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3-D Map Building in Dynamic Environments by a Mobile Robot Equipped with Two Laser Range Finders

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Abstract: When an autonomous mobile robot acts in constructed environments, a map that has the information about obstacles is necessary for the mobile robot. Even if a map is given, however, the mobile robot cannot start its action without the information of its present location on the map. Therefore, techniques of map generation and self-localization are important for mobile robots. In this paper, we propose 3-D SLAM (Simultaneous Localization and Mapping) method by a mobile robot equipped with two LRFs (Laser Range Finders). The robot measures the distance between obstacles around it with LRFs at multiple positions, and generates a map by integrating these range information. The integration is realized by using an odometry (dead-reckoning method) and ICP (Iterative Closest Point) algorithm. Experimental results have shown the validity of the proposed method.

Keywords: Map Building, SLAM, Dynamic Environment

1. INTRODUCTION

Introduction of autonomous mobile robots such as guard robots and nursing robots is expected with development of robot industry in recent years. Generally, autonomous mobile robots need the information of obstacle positions when they work in a field. One of the methods to know the information of obstacle positions is a two-dimensional (2-D) plane map of surrounding environment. A robot can search out the safe path if it knows the information of obstacle positions from a 2-D plane map of surrounding environment. However, a 2-D plane map does not necessarily exist. Therefore, when a mobile robot has no map, it needs to generate a 2-D plane map by itself [1]. Additionally, a mobile robot cannot avoid obstacles that are not on the same plane with a 2-D plane map. In this case, three-dimensional (3-D) map generation of surrounding environment becomes important for a robot [2-3]. In this paper, we propose a method for 3-D SLAM (Simultaneous Localization and Mapping).

Another problem is existing moving objects in the environment. The detection and the tracking of moving objects by a mobile robot are generally performed[4-7]. When moving objects are written at a map, it is not a correct map. Therefore, we propose a new technique to detect existing moving objects in the environment, and to remove them from a map.

2. SUMMARY

Figure 1 (a) shows a mobile robot used in this study. Figgure1 (b) shows a LRF (Laser Range Finder) used in this study. Two LRFs are put on a mobile robot. One LRF measures the plane that is parallel to a floor, another RLF measures the plane that is perpendicular to a floor. It is put on a turntable and can acquire 3-D data of circumference 360 degrees (Fig.2).

Figure 3 shows the whole aspect of the map generation system. The mobile robot estimates its position and orientation from the odometry and the LRF data by using ICP (Iterative Closest Point) algorithm[8]. At the same time, the robot generates a map by aligning measurement data based on the estimated positions and orientations. In addition, the robot detects and removes moving objects by considering a difference between measurement data acquired before and after the movement.

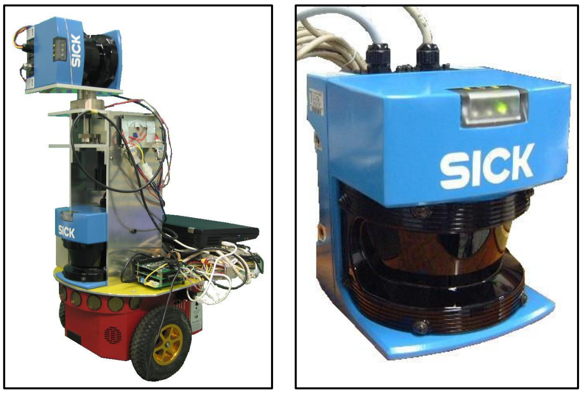

(a)Mobile Robot (b)LRF

Fig.1 Mobile Robot and LRF

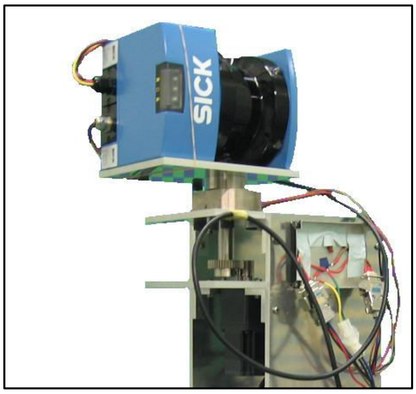


Fig.2 Rotatable LRF

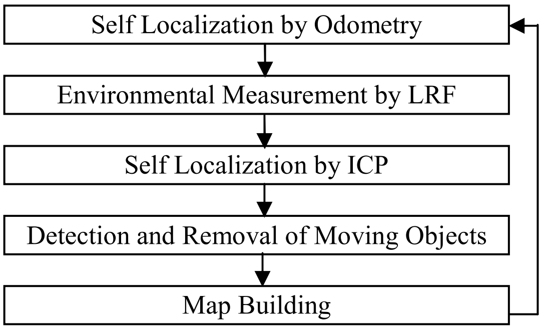


Fig.3 Flow Chart (Map Generation)

3. 2-D GENERATION

3.1 Estimation of positions and orientations

Map generation is performed using the information acquired by two LRFs on the mobile robot. However, it is difficult to acquire the distances between the mobile robot and all obstacles in the environment from one position, because there are limitations in a measurable range of the LRF and problems of occlusions. Therefore, the robot measures environment from multiple positions while it moves. And the map is generated by integrating each measurement data acquired by the LRFs. It is necessary to estimate the positional and orientational relationship among all measurement positions in order to generate whole map of the environment by integrating all measurement data.

In this study, the mobile robot estimates its position and orientation from the odometry and the LRF data by using ICP algorithm.

ICP algorithm is an alignment method of multiple point groups (Fig.4). It minimizes the error function by iterative computation using the over lapping area measured by the LRF at multiple positions. Here, let M and S be point groups, respectively. Point group M is measurement data acquired after the mobile robot moves, while point group S is data before it moves. Let two points $\boldsymbol{m}_j$, $\boldsymbol{m}_k$ ($1 \le j \le N$, $1 \le k \le N$) that are the nearest points to point $\boldsymbol{s}_i$ ($1 \le i \le N$) in point group M be corresponding points about point $\boldsymbol{s}_i$ in point group S. The straight line that consists of the two points $\boldsymbol{m}_j$, $\boldsymbol{m}_k$ is used instead of corresponding points. This algorithm calculates the parameters ($\mathbf{R}$, $\mathbf{t}$) to minimize E that means the square sum of the distance between each point and straight line (Equation (1)). Parameters ($\mathbf{R}$, $\mathbf{t}$) indicate the orientational and positional relationship between point group M and S. In other words, these parameters mean the movement of the mobile robot. $\mathbf{R}$ is a rotation matrix of 2×2 (or 3×3), and $\mathbf{t}$ is a translational movement vector.

$$E(\mathbf{R},\mathbf{t}) = \sum \frac{\left|(\mathbf{R}\mathbf{s}_i + \mathbf{t})(\mathbf{m}_k - \mathbf{m}_j)_\perp + \mathbf{m}_k \mathbf{m}_{j\perp}\right|^2}{\left\|\mathbf{m}_k - \mathbf{m}_j\right\|^2} \qquad (1)$$

where $\boldsymbol{m}_\perp$ means the vector which is perpendicular to $\boldsymbol{m}$, and its size is $|\boldsymbol{m}|$.

In our method, the initial values of parameters ($\mathbf{R}$, $\mathbf{t}$) are decided with information acquired by the odometry. The iterative computation is executed before E becomes smaller value than a threshold value.

ICP algorithm converges by a downhill simplex method. This method does not use a derivative function, and implementation is simple. This method is suitable for ICP algorithm that a derivative function changes greatly when the ($\mathbf{R}$, $\mathbf{t}$) pettiness change.

However, the ICP algorithm cannot completely get rid of the error of the self localization. By a process of generating a map, small error accumulates when the robot repeats a lot of self localization. As a simple method, the robot reduces the error by reducing the number of times of the self localization. This method is not good because a space of self localization points becomes large. Therefore, the robot estimates positions and orientations by current data and past data before the constant number of times when the robot generates the map at the constant number of times (Fig.5). By this, the robot revises the error of the self localization and improves the precision of the map.

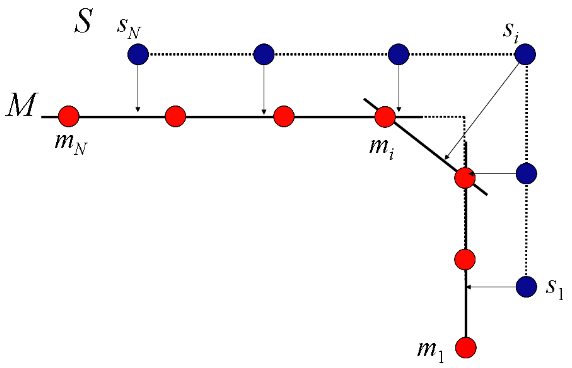


Fig.4 ICP Algorithm

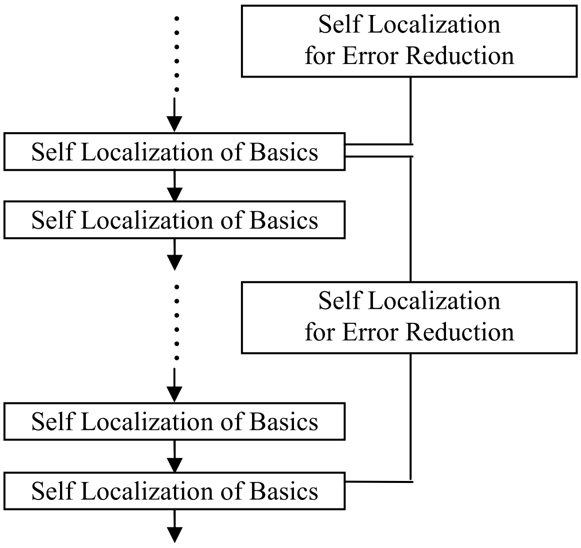


Fig.5 Flow Chart (Revision of Accumulated Error)

3.2 Detection and removal of moving objects

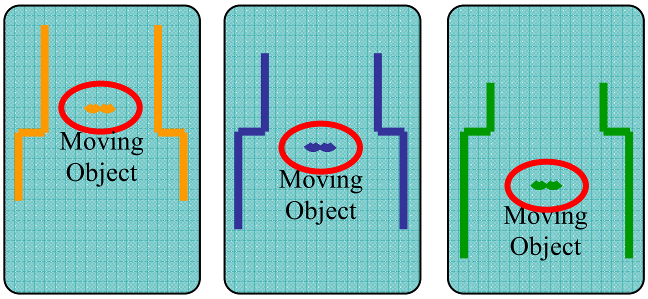
Because there are not always moving objects in the same place, the map generation should make the map only for still objects. However, moving objects is written on the map when there are moving objects during a measurement in the environment. Therefore, it is necessary to remove them from a map.

In this study, the mobile robot detects and removes moving objects by considering a difference between measurement data acquired before and after the movement (Fig.6).

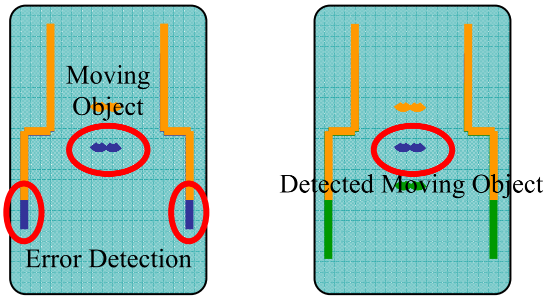
The robot compares measurement data at the current position (t) (Fig.6 (a)) with measurement data at the past position (t-1) (Fig.6 (b)) and detects a difference. The mobile robot subtracts measurement data at the current position from measurement data at the past position (t-1) and detects difference as moving objects. However, this method misdetects some still objects as moving objects (Fig.6 (d)). Therefore, the mobile robot compares measurement data at the past position (t-2) (Fig.6 (c)) in addition to it. The robot subtracts measurement data at the current position and the position (t-2) from measurement data at the position (t-1) and detects data as moving objects. By this, the robot detects only moving objects precisely.

4. 3-D GENERATION

If a mobile robot has only a 2-D plane map, the robot cannot avoid obstacles that are not on the same plane with the 2-D plane map. In this case, 3-D map generation of surrounding environment becomes important for a mobile robot. In this paper, we propose a method for 3-D map generation of environment.



(a) Position (t) (b) Position (t-1) (c) Position (t-2)



(d) Moving Object in (b) [(b)-(a)]

(e) Moving Object in (b) [(b)-(a)-(c)]

Fig.6 Detection of Moving Object

The robot measures 3-D data by the LRF put on a turntable. The LRF measuring the plane that is perpendicular to a floor turns, and the mobile robot acquire the 3-D data of circumference 360 degrees.

Figure 7 shows construction of a 3-D measurement system. The turntable turns by a stepping motor. This motor has a function of highly precise rotary angle detection. A PC controls the stepping motor by a motor driver and a PLC (Programmable Logic Controller). The self localization data of the motor is sent to the PC through the motor driver and the PLC.

The 3-D map is generated by alining measurement data acquired at each angle. The alining of the 3-D data by use of self localization of the robot and the angle information of the turntable. Figure 8 shows an acquisition method of the robot position information when the robot measures 3-D data. The 3-D LRF measures circumference environment. However, the robot can not estimate positions and orientations at all the position of 3-D LRF measurement, because it takes time the self localization than the measurement interval of the RLF. Therefore, the robot makes a trace of linear interpolation for the alining of the 3-D data from self localization of the robot. An error of the position information to use for alining 3-D measurement data occurs by interpolation linear shape.

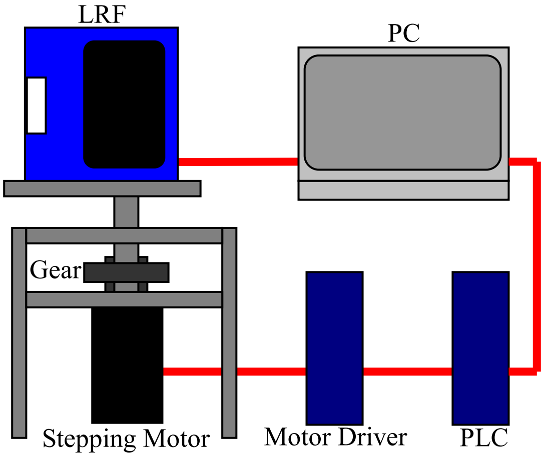


Fig.7 3-D Measurement System

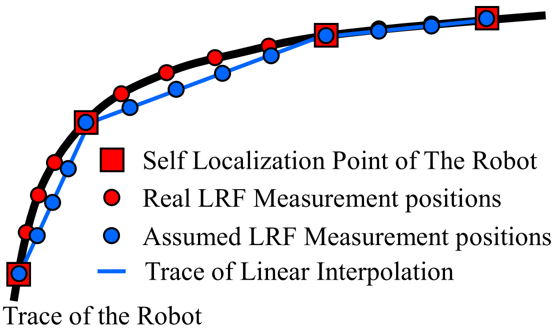


Fig.8 Alinement of 3-D Data

However, the time of self localization is short enough for the movement speed of the robot. Therefore,the error of the position information to use for alining 3-D measurement data is small so as to be able to ignore it

The mobile robot dose not use measurement data at the time of rotary start and end, to remove the influence of the back lash of the gear and the change of the rotary speed.

5. EXPERIMENT

5.1 2-D map generation

Our mobile robot used two LRFs (SICK, LMS 200-30106) that can measure distance by the propagation time of the pulse of laser light, and can measure direct distance between obstacles around the robot and the robot itself. The maximum sensing ranges of distance and of angle are 30m and 180deg, respectively. The maximum error of the measurement is 4cm. The resolution of sensing angle is 0.5deg. The measurement of the circumference environment by the LRF is performed once in 0.026 second while turning a turntable.

The experiment environment is shown in Fig.9. We performed the experiment in an indoor corridor. There was a human who was walking in environment. In this environment, the mobile robot equipped with two LRFs ran and generated a map.

The experiment result is shown in Fig.10. In Fig.10 (a), a moving object is detected. The moving object detected in Fig.10 (a) is removed (Fig.10 (b)). Table 1 shows the comparison of true value and measurement data. We compared ground truth with measurement data of each positions (*a* - *c*) in Fig.10 (b).The map generation error is within the measurement error range of the LRF.

5.2 3-D map generation

The experiment environment is shown in Fig.11. The experiment result is shown in Fig.12. Figure 12 (a) is a plan view in experiment environment. Figure 12 (b) is the figure which looked at the experiment environment from slippage.

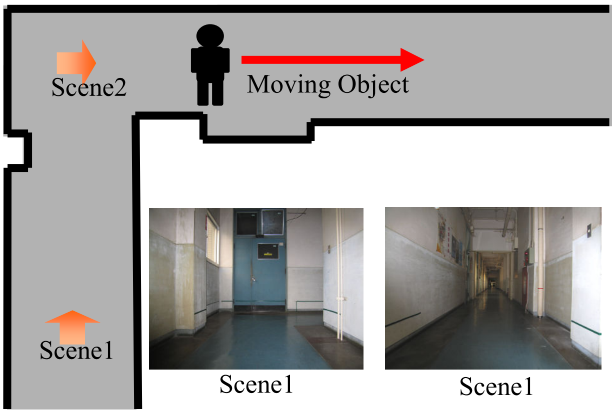
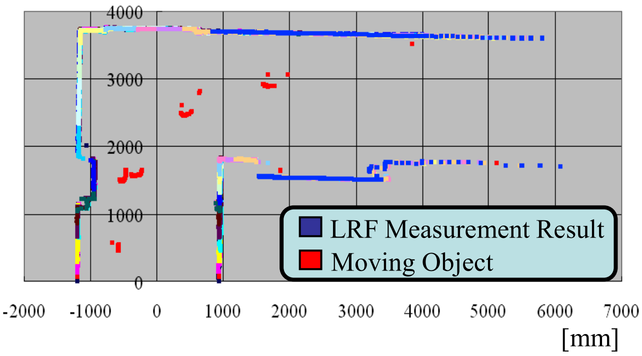
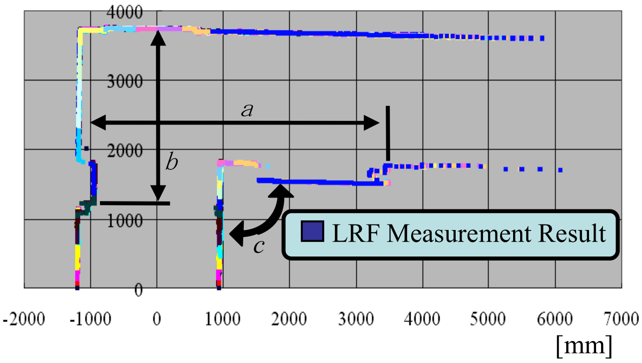


Fig.9 Experiment Environment 1

In Fig.12, the experiment environment 3-D map is generated. The effectiveness of this study is proved by the experiment result.



(a) Detection Moving Objects



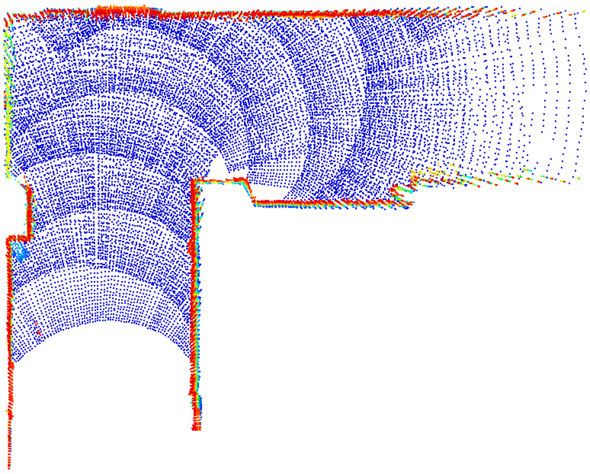
(b) Removal Moving Objects

Fig.10 2-D Map

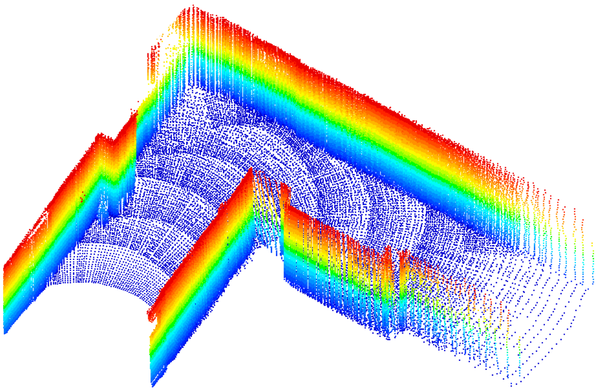
Table 1 Map Generation Accuracy

	True value	Measurement data
a	4668 mm	4696 mm
b	2514 mm	2541 mm
c	90 deg	90 deg

Fig.11 Experiment Environment 2



(a) 3-D map 1



(b) 3-D map 2

Fig.12 3-D Map

6. CONCLUSION

In this paper, we propose the method of generating a 3-D map by using the mobile robot equipped with two LRFs. We also propose 3-D SLAM method of the robot. The robot generates the environmental map and estimates its position and orientation by utilizing the method based on ICP algorithm.

From the experimental results, the validity of our map generation method and self-localization method is verified.

As a future works, we have to construct the 3-D map generation method in dynamic environment.

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