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Localization of robots under two-dimensional indoor conditions

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Abstract. In the 21st century, driven by the vigorous development of science and technology, intelligent services are developing under a unprecedented speed. With the progress of new science and new technology, robots have made a qualitative leap in artificial intelligence, sensing hardware equipment and other aspects. The emergence of mobile robot has replaced many ineffective mechanical labor and liberated a large number of labor. However, in reality, the environment of the moving robot is relatively complex, with many dynamic obstacles and environmental terrain bending, so a reasonable and efficient path planning can greatly save the traveling time of the mobile robot. At the same time, if the mobile robot accurately find the position of its own body and the position of obstacles, it can reach the target safely. Therefore, it is a useful research topic to study the positioning and mapping methods and the path planning method in the navigation technology of moving robot. This article mainly discuss some popular methods of localization under two-dimensional and demonstrate the weakness.

Keywords: wheel encoder, two-dimensional localization, topological map, raster map, Trilateral Localization Algorithm.

1. Introduction

In the 1960s, the first mobile robot Shakey came out, which fully applied artificial intelligence technology and was equipped with electronic cameras, triangular rangefinders, collision sensors and drive motors. Due to the limitation of technology at the time, Shakey needed to spend hours on environment awareness and analysis. But it has been able to solve simple problems like perception and planning. After several decades, the technology of robot intelligence has improved a lot, many cutting edge technology company publish artificial intelligence robot. However, as far as technology is concerned, the whole area is still in its infancy, but both the ripening of the product and the ripening of the application are increasing at a rapid rate. We will discuss localization and navigation of indoor robots in two main part respectively. In the work, we discuss how to calculate the path of robot during moving and introduce a new installing encoder position, then we discuss topological map and Raster map that to calculate the position of the robot under a Two - Dimensional coordinate depending on the path of robot we have known previously, finally we discuss a completely different method Trilateral Localization Algorithm in localization technology area.

Different from outdoor GPS positioning which has been quite mature, indoor positioning still has many infancy technology. The commonly used indoor positioning techniques are: inertial navigation positioning, beacon-based positioning technology, and mapping based positioning technology

(1) The principle of map matching positioning technology is to scan and detect the surrounding environment through the sensors carried by the mobile robot, then computer builds a local map and match with the existing map to obtain robot's position. At present, SLAM [1] is the most widely used solution of map matching localization technology. In the work, we discuss this technology.

(2) The inertial navigation and positioning technology is a kind of location information obtained from the gyroscope and accelerometer for integral. Inertial navigation and positioning technology have the advantages of high initial positioning accuracy, but it is difficult to avoid the cumulative error.

(3) The principle of beacon-based positioning technology like Bluetooth localization method [2] is that the mobile robot establishes a specific position relationship with the beacon through its own sensor, and solves the current coordinates of the robot according to the location of the beacon and its own position. In the work, we mainly discuss this kind of technology.

2. Path calculation

When we are locating our robots or planing the paths of robot, it is necessary to know the position information of the robot. This paragraph studies the positioning of the robot in the two-dimensional state. In the 'figure 1', the robot is assumed to be in a Cartesian coordinate system $X_W O_W Y_W$that is a two-dimensional plane, the coordinate origin is the initial position center of the robot. We use $(x_w, y_w, \theta_w)$to represents the the location of robot in coordinate and yaw Angle of the robot respectively, then the position and orientation of robot at time can be written as $(x_w, y_w, \theta_w)^T$.We establish a new local coordinate system $X_R O_R Y_R$with the center point of the robot, and the origin of the coordinate system is the center of the robot. Then we can represent a vector of the motion state of the robot as $[x_R, y_R, \theta_W]$. The $\theta_R$is consistent with the θ_W above paragraph.

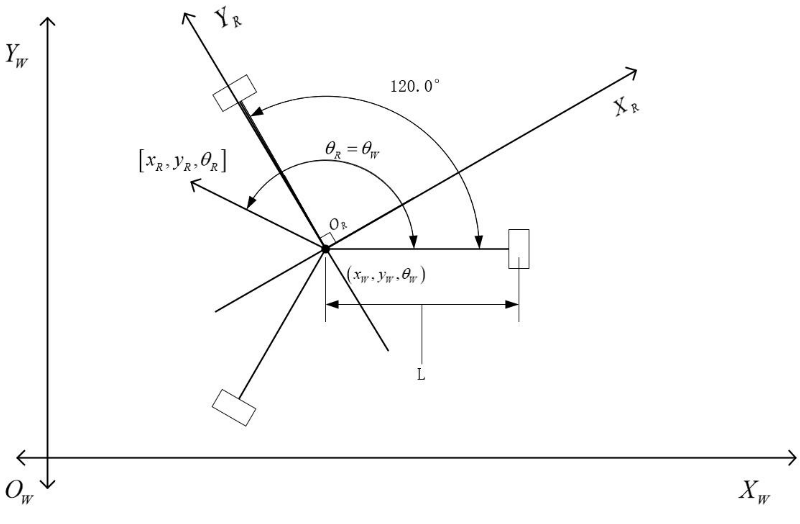

Figure 1. The positions of robot and encoder wheels under coordinate.

If we assume the robot is in the world coordinate system$X_W O_W Y_W$, (x_W, y_W, θ_W) is the location of the robot in the world coordinate system. If we set up a new point k in the coordinate, and $(x_R, y_R)$is location information of robot in the local coordinate system of the robot, then point k in the world coordinate system can be expressed as(x_{RW}, y_{RW}). The transformation formula of point k between world coordinate and local coordinate can be written as:

$$\begin{pmatrix} x_{RW} \\ y_{RW} \end{pmatrix} = \begin{pmatrix} x_W \\ y_W \end{pmatrix} + \begin{pmatrix} cos \quad \theta_W & -sin \quad \theta_W \\ sin \quad \theta_W & cos \quad \theta_W \end{pmatrix} \begin{pmatrix} x_R \\ y_R \end{pmatrix} \ [3]$$

In last paragraph k only represents a point, but we can also let $\boldsymbol{k}$ represent as a vector in the local coordinate system of the robot, so the vector can be seen as the moving direction and distance of robot. In that case, in the last equation, if $X_R, Y_R$is seen as the vector of robot in coordinate system of the robot, X_w, Y_w is the robot previous position, and X_{RW}, Y_{RW} is the new position of robot after movement. The last equation can also be used for calculating the position of robot during moving. We can approach the robot path by several short straight movement. 'Figure 1.2'If each short part is short enough, we can get the path of robot by integrating each short movement $[x_W, y_W, \theta_W]$ together, in which the angular displacement does not need to be transformed.

We have discussed how to find the position of robot when the vector of the robot at each moment is known. In this section, we will mainly discuss how to find the vector that is the the vector k of the robot at a moment. Today, odometer that is a kind of positioning sensors has become the default configuration of autonomous mobile robot, its main principle is through the encoder in robot on wheels to count. Encoder is a device that compiles and converts a signal (such as a bit stream) or data into a signal form that can be used for communication, transmission and storage. The encoder converts angular displacement or linear displacement into electrical signal. According to the working principle, encoders can be divided into incremental type and absolute type. In this section, we use incremental encoder that converts the displacement into a periodic electrical signal. The electrical signal can be then converted into a counting pulse that is used to represent the size of the displacement. Mostly, the encoders are installed at the end of the electric motor to account the angular displacement, but we use three extra encoder under the plate of robot to account the the displacement of robot. We use three coding wheels, the angles of the axes of the three wheels are 120 degrees, and the centers of the coding wheels are distributed on the same circle. Let V_1, V_2, V_3 be the rotational speed of the three coding wheels, ω is the rotational angular velocity of the platform as a whole, V_x, V_y is the moving velocity of the platform relative in the world coordinate system, and L is the vertical projection distance from the center of the platform to the center of the coding wheel. in the omnidirectional movement, the coding wheels are placed in similar positions. Since the coding wheel in omnidirectional movement has a similar positions that are the angles of the axes of the three wheels are 120 degrees, we can replace the driving wheel with the angular speed of the coding wheel, while the other variables remain unchanged. The formula of omnidirectional movement[4] is for calculating the angular speed of wheel based on the the displacement of robot. Thus, we can get a formula for calculating the displacement of robot based on the angular speed of the coding wheel by transforming omnidirectional movement formula. By the same token, the ω can be calculated by the same way.

$$\begin{pmatrix} V_X \\ V_Y \\ \omega \end{pmatrix} = \begin{pmatrix} \frac{-2}{3} & \frac{1}{3} & \frac{1}{3} \\ 0 & \frac{-\sqrt{3}}{3} & \frac{\sqrt{3}}{3} \\ \frac{1}{3L} & \frac{1}{3L} & \frac{1}{3L} \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \\ V_3 \end{pmatrix}$$

3. Map model

Topological map：

The topological map is made by Vertex and Edge. The vertex contains the position information, and the edge contains the the information about to next vertex. In the topological map, the path of robot is many small straight line, these lines represent the distant of robot in a certain time or in certain contexts. When these small lines add up end to end, the robot path can be calculated, and a simple map can be made.

The popular topological map can be divided into three part. The most basic topological map only record the vertex and edge in a mechanically way, for instance recording the position at a certain interval. In such a map, each edge has only two information, pointing to the previous vertex and the next vertex. This approach has been adopted by many, such as the work of Matthew R. Walter et al. at MIT[5] on semantic closed-loop. The elements in this kind of topological map do not have any semantic meaning, but just some location information. Therefore, this kind of topological map can not

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be used in a wide range, since it is not a real may in the world, but the “safe” path that the robot has explored before.

The second kind of map model is dividing the whole context into many small map based on the similarities or the differences of each map. The most representative example is Blanco’s work on mixed map in 2007. [6] The map with similar context will be in one part. This map model has basic semantic information. However, each segmentation is not stable and inflexible, so the vertex and edge can not represent the features like corner or corridor in the real world. The robot can not follow the original path during movement, which has an adverse effect on loopback detection.

The third class, the space environment is the content of the semantic extraction for topological vertex. For indoor scene, the space of a typical semantic node has corridors, room, intersections and stair and so on. The edge and vertex constitute the global topological map. In this kind of map, the scenarios of the semantics of the topological node corresponding more clear with the actual scene. And more of the upper space abstract can also help algorithm of intelligent understanding of space.

Raster map:

In the raster map, the whole map will be divided evenly by several fixed size grids. In addition to position parameter contained by each grid, each grid also has a parameter P representing the probability that the shed grid is occupied by obstacles, $0<P<1$, the 0 means idle grid and 1 means obstacle. Initially, we consider that each grid has an equal chance of having an obstacle and not having an obstacle with a probability of 0.5[7].

When the robot moves from its initial position to a new position, it will get a new series of environmental data through sensors. These data indicate the obstacles position information that is detected by the sensors during moving from starting point, then the raster probability can be updated according to certain rules (generally the Bayes criterion). The robot continues to move forward, constantly getting new environment data, and using this data to update the raster probability until the robot stops probing the environment. Finally, according to the probability value of the grid, the robot can determine which grids have obstacles and which grids are idle, so as to construct the grid map.

4. Trilateral Localization Algorithm

This section will discuss a new localization method that is Trilateral Localization. We have a lot of signal generators in the room like routers that can be seen as beacons. If we calculate the distance and angle between the device and the beacons, we can obtain the position of the device.

The function [8] of Trilateral Localization is measuring the distance between the device and three non-collinear beacon nodes. The location of the three beacon nodes is respectively taken as the center of the circle, and the distance between the device is taken as the radius to make three circles as shown in ‘Figure 2’. If there is no error in ranging, the three circles will intersect at a point, which is the position coordinate of the mobile node.

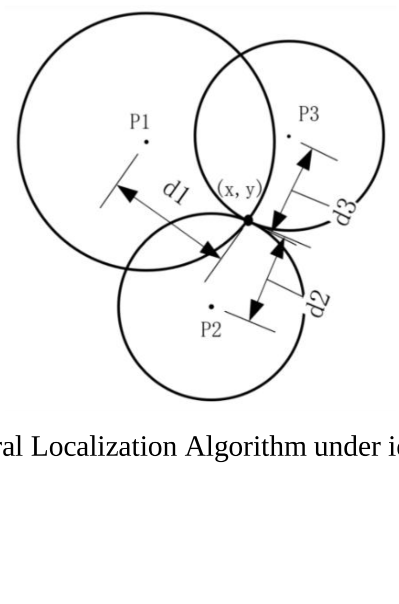

Figure 2. Trilateral Localization Algorithm under ideal circumstance.

In the ‘figure 1.3’, d1, d2, d3 represent the distance between the device and the beacon respectively. (x,y) means the location of the device. P1,P2,P3 represent the location of the beacons. In the real world, we can get the distance information through calculation.

$$\begin{cases} d_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \\ d_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \\ d_3 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} \end{cases} \tag{1}$$

The position coordinate of the device can be obtained as (x,y) from the equation (1) like:

$$\begin{bmatrix} x \\ y \end{bmatrix} = \frac{1}{2} \begin{bmatrix} x_1 - x_3 & y_1 - y_3 \\ x_2 - x_3 & y_2 - y_3 \end{bmatrix}^{-1} \begin{bmatrix} {x_1}^2 - {x_3}^2 + {y_1}^2 - {y_3}^2 + {d_3}^2 - {d_1}^2 \\ {x_2}^2 - {x_3}^2 + {y_2}^2 - {y_3}^2 + {d_3}^2 - {d_3}^2 \end{bmatrix} \tag{2}$$

The deficiencies of Trilateral Localization Algorithm

Due to the error in ranging between device and beacon node, the three circles made cannot meet at one point. Due to the uncertainty of interference, the radius of circles may be far smaller than the actual distance or far grater than the actual distance as shown in ‘Figure 3’.

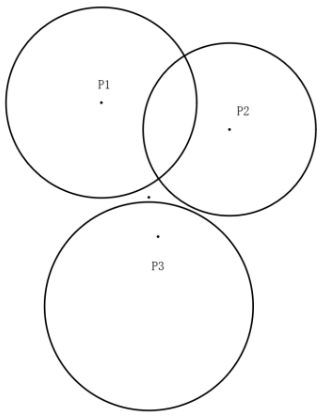

Figure 3. Trilateral Localization Algorithm under special circumstance.

The solution to the deficiencies

If the radius is greater than the actual distance, we will get two intersection points between each two beacons based on measurement data after calculation. According to the intersection, the distance between each point can be obtained. Then, the points with large distance between the third point were deleted, while the points with small distance were retained. Using the same method to calculate the points of the other two groups of combined circles, and finally distribute the weights by RSSI value or Angle weight function, with x=a1 x1+a2 x2+a3 x3,y =a1 y1+a2 y2+A3 Y3 is the calculated position coordinate of the mobile node, where A1 + A2 + A3 = 1. x and y are the location of the device.

The algorithm idea in literature [9] is to further reduce the shaded area by comparing the RSSI value of each beacon node received by the mobile node, so as to achieve the purpose of improving the accuracy. But this does work if the measuring radius is smaller than the real radius.

(2)Under the circumstance that the measuring radius is smaller than the real radius.

① The distance between current mobile device and each beacon node are measured k times, and the data are stored in the matrix M.

② Check whether there is data in each row of matrix M is greater than the L that is the maximum communication distance range between beacon nodes and mobile device. If L exists, the row containing L will be deleted, otherwise retain

③ Calculate the variance of each row, if the variance is too complex for computer to calculate. We can delete the greatest and the smallest data in each row, and then calculate the average distance of remaining data.

After above calculations, we have known the location of three beacons and the measuring radius.

We use the Euclidean distance formula to find the distance between three beacon nodes, and compare the distance we calculate with the measuring radius. If the distance between two beacons is larger than the sum of two measuring radius, which means the measuring data is larger than the real data. If the distance between two beacons is smaller than the sum of two measuring radius, which means the measuring data is smaller than the real data. If the distance between two beacons is same with the sum of measuring two radius, which means the measuring data is right.

If any two circles are separated or tangent from each other according to the previous step, then there is no overlap between the three circles. If any two circles intersect according to the previous step,we need to calculate the intersection points and delete intersection point further to the center of the third circle, then we are supposed to calculate the distance L2 between the remaining intersection point and the center of the third circle. If the L2 is smaller than the radius of the third circle, we can say that the three circles have overlapping parts. We could set an adaptive factor[10] to adjust the measuring radius until the overlapping area of the three gardens changed

5. Conclusion

In this work, we mainly discuss localization in two-dimensional coordinate. We use encoder to calculate the path data of the robot and use the to approach the location of robot by two kinds of maps that are Raster map and topological map. We discuss a completely different thinking localization way that is Trilateral Localization Algorithm and introduce the advantages and drawbacks that are the error of the measuring data. We then divide these deficiencies into two parts that are measuring data is smaller than the real life and greater than the real life, and discuss how to solve them. Trilateral Localization Algorithm can be widely used in our real life. Many things in the real life can be seen as beacon like router. Next step, We will use LiDAR to further reduce the error and introduce a new SLAM algorithm.

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