Pre-Mapping System with Single Laser Sensor Based on Gmapping Algorithm

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***Abstract*—Knowing physical structure of the unknown environment is a requirement in some natural disaster situations such as earthquake, fire accidents or flood. Many existing algorithms in literature have been developed for the purpose of extracting map of unknown environment. These algorithms called as SLAM (Simultaneous Localization and Mapping). But still there are problems in SLAM to be solved. One of these problems referred in literature as chicken-egg problem. Another struggling problem is requirement of more parameters to execute and generate accurate map and pose estimation. That makes systems' structures more complicated and hierarchical. In this study, parameters of Gmapping SLAM algorithm are reduced to avoid complicated structures and execute in a low cost handheld system. In the second step, a rough map is generated by designed handheld system. This rough map called as pre-map. Purpose of the generated pre-map is to use it in other studies, to assist solving localization problem.**

***Index Terms*—pre-mapping, LIDAR, GMAPPING, scan matching, grid base mapping, rao-blackwellized**

I. Introduction

Localization and Mapping algorithms are used in unknown environment extraction based on some sensors such as laser, ultrasonic or image to generate maps in 2D or 3D [1]-[3]. Necessity of mapping and localization is appeared to take as advantage of known geometric structure of indoor environments. In the beginnings, most experiments of simple mapping algorithms were used in military field. With rapidly improving algorithms and advanced sensors, mapping and localization solutions gradually are being used in real life. One of the impressive examples can be seen on search and rescue fields. Studies over these fields are being applied in natural disasters like fire, flood, and earthquake [4]. Under these conditions, generated maps of unknown environments make easier and faster to interfere and attain more life. Even if generated maps are not accurate, robots can use maps so called as pre-map to define their positions. Such as in that case, bomb disposal experts also use pre-maps. That maps help to define localization of robots in indoor environments to intervention to the bomb by robots [5]. These techniques have been developed to intervene to the bomb in short time for indoor environments and this will prevent late responses caused by missing plans or duration of reaching the plan of building.

Mapping or localization algorithms are not only applying on the search and rescue fields but also using on the purpose of some public servant. Robots programmed with autonomous exploration or navigation algorithms which is using the known map are in charge to guide people in public areas such as museum, technical facilities etc. Pre-mapping is also necessity in those applications to know environment [6].

In spite of the significant necessity of generating map and defining localization, there are still unsolved problems on algorithms. Generate maps of unknown environment and define the localization of robots are the main challenges of SLAM (Simultaneously Localization and Mapping) algorithms. Mainly used SLAM algorithms are FastSLAM, EKF (Extended Kalman filter), Gmapping, QuickSLAM [7], [8]. These algorithms operate based on single or combined sensors. Moreover in some studies, sensor fusion applied to these algorithms to maintain more accurate map [9].

In this study, one of the SLAM algorithms, the Gmapping is used for mapping and localization with single laser sensor. Moreover scan-matching method is also used to support more accurate map depends on pose estimation. In hardware side, a portative system is designed to execute algorithm in. The scope of this study is to get a rough map over the area by designed portative handheld system in shortest time with minimum cost. This process can be named as pre-mapping. The pre-mapping brings a solution of chicken-egg problem and other complex problems in SLAM algorithms [10]. In this study, this solution is maintained using single laser sensor with Gmapping algorithm. Using only laser sensor measurements for localization and mapping as a data for the pre-mapping was tested in different environments. Pre-mapping can bring low cost solution for autonomous exploration and navigation problems. Furthermore generated roughly maps will be used in next studies to solve this problems.

In the scope of this paper, related works over this field presented in Section II. Moreover, the differences between approaches are explained in the same section. Explanations of the algorithms used in this study explained in Section III. Section IV explains hardware configuration of designed handheld system in details.

Manuscript received May 5, 2013; revised June 15, 2012; accepted July 17, 2012.

doi: 10.12720/ijoee.1.2.97-101

Test results are presented in Section V. In the last part of the paper is conclusion with the future works.

II. RELEATED WORKS

Various studies have been presented over SLAM algorithms. EKF, FastSLAM and Gmapping are the most used SLAM algorithms in indoor or outdoor scenarios [8].

Within all SLAM algorithms, most of these studies require odometer information and distance measurements as a minimum requirement to execute the algorithm. To dispose the necessity of odometer information, scan-matching methods are used in some studies such as [11]. Hanhel et al. is used Rao-Blackwellized particle filter as a SLAM algorithm and scan-matching method for calculating the odometer data from scan-matching process which is different from the approach of this study. In this study scan-matching is used to enhance the Gmapping algorithm with pose estimation and odometer information is not used.

The approach presented in [12] is to generate map and localize robot using single data from LIDAR. In the same study, Iterated Extended Kalman Filter (IEKF) algorithm was used to generate map and to solve the localization problem. IEKF is used without odometer information and it maintains mapping with single LIDAR sensor. The calculation cost of IEKF with covariance matrix calculation for each landmark is expensive from the approach of presented in this study. Difference is that the Rao-Blackwellized Particle Filter (RBPF) is estimating the posterior without keeping covariance matrices. The IEKF is the algorithm which works with one initial guess, when the RBPF is keeping N number of initial guess states and which increases the accurate pose estimation.

Another study in literature has made about map generation based on multi robot [13]. In the paper, the island-merging process was used by Howard et al. Maps are generated separately on each robot over the stage. The final map is represented after merging all separately generated maps.

In the same study, odometer data is required to form accurate map and to localize of the robots in the field. As each robot moves through the environment, odometer and laser data are used together to update the robot's current pose and to estimate the map [13]. The low cost solution as pre-mapping for mutli-robots could be one of the solutions for kidnapping problem.

Another technique used in SLAM is Scan Matching. The complexity of methods on scan-matching is depends on the number of scan points. Some approaches on the scan-matching methods are Iterative Matching Range Point (IMRP) [14], Iterative Dual Correspondences (IDC) and Polar Scan Matching (PMS).

The performance of the study made by Diosi et al. for PMS is sufficient, but the along corridor error was generally large because of two parallel walls of the corridor in polar coordinates, the match result is likely to drift in the direction of the corridor mentioned in paper [15].

Some other studies over this field are presented in [16]. In this study 3D laser for the scan-matching with Delayed State EKF algorithm for outdoor environment is used. Using existing 2D SLAM techniques, they underline several advantages, predominantly due to the probabilistic nature of the algorithm, maintaining a state vector of poses and corresponding pose uncertainties can be used to detect potential loop-closures [16].

One of the important steps presented in our paper is to generate a map, without odometer data. Detailed explanation about scan-matching and grid based mapping are presented in next section.

III. METHODS

The Scan-matching method and grid map based Gmapping algorithm for pose estimation and map generation are used in this study.

Mostly SLAM algorithms are based on a general probabilistic Bayes filter as in (1), using some measurements for estimating density of unknown probability. [17]

$$p(x) = \sum_{i=1}^{N} w_i \delta_s(x) \tag{1}$$

As a SLAM approach in this study, the Gmapping algorithm was used. It is based on Rao-Blackwellized particle filter (RBPF) to learn grid maps from laser range data. The joint posterior (2) between map m_t, and the state $x_{1:t} = x_1,\ldots,x_t$ of the robot is been estimated by using measurement data from laser scan $z_{1:t} = z_1,\ldots,z_t$ [17].

$$p\left(x_{1:t}, m \mid z_{1:t}, u_{1:t-1}\right) \tag{2}$$

EKF and other Kalman filter based algorithms are efficient for representing linearized distribution, but the RBPF is a better way to represent non-gaussian distribution, because in real world measurements are not linearly distributed, which is suitable for presented test environments [18]. Basic principle of RBPF is to set state of hypotheses, where each particle keeps state, with measurements obtained by laser sensor. Each landmark is associated to the corresponding particle. With given weights the strongest hypotheses is kept, after re-sampling the weak one is been omitted [19], [20].

Each state represents the posterior and each particle can be defined as a potential pose of the robot.

$$p\left(x_{1:t}, m \mid z_{1:t}, u_{0:t-1}\right) = p\left(x_{1:t} \mid z_{1:t}, u_{0:t-1}\right) * p\left(m \mid x_{1:t}, z_{1:t}\right) \tag{3}$$

Each particle filter can carry map and this particle is being selected with a probability proportional equation as in (3) to the likelihood of the observations relative to its own map.

The aim of this study is to obtain costless solution for one of the main localization problem of SLAM. To avoid control data for verification in defining the pose from odometer or other control data this study presents using the Gmapping algorithm without odometer data. The pose estimation is defining using single laser sensor data.

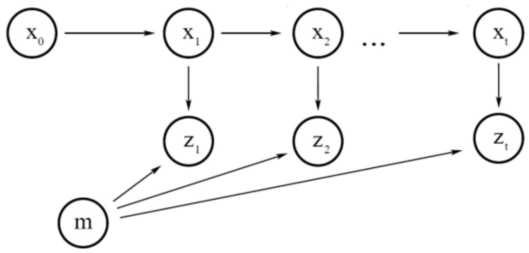

Figure 1. Diagram of gmapping algorithm without odometer data.

Fig. 1 shows the flow of the Gmapping algorithm without control data. For x_t defines state, z_t refers measurement and the m_t represents obtained map. As it seems in Fig. 1, the control data is not being used. The alternative for this solution also could be to define very small value for u=0.01, so the control will not affect to the calculation.

Main three steps used in this algorithm:

- Initial state guess. The pose is obtained from the previous pose with measurement z_{t-1}.
- Scan-matching algorithm obtains map m_{t-1} from initial state guess.
- Updates of particles.

Updates of these particles are based on measurements z_t. The map m_t of particle is updated relying on state x and measurement z_t.

Scan-matching is used to align current scanned map with constructed map. Scan-matching was used to align between current scan z_t with given initial state x_{t0} and map m_{t-1} [20], [21]. Scan-matching algorithm is been applied on map m_{t-1} starting from initial state x_t *(4)*. The algorithm is searching for aligning only on limited areas of state x_t.

$$x_t'^{(i)} = x_{t-1}^{(i)} \oplus u_{t-1}$$

$$\grave{x}_t^{(i)} = \mathrm{argmax}_x \, p\left(x \mid m_{t-1}^{(i)}, z_t, x_t'^{(i)}\right) \qquad (4)$$

The particles with high hypotheses of state x_t *(4)*, is being selected by scan-matching. According to this result the next state is been calculated according to (5).

$$p\left(z_t \mid m_{t-1}, x_j\right) \rightarrow p\left(x_j \mid x_{t-1}, u_{t-1}\right) \qquad (5)$$

At this step the weights are been computed by the normalizer in (6).

$$n^{(i)} = \sum_{j=1}^{K} p\left(z_t \mid m_{t-1}^{(i)}, x_j\right) p\left(x_j \mid x_{t-1}^{(i)}, u_{t-1}\right) \qquad (6)$$

The map m_t of particle at t is updated according to the state x_t and the measurement z_t [22].

IV. System Design

Approach of this study is to minimize the calculation cost of Gmapping algorithm and design a portative handheld system to generate pre-map based on combine solution of Gmapping and scan-matching methods together. Gmapping with fewer parameters and scan-matching algorithms which are amplified in section III, executed on the designed portative system to form pre-maps and pose estimations based on single laser range scanner. This process should be completed in short time because of pre-mapping concept.

Within all system, the lithium battery as power unit, mini PC as Central Processor Unit and Laser Sensor as Long Distance Range Measurement Unit are used.

FitPC [23] selected as core unit to execute Gmapping algorithm and scan-matching method. FitPC is characterized as minicomputer based on Intel architecture with 1 GB ram and 1.6 GHz CPU [23]. System configuration is sufficient to run algorithms because of fewer parameter necessities when compare regular Gmapping detailed in section III. Hokuyo URG-04 LX as a laser sensor for getting measurements used in algorithm. The main differences between laser sensors are about maximum distance capability in measurements and angle disparity range. Specifications of the sensor used in the study are 240 degree scan angle and 4 meter detection of distance range [24]. System design is shown in Fig. 2a. Fig. 2b is taken while testing designed pre-mapping handheld system with the algorithm on labyrinth arena. All test results will be presented in next section.

Figure 2a. Hardware Design

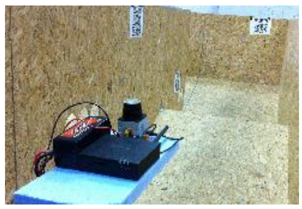

Figure 2b. Test arena

V. Test Results

Portative handheld pre-mapping system with algorithms tested in three different environments with distinctive scenarios. Number of tests can be raised according to the intention. Main purpose in adopted tests is to observe the alteration occurred on maps generated by algorithm depended on laser data for pre-mapping. Tested areas are selected to observe maximum effects of sensor data on algorithm while doing pre-mapping.

First test area shown in Fig. 3a is designed as a labyrinth. After measurements gathered from laser sensor, algorithm is executed on local minicomputer in handheld system. Generated pre-map is shown in Fig. 3b after promenading on test arena. The main reason of testing the system in labyrinth is to evaluate the performance of

Gmapping algorithm for mapping and Scan-matching method for pose estimation in narrow environments. Also combining of this information, to see localization of the handheld system is another purpose. Created map has strict walls because of Gmapping algorithm underlying grid base mapping. Grid base mapping gives successful results when correct measurements come from laser sensor. In this scenario, laser gathers exact data easily regarding to distance between walls. Moreover pose estimations are mostly accurate in each step of labyrinth. Otherwise scan-matching could affect the allocation of the walls. Pose estimations made by scan matching method as cited in Section III. Scan-match gives reasonable success rate when exact data comes from laser sensor as well as grid-based mapping algorithm.

Figure 3a. Test Arena I - Labyrinth

Figure 3b. Generated Map

Another testing area is classroom environment with long corridor and coordinated tables. Classroom arrangement and information about the dimension can be seen in Fig. 4a. Dimensions of the environment are given since created maps accuracy is directly related with this information. The pre-mapping result of test arena can be observed in Fig. 4b generated by handheld system.

System was promenaded in a manner of 15cm above from the floor and between the desks. Reason of this manner is to see effects of symmetric data information coming from laser on generated map owing to allocation of all legs of the desks are in a symmetric settlement. Direction of system's promenade is signed with arrow in Fig. 4b. Legs of the tables are also has been defined as an obstacle by the algorithm because of the altitude of handheld system with small pose estimation error. Most part of the promenade has correct pose estimation by scan-matching algorithm. Errors occur depending on complicated data caused by symmetric legs settlement of the desks. Scan-matching has fallen in conflict when symmetric information comes and that caused mismatch of landmarks. This conflict can be seen in the back row desks. Desks' legs assumed as wall by scan-matching because of long time duration in generated pre-map.

Another approach of this test is to observe the effects of distance measurement information coming from different angles on generated map based on grid based mapping. At this point, dimensions given on Fig. 4a is playing effective role. Fig. 4b shows that the limits of laser sensor in distance range can effect on generating map. That effect occurred on generated map in left side over 4 meter distance as tarnishing. Over 4m range, laser gather insufficient data because out of range. It is merging immediately and map is generated with lack of all data. On the other hand, same algorithm can generate success map when the data is enough as seen in Fig. 4b. Under 4m distance areas are drawn in a success way.

Figure 4a. Test Arena II - Classroom

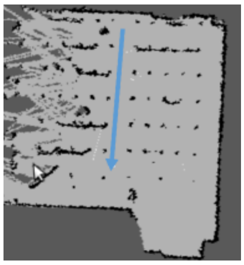

Figure 4b. Generated Map

Final test is applied on the crowded exhibition area. Area as shown in Fig. 5a is full with stands and wider when compared to the labyrinth. The hall's width is 2.4 meter. Turning points of connected halls has 3m for one side and 7m for another side to the wall. The handheld system was promenaded in these two halls and the connection point of them. The generated pre-map on the remote computer is shown in Fig. 5b.

Figure 5a. Test Arena III – Exhibition

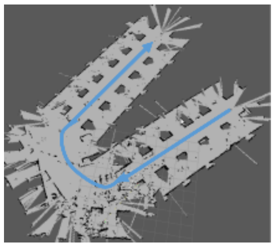

Figure 5b. Generated Map

Main goal is in this test to evaluate performance of the algorithm on both corners and halls. This test represents combination of the previous tests. Grid based mapping generates maps at the moment of t with the information of $t-1$ as proved in section 3 (8). In this scenario, tarnishing is expecting because of wide angle turning points of halls as can be seen in Fig. 5a, but also there is some priority information from hall used in algorithm. Halls created on generating map in a success way. Also stands recognized as obstacles as seen on Fig. 5b. But tarnishing occurred when laser data is insufficient where the turning point starts. But algorithm concluded success one side because of some priority information. This can be seen on generated map at the connection point. On the other hand, another side much tarnished than previous test because of 7m distance. Over 5m distance, neither laser gathers any data nor grid based map algorithm works. There is only scan-matching algorithm tries to build the map on grid based map learning. Aligning with the previous and the next results of scan matching generates this map. Also scan-matching algorithm can't estimate pose accurately when no data coming from laser sensor at the corners. In the holes, more success has been observed but when pre-mapping tests come to the corners, this estimation error raises. Within all test in area, poses were slip several times because of wrong scan matching points. This also caused localization losing of the system on the map. As it can be seen on generated pre-map, halls are not parallel because of wrong pose estimation. Accurate overlapping process cannot be done with the discontinuous data coming from the laser sensor because of exceeding sensor range distance on scan-matching also.

VI. Conclusion

In this paper, Gmapping algorithm and Scan-matching method for mapping and localization based on single laser sensor data without odometer information was presented. Besides the algorithm, a system design is also developed to execute algorithms with fewer parameters. Main purpose of the system is to produce a pre-map of the area based on those algorithms. The pre-mapping system can be a solution for chicken-egg problem in SLAM and a solution for kidnapping problem in localization. With obtained pre-mapping, exploration of an environment for autonomous robots is much easier and navigation algorithms over the known map are more effective. The study aims to offer a pre-mapping solution for this type of applications. As a future work, it is planned to use this pre-mapping handheld system to realize an autonomous search and rescue robot. Improvements will be examined in terms of exploration, navigation and mapping algorithms in similar.

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