# Development of ball direction prediction system for wheeled soccer robot goalkeeper using trigonometry technique and neural network method

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**Abstract.** In this research, trigonometry technique and Neural Network method were implemented to predict the ball direction for wheeled soccer robot goalkeeper. The performance of goalkeeper robot in Wheeled Soccer Robot Contest is very important. The crucial problem with goalkeeper robot is the delay in ball detection by the camera because the results of the captured images are always slower than the pictures that have been captured. This causes the robot response to block the opponent's kicked ball being late. Trigonometry technique is one technique that can be used to predict the direction of the ball based on trigonometric mathematical formulas. The used input variables are the location of the last ball position (x–last ball and y-last ball) and the location of the current ball position (x-current ball and y-current ball). In this system a Neural Network method is also implemented to estimate the ball distance from goalkeeper robot. The result shows the goalkeeper robot successfully predicts the ball direction very well and it can estimate the ball distance with 7.06 cm error accuracy. By implementing this method can optimize the performance of the goalkeeper robot in saving the goal.

## 1. Introduction

Indonesian Wheeled Robot Soccer Contest is one of division in Indonesian Robot Competition that have been introduced since 2017 [1]. The contest matches refer to the Middle Size League (MSL) which is a robot soccer contest at the world level with adjustments in several rules. The goalkeeper robot is one of the robots in Indonesian Wheeled Robot Soccer Contest which has the task of keeping the goal area from the opponent's kicked ball that coming from all directions. The movements of goalkeeper robot are determined by the position of the ball in the field and the ball was detected by the goalkeeper's camera. The crucial problem that makes the goalkeeper robot's performance not optimal is the delay in capturing pictures by the camera from its actual condition. This caused the goalkeeper robot's response to block the ball too late and increase the chances of the opponent's kicked ball becoming a goal.

In this paper is discussed the ball direction prediction in the goalkeeper robot using Trigonometry Technique and Neural Network method. Trigonometry Technique is one of method that can be used to predict the ball direction based on trigonometric mathematical formulas [2].The used input variables are the last location of the ball and the current location of the ball on the camera frame. The input data will be calculated using a trigonometric formula, so it can predict the direction of the ball. The goalkeeper has camera sensor that used to detect the ball. In this research, the ball detection system using colour threshold method. In this method, the captured images by the camera are converted to binary images [3] [4]. For simplicity reason, the previous original image with RGB colour space was converted to HSV [5]. The area of the object will be determined as midpoint, so the coordinates of the ball can be known. These coordinates will be processed on the Trigonometric Technique, so it can predict the coordinate of ball coming location. The ball coordinate location and the prediction of ball coming location will be calculated using the Neural Network method. The Neural Network is an information processing system that adopts the abilities of the human brain [6]. With Neural Network algorithm, the system can estimate the ball distance from goalkeeper robot.

## 2. Methodology

### *2.1. Mechanical design*

Robot mechanics are designed with dimensions of 50 x 50 x 78 centimetres. Robot construction uses 3 millimetres iron plate on the bottom base, and also 3 millimetres aluminium plate on the upper base. As for the robot frame is using a 0.5 x 1 inch aluminium pipe. Figure 1 is a mechanical construction that has been made.

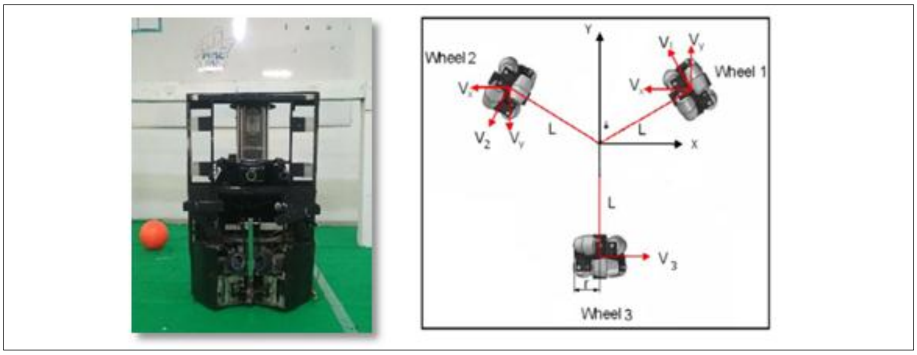


**Figure 1.** Robot construction (left) and kinematics representation (right).

The three Omni-Directional Drive System is also represented in Figure 1 [7]. Robot kinematics are using Three Omni-Directional Drive Systems which have 3 Omni wheels arranged symmetrically (120°) apart. The three Omni-Directional Drive System is represented to get the speed of each of the Omni wheels that equals to the speed of the motor multiplied by the radius of the Omni wheel. It was arranged symmetrically with different angles between the wheels as in equation 1 – 3 [7].

$$V_x = V_3 - V_1 \cos\delta \; - V_2 \cos\delta \quad (1)$$

$$V_x = V_3 - V_1 \cos\delta \; - V_2 \cos\delta \quad (2)$$

$$V_\theta = V_1 \,/\, L + V_2 \,/\, L + V_3 \,/\, L \quad (3)$$

$$V_{i\,(1,2,3)} = w\,.\,r \quad (4)$$

*2.2. Ball detection software design*

In this research, ball detection in a robot keeper uses a camera sensor with a ball segmentation method based on colour parameter. The used camera is a webcam type that has 30 fps frame rates. The software mechanisms are : initializing the ball colour, image capturing, RGB to HSV conversion, colour threshold, find the ball counters and the last step is determine the ball location. Here are the explanations of each mechanism step:

*2.2.1. Initializing the ball color.* The first phase is the initialization of color parameter values like hue, saturation, and value also morphology parameters of the ball with manual calibration. In this research the detected ball was orange.

*2.2.2. Image capturing.* Image capturing is the process of getting a digital image from a visual sensor, like a camera. A digital image can be represented as a two-dimensional matrix that can be represented by f (x, y), where the values of x and y are the brightness level of an image. Digital images coordinates start at (0,0) and end at (M-1, N-1) [8].

*2.2.3. RGB to HSV conversion.* RGB is the most commonly used color space in image processing, the RGB color model consists of 3 main components, namely R (red), G (green) and B (blue). Whereas HSV is a better color space when used for image processing. Equation 5 - 8 is a formula for converting RGB values to HSV values [8].

$$V = max\, R, G, B \tag{5}$$

$$V_m = V - min\, R, G, B \tag{6}$$

$$S = \begin{cases} 0 & if\ V = 0 \\ \frac{V_m}{V} & if\ V > 0 \end{cases} \tag{7}$$

$$S = \begin{cases} 0 & if\ V = 0 \\ \frac{V_m}{V} & if\ V > 0 \end{cases} \tag{8}$$

*2.2.4. Color threshold.* Color threshold is the simplest image processing method that used to get digital images with binary format (1 or 0) *[9]*. This phase aims to divide the object area (1) and background (0) in digital image. The threshold value is suitable to initialize the color value at initial phase which includes the value of H max, S max, V max, H min, S min, V min, Dilation (Morphology), Erosion (Morphology). Dilation and erosion can reduce the noise by increasing or decreasing the size of object segmentation around the object. Thresholding can be expressed in the Equation 9.

$$g(x, y) = \begin{cases} 1, & if\ f(x, y) \geq T \\ 0, & if\ f(x, y) < T \end{cases} \tag{10}$$

*2.2.5. Find the ball contours.* After the image becomes binary, it continues with the ball contour find phase for each pixel that indicated as an object (has 1 value). The contour find phase of the ball is done to simplify the detection of the ball based on the shape.

*2.2.6. Determine the ball location.* The initial process of determining the location of the ball by drawing a square on the frame. This process aims to get the coordinates of the location of the ball in the frame. The process of drawing this square is based on a point that is tangent to the contour of a ball.

*2.3. Ball prediction software design*

Trigonometry Technique is one technique that can be used to predict the direction of the ball for a goalkeeper robot based on trigonometric mathematical formulas [10]. In this technique, there are two stages of the calculation process including the initial stage and the prediction stage. The prediction stages are: initialization of time interval, find the last location and current location off the ball, calculate the ball movement distance, determine the ball direction prediction, calculate the ball movement angle, and determine the prediction of ball coming position. Here are the explanations of each step:

*2.3.1. Initialization of time interval.*The first phase is initializing the initial interval time. Interval time's variables will be used in calculating trigonometric techniques in next phase.

*2.3.2. Find the last location and current location off ball.* The distance between the last frame and the current frame is separated by the initial time interval (t) that is the value was determined at the initial phase. The current ball variable position is the ball coordinates on the x and y axis of the current frame, while the last ball variable position is the ball coordinates on the x and y axes of the last frame.

*2.3.3. Calculate the ball movement distance. The* Equation 10 and 11 are used to determine the distance of the ball in each axis in the frame.

$$dx = xcurrent\ ball - xlast\ ball \tag{10}$$

$$dy = ycurrent\ ball - ylast\ ball \tag{11}$$

From the dx and dy value, we can get the distance of the ball movement by calculating the hypotenuse of the triangle. Figure 2 illustrates the relationship between dx, dy, and hypotenuse (s).

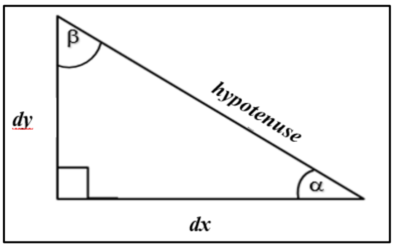


**Figure 2.** Relationship between dx, dy and hypotenuse.

In right triangle, the hypotenuse can be calculated using dx and dy using Equation 12 based on the Pythagoras concept. In this technique, the hypotenuse of the triangle represents the distance of the ball's movement.

$$hypotenuse = \sqrt{dx^2 + dy^2} \tag{12}$$

*2.3.4. Determine theball direction prediction.* There are several conditions to determine the direction of ball movement. Figure 3 is the conditioning of ball movement direction with coordinates f (0,0) in the upper left corner of the frame.

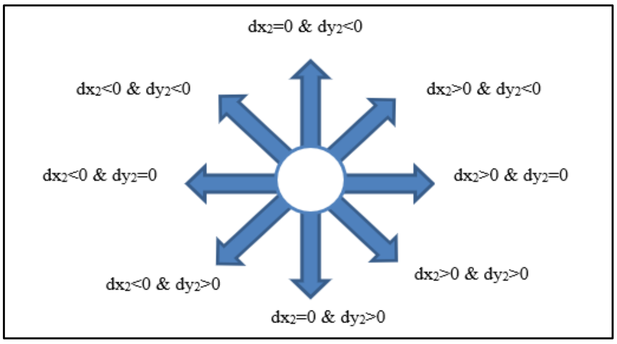


**Figure 3.** Conditioning of ball movement direction.

*2.3.5. Calculate the ball movement angle.* The ball movement angle was represented in Figure 4. The ball movement angle can be calculated using trigonometric equation. By dx, dy, and hypotenuse value, the trigonometric concept can be implemented using Equation 13 and 14.

$$\alpha = sin^{-1}\frac{dx}{hypotenuse} \quad (13)$$

$$\beta = sin^{-1}\frac{dy}{hypotenuse} \quad (14)$$

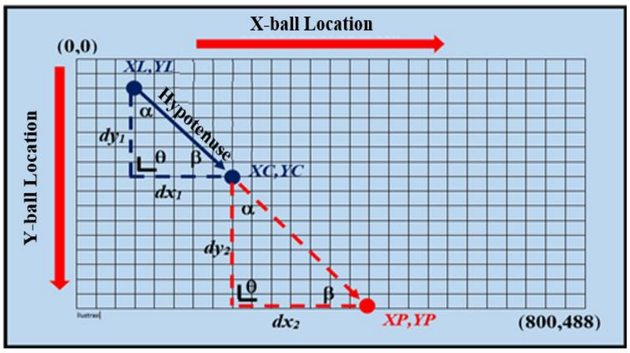


**Figure 4.** Representation of ball movement angle.

*2.3.6. Determine the prediction of ball coming position*. From the angle of the formed triangle which is represented in Figure 4, we can find the prediction of next ball location when attracted to the maximum y-coordinate in the frame (YP). These x ball coordinates will represent the predicted value of the ball coming location (XP). The XP can be calculated using Equation 15 - 17.

$$dy_2 = Ymax - YC \quad (15)$$

$$XP = XC + dx_2 \quad (16)$$

*2.4. Neural Network Architecture*

In this research, Neural Network method is used to estimate the ball distance from goalkeeper robot. The Neural Network architecture is shown in Figure 5.

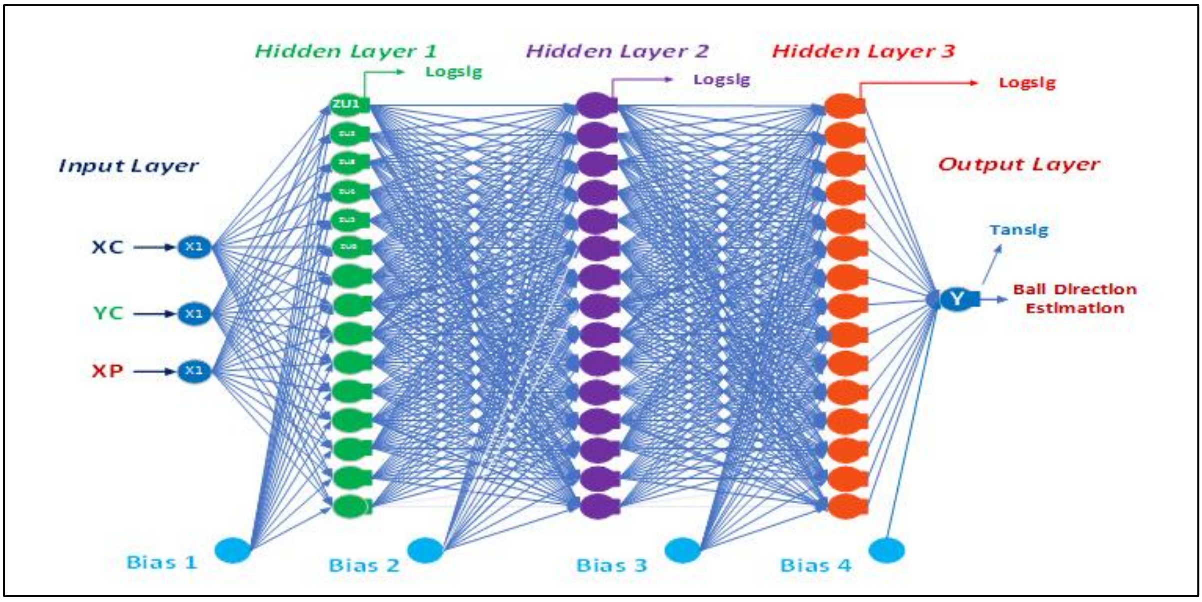


**Figure 5.** Neural network architecture.

The Neural Network has five layers. They are input layer, 3 hidden layers, and output layer. The input layer consists of 3 nodes (x-ball location (XC), y-ball location (YC), and the prediction of ball coming location (XP)). In each hidden layer consists of 15 nodes. The output layer consists of 1 node (ball distance estimation). The hidden layer and the output layer are connected with biases, it prevent the emergence of zero values because the bias is worth to 1. Each arrow has a weight value that obtained from the results of training using the levenberg marquardt back propagation method. The training stage was delivered by using 601 dataset.

## 3. Experiments and data analysis

*3.1. The experiment of ball direction prediction*. This experiment aims to determine the results of the Trigonometric Technique calculation in predicting the ball direction and ball coming location (XP). The experiment was conducted by rolling the ball to the middle, right and left of the robot. The results are shown in Figure 6–8 and Table 1.

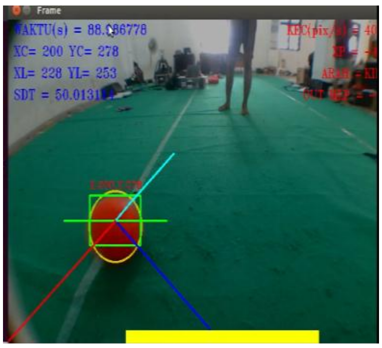


**Figure 6.** Ball prediction when the ball is rolling to the left.

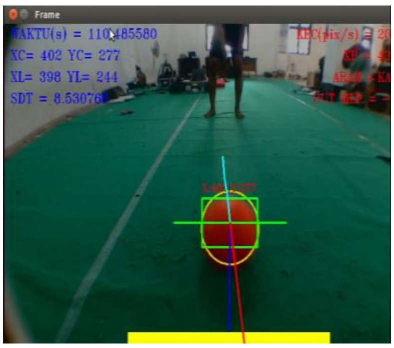


**Figure 7.** Ball prediction when the ball is rolling to the middle.

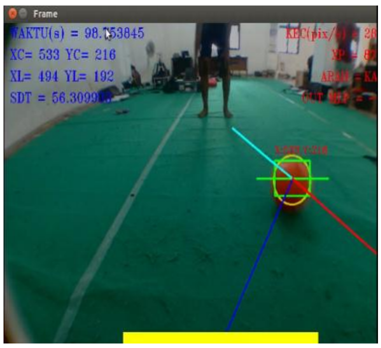


**Figure 8.** Ball prediction when the ball is rolling to the right.

**Table 1.** The results for ball direction prediction experiment.

| XC | YC | Kick Ball Angle | XP | Difference of XC and XP | Direction |
|---|---|---|---|---|---|
| 397 | 121 | 53,13 | -39 | 436 | Left |
| 394 | 124 | 53,13 | -38 | 432 | Left |
| 383 | 131 | 57,53 | -115 | 498 | Left |
| 388 | 171 | 3,37 | 427 | 39 | Right |
| 388 | 181 | 3,37 | 403 | 15 | Right |
| 389 | 185 | 0,00 | 404 | 15 | Left |
| 428 | 151 | 50,20 | 845 | 417 | Right |
| 441 | 159 | 55,62 | 844 | 403 | Right |
| 447 | 162 | 55,62 | 784 | 337 | Right |

Table 1 is the result of ball location prediction experiment. The result shows the system can predict the kicked ball direction and ball coming location very well. If the kick angle is large, then the XP location is far to the current ball location (XC). Conversely, if the kick angle is small, then the XP location is close to the current ball location (XC).

3.2. *The experiment of the ball distance estimation.* This experiment aims to determine the accuracy of the Neural Network method in estimating the distance of the ball from goalkeeper robot. The Neural Network uses 3 input data (x ball location, y ball location, and ball coming location). The experiment was conducted by rolling the ball towards the goal area which is presented in Figure 9. The results of the experiment are shown in Table 2.

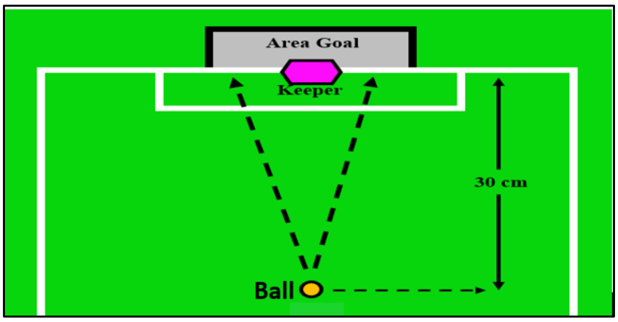


**Figure 9.** The representation of ball rolling position.

**Table 2.** The results for the experiment of ball distance estimation

| XC | YC | XP | Actual Distance (cm) | Prediction Distance (cm) | Error (cm) |
|---|---|---|---|---|---|
| 404 | 101 | 751 | 60 | 51.253 | 8.747 |
| 410 | 105 | 867 | 60 | 71.219 | 11.219 |
| 414 | 107 | 868 | 60 | 70.478 | 10.478 |
| 424 | 114 | 901 | 60 | 66.866 | 6.866 |
| 428 | 117 | 891 | 60 | 66.846 | 6.846 |
| 439 | 125 | 891 | 60 | 64.759 | 4.759 |
| 446 | 129 | 1004 | 60 | 69.252 | 9.252 |
| 458 | 136 | 996 | 60 | 66.015 | 6.015 |
| 476 | 146 | 997 | 60 | 64.037 | 4.037 |
| 485 | 165 | 1019 | 60 | 62.390 | 2.390 |
| | | | **Error Average** | | 7.06 |

Table 2 shows the results for the experiment of ball distance estimation. From 10 samples the average error of the actual ball distance estimation is 7.06 cm. The error was caused by the limitations of training data on the Neural Network method, so the system cannot accurately predict if the condition is far from the data that has been trained.

## 4. Conclusion

The results of ball coming prediction are strongly influenced by the value of ball movement angle. If the angle is large, the ball coming prediction is far from the ball current location. Conversely, if the angle is small, the ball coming prediction is close to the ball current location. Error of the actual ball distance estimation is 7.06 cm, The distance estimation error was existed due to the limited training data on Neural Network method, so the system cannot accurately predict the condition is far from the data that has been trained.

## 5. References

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