Dual-Circle Self-Localization Algorithm for Omnidirectional Vision Robots

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Abstract—This paper proposes a new self-localization algorithm, called dual-circle self-localization algorithm, for use in omnidirectional vision robots. When an autonomous robot navigates in the field, it senses the environment by an omnidirectional vision device fitted on the robot. The landmarks information is acquired by using image processing and pattern recognition techniques. Robot position on the field can be estimated with the proposed method by using these landmarks information. Comparing with other self-localization methods, the dual-circle self-localization algorithm requires only three landmarks information in the image for identifying the robot position, which is very efficient for image processing. Practical experiments on an autonomous robot have demonstrated that the proposed algorithm can achieve a satisfactory performance to locate the robot.

Keywords: Omnidirectional image, autonomous robot, self-localization

I. Introduction
It is important for an autonomous robot to perceive its position on the field [1]. When the robot obtains the information in working space, it can help the robot to analyze the environment for path planning [1]. As a result, sensor devices have been widely used on robots, for example, infra-red, laser detector, and ultrasonic sensors [2], etc. The robot then estimates its position on whole space by fusing sensor information and the virtual map. As an attempt to solve this problem, this paper proposes a new self-localization method, called dual-circle self-localization algorithm, for autonomous robots [5] which sense environment with omnidirectional image device. The landmark information can be obtained from omnidirectional image. Several geometrical theorems regarding the definition of a circle by three points and relationship of two intersecting circles are utilized for calculating robot position coordinates in the environment. Comparing with Monte Carlo localization, the dual-circle self-localization algorithm uses the concept of vector and algebra to locate the robot position in a more efficient way. The method can calculate the position of robot immediately when landmarks information become available without wasting too much time for making particles convergent by iterations. It doest not require the memory information in Odometry feedback.

The rest of the paper is organized as follows. Section II describes the omnidirectional vision device. Section III introduces the dual-circle self-localization algorithm. Experiment results are described in section IV. Conclusions are drawn in Section V.

II. Omnidirectional vision device
The autonomous robot moves along the environment by using camera to detect the environment around. The landmarks recognized from image processing allow the robot to decide the navigation and path planning.

In general, conventional cameras have restriction and are unable to get the environmental information fetched around the robot at the same time. As a result, the robot must constantly rotate the camera for grabbing images. Alternatively, more cameras have to be set up to analyze the environment. To overcome this problem, omnidirectional image devices combining a convex mirror and a camera were proposed. As shown in Fig. 1, omnidirectional image device utilizes the characteristic of convex mirror to get environmental information around the robot by a camera at the same time based on the principle that optics of surface of the mirror reflects. The horizontal angle is 360 degrees field of view by omnidirectional devices.

![Fig. 1 An omnidirectional image device fitted into a robot.](image)

Omnidirectional image device adopt convex mirror principle that optics reflect, which allows the camera to obtain information of the image around the robot. Unfortunately, this will cause the camera to get distorted images. The distortion problem deteriorates from the image centre of the image (centre of the surface of the mirror) and radiates outward. However, the information we need still can be extracted form the distorted image. Although the target in the omnidirectional image is distorted by the convex mirror reflected. The angles $\theta$ between two targets in the image and in the real environment are equivalent as described in Fig. 2.
As is well known in geometry, any three different points can define a circle in a two-dimensional plane. Four points produce two circles intersecting each other with two intersection points. Therefore, we assume that the autonomous vision robot moves on the field with three landmarks recognized from the omnidirectional images. Taking the robot as the fourth point in addition to the three landmarks, we have two circles with two intersecting points. One of the two points is a known landmark, the other one is the coordinate position of the robot. Fig. 3 illustrates the dual-circle self-localization algorithm based on the concept mentioned earlier so that the autonomous robot finishes localizing and estimating the position of the robot on the field.

III. Dual-Circle Self-localization Algorithm
Before stating the dual-circle self-localization algorithm, some mathematical backgrounds need to introduced first:

1. Relationship between the included angles and center of a triangle: As shown in Fig. 4, there are three points $A, B$, and $C$ on a two-dimensional plane. By suitable connections, they form a triangle and a circle. The center of the circle is point $O$, which is also the triangle’s weight center. The angle $a$ and $b$ are defined as the included angles $\angle BAC$ and $\angle BOC$, receptively. We can obtain the relation between angles $a$ and $b$ as (1) below.

\[
a = \frac{1}{2} b \tag{1}
\]

2. Relationship between two intersection points and centers when two circles intersect: As shown in Fig. 5, there are two intersected circles with centers $O_1$ and $O_2$ and two intersection points $D$ and $E$, respectively. Four points, $D$, $O_1$, $E$, and $O_2$ form a rhombus by connecting them. The relationship among four angles, $c$, $d$, $e$, and $f$ is:

\[
\angle c = \angle d, \quad \angle e = \angle f \tag{2}
\]

When the autonomous robot $p^{(e)}$ moves, it obtains the information of three landmark coordinates, $p^{(f)}_r$, $p^{(g)}_r$, and $p^{(h)}_r$, from omnidirectional images. In the real-world environment, the landmarks are $p^{(f)}_e$, $p^{(g)}_e$, and $p^{(h)}_e$. They are shown in Figs. 6 and 7.

Employing the law of cosines, we can obtain angle $\theta_{de}$ and angle $\theta_{ef}$.

\[
\theta_{de} = \cos^{-1}\left(\frac{p^{(e)}_i \cdot p^{(e)}_j}{\|p^{(e)}_i\| \|p^{(e)}_j\|}\right) \tag{3}
\]

\[
\theta_{ef} = \cos^{-1}\left(\frac{p^{(e)}_j \cdot p^{(e)}_k}{\|p^{(e)}_j\| \|p^{(e)}_k\|}\right) \tag{4}
\]
From points $p^{(e)}$, $p^{(f)}$, and $p^{(g)}$, we need to get the coordinate of the center $o^{(e)}$ of the circle. First, we reduce the magnitude of the vector originating from $p^{(f)}$ to $p^{(g)}$. Secondly, rotate the vector with $90 - \theta^{(g)}$ degree. Thirdly, re-scale the vector magnitude by a factor. Finally, $o^{(e)}$ can be obtained by adding the vector and point $p^{(f)}$ as described in (5), (6), and Fig. 8.

$$\vec{v}^{(e)} = p^{(e)} - p^{(f)}$$

$$o^{(e)} = \frac{1}{\cos(90 - \theta^{(g)})} \left[ \frac{1}{2} \left( \vec{v}^{(e)} \right) + p^{(f)} \right]$$

Similarly, we also obtain center point $o^{(h)}$ by (7) and (8), which is illustrated in Fig. 9.

$$\vec{v}^{(h)} = p^{(h)} - p^{(g)}$$

$$o^{(h)} = \frac{1}{\cos(90 - \theta^{(g)})} \left[ \frac{1}{2} \left( \vec{v}^{(h)} \right) + p^{(g)} \right]$$

After getting the coordinates of circle’s center points, we proceed to derive the robot position by calculating the coordinate of intersection points. As shown in Fig. 10, angle $\theta^{(op)}$ can be obtained using the law of cosine.

$$\vec{v}^{(op)} = p^{(op)} - o^{(e)}$$

$$\vec{v}^{(op)} = o^{(h)} - o^{(e)}$$

$$\theta^{(op)} = \cos \left( \frac{\vec{v}^{(op)} \cdot \vec{v}^{(op)}}{\|\vec{v}^{(op)}\| \cdot \|\vec{v}^{(op)}\|} \right)$$

Finally, we rotate the vector $\vec{v}^{(op)}$, which originates from $o^{(op)}$ to $p^{(o)}$, with $2\theta^{(op)}$ degrees for adding with the coordinate of point $o^{(op)}$. Thus, we get the robot position $p^{(o)}$.

$$p^{(o)} = R(2\theta^{(op)}) \vec{v}^{(op)} + o^{(op)}$$

**IV. Simulation and Experiments**

In the section, we start to simulate the dual-circle self-localization algorithm to make sure the method is feasible to obtain satisfactory results. After simulation, some experiments are implemented using omnidirectional autonomous vision robot. By comparing the robot’s moving path and the localization result, we observe that excellent performance have been obtained.

We choose the robot soccer game field for testing the localization performance. The field is 6 meters in length and 4 meters in width. The vector from yellow goal to blue goal is defined as the X coordinate axis. The omnidirectional vision regards two goals and four corner cylinders on the field as landmarks when robot navigates.
Fig. 11 Block diagram of the proposed dual-circle self-localization algorithm for simulating the localization performance in a robot soccer game field.

The coordinate of the robot position is assumed as \( p_{e}^{(r)} \) on the virtual field. The landmarks \( p_{f}^{(e)} \), \( p_{s}^{(e)} \), and \( p_{h}^{(e)} \) and angles \( \theta_{fg} \) and \( \theta_{gh} \) between landmarks and image center are generated from landmarks generator. The dual-circle self-localization algorithm analyses information for deriving the central positions \( (o_{fg}^{(r)}) \) and \( (o_{gh}^{(r)}) \) in the two circles. Then, it computes the intersection point \( p^{(v)} \) for locating the robot on the game field as illustrated in Fig. 11.

Fig. 12 Function simulation in robot localization

After simulation, we integrate the localization module with the omnidirectional robot vision. On the game field, the robot grabs images from the omnidirectional device for recognizing environment information. The localization function employs landmarks information and estimates its position on global coordinate. When the robot navigates on the field, it compares the designated path with localization results for adjusting its direction and velocity. At the same time, it also records all information. Fig. 12 shows the experiment results of the dual-circle self-localization algorithm for self-localization, where moving loci (solid line) of the robot and designated path (dot line) are depicted. As shown in this figure, satisfactory results in estimating the robot position have been obtained, which validates the effectiveness of the proposed approach.

Fig. 12 Experiment results of the proposed algorithm showing the self-localization loci of a robot.

V. Conclusion

In this paper, a new robot localization method, called dual-circle self-localization algorithm, is proposed. It is suitable for autonomous robot fitted with an omnidirectional vision device. In a working space, the robot recognizes more than three landmarks from omnidirectional images for deriving its position using the method. The method makes use of basic geometry concepts, which significantly accelerates the localization process. In light of satisfactory simulation and experimental results in localization, the proposed method is suitable for implementation in practical applications. Finally, the method is implemented within an omnidirectional vision robot to estimate its global position on soccer robot game field. As shown in the experiments, the results are satisfactory.

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References