SOFTWARE IMPLEMENTATION AND COMPUTER SIMULATION OF THE FAST-SLAM ALGORITHM FOR TARGETING A MOBILE ROBOT IN A CLOSED SPACE

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Abstract. This work is devoted to software implementation and computer simulation of the Simultaneous Localization and Mapping method, namely Fast-SLAM for orientation of mobile robot in a confined space. The paper considers the most common simultaneous localization and mapping methods (SLAM). For software implementation of the Fast-SLAM method, we obtained a simplified mathematical model of a mobile robot, namely, simplifications and restrictions were introduced to the existing mathematical model of a mobile robot, which takes into account many environmental influences. The Fast-SLAM method is presented in the form of a “black box”, at the input of which the landmark coordinates read from sensors are sent, and the position of the mobile robot is estimated, and the estimated landmark coordinates are obtained at the output. With each subsequent coordinate estimate, the existing ones are updated, and thereby, the error of the estimates decreases.

Keywords: simultaneous localization and mapping method, SLAM, Fast-SLAM, software implementation, mobile robot.

1 Introduction

The simultaneous localization and mapping method (SLAM) is one of the most relevant in the field of robotics. The concept of the SLAM process can be presented with a simple example. Let us consider a mobile robot equipped with a set of wheels connected to an engine and a camera. Such a small set is a physical device that can change the speed and direction of movement.

Let us imagine that a robot is controlled remotely by an operator to display hard-to-reach spots. Drives allow the robot moving, and camera provides sufficient visual information for the operator to understand where the surrounding objects are and how the robot is oriented towards them. The things a person — an operator — does is an example of SLAM.

The location of objects in the environment is the mapping and creation of robot's location relative to the objects of the surrounding world, which is an example of localization.

SLAM is trying to provide robots with the ability to autonomously perform the localization and mapping process. Solving the SLAM problem will allow robots creating cards without any human assistance (Martins et al, 2018).

Solving the SLAM problem will open up great opportunities in mapping and localization of technical systems. Maps can be made in areas that are dangerous or inaccessible to people, such as deep-sea environments or in an unstable surface of the Earth. Also, solving the SLAM problem will help eliminate existing localization problems associated with the global positioning system (GPS) or with artificial marks. This would help make navigation in space, in particular in places close to space stations or planets. Even in places where GPS is widely used, SLAM methods can make a significant contribution to mapping, since today GPS can only give approximate coordinates of objects whose accuracy cannot contribute to the robot's task. Due to the root mean square total error equal approximately to 13.1 m. (Anuchin & Emelyantsev, 2003), GPS cannot be used by mobile robots in small rooms or in areas with strong interference from the outside, making it difficult to transmit and receive the necessary data. Using artificial marks for localization provides fairly accurate data on robot's location and obstacles, but there remains a problem with the transmission of data at a distance, and the installation of marks is an expensive undertaking in terms of time and money (Hiebert-Treuer, 2007).

2 Problem Statement

The work is devoted to the software implementation of the Fast-SLAM algorithm and the development on its basis of an application for modeling the process of movement and localization of a mobile robot in an enclosed space. Based on the foregoing, the following tasks can be formulated:

1. An overview of the most common simultaneous localization and mapping methods (SLAM);
2. Development of a mathematical model of the movement of a mobile robot and sensor models;
3. Development of a software module that implements the Fast-SLAM algorithm;

3 Results And Discussion

Having examined such common SLAM methods as Vision SLAM (V-SLAM), Distributed Particle SLAM (DP-SLAM), Extended Kalman Filter SLAM (EKF-SLAM) and Fast-SLAM, which differ from each other using different hardware and calculation algorithms, we can indicate their advantages and disadvantages.

Let us list the advantages and disadvantages of some SLAM methods (Klette, 1998: Nister, 2004: Taketomi, 2017).

Let us highlight the main advantages of the V-SLAM method:

1. Based on the basic principles of SLAM methods;
2. Availability of application programs for image processing and pattern recognition.

The disadvantages of the V-SLAM method include:

1. Demanding cameras with high resolution for more accurate pattern recognition;
2. Applicability in small rooms.

The advantage of the EKF-SLAM method is the ability to predict the system state based on the previous step and its correction based on data received from sensors. The disadvantage of the EKF-SLAM method is the complexity of the calculations and initial determination of the location of robot, which can cause a large error (Alcantarilla et al, 2010: Smith & Cheeseman, 1990: Guivant, 2001).

The positive side of the DP-SLAM method is the possibility of its application in rooms with a large area and the relatively small complexity of calculations. The negative side is the need for accurate measuring instruments (Eliazar & Parr, 2003).

The advantages of the Fast-SLAM method are as follows:

1. Relatively low computational complexity compared to DP-SLAM;
2. Application of a particle filter that allows mapping out the particles with the highest weight;
3. Application of a Kalman filter with the ability to predict the current position of the robot;
4. Application of the algorithm in rooms with a large area.

The disadvantages of the FAST-SLAM method include the ability to determine the initial location of robot with an error due to the use of the Kalman filter (Sobchenko & Ukhandeev, 2014).

The task of developing a mathematical model of the movement of mobile robot is quite common. In this regard, we can find a lot of sources, in which this model has already been developed and described. In the work (Bartenev et al, 2011). a mathematical model of the motion of mobile robot with two independent driving wheels was obtained. Upon receipt of the model, many forces were taken into account, affecting on the robot from the outside and on its behavior. The model turned out to be quite complicated. A simplified model of mobile robot is described in (Kurganov, 2016):

$$\begin{cases} \ddot{x} = \frac{1}{m}(F_x + mV_y\omega), \\ \ddot{y} = \frac{1}{m}(F_y - mV_x\omega), \\ \ddot{\theta} = \frac{1}{m}(M_\theta - M_C), \end{cases}$$

where

- F - longitudinal movement force associated with the torque of both wheels equal to:

$$F = \frac{1}{r}(M_R - M_L),$$

- M_θ - angular torque equal to:

$$M_\theta = L(F_R - F_L) = \frac{L(M_R - M_L)}{r},$$

- M_R - right wheel torque equal to:

$$M_R = F_R * r,$$

- M_L - left wheel torque equal to:

$$M_L = F_L * r.$$

The indicated mathematical model of the robot is obtained taking into account the Coriolis force and centripetal acceleration that arise when the robot moves in turns.

By introducing the following restrictions, to simplify the robot's movement model, let us assume that the robot slides on a flat surface, that is, external forces do not act on it. Neglecting the Coriolis force and centripetal acceleration, let us suppose that the traction of the wheels and the surface are perfect, that is, the wheels do not slip; we obtain a simplified mathematical (kinematic) model of mobile robot movement:

$$\begin{cases} \dot{x} = v \cos\theta \\ \dot{y} = v \sin\theta. \\ \dot{\theta} = \omega \end{cases}$$

The resulting robot movement model can be depicted in the form of Figure 1.

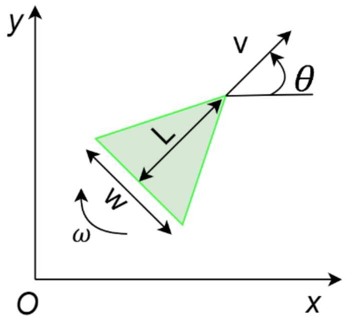

Figure 1. Graphic model of mobile robot

Figure 1 shows:

- V - longitudinal (linear) speed of the mobile robot
- L - length of the robot;
- w - distance between the robot's wheels, width of the robot;
- θ is - movement direction of the relative axis Ox;
- ω - angular velocity of the robot.

In this work, we use a laser range finder to determine the coordinates of landmarks and the distance to them. Therefore, we can name the following as the concerned parameters of the laser range finder:

- range of action;
- time between adjacent measurements.

Based on the described requirements, we obtain a simplified sensor model (Figure 2) with a radius of action r and a viewing angle of 180 degrees.

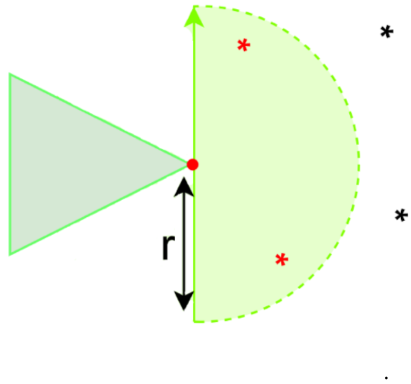

Figure 2. Graphical model of the sensor

The Fast-SLAM method can be represented in the form of a "black box", at the input of which the landmark coordinates read from sensors are sent, and the position of the mobile robot is estimated, and the estimated landmark coordinates are obtained at the output (Figure 3).

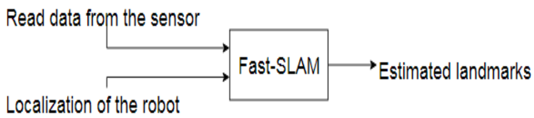

Figure 3. The Fast-SLAM method

We present the Fast-SLAM method in the form of a block diagram (Figure 4), in which each block is designed for a specific stage of the simulated SLAM method (Puspitasari et al, 2019).

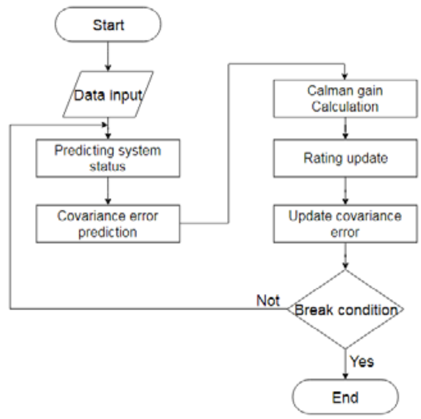

Figure 4. Fast-SLAM algorithm

A visualization of the above method is presented in Figure 5.

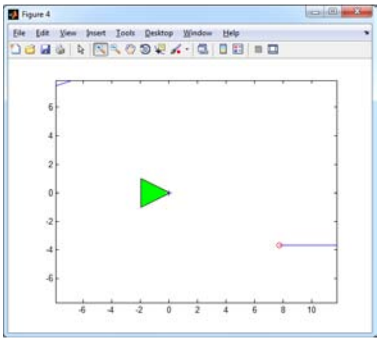

Figure 5. A visualization of the Fast-SLAM algorithm

In this work, a bypass of obstacles, which are landmarks for a mobile robot, is implemented. Bypass means a change in the trajectory of the mobile robot in order to avoid a collision with a landmark and return to the route. The result is shown in Figure 6

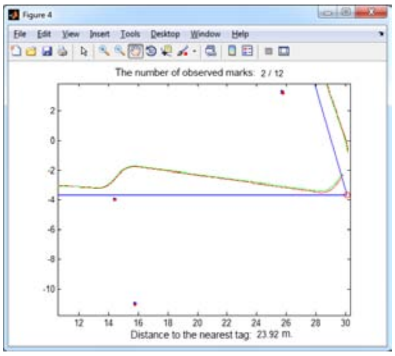

Figure 6. The work result of the obstacle bypass algorithm

For ease of use, as well as setting simulation parameters, we developed a graphical user interface. The user interface is used to determine the values of most parameters of the model, and is presented in Figure 7.

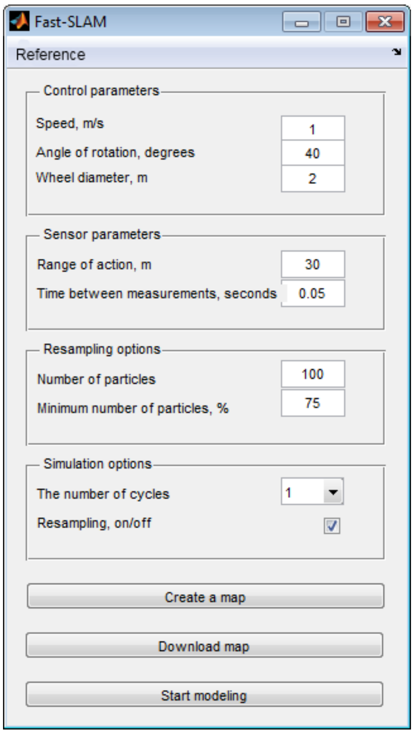

Figure7. The settings window for the simulation parameters of the Fast-SLAM algorithm

The main window of the Fast-SLAM software module is divided into four main semantic blocks: “Control parameters”, “Sensor parameters”, “Oversampling parameters” and “Simulation parameters”. One can set certain parameters of the simulation object in each block.

As a result of this work, we performed a review of the main common SLAM methods, described the principles of their work, and indicated the main advantages and disadvantages of each method. For software implementation, we developed a simplified mathematical model of the movement of mobile robot. For the sensor, with the help of which the marks are detected and the distance to the nearest one is calculated, we implemented a model with a certain set of parameters. A software module that implements the Fast-SLAM algorithm takes into account the following main parameters when modeling:

- speed, rotation angle and wheel diameter of the mobile robot;
- range and time interval between two adjacent measurements of the mark detection sensor.

To enter the parameters necessary for modeling the Fast-SLAM algorithm, we developed a graphical user window with checking the entered data for correctness. In the process of analyzing the operation of the implemented module, we determimed the parameters that have the greatest impact on the final result, namely on the determination of the mark coordinates.

4 Summary

Based on the obtained simulation results, it is possible to study the robot's behavior, to study the trajectory of its movement, depending on the input parameters taken into account, for example, such as the speed of mobile robot.

5 Conclusions

The tasks set may be considered achieved. The results can be used in further studies to improve the localization and mapping of mobile robots, and, if possible, to develop new SLAM methods.

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