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SIMULTANEOUS LOCALIZATION AND MAP BUILDING FOR MOBILE ROBOTS

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Abstract—*It is shown that the efficiency of mobile robots depends on the solution of navigation problem and the most popular approach to the solution of it is Simultaneous Localization and Map Building – method used in mobile autonomous vehicles for map building in an unknown space or for map update in beforehand known space with simultaneous control of the current location and traveled distance. The solution of the simultaneous localization and map building problem based on Extended Kalman Filter.*

Index terms—Mobile robot; simultaneous localization and map building; Extended Kalman Filter.

I. INTRODUCTION

In modern world there is a great need in mobile robots. Mobile robots have the capability to move around in their environment and are not fixed to one physical location. Mobile robots can be autonomous. It is means that they are capable of navigating an uncontrolled environment without the need for physical or electro-mechanical guidance devices.

Autonomous robots are used in many areas of our lives.

Classification of robots:

– land or home robots;
– delivery & Transportation robots;
– areal robots;
– underwater robots;
– polar robots.

The mobility of robots is the degree to which robots are able to freely move through the world. The first practical use of robots was in industrial settings with so-called robot manipulators. These robots have the task to manufacture products like cars. They are programmed in such a way that they can repeat the same sequence of actions over and over again, faster, cheaper, and more accurate than humans. Typically they consist of a movable arm fixed to a point on the ground, which can assemble or manufacture different parts. Besides moving around this fixed point, the robots are not capable of moving freely and therefore they are not very mobile. If we want robots that can do everyday tasks like cleaning the floor or delivering mail, they will have to be more mobile than the robot manipulators. That is, they have to be able to move around freely in a world while performing their tasks.

Robot navigation is the task of an autonomous robot to move safely from one location to another. The general problem of navigation can be formulated in three points:

1) The robot has to know where it is in order to make useful decisions. Finding out the whereabouts of the robot is called robotic localization.

2) In order to fulfill some task the robot has to know where it is going. It has to identify a goal and this problem is therefore known as goal recognition.

3) Once the robot knows where it is and where it has to go it has to decide on how to get there. Finding a way to get to the goal is known as path planning.

The navigation task is difficult due to a number of complex problems. Some issues that complicate navigation are limits on computational power, difficulties in detecting and recognizing objects, difficulties in avoiding collisions with objects, and the difficulties involved in using information provided by the environment.

Robots need to recognize structures like objects and landmarks in order to be able to perform their tasks. If these structures in an environment are not known in advance, image processing may need a lot more computational power than if the structures are known. Also, solutions that work in environments with known structures may not work if the structures are not known. Whether or not structures are known in advance or not, recognition of these can come with a significant amount of uncertainty.

At all costs robots should avoid colliding with the obstacles in their environments. In dynamic environments, that is, where there are multiple moving obstacles, obstacle avoidance is a difficult problem. Although the dynamics of moving obstacles can sometimes be predicted, like when trains run on a track, sometimes the dynamics may be more uncertain, like playing children running around. A robot uses path planning techniques to plan a collision free path from one location to another location. If the obstacles in the environment are dynamic, the path planning problem is NP-hard

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An important component of mobile robots is navigation. Robot's navigation means the robot's ability to determine its own position in its frame or reference and then to plan a path towards some goal location. In order to navigate in its environment, the robot or any other mobility device requires representation, i.e. a map of the environment and the ability to interpret that representation.

In this article will be considered the simultaneous localization and map building (SLAM). Simultaneous localization and map building is a process by which a mobile robot can build a map of an environment and at the same time use this map to deduce it's location. In SLAM both the trajectory of the platform and the location of all landmarks are estimated on-line without the need for any a priori knowledge of location. Robot location and map estimation are highly correlated and cannot be obtained independently. The full covariance matrix needs to be maintained and updated following each observation.

II. PROBLEM STATEMENT

Consider a mobile robot moving through an environment taking relative observations of a number of unknown landmarks using a sensor located on the robot.

At a time instant k, the following quantities are defined:

x_k is the state vector describing the location and orientation of the vehicle;

u_k is the control vector, applied at time $k-1$ to drive the vehicle to a state x_k at time k;

m_i is a vector describing the location of the ith landmark whose true location is assumed time invariant.

z_{ik} is the an observation taken from the vehicle of the location of the ith landmark at time k. When there are multiple landmark observations at any one time or when the specific landmark is not relevant to the discussion, the observation will be written simply as z_k.

In addition, the following sets are also defined:

– $X_{0:k} = \{x_0, x_1, ..., x_k\} = \{X_{0:k-1}, x_k\}$ is the history of vehicle locations.

– $U_{0:k} = \{u_1, u_2, ..., u_k\} = \{U_{0:k-1}, u_k\}$ is the history of control inputs.

– $m = \{m_1, m_2, ..., m_n\}$ is the set of all landmarks.

– $Z_{0:k} = \{z_1, z_2, ..., z_k\} = \{Z_{0:k-1}, z_k\}$ is the set of all landmark observations [2].

III REVIEW OF SLAM METHODS

A number of approaches have been proposed to address the SLAM problem: filter estimation approach based on Extended Kalman Filter (EKF). The full covariance SLAM solution based on EKF requires that the system state vector consists of the states of robot and the states of all landmarks in the map. Robot location and map estimation are highly correlated and cannot be obtained independently. The full covariance matrix needs to be maintained and updated following each observation. Due to the high computational complexity of full SLAM solution, many methods for reducing the computational requirements have been proposed.

In [1] the computational complexity is decreased by limiting the number of landmarks presented a method for choosing the best landmark in the environment while maintaining the SLAM algorithm as convergent and consistent as possible. It is presented a method for removing a large percentage of the landmarks from the map without making the map statistically inconsistent. It is considered an approximation technique for the state covariance matrix updating. These approximation SLAM solutions assume that the correlations between landmarks could be minimized or eliminated.

III. LOCALIZATION PROBLEM

The localization problem is an important problem. The general localization problem has a number of increasingly difficult problem instances. In the position tracking problem the robot knows its initial location. The goal of the localization is to keep track of the position while the robot is navigating through the environment. Techniques that solve this problem are called tracking or local techniques [3].

In determining its location, a robot has access to two kinds of information. First, it has a-priori information gathered by the robot itself or supplied by an external source in an initialization phase. Second, the robot gets information about the environment through every observation and action it makes during navigation.

In general, the a-priori information supplied to the robot describes the environment where the robot is driving around. It specifies certain features that are time-invariant and thus can be used to determine a location. The a-priori information can come in different flavors. Examples of these are maps and cause-effect relationships.

The robot may have access to a map describing the environment. Such a map can be geometric or topological. Geometric maps describe the environment in metric terms, much like normal road maps. Topological maps describe the environment in terms of characteristic features at specific locations and ways to get from one location to another. A map can be learned by the robot in advance in an exploration phase, or it can be given by an external source in an initialization phase. A third option is that the robot learns the map of the environment while it is navigating through it, which is known as SLAM.

Another way of supplying a-priori information to the robot is in terms of cause-effect relationships. Given the input from the observations, these relationships tell the robot where it is. Possibly the robot can adjust these cause-effect relationships while navigating through the environment.

The robot senses the environment by means of its sensors. These sensors give momentary situation information, called observations or measurements. This information describes things about the environment of the robot at a certain moment. Observations made from the environment provide information about the location of the robot that is independent of any previous location estimates.

IV. KALMAN FILTER

Using Kalman Filter for getting estimations of process state vector by series of noisy measurements it’s necessary to present the model of this process according to the filter structure –as matrix equation of particular type. In EKF system state x_k and observations z_k don’t have to be linear state functions, but they have to be differentiable:

$$x_k = f(x_{k-1}, u_{k-1}) + w_{k-1};$$

$$z_k = h(x_k) + v_k,$$

where w_k is the normal random process with zero mathematical expectation and covariance matrix $\mathbf{Q_k}$, which describes the random nature of the system evolution/process $w_k \sim N(0, \mathbf{Q_k})$;

v_k is the white Gaussian noise of measurements with zero mathematical expectation and covariance matrix $\mathbf{R_k}$.

The initial state and vectors of random processes on each time $\{x_0, w_1, ..., w_k, v_1 ... v_k\}$ are regarded independent. In the moment k it is produced a measurement z_k of true state vector $\mathbf{x_k}$, which are connected to each other by the equation:

$$z_k = H_k \mathbf{x_k} + v_k.$$

The filter state is defined by two variables:

1) $\hat{x}_{k|k}$ is the a posteriori state estimation of object in the moment k, received by the results of observations until time k inclusively.

2) $P_{k|k}$ is the a posteriori errors covariance matrix, which sets the precision estimate of state vector received estimate and which include an error variances estimate of calculated state and covariance, which show the detected relationships between state parameters of the system.

The main idea applied in EKF, consists in approximation of state functions and monitoring with use of their first derivatives.

Iterations of Kalman filter are divided into two phases: extrapolation and correction. During the extrapolation the filter receives preliminary state estimate of the system on the current step by the final state estimate from previous step. This preliminary estimate also called a priory state estimate, because for its receipt not use observations of corresponding step. In correction phase the a priory extrapolation is supplemented with corresponding current measurements for correction of estimation. Adjusted estimate also called a posteriori state estimate, or estimate of state vector. Usually this two phases alternate: extrapolation is produced by results of correction until next observation, and correction is produced together with available observations on next step and so on.

A. Extrapolation stage

Extrapolation (prediction) of state vector of the system by estimate of state vector and applied control vector from stem $k-1$ to step k:

$$\hat{x}_{k|k-1} = f(\hat{x}_{k-1|k-1}, u_{k-1}).$$

Covariance matrix for extrapolate state vector:

$$P_{k|k-1} = F_{k-1} P_{k-1|k-1} F_{k-1}^{\mathrm{T}} + Q_{k-1}.$$

B. Correction stage

Deviation of obtaining on step k of observation from observation, expected at the produced extrapolation:

$$\tilde{y}_k = z_k - h(\hat{x}_{k|k-1}).$$

Covariance matrix for error vector:

$$\mathbf{S_k} = H_k P_{k|k-1} H_k^{\mathrm{T}} + \mathbf{R_k}.$$

Optimal gain matrix by Kalman, which formed on the basis of covariance matrix, available extrapolation of state vector and received measurements:

$$\mathbf{K_k} = P_{k|k-1} H_k^{\mathrm{T}} S_k^{-1}.$$

Correction of previously received extrapolation of state vector – obtaining estimate of state vector of the system:

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + \mathbf{K_k}\tilde{y}_k .$$

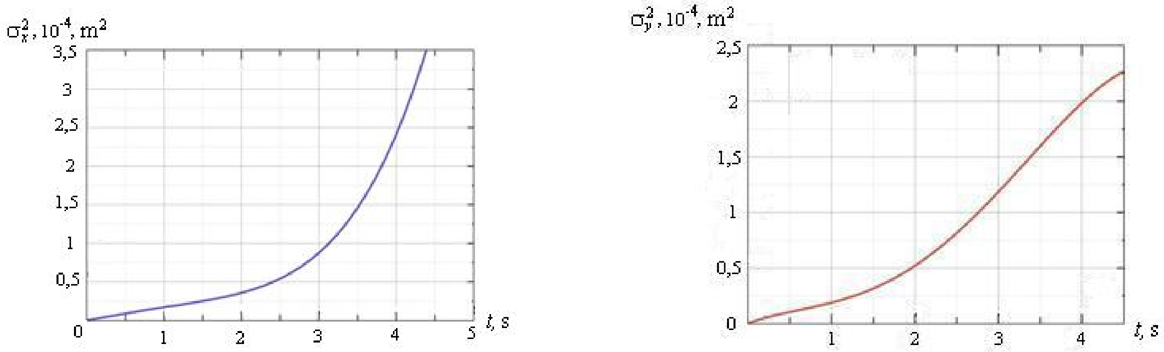
Calculation of covariance matrix of evaluate of state vector of the system:

$$\mathbf{P_{k|k}} = (I - \mathbf{K_k} H_k) P_{k|k-1} .$$

Matrices of state and observations changes of the system are determined by Jacobians:

$$\mathbf{F_{k-1}} = \left.\frac{\partial f}{\partial x}\right|_{\hat{x}_{k-1|k-1},\, u_{k-1}}, \quad \mathbf{H_k} = \left.\frac{\partial h}{\partial x}\right|_{\hat{x}_{k|k-1}} .$$

Graphics of errors action – squares of root mean square deviation for coordinates of robot position $x(a)$ $y(b)$ shown in Fig. 1.



a

b

Fig. 1. Graphics of errors action – squares of root mean square deviation for coordinates of robot position: (a) is the x; (b) is the y

V. CONCLUSIONS

It is considered the problem of SLAM for mobile robots. For the solution of this problem it is used EKF. It is executed an errors analysis of mobile robot coordinate determination.

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В. М. Синєглазов, Р. С. Новодранов. Одночасна локалізація та побудова карти для мобільних роботів

Показано, що ефективність мобільних роботів залежить від вирішення навігаційної задачі і найбільш популярний підхід до вирішення цієї задачі це одночасна локалізація і побудова карти – метод, що використовується в автономних транспортних засобах для побудови карти в невідомому просторі чи оновлення карти в попередньо відомому просторі з одночасним контролем поточного місцезнаходження і пройденого шляху. Вирішення задачі одночасної локалізації та побудови карти базується на розширеному фільтрі Калмана.

Ключові слова: мобільний робот; одночасна локалізація та побудова карти; розширений фільтр Калмана.

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В. М. Синеглазов, Р. С. Новодранов. Одновременная локализация и построение карты для мобильных роботов

Показано, что эффективность мобильных роботов зависит от решения навигационной задачи и наиболее популярный подход к решению этой задачи это одновременная локализация и построение карты – метод, используемый в автономных транспортных средствах для построения карты в неизвестном пространстве или обновление карты в заранее известном пространстве с одновременным контролем текущего местоположения и пройденного пути. Решение задачи одновременной локализации и построения карты базируется на расширенном фильтре Калмана.

Ключевые слова: мобильный робот; одновременная локализация и построение карты; расширенный фильтр Калмана.

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