Simultaneous Localization and Mapping Literature Survey

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Abstract- *This paper presents the state of the art in Simultaneous Localization and Mapping. SLAM has been a constant research subject for the last thirty years due to the necessity of determining the position and the path of a robot in an uncertain environment. The following paper addresses different methodologies for implementing solutions to the SLAM problem. In particular we plan to research the simultaneous localization and mapping of an autonomous vehicle with ultrasonic sensor and camera [2], [3], [4]. This paper presents also two new optimized algorithms: the differential evolution algorithm and the Unscented FastSLAM algorithm for determining the position and direction of a conveyance device that is moving in uncertain surroundings. Furthermore we will review a proposed method for measuring the accuracy of the most known techniques used in determining the trajectory of an autonomous robot in an unknown environment. It appears that there is no definite solution to our problem even if the research has been ongoing for the past three decades in this field. Due to the numerous uncertainties and the computational complications that arise from these methods it becomes obvious that when dealing with large spaces and moving objects there isn't an established solution to mapping and consequently the trajectory of the robot is still variant upon the environment.*

Key Words: SLAM, Autonomous vehicle, Unmanned aerial vehicle (UAV), Information filtering (IF), Particle Filter

I. Introduction

The field of robotics is still missing a general acknowledged solution to solving the SLAM problem. SLAM represents the simultaneous localization and mapping by a robot of the surrounding space. In the past decades a tremendous effort has been put in finding a perfect solution to this problem due to the necessity of building autonomous vehicles used in fields like search and rescue, entertainment or transportation. These autonomous vehicles should be able to determine their position relative to a map that they are able to generate. When the position of the robot is known relative to the space that surrounds him, the problem is less complicated since it has limited computational complexity [5] and the only errors that are taken in consideration are the ones coming from the sensor that evaluates the environment. This problem expands when the initial position of the robot is not known and besides the uncertainty of the map quality we have to take in consideration approximations and possible errors in determining the actual position of the robot [8].

Another unknown that we are dealing with when talking about space recognition and mapping is the sensor employed for such a task. Laser-based, sonar based or vision based sensors are the ones that stand out and were most used by researchers [1].All of them have advantages and disadvantages. The most recent focus is on vision based sensors since they offer the highest resolution and a good range but that comes with the disadvantage of complications in processing the output of the sensor.

The algorithms used for solving the SLAM problem can be divided in three categories. The first category uses a covariance matrix combined with an extended Kalman filter. It is known that this method has two problems: one is known as the scaling problem which refers to the computational complications and the second one is the convergence problem that refers to data association. The second category of algorithms is based on Rao-Blackwellized particle functions. These algorithms have the drawback of the correlation between the number of maps used equal to the number of particles in the filter. The second problem is in estimating the number of particles required. The third category is referred to as scan matching methods. These methods are not very useful since they are limited to improving odometer data [5].

The remainder of this paper is organized as follows: In section II we will review in detail the latest algorithms proposed. In section III we will segment the research done and the field and emphasize what has been done after 2008.Section IV will present conclusions and directions suggested for future research.

II. Overview of the Previous Works

Mapping is a frequently studied problem in robotics literature. For mobile robots mapping can be classified according to the underlying estimation techniques used in building that chart. The most popular approaches are described below;

SLAM represents the simultaneous localization and mapping by a robot of the surrounding space.

The basic idea behind SLAM is to obtain a map of the environment and estimate where the robot is located within that map concurrently. Furthermore the map and the robot's pose both have to be estimated at the same time to accomplish the task well.

SLAM problem involves finding appropriate representation for both observations of the environment and the motion of the robot. In order to do so, the vehicle or robot must be equipped with a sensorial system capable of taking measurements between landmarks and the vehicle itself while it is moving in the map. It is also known as a Concurrent Mapping and Localization challenge. The aim of this paper is to introduce previous work on this issue, to list some advantages and disadvantages of current available techniques and also to identify gaps in research like possible new directions for improvement in future.

In 2001, a paper [11] was published by W.M Gamini Dissanayake which used MMW (millimeter waves) to build relative maps. EKF [12], EIF [13] and PF [14] methods might be sufficient for some applications to learn local maps only [15].

In addition, other papers focused in improving the way the information is received from the outside space and consequently the way that the map is estimated. The improved usage of ultrasonic sensor for detecting obstacles and walls for wheel-based robots for immediate localization was presented by Sungyoung Jung [16]. This algorithm showed high degree of accuracy and also could solve the "kidnapping" problem in a fast operating time. There are methods used to correct the poses of the robot based on the inverse of the covariance matrix [14]. The main advantage of SEIFs (sparse extended information filter) is that they make use of the approximate sparsity of the information matrix.

Another method was proposed in 2005, a smoothing method called Square root smoothing and mapping (SAM) [17]. Compared with EKF-based methods several advantages could be mentioned such as covering non-linearity and the speed in computing.

Differential Evolution Solution to the SLAM Problem [5] is the name of the other paper which presented a new solution for the SLAM problem and was published in 2007 by Luis Moreno and his colleagues. Chanki Kim provided a robust new algorithm based on the scaled unscented transformation called Unscented FastSALM(UFastSLAM) in 2008 [6].

Due to the necessity of having useful details and also perfect trajectory the research extended on the existing Kalman filter (EKF) [10].Besides EKF there is another method to solve SLAM which is called Information Filtering (IF) or Extended (EIF). EKF by approximating the robot motion using linear functions accommodates the nonlinearities from the real world. One of the advantages of IF over EKF is that the data is filtered by simply summing the information matrices and vector providing more accurate estimates [11]. Secondly, IF are more stable than KF. Finally, EKF is very slow when estimating high dimensional maps because every single vehicle measurement generally effects all parameters of the Gaussian, therefore the updates requires prohibitive times when dealing with environments with many landmarks [11]. For high dimensional state spaces the need to compute all these inversions is generally believed to make the IF computationally poorer than Kalman filter. In fact this is one of the reasons why the EKF has been vastly more popular than EIF. These limitations do not necessarily apply to problems in which the information matrix possesses structure [7].

There are by now a few examples of successful EKF SLAM implementations. Another popular approach is the FastSLAM method [6] which uses particle filters. Inconsistencies due to poor data association, linearization errors and particle depletion are the main disadvantages of both methods. Fortunately digital cameras are today ubiquitous and since their measurements are so accurate at very low cost in comparison with other sensors they have become very popular and commonly used. This reason has spawned a field in which the SLAM problem is solved only with cameras [9]. Without any other sensors measuring the platform dynamics, the image frame rate and the visual information contents in the environment are the only limiting factors for the ego motion estimation and hence the map quality.

Different cameras have been used in experiments. An omnidirectional camera can be used to estimate the distance of the closest color transition in the environment, mimicking the performance of laser rangefinders. These measurements are introduced into particle filter to determine the position of the robot within a previously constructed map. Eventually only one camera was used (called MonoSLAM). The proposed method, which takes place in real-time, extracts a reduced but sufficient number of salient image features through which are identified by their associated image, patches [18].

The Expectation Maximization based method (EM) is a statistical algorithm that was developed in the context of maximum likelihood (ML) estimation and it offers an optimal solution, being an ideal option for map-building but not for localization [5]. This way is useful and can build a map when the robot's pose is known, for instance, by means of expectation. The main advantage of EM over KF is that it can tackle the correspondence problem surprisingly well.

III. The Proposed Approach to the problem

This survey tries to identify the best method for solving the SLAM problem to compare advantages and disadvantages related to previous papers.

This survey is bringing insightful information on filtering techniques. As far as data association problem is concerned, it is well known that it is completely dependent on the ability to find proper features, which in underwater scenario is a considerably critical task, mainly because of amount of noise and errors, the dynamism of the environment and the lack of significant landmarks. In addition the use of vision to define landmarks seems to open a wide range of different possibilities and

The limitation that arises from using cameras comes from the dynamism of the robot environment, i.e. changes of location of other agents in the environment create a big challenge since there is no perfect algorithm that could be useful for dynamic environments.

IV. Summary

In this paper we reviewed traditional methods of solving SLAM such as Kalman Filtering Particle Filtering, EM and IF methods and we also analyzed some new methods which use cameras to build maps for mobile robots in unknown environments.

Obviously more research is needed since there is no perfect solution to the SLAM problem. When the environment is changing the system should adapt the mapping and the trajectory accordingly. The maps need to contain more details especially when dealing with noisy environments like water.

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