be obtained. Let's \(\varphi\) is an angle of vertical scanning and \(\theta\) is an angle of horizontal scanning, then the \((X, Y, Z)\) position of each scanned spot are determined according to the equation (3) to (5).

\[
X_i = R_i \cdot \cos \varphi \cdot \sin \theta \quad (3)
\]

\[
Y_i = R_i \cdot \cos \theta \cdot \cos \varphi \quad (4)
\]

\[
Z_i = H + R_i \cdot \sin \varphi \quad (5)
\]

Where, \(i\) is the count of the scanned spot, \(R\) is Euclidean distance measured by the LRF and \(H\) is the height of the LRF from ground.

Finally, the coordinate estimated based on LRF measurement is converted to world coordinate by multiplying them with transformation and translation matrix of the robot movement.

6. Occupancy Grid Map Based Obstacle Avoidance Control

The process of producing an occupancy grid map begins with converting current environment map to small grid cells which are 0.5m x 0.5m per cell. Then, store related 3D information data acquired using LRF and also self location into each grid cell. The information are the height of obstacle, spot point of LRF detected corresponding to the grid cell. The information is updated according to EKF concept as explained in the next section. Next, each grid cell is classified whether corresponding area is safe or unsafe to the robot to go through the area. After that, an occupancy grid map is
constructed. Lastly, according to the information of classified area, a safe path is planned. The safe path is the shortest possible path to the robot to go through until targeted goal. Fig. 5 shows the image of the occupancy grid map development process.

Fig. 5 Process of a developing occupancy grid map

7. COB and LRF Based SLAM

In the formulation of the SLAM problem, the EKF is used to provide estimates of robot and obstacles location. As already well known, the process of minimizing noise associated with the measurement data is a recursive process between estimation and updated data [12]. Fig. 6 shows that EKF is used to estimate the location of the robot based on LRF and COB data.

Fig. 6 EKF applied to estimate robot location

COB data and LRF data shown in the above block diagram are updated referring to azimuth sensor and attitude sensor data and according to the following equation for each time the data were updated.

\[
\begin{bmatrix}
\hat{P}_{CD} \\
\end{bmatrix}
= \begin{bmatrix}
R_{GC}(\theta)R_{GC}(\phi)T_{GC}
\end{bmatrix}
\begin{bmatrix}
P_{CD} \\
\end{bmatrix}
\]

(6)

Where, \(P_{CD}\) is 3D distance data in global coordinate and \(P_{CD}\) is robot coordinate based on calculated COB data and measured data by LRF. \(R_{GC}(\theta), R_{GC}(\phi)\) and \(T_{GC}\) are the rotation matrix of azimuth data (yaw angle) and attitude data (roll and pitch angle). Whereby, \(T_{GC}\) is the translation matrix. Furthermore, Fig. 7 shows the detail how the data from LRF and other sensors are handled in formulating SLAM problem.

Fig. 7 Detail of data handling

8. Experiment and Results

The aim of this experiment is to verify the effectiveness of developed algorithm in integrating all data from sensors that are used. If the algorithm is workable and all data acquired from the sensor is accurate, a good map could be produced, hence SLAM problem could be solved.

The experiment was held at a parking space in front of our laboratory in Chiba University as shown in Fig. 8. Measurement was done for every 2 meters the robot moved. The LRF was rotated 180° as one cycle measurement. Anyhow, since the size of the robot quite big, and for safety reason the experiment was stopped after the robot moved for about 8 meters. However, referring to Fig. 9, only a small angle correction error happened (see the portions in circle) due to azimuth sensor data accuracy problem. Attitude sensor used in this experiment also produced fairly big noise, but it did not affect the result since the experiment done on a flat surface. Whereby, Fig. 9 shows a map constructed according to equation (6) and Fig. 10 shows a 3D image of the map.

Fig. 8 Experiment environment

Fig. 9 Constructed map of the environment

Fig. 10 3D image of the map
9. Conclusion and Future Plan

Even though the experiment done in a limited space, gathered data shows that the algorithm used is workable to solve SLAM problem. Better precision of environment map and robot location could be achieved by further tuning azimuth sensor and attitude sensor together with minimizing robot foot slippery problem during walking.

As for future plan, an experiment is planned to be held as soon as possible in further challenging environment where the effect of attitude sensor could not be neglected anymore and SLAM problem formulation also will become tougher. Wireless communication problem should be solved in order to enable real time environment map construction. For faster obstacle avoidance and navigation, another sensor will be used together with current rotating LRF; since time taken to complete a cycle measurement was quite long. A stereo vision camera could be used in future for another tasks of locomotion, not limited to only obstacle avoidance, but further challenging tasks, such as climbing up stairs, step over of an obstacle and etc.

References


