Localization Algorithm using Virtual Label for a Mobile Robot in Indoor and Outdoor Environment

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Abstract: The scanning laser range sensors provide range data consisting of a set of point-measurements. The laser sensor (URG-04LX) has a distance range of approximately 0.02 to 4 meter and scanning angle range 240 degrees. Usually, such a range image is acquired from one view-point by "moving" the laser beam using rotating mirrors/prisms. The orientation of the laser beam can be easily measured and converted into coordinates of the image. This paper conducts localization using virtual labels with environment distance data gotten from the 2D distance laser sensors. This method puts virtual labels on special feature and points which is on the way of mobile robot path. The current location is calculated by combining the virtual label and the range image of laser range finder.

Keywords: Virtual Label, Laser Range Finder, Encoder, Localization

I. INTRODUCTION

Mobile robots have been applied in various fields such as logistics automation, security, industrial automation and consumer products, and etc. The absolute positioning of mobile robot becomes essential part. The research for the localization problems are focused on robust and minimum error against unknown environment. As advance of mobile robot technologies, localization for mobile robots is widely researched and developed such as a dead reckoning system, an active badge system, an active beacon system and the localization system using a landmark, a RFID and a GPS [1-8].

The dead reckoning system is one of well-known localization method based on measuring the relative position. The dead reckoning system has an advantage of high sampling rate and outstanding accuracy in short interval. However, this system cannot avoid inevitable accumulation of the error because of time integral term with current direction and distance. Especially, cumulative error of the direction angle may cause infinitely large positioning error as time passed [1], [2].

In order to detect the location of people inside building, the active badge system with infrared ray has been researched. However, this system has problems such as the short communication distance and weakness performance against sunshine [4]. Active beacon system with ultrasonic sensors is known as relatively high accurate performance and low power consumption. However, this method gets influences with an obstacle between a transmitter and a receiver, external temperature, and noise [5].

The localization method using a landmark or a RFID is robust to external environment such as changes in temperature or solar light. However, it has fatal defect in that it can be applied only to limited space where RFID tag or landmark is able to be attached. In addition, it is impossible to use outdoors [3], [4]. In outdoors, GPS (global positioning system) is most powerful localization method to recognize the absolute position. However, it has a limitation area of GPS signal and low position accuracy [6].

In order to solve these problems, this paper proposes the localization method with virtual labels to become robust against space constraints and indoor/outdoor environments. The proposed method is based on virtual labeling techniques. This paper uses a laser range finder and an encoder in indoor environment. And, in outdoor environment, a GPS only is adopted to calculate initial position.

The paper is divided into the following sections: generation of range finder scans (section 2), and localization with virtual label algorithm (section 3). Section 4 shows experiment results of implementation within typical indoor/outdoor scenes. And conclusion and future work are discussed in Section 5.

II. LASER RANGE FINDER SCANING

This study constructs a mobile robot equipped with a laser range finder as shown in Fig. 1. 2D laser range finder (URG-04LX) made by HOKUYO Co. LTD is used. URG-04LX has 100 ms cycle time and 765 resolutions from 60 mm to 4,095 mm distance value divided by 0.36 degree. Specifications of the laser range finder are listed in Table 1.

Figure 1. Laser range finder & Indoor environment

TABLE I. SPECIFICATIONS OF URG-04LX

	Spec.
Measuring area	60 to 4095 mm , 240 °
Accuracy(Repeatability)	60 to 1000 mm : ± 10 mm 1000 to 4095 mm : 70 mm
Angular resolution	Step Angle : 0.36 ° (360 ° /1024 steps)
Scanning time	100 ms/scan

Figure 2 shows output data of the laser range finder in indoor environment. This sensor is available to scan 240 degree and 765 distance output data according to distance each cycle at 100ms. In this paper, localization is calculated in 210 degree areas. 600 distance output data are used to build 2D coordinates including the virtual label as shown in Fig. 3. This distance output data is transformed to 2D coordinates by using equation (1) and (2).

$$x_i = D_i(\cos(i \times 0.3515625))(\frac{3.14}{0.5\pi}), \ i = 0,1,2,...,600 \quad (1)$$

$$y_i = D_i(\sin(i \times 0.3515625))(\frac{3.14}{0.5\pi}), \ i = 0,1,2,...,600 \quad (2)$$

Where, θ_i (0.3515625) is the angular resolution from 1 point to 600 point and D_i is the distance output data. Figure 3 shows distance conversion of 2D coordinates.

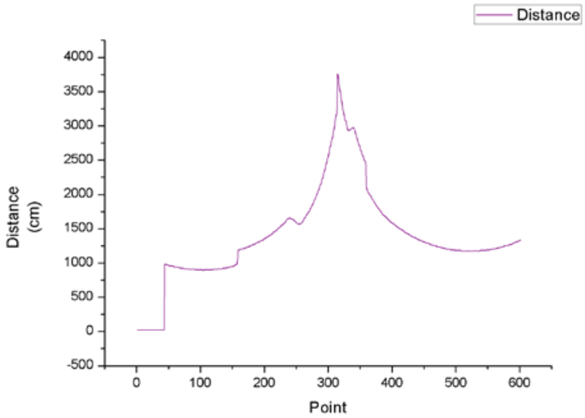

Figure 2. Distance data of a laser range finder

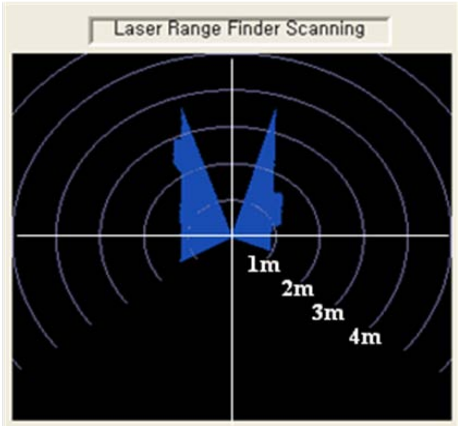

Figure 3. Distance data conversion of 2D coordinates

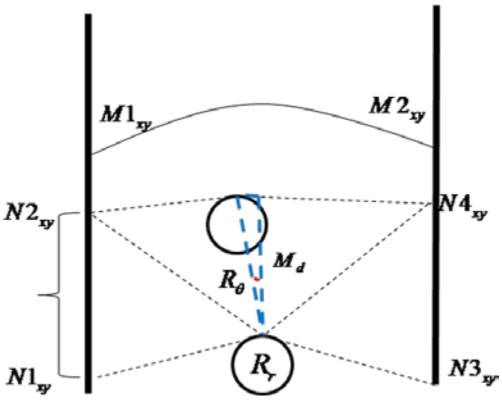

Figure 4. Segmentation area

It is necessary to classify movable area ($Mk_{x,y}$) and non-movable area ($Nk_{x,y}$) in transformed coordinates (x_i, y_i). In Fig. 4, Nk_{xy} is used to map virtual label and Mk_{xy} is used to determine mobile robot's path. After determining $Mk_{x,y}$ and $Nk_{x,y}$, the map is generated with considering radius of robot (R_r), moving distance of robot (M_d), and direction of robot (R_θ). As repeating and accumulating of above proposed process using equation (3), (4), virtual label is named on the map simultaneously.

$$X_{map_j} = Nk_x \quad (3)$$

$$Y_{map_j} = Nk_y \quad (4)$$

By using the proposed virtual label algorithm which is explained in section 3, a map is effectively generated in indoor or outdoor environment. Only for the outdoor circumstance, GPS is used to get initial position additionally.

III. VIRTUAL LABEL ALGORITHM

Before moving the mobile robot, the virtual label should be allocated on the map which can be generated by scanning the current circumstance with laser range finder. The virtual label is not needed to be on real points, lines and space in the circumstance. As the name **'virtual', the label can be generated on virtual structures** which do not exist in real space. Then, the temporary virtual wall is allocated in the left and right of 45 degree space.

The proposed virtual label method is accomplished as following procedure,

[Step 1] In order to initialize current position of mobile robot, scan the circumstance.

[Step 2] Label on the map using scanned data, feature points, lines and spaces.

[Step 3] If feature points, lines and spaces cannot be found, virtual wall and label will be generated on the map as shown in Fig. 5. The virtual walls are built on both sides. And the virtual labels (VLm_x, VLm_y) are attached on 45 degree diagonal position on the virtual walls.

[Step 4] Let a current robot position localize by using distance (D_n) and angle (R_θ) toward the label.

[Step 5] Movable domain ($M1_{x,y}$, $M2_{x,y}$) and not movable domain ($N1_{x,y}$, $N2_{x,y}$) have to be added on the map involving the label.

[Step 6] After moving mobile robot, returned to the Step 1.

The position of mobile robot is acquired by using distance D_n and $VLm_{x,y}$. The current position is calculated by using the following equation (5) and (6).

$$R_x = (VLm_x \pm D_n) \quad (5)$$

$$R_y = (VLm_y) \quad (6)$$

Where, D_n is the distance from mobile robot to virtual label ($VLm_{x,y}$).

Figure 6 is the block diagram of virtual label allocation.

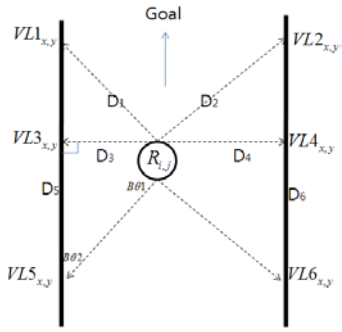

Figure 5. Virtual labeling for indoor environment

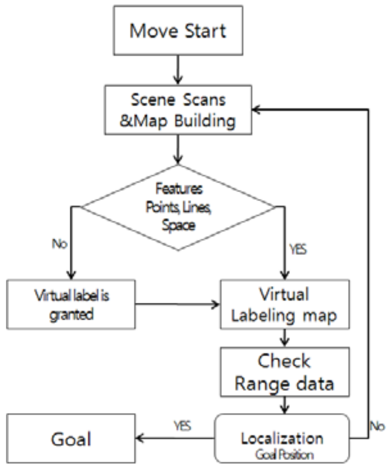

Figure 6. Block diagram of a virtual labeling

IV. EXPERIMENTS

In order to evaluate the localization and map formation of the proposed virtual label algorithm, the moving experiments of mobile robot were carried out in indoor environment showed as Fig. 1 and outdoor environment showed as Fig. 7.

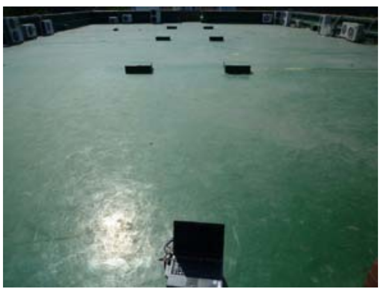

Figure 7. Outdoor environment

Experiment (Indoor)

In indoor environment, the virtual labeling algorithm is applied to generate the map for localization. The map applied the virtual label algorithm is shown as Fig. 8. The distance between start and goal point is 10 m straight path. The test condition is selected to compare localization effect by using encoder data with localization effect by using the virtual label algorithm in indoor environment. The mobile robot speed is 0.54 m/s. Test result with the virtual label algorithm is shown as Fig. 9.

After 5 times experiments over 5 times, location error of mobile robot was found as about $\pm 2cm$. In previous study, repetitive error was about $\pm 3cm$ by using encoder [3]. However, localization by using encoder data is not much different. Thus, the experiment shows that virtual label algorithm is precise localization method.

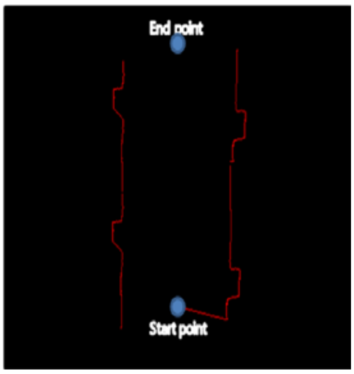

Figure 8. Map building of an indoor environment

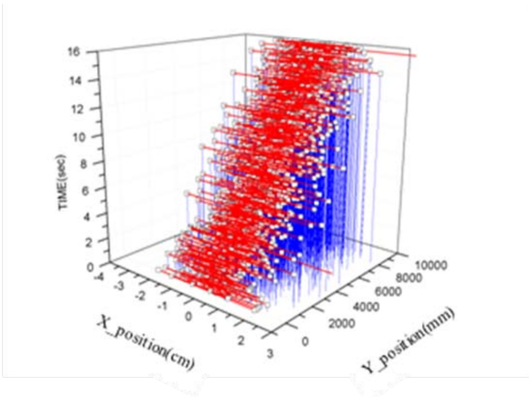

Figure 9. Moving trajectory of mobile robot with the virtual labeling algorithm in indoor

Experiment (outdoor)

In outdoor environment, with mobile robot equipped with a laser range finder and a GPS, the virtual labeling algorithm is applied to generate maps for localization. GPS sensor only is adopted to calculate an initial position. The map obtained by applying the virtual label algorithm is shown in as Fig. 10.

The distance between start and goal point is 17 m straight path. The mobile robot speed is 0.54 m/s. The result of 5 times repetitive driving is shown as Fig. 11. If there is not the space to make label in the scan data of range finder, label is allocated to virtual wall for localization.

After experiments over 5 times, repetitive error of mobile robot is about $\pm 4cm$ because of rough road in outdoor. And the repetitive error by only using encoder was about $\pm 10cm$. Thus, localization with the virtual label algorithm is superior to localization method with the GPS.

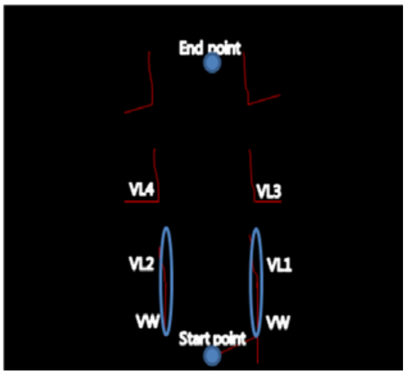

Figure 10. Map building of an outdoor environment

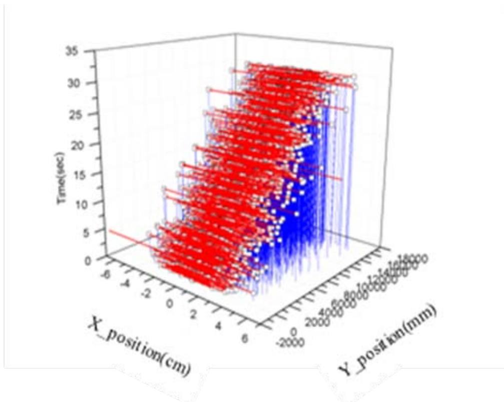

Figure 11. Moving trajectory of mobile robot with the virtual labeling algorithm in outdoor

V. CONCLUSION

In order to localize and build a map in indoor/outdoor environments, this study proposed the localization algorithm with the virtual label algorithm. And this paper carried out experimental test using mobile robot to evaluate the proposed virtual label algorithm. In the experimental test, the proposed virtual label algorithm performed precise localization result that location error of mobile robot is about $\pm 2cm$ in indoor environment and about $\pm 4cm$ in outdoor environment. In the future work, it will be improved to have localization maximum error within $\pm 5mm$ in the various indoor/outdoor environments. In addition, it will be compared with other localization algorithms.

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