International Journal of Interdisciplinary Innovative Research & Development (IJIIRD)

ISSN: 2456-236X

Vol. 03 Special Issue | 2019

Simultaneous Localization and Mapping (SLAM)

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ABSTRACT

Simultaneous localization and mapping (SLAM) is a technique applied in artificial intelligence mobile robot for a self-exploration in numerous geographical environment. SLAM becomes fundamental research area in recent days as it promising solution in solving most of problems which related to the self-exploratory oriented artificial intelligence mobile robot field. For example, the capability to explore without any prior knowledge on environment it explores and without any human interference. The unique feature in SLAM is that the process of mapping and localization is done concurrently and recursively.

The aim of this paper is to provide an insightful review on information background, recent development, feature, implementation and recent issue in SLAM.

Keywords—Mobile Robot, self-exploratory, SLAM Simultaneous localization and mapping.

1. INTRODUCTION

In a past few decades, lots of research that focus on the autonomous navigation of mobile robots has been done. The objective is to find the best technique or solution to makes the robot capable to autonomously navigate without any prior knowledge on the environment it explores. In robotic field, autonomous robot becomes current most successful achievement as the robot itself able to perform tasks or behavior without human interference such as self-exploration. The objective of the robot is to self-explore on the unknown environment and avoiding the numerous landmarks and obstacles within the environment. For example like an exploration in grounded area such as terrain, sea, aerial space and any places which possibly unreachable or potentially harmful to human can be done by the autonomous mobile robot.[7] the SLAM concept is considered as one of the keys towards truly autonomous robots, and as such is an essential aspect of self-driving cars. However, many issues are still preventing the use of SLAM algorithms with vehicle and robot that should be able to drive for hundreds of kilometers in very different conditions.

Autonomous robot is a robot that capable to act and perform the designated tasks itself without the human interference. The autonomous robot or more scientifically called as artificial intelligence robot able to 'think' when making decision and 'act' based on the decision make. The mobile robot will know how it should move and 'act' to move as a response. It normally obtained the raw data that captured by the mobile robot hardware devices such as laser sensor, sonar sensor or camera.

2. IMPLEMENTATION

A SLAM objective is to make robot relatively generate a consistent map of an environment and at the same time use the generated map to estimate the location of the landmarks and robot. An interesting fact of SLAM is that it does not require any prior knowledge of mobile robot and landmarks location since the platform trajectory and landmarks location are estimated and computed online. Suppose a robot exploring through and environment, using a sensor device to observe and estimate the landmark location in the environment. Figure 1 shows the SLAM fundamental implementation that depicts the SLAM state of the art.

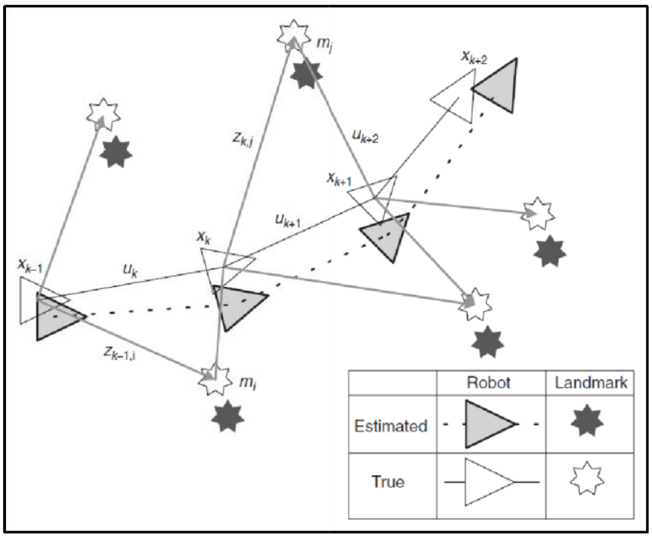

Fig. 1. SLAM state of the art

Based on the Figure 4, both robot and landmarks location are estimated simultaneously. A true robot and landmarks location are unknown and not measured. Observations done are between true robot and landmark locations. Following variables are defined at time *k[2]*

k :Time instant

x_k : Robot Location

X_k : Sequence of robot location

u_k : Odometry between time k-1 and k

U_k :Sequence of Robot Odometry.

m_i :Map of the comprised of landmarks, objects, surfaces and their respective locations.

Z_k :Sequence of measurements between robot and landmarks assuming one measurement per time step.

For robots, x_k are comprises of its position in the plane (Two dimension vector) and orientation in the plane (Third dimension vector). For the robot path X_k, it is taken from time $k = 0$ and defined as:

$$X_k = \{ x_0, x_1, x_2, x_3, ..., x_k \} \quad (1)$$

For the relative motion U_k between two time steps, k - 1 and k, it is defined as:

$$U_k = \{ u_0, u_1, u_2, u_3, ..., u_k \} \quad (2)$$

It is not appropriate to relied only on robot odometry U_k to determine robot location within a plane because in real application, it suffers the lack of precision required for accurate localization.[7] It is due to the structure of environment surfaces and robot misbehaves action such as wheel slippage. Taking into consideration, robot cannot only depend on odometry measurement alone but also relies on continuous sensory measurement Z_k for more accurate true location estimation. The sequence of sensory measurement Z_k per time step is defined as:

$$Z_k = \{ z_0, z_1, z_2, z_3, ..., z_k \} \quad (3)$$

Once all the required information are obtained and defined, next steps are building a map view of environment and location prediction. SLAM technique is using probabilistic approach which applies a probability distribution to predict the robot and landmarks location from the generated map. The probability distribution form, P is defined as:

$$P(x_k, m \mid Z_k, U_k) \qquad (4)$$

From here, it can be read as the probability of the position at time k and map given the history of measurements and odometry data. In addition, it also requires additional relationship, which is observation model. Observation model identifies the relationship between the robot position x_k and odometry u_k which is defined as:

$$P(\, x_k \,|\, x_{k-1},\, u_k \,) \qquad (5)$$

Another model required is motion model. Motion model identifies the relationship between sensory measurements z_k, map environment m and robot position x_k which is defined as:

$$P(\, z_k \,|\, x_k,\, m \,) \qquad (6)$$

In general application, robot is able to detect landmark range, relative direction and the unique identity in typical environment. These understanding can be used as a basis to derive a measurement model. By applying probability distribution into measurement model, it can be defined as:

$$P(\, z_k \,|\, x_k,\, m \,) \sim N(\, h(\, x_k,\, m \,),\, Q_k \,) \qquad (7)$$

where $h(\, x_k,\, m \,)$ is an arbitrary function that represent sensory equipment operation, N is two dimensional normal distribution and Q_k is two dimensional noise covariance. Function h returns a computed measurement by using the position and environment map as inputs.

For the motion model, a normal distribution is applied which focuses on kinematic motion model covariance. The motion model derivation is defined as:

$$P(\, x_k \,|\, x_{k-1},\, u_k \,) = N(\, g(\, x_{k-1},\, u_k \,),\, R_k \,) \qquad (8)$$

where $g(\, x_{k-1},\, u_k \,)$ is standard kinematic function and R_k is a three dimensional noise covariance. Function g combine previous position x_{k-1} and the position changes in terms of odometry u_k to return the new position x_k.

The robot will update its position and landmark measurement at previous time step k - 1 with improved precision from the data it gathers from other landmark and previous robot position at time step k. The process is done continuously to update the robot measurement until the robot finish its exploration in the environment.[7]

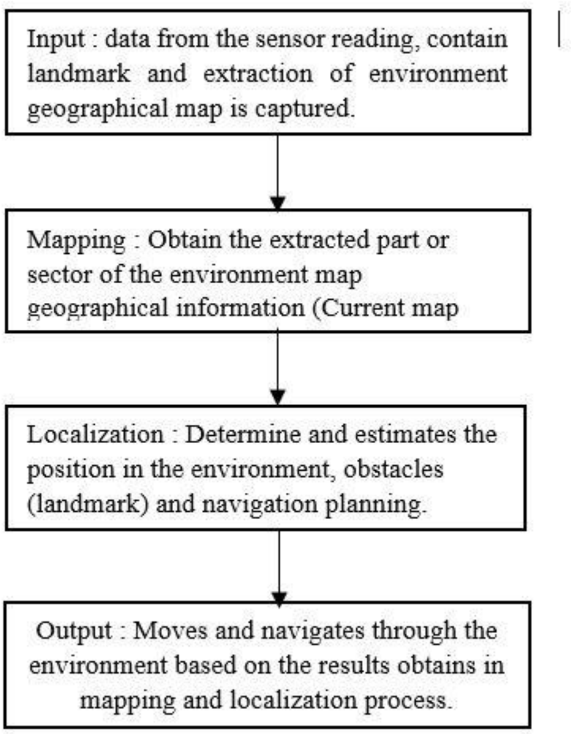

Fig.2 General steps perform in autonomous mobile robot

3. LIST OF METHODS

1. EKF SLAM
2. FASTSLAM 1.0
3. FASTSLAM 2.0
4. L-SLAM (MATLAB CODE)
5. GRAPHSLAM
6. OCCUPANCY GRID SLAM
7. DP-SLAM
8. PARALLEL TRACKING AND MAPPING (PTAM)
9. LSD-SLAM (AVAILABLE AS OPEN-SOURCE)
10. S-PTAM (AVAILABLE AS OPEN-SOURCE)
11. ORB-SLAM (AVAILABLE AS OPEN-SOURCE)
12. ORB-SLAM2 (AVAILABLE AS OPEN-SOURCE)
13. ISAM (INCREMENTAL SMOOTHING AND MAPPING) ETC…

4. SENSOR THEORY

The sensors used in this thesis are a gyroscope, wheel encoders, and a LIDAR. The measurements from these sensors provide the necessary input to the SLAM algorithms. The SLAM algorithms will process this data in order to present a map of the surrounding environment, including the pose of the vehicle positioned within the map. The following sections will provide a description of each sensor mentioned.

4.1 Gyroscopes

Gyroscopes have been widely used for military and civilian purposes the last century. Not only for aeronautical purposes but also by the marine. The traditional gyroscopes used to be mechanical. However, what is being used in many applications nowadays are MEMS gyroscopes (micro-electro-mechanical systems), which are being used in cell phones, robotic projects, and for military purposes.Gyroscopes in general can be described by the the formula of Coriolis force $Fc = -2 * m * (\omega * v)$ As can be seen from the Coriolis force is depending on the mass m of an object, the angular velocity ω as well as the velocity v of the object. This object is a part of the gyroscope and the mass of the object as well as the velocity of the object are known. Given that the object rotates, and by having information about the mass and velocity of the object the angular velocity can be detected. Given the angular velocity, the total angle that the vehicle has rotated can be calculated as a = Z t 0 ψdt [8].

4.2 Wheel encoders

Wheel encoders are being used to provide the microcontroller with information about the velocity of the vehicle. There are several different types of wheel encoders based on different technologies, such as, optical wheel encoders, mechanical as well as magnetic wheel encoders just to name a few. In this thesis a magnetic wheel encoder is being used which consists of a Hall Effect sensor and a number of magnets. The Hall effect sensor outputs a high voltage level whenever the magnetic field surrounding it is sufficiently strong, (a magnet passing by). The pulse outputted by the Hall Effect sensor is being registered by the microcontroller. By counting the number of pulses generated since the previous sampling instance, the microcontroller is able to estimate the speed of the vehicle.[8]

4.3 Laser range finder

Laser Range Finders (LIDAR) can be used to measure the distance to objects in the vicinity of the vehicle. A laser range finder consists of a laser emitter and receiver, and is sometimes mounted on a rotating motor in order to measure distances in every direction of the vehicle. The basic operation principle is that a short pulse of light is emitted, reflected on an object, and then received. The time twait between the emitting and receiving can then be used to calculate the distance d to the object as[8]

$d = 1/2\, ct_{wait}$ where c is the speed of light.

5. FEATURE OF SLAM

There are three main features in SLAM that is mapping, localization and navigation.

5.1 Mapping (Environment Representation)

Before the mobile robot starting to explore or navigate in unknown environment, it requires map on the environment it want to explore as prior knowledge. Mapping gives capabilities for mobile robot to generate a map of the environment using the hardware sensor to receive the data of the environment.[1] From the data, a map is generated and the types of map representation are topological, geometric, grid or mixed map.[2] Then, it will be used by mobile robot to localize and recognize its own position and landmark.

5.2 Localization (Location Estimation)

Localization is one of the SLAM features as the mobile robot able to calculate and estimate landmark position and mobile robot trajectory based on the generated map from the mapping process.[2] Localization means that the mobile able to 'think' itself by calculating and estimating it trajectory, landmark location and able to recognize nearby obstacles based on the information received from the mapping process. Localization makes the robot able to recognize its own location, surrounding environment and avoid any nearby obstacles.

5.3 Navigation (Path Planning)

These features combine both mapping and localization features where the mobile robot makes an appropriate path planning from the information received during mapping and localization process. As the mobile robot navigates throughout the environment, mapping and localization process were executed recursively in order to update the mobile robot knowledge on surroundings environment. The mapping and localization process are to ensure that the mobile robot be able to navigate on surrounding environment efficiently. The characteristics of navigation planning made by the mobile robot are make appropriate path based on information received, response to surrounding environment and be able to backtrack to origin point or starting point after exploration.

6. ISSUE IN SLAM

There exist several major issues arise in SLAM that is uncertainty, correspondence, data association and time complexity. Each problems mentioned will be discussed to point out it impacts to the SLAM.

6.1 Uncertainty

In uncertainty, there are two major issues known as location and hardware uncertainty [5]. Both issues hugely affect to the SLAM capabilities in performing it functionality. Location uncertainty is one of the difficulties faces by SLAM as it determines how capable the mobile robot can handle the multiple paths happens in environment location. It is simple for the mobile robot to move from one point to another point in single linear path and trackback to origin point as it path is linear and easily recognized [4]. However, in real environment, there are multiple paths for the mobile robot to travel and navigate in environment form one point to another. Hence, such problem causes the high degree of location uncertainty for the mobile robot to choose the appropriate path and recognize it actual or absolute position. In hardware uncertainty, noises of hardware used in the mobile robot components lead to the information extracted were inaccurate [4]. Such inaccurate information received will be calculated and processed to recognize the mobile robot position, landmark and other related information.

6.2 Correspondence

Correspondence is considered as the biggest problem faces in SLAM since these problems greatly affect the landmark identification process in SLAM. The reason is that how capable of the SLAM to distinguish one particular landmark are unique and different from other identified landmarks [6]. For simple example, two different obstacles (landmarks), like two rocks, which is rock A and rock B. Both rocks have similar shapes but the only different is that rock A are slightly bigger than rock B. Human can easily recognize the difference but not the robot. As we know, mobile robot does not have a human ability to differentiate landmark identities easily, which is why it heavily depends on the hardware to view or measured the environment [4]. Due to the environment information were extracted from mobile robot hardware such as laser sensor, it is difficult for the mobile robot to recognize the new landmark whether it is differ or same from previously observed landmark.

6.3 Data Association

In data association issues or problem, it does concern on the SLAM capabilities to makes the mobile robot able to return to its origin point or previously mapped area after a long exploration of the environment [5]. The difficulties part were point out when the mobile robot attempt to associate the current landmark with previously observed landmark in order to return to previous origin point or mapped area. Data association process was used to estimates the landmark correspondence of mobile robots to backtrack to its origin point based on the previous map and identified landmarks [6].

6.4 Time Complexity

Time complexity issues is about the difficulties or problem rise is the how fast the implemented SLAM algorithm or methods to process, calculate and compute the received information to produce expected results that will be used by the mobile robot [5]. As we know, SLAM carries out mapping and localization process concurrently and recursively during navigation. Such multiple processes executed concurrently in a short amount of time need to be handled and managed effectively. Hence, the performance and time complexity of the SLAM algorithm or methods become the key element to produce reliable results for the mobile robot to successfully explore the environment and reducing the error rate [6].

7. FUTURE SCOPE

SLAM is the core of most robots trying to navigate autonomously today. Coming to the future, we see SLAM still being relevant with added improvements in methods as more research is done in the field. A little farther ahead in the future there might be techniques that take a new perspective on the problem and solve it better, but I think that will be really far in the future (say 20–40 years) and for that to be implemented in mainstream products would take even longer. SLAM would still be relevant but in a different form than we are familiar with today. Since SLAM is such a fundamental problem it would still be relevant similar to how understanding Newton's gravitational model is still relevant to understanding relativistic models.

So, in the future we see it being used extensively for a lot of autonomous navigation tasks even more than it is now.

8. CONCLUSION

SLAM technique becomes a huge achievement in solving the autonomous mobile robot problem and it considered as 'holy grail' in artificial intelligence mobile robot fields. The effectiveness of the SLAM in solving problem of mobile robot mapping and localization really gives a huge contribution to the self-exploratory oriented mobile robot

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