# ROBOT LOCALIZATION BASED ON VISUAL LANDMARKS

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Keywords: Position system, Vision-based localization, Triangulation, Minirobot, Visual landmarks.

Abstract: In this paper, we will consider the localization problem of the autonomous minirobot Khepera II in a known environment. Mobile robots must be able to determine their own position to operate successfully in any environments. Our system combines odometry and a 2-D vision sensor to determine the position of the robot based on a new triangulation algorithm. The new system uses different colored cylinder landmarks which are positioned at the corners of the environment. The main aim is to analyze the accuracy and the robustness in case of noisy data and to obtain an accurate method to estimate the robot's position.

## 1 INTRODUCTION

Vision-based localization is the process to recognize the landmarks reliably and to calculate the robot's position (Borenstein et al., 1996). Researchers have developed a variety of systems sensors, and techniques for mobile robot positioning. (Borenstein et al., 1997) define seven categories for positioning system: Odometry, Inertial Navigation, Magnetic Compasses, Active Beacons (Trilateration method and Triangulation method), Global Positioning Systems, Landmark Navigation, and Model Matching. Some experimental systems that work on localization are using mobile robots equipped with sensors that provide range and bearing measurements to beacons (Witkowski and Rückert, 2002) and some other work with vision sensors (Chinapirom et al, 2004).

Because of the lack of a single good method, developers of mobile robots usually combine two or more methods (Borenstein et al., 1997). To predict the robot's location, some systems combine odometric measurements, landmark matching, and triangulation with observations of the environment from a camera sensor (DeSouza and C.Kak, 2002; Yuen et al., 2005). (Martinelli et al, 2003) combine the odometric measurements, uses encoder readings as inputs, and the readings from a laser range finder as observations to localize the robot.

Many solutions to the localization problem included geometric calculations which do not consider uncertainty and statistical solutions (Kose et al., 2006). Triangulation is a widely used to the localization problem. It uses geometry data to compute the robot's position in indoor environment (Shoval et al., 1998).

Triangulation is based on the measurement of the bearings of the robot relatively to the landmarks placed in known positions. Three landmarks are required at least for solving the triangulation. The robot's position estimated by the triangulation method is based on find the intersection of the two circles which passes through the robot and two landmarks, show figure 1.

Cohen and Koss, 1993 present four methods for triangulation from three fixed landmarks in known locations in an environment: iterative search (IS), geometric triangulation (GT), iterative Newton Raphson (NR) and geometric circle intersection (GCI). NR and GCI methods are found to be the most efficient ones. IS and GT are not practical.

The geometric triangulation method is based on the law of sins and works consistently only when the robot is within the triangle formed by the three landmarks (Casanova et al., 2002, Esteves et al., 2003). The geometric circle intersection method is widely used in literature. It fails when the three landmarks and the robot lie on a same circle. Betke and Gurvis, 1997 are using more than three beacons.

The landmark is written as a complex number in the robot-centered coordinate system. The processing time depends linearly on the number of the landmarks. Casanova et al (Casanova et al., 2002; Casanova et al., 2005) address the localization problem of moving objects using laser and radiofrequency technology through a geometric circle triangulation algorithm. They show that the localization error varies depending on the angles between the bacons.

In this paper, a system for global positioning of a mobile robot is presented. Our system combines odometry and 2-D vision data to determine the position of the robot by a new Alternative Triangulation Algorithm (ATA). ATA is obtained from a set of equations from the triangles between the robot and the landmarks. We present simulation results for noisy input data to estimate the robot's position with respect to the environment.

In the next section, the robot platform is described. Section 3 describes the triangulation method based on the law of cosine. Section 4 contains the description of the new Alternative Triangulation Algorithm. Results are given in section 5.

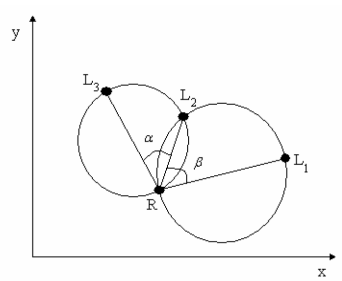


Figure 1: The robot's position is the intersection of two circles. Each one of the two circle passes through the robot and two landmarks.

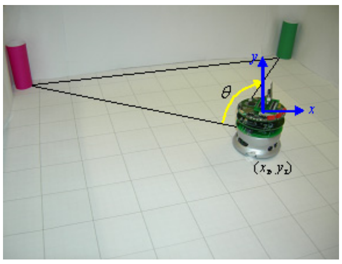


Figure 2: Khepera with the camera module in the test environment.

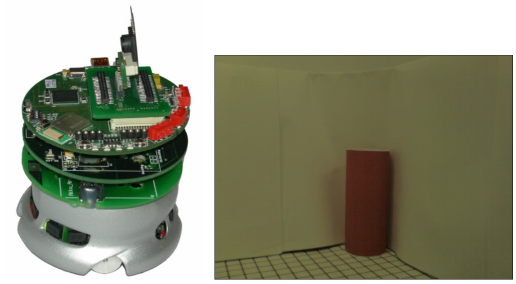

Figure 3: Khepera minirobot II equipped with FPGA module and 2D color CMOS camera module, and a typical image with 640 x 480 pixels from camera module.

## 2 ROBOT PLATFORM

The main idea is the detection of landmarks of different color by using a CMOS color sensor. For this, the robot gets pictures of the environment in different orientations and/or from different positions. An image processing algorithm will be used to extract the centre of each landmark; details are given in (Ebied et al., 2007). Also the different angles between different landmarks as viewed from the mobile robot will be calculated using the odometry method as show in figure 2. Then we develop a new alternative triangulation algorithm to calculate the robot's position based on parameter set (angles) and the knowledge of the positions of the landmarks.

The positioning system has been implemented on the minirobot Khepera (K-Team, 2002) that uses an additional camera module, as show in figure 2. The camera is a 2D color CMOS camera from Transchip, model TC5740MB24B. To control the camera we use an FPGA module that is equipped with USB 2.0 port. Via the USB port the programmer is able to see on a computer screen what the robot is capturing. The received images have a resolution of 640 x 480 pixels in 8 bit RGB color, see figure 3.

## 3 THE TRIANGULATION ALGORITHM

This section shows how to apply well-known triangulation algorithm (Betke and Gurvis, 1997) to the robot localization problem. If the positions of the landmarks are known and also the angles between the landmarks relative to the robot's position are known, then we can use the law of cosine to calculate the distance between the robot and the three landmarks. Let $(x_i, y_i)$, $i$=1…3 be the positions of the landmarks $L_1$ … $L_3$ in the Cartesian coordinate of the environment. From the triangle between the robot and the landmarks $L_1$ and $L_2$ , we get the following equation by applying the law of cosine

$$\left(x_1-x_2\right)^2=d_1^2+d_2^2-2d_1d_2\cos\left(\theta_1*\frac{\pi}{180}\right) \tag{1}$$

where $d_i$, i=1…3 are the unknown distance between the landmarks and the robot's position, and $\theta_1$ is the angle between landmarks $L_1$ and $L_2$ relative to the robot' position, as shows in figure 4.

With three landmarks, there are three pairs of landmarks (i.e. landmarks 1 and 2, 2 and 3, and 1 and 3). So we can get system of equations to determine the distance $d_i$ between the robot's position and the landmarks $L_i$, by applying the law of cosine to all pairs of landmarks

$$\left(x_1-x_3\right)^2=d_1^2+d_3^2-2d_1d_3\cos\left(\theta_2*\frac{\pi}{180}\right) \tag{2}$$

$$\left(x_2-x_3\right)^2=d_2^2+d_3^2-2d_2d_3\cos\left(\theta_{12}*\frac{\pi}{180}\right) \tag{3}$$

Where $\theta_2$ is the angle between landmarks $L_2$ and $L_3$ relative to the robot' position, as shown in figure 4. The system of nonlinear equations (1), (2), and (3) can be solved using a least square method. Once the distances $d_i$ are found, the robot's position ($x_r$ ,$y_r$) can be estimated from solving the following equations:

$$d_1^2 = \left(x_1-x_r\right)^2 + \left(y_1-y_r\right)^2 \tag{4}$$

$$d_2^2 = \left(x_2-x_r\right)^2 + \left(y_2-y_r\right)^2 \tag{5}$$

$$d_3^2=\left(x_3-x_r\right)^2+\left(y_3-y_r\right)^2 \tag{6}$$

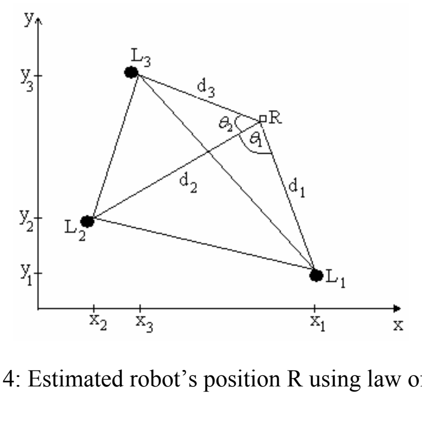


Figure 4: Estimated robot's position R using law of cosine.

# 4 AN ALTERNATIVE TRIANGULATION ALGORITHM

In the alternative triangulation algorithm, also at least three landmarks are required to estimate the robot's position. We can use the triangles between the robot and the three landmarks to estimate the robot's position. From the triangle between the robot and the landmarks $L_1$ and $L_2$, we get the following equations

$$\tan\left(\theta_{1a}*\frac{\pi}{180}\right) = \frac{x_1-x_r}{y_r-y_1} \tag{7}$$

$$\tan\left(\theta_{1b}*\frac{\pi}{180}\right) = \frac{x_r-x_2}{y_r-y_2} \tag{8}$$

The angles $\theta_{1a}$ and $\theta_{1b}$ can be computed from the measured angle $\theta_1$, as shows in figure 5.

$$\theta_{1a} + \theta_{1b} = \theta_1 \tag{9}$$

We can apply the same equations to another pair of landmarks and get a system of six equations in six unknown variables which can be solved to give us an estimate for the robot's position ($x_r$, $y_r$). Applying the same equations on the triangle between the robot and the landmarks $L_2$ and $L_3$, we get the following equations

$$\tan\left(\theta_{2a}*\frac{\pi}{180}\right) = \frac{y_r-y_2}{x_r-x_2} \tag{10}$$

$$\tan\left(\theta_{2b}*\frac{\pi}{180}\right) = \frac{y_3-y_r}{x_r-x_3} \tag{11}$$

$$\theta_{2a} + \theta_{2b} = \theta_2 \tag{12}$$

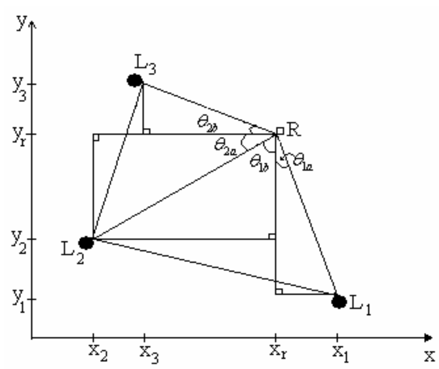


Figure 5: An alternative triangulation algorithm to estimated robot's position R using three Landmarks.

## 5 RESULTS AND DISCUSSION

Four distinctly coloured landmarks are placed at known positions at the edges of the environment. For a robot's environment with a size of 62 x 74 $cm^2$, the floor of the environment will be divided into squares (cells) that are used to determine the position of the robot. We have used a grid with 11 by 13 lines in each direction which results in a data set of 143 robot's position. The robot's position error is considering as the Euclidean distance between the estimated robot position and the actual robot position. We averaged the robot's position error over 143 places in the environment.

In the first experiment, the alternative triangulation algorithm has been used to estimate robot's position in the experimental environment. The experiments deal with different combinations of three landmarks. In Figure 6, the position error has been plotted as a function of the robot's position. The average of the position error is 0.35cm which is limited between 0.02cm and 3.5cm. Maximum error is obtained when the two angles between three landmarks relative to the robot's position is less than 90°. It is easily to overcome the error in robot's position by using all the visible landmarks.

Using several landmarks yield a more robust robot's position estimate. If we have n landmarks, there are many different combinations of the three landmarks that can be used to compute the position of the robot. We can obtain the minimum position error by using two different ways. First, we can calculate the average from the estimated robot's position from all different groups of three landmarks. Or by using a suitable algorithm to select the best 3 landmarks with at least one angle greater than 90°.

The position error average from all different groups of landmarks is 0.253cm which is limited between 0.022cm and 0.935cm. The position error, based on selecting the best 3 landmarks with at least one angle greater than 90°, is 0.242cm which is limited between 0.021cm and 0.767cm. So by using a suitable algorithm to select the best 3 landmarks with at least one angle greater than 90°, we can obtain the minimum position error, as show in figure 7.

The second experiment deals with the triangulation algorithm based on the law of cosine. Solving system of nonlinear equations using the least square method requires making a starting guess of the robot's position. Table 1 shows the results of the experiments in which the starting guess of the solution takes across the environment diagonal. Our results show the minimum, maximum, mean, and standard deviation of the position error. We begin to receive a minimum of the position error close to the environment center. The mean of the position error is 0.0035cm when the center coordinate of the environment is used as the starting guess.

The last experiment, we consider the robot's position problem for noisy angle data that are measure using odometry method. Errors in odometry are caused by the intersection between the wheels and the terrain, for example slippage, cracks, debris of solid material, etc. (Borenstein et al., 1997). We add a random noisy angle $\Delta\theta$ of degree to each actual angle. Table 2 shows the position error using the alternative triangulation algorithm with different combinations of three landmarks, and using the random generated angles $\Delta\theta$ on the specified interval [-3°, 3°] which are added to the actual angles.

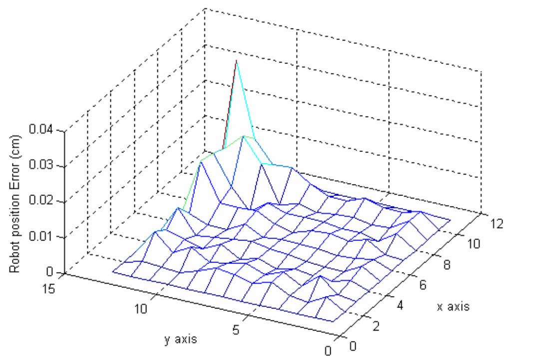


Figure 6: Estimated robot's position using an ATA. Three landmarks have been placed at the right and left bottom corner and at the left top corner of the environment. The maximum error happened when the robot was been almost on the same line with one of the landmarks parallel to the x-axis.

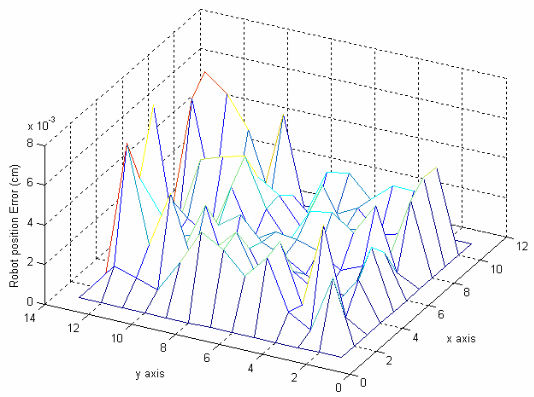


Figure 7: By using a suitable algorithm to select the best 3 landmarks with at least one angle greater than 90°.

Table 1: Minimum, maximum, mean, and standard deviation values (in cm) for the robot's position error at different starting guess of the solution.

| | (10,10,10)cm | (15,15,15)cm | (20,20,20)cm |
|---|---|---|---|
| min | 0,0002 | 0,0002 | 0,0002 |
| max | 66,0609 | 66,0609 | 0,0351 |
| mean | 8,0755 | 1,8593 | 0,0035 |
| std | 18,1959 | 10,5717 | 0,0046 |

Table 2: Minimum, maximum, mean, and standard deviation values (in cm) for the robot's position error of different groups of landmarks. The results from selecting the suitable three landmarks with at least one angle greater than 90° are given in column Select.

| | Landmark groups | | | | | |
|---|---|---|---|---|---|---|
| | 1, 2, 3 | 1, 2, 4 | 2, 3, 4 | 1, 3, 4 | average | Select |
| min | 0,222 | 0,102 | 0,097 | 0,047 | 0,106 | 0,20 |
| max | 8,631 | 10,12 | 11,01 | 21,24 | 6,490 | 4,07 |
| mean | 1,924 | 1,944 | 2,136 | 2,154 | 1,403 | 1,50 |
| Std | 1,511 | 1,602 | 2,065 | 2,520 | 0,897 | 0,88 |

## ACKNOWLEDGEMENTS

This work is a result of common research between the Department of System and Circuit Technology, Heinz Nixdorf Institute, University of Paderborn and Scientific Computing Department, Faculty of Computer and Information Sciences, Ain Shames University. It is also supported from the Arab Republic of Egypt cultural department and study mission.

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