Simultaneous Localization and Mapping

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***Abstract* – This paper presents an approach for unknown indoor environment exploration using a simultaneous localization and mapping system. SLAM is the process by which a mobile robot can build a map of an environment and at the same time use this map to compute its own location. We propose a SLAM system using ARDUINO board. The algorithm accuracy in the real scenario test is not comparable to more complex EKF-SLAM algorithm. SLAM is a technique applied in artificial intelligence mobile robot for self exploration in numerous geographical environments. 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.**

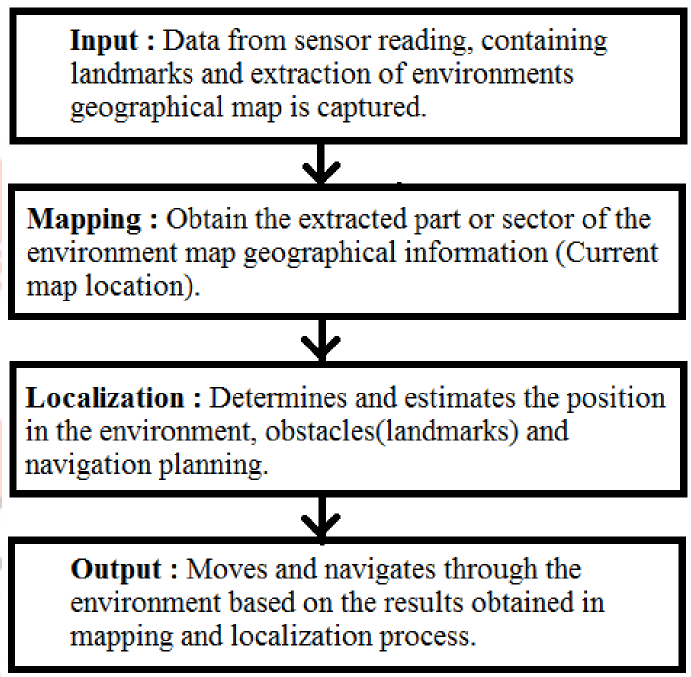
I. INTRODUCTION

Autonomous mobile robot which is an intelligent agent must be able to explore and navigate through any kind of environment either it is known or unknown without any human interference in order to achieve its desired goals. Leonard and Durrant-Whyte [1] summarized the problem of navigation into answering these questions:
"Where am I?", "Where am I going?" and "How should I get there?"

The first question is about localization problem, which intend to obtain robot's pose estimations based on data obtained from robot's sensors and previously obtained information about the environment. The second question is specifying a goal and the third question is being able to do path planning to achieve the specified goal.

Thrun[2] stated that in order to build truly autonomous mobile robots, one of the most important problems is the mapping problem. During localization problem, the mobile robot need refer to some reference system and a map is required to be constructed for its navigation purpose. By solving these two problems together, robot's pose and the map of the environment can be estimated and this solution is known as Simultaneous Localization and Mapping. It is a problem that if a mobile robot is placed in an unknown location in a prior unknown environment, the mobile robot is able to build a map of the environment using local information perceived by its sensor while estimating its position within the map simultaneously[3, 4].

Many researches were conducted to make the mobile robot able to explore without any prior knowledge on environment it explores, increasing the estimation accuracy and reducing the error occurs during exploration. Several techniques have been introduced in finding the suitable technique to solve challenges faced in autonomous mobile robot as mentioned earlier. Nowadays, SLAM became the fundamental element in most recent study conducted in robotic field. Figure shows the basic concept of how the autonomous mobile robot works.



General steps performed in SLAM

This paper is organized as follows. Section II reviews the SLAM background and its process overview. Section III discuss about recent development of SLAM. Section IV explains about SLAM features. Section V is about issues in SLAM. Section VI is the paper conclusion.

II. SLAM

Simultaneous Localization and Mapping is a technique used for mobile robot to build and generate a map from the environment it explores. The process of mapping and localization in SLAM is done concurrently where the mobile robot relatively creates the map. The created map is used to calculate and estimate landmark position and mobile robot trajectory [2]. SLAM advantage is that it able to generate geometrically consistent environment map and localized robot position and landmark concurrently. These became the major factors which make SLAM the most appropriate technique in autonomous mobile robot field [3].

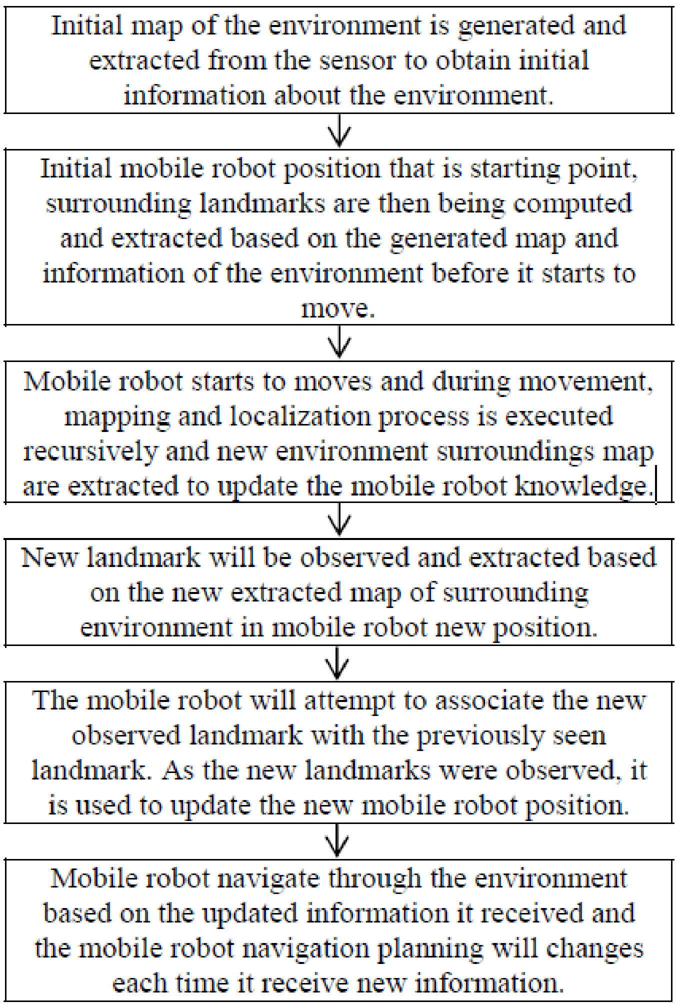
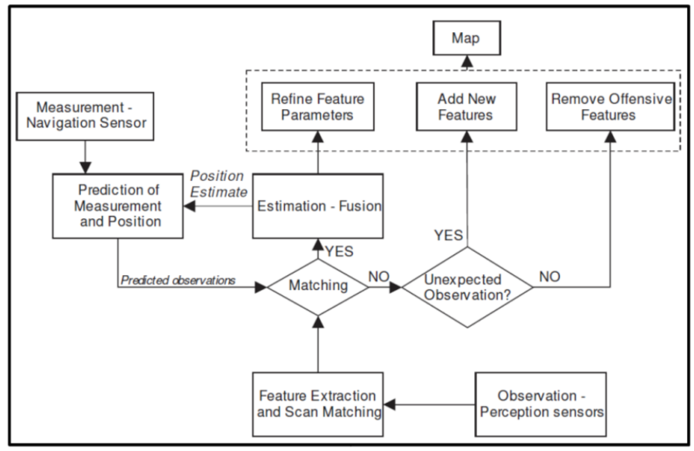


Fig. 2. SLAM process overview

The idea of SLAM problem was introduced in [1] which originates or inspired from the previous work done in [4]. Work done in [1] introduced the first SLAM algorithm called as EKF-SLAM. This SLAM algorithm implements an EKF method in solving the SLAM problem. The approach was using probabilistic method to limit the impact of inaccurate sensor reading on the accuracy of reading map of mobile robot [5]. Since that, it became the standard implementation in SLAM and most of the new SLAM methods introduced also implement EKF method in solving the SLAM problem. Figure 2 shows the overview of SLAM process and figure below shows block diagram of SLAM process.



III. EVOLUTION OF SLAM

The conceptual break-through came with the realization that the combined mapping and localization problem, once formulated as a single estimation problem, was actually convergent. Most importantly, it was recognized that the correlations between landmarks, that most researchers had tried to minimize, were actually the critical part of the problem and that, on the contrary, the more these correlations grew, the better the solution.

Through the past decades since the introduction of SLAM technique in artificial intelligence mobile robot, SLAM continues to evolve exponentially. The evolution of SLAM keeps continues until today to improve the efficiencies and qualities of SLAM algorithm in terms of precision, estimation and error rate reduction.

In 1986, the work done in [4] introduces the concept of implementing the estimation of spatial uncertainty at IEEE Robotics and automation Conference in San Francisco. It became the starting point to the pre-development of SLAM technique. Then in 1991, [1] develop SLAM technique based on the precious work done in [4] which using probabilistic approach in solving SLAM problem. This work introduces the implementation of Extended Kalman filter which later introduced the first SLAM algorithm that is EKF-SLAM.

Year	Work	Author
2002	FastSLAM algorithm	M. Montemerlo, S. Thrun, D. Koller, and B. Wegbreit
2006	Square Root Smoothing and Mapping (SAM)	F. Dellaert and M. Kaess,
2008	UFastSLAM	C. Kim, R. Sakthivel, and W. K. Chung,
2009	Differential Evolution technique.	L. Moreno, S. Garrido, D. Blanco, and M. L. Muñoz

IV. FEATURES OF SLAM

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

A. Mapping (Environment Representation)

Before the mobile robot starting to explore or navigate in unknown environment, it requires map of the environment. Mapping gives capabilities for mobile robot to generate a map of the environment using the hardware data sensor to receive the data of the environment. From the data, a map is generated and the types of map representation are topological, geometric, grid and mixed map [3]. Then, it will be used by mobile robot to localize and recognize its own position and landmark.

B. 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 [3]. Localization makes the robot able to recognize its own location, surrounding environment and avoid any nearby obstacles.

C. Navigation (Path Planning)

This feature combine both mapping and localization feature 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 surrounding environment [2]. 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.

V. ISSUES IN SLAM

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

A. Uncertainty

In uncertainty, there are two major issues known as location and hardware uncertainty [7]. Both issues hugely affect to the SLAM capabilities in performing its functionality. Location uncertainty is one of the difficulties faces by SLAM as it determines how capable the mobile robot can handle the multiple paths happen 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 [6]. However, in real environment, there are multiple paths for the mobile robot to travel and navigate from 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 [6]. Such inaccurate information received will be calculated and processed to recognize the mobile robot position, landmark and other related information.

B. 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 [8]. 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 is 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 [6]. 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 different or same from previously observed landmark.

C. 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 [7]. 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 [8].

D. 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 [7]. 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 [8].

VI. CONCLUSION

The problem of simultaneous localization and mapping has seen great progress over the last 30 years. Along the way, several questions have been answered, while many new and interesting questions have been raised, as the result of the development of new applications, new sensors, and new computational tools.

We are entering in the robust-perception age, which poses a new and broad set of challenges for the SLAM community, involving four main aspects: robust performance, high-level understanding, resource awareness, and task-driven inference.

From the perspective of robustness, the design of failsafe, self-tuning SLAM systems is a formidable challenge with many aspects being largely unexplored. For long-term autonomy, techniques to construct and maintain large-scale time-varying maps, as well as policies that define when to remember, update, or forget information, still need a large amount of fundamental research; similar problems arise, at a different scale, in severely resource constrained robotic systems.

SLAM systems are not able to provide a tightly-coupled high level understanding of the geometry and the semantic of the surrounding world; the design of such representations must be task-driven and currently a tractable framework to link task to optimal representations is lacking.

SLAM still constitutes an indispensable backbone for most robotics applications and despite the amazing progress over the past decades, existing SLAM systems are far from providing insightful, actionable, and compact models of the environment, comparable to the ones effortlessly created and used by Humans.

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