Ball Direction Prediction for Wheeled Soccer Robot Goalkeeper Using Trigonometry Technique

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Abstract

In this research Trigonometry Technique was implemented to predict the ball movement 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 camera images captured are always slower than the pictures that have been captured. This causes the robot's response to block the opponent's kick ball being late. Trigonometry Technique is one technique that can be used to predict the direction of the ball movement based on trigonometry mathematical formulas. The input data used is 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). The outputs are the prediction of the next ball location (x-predict ball and y-predict ball) and the prediction of ball movement direction prediction. The results are the goalkeeper's robot successfully predicts the opponent's kick direction with 90% accuracy and can predict the location of the next ball very well. By implementing this method, it is expected to optimize the performance of the goalkeeper robot in saving the goal.

Keyword: trigonometric technique; prediction; direction; ball; wheeled soccer robot goalkeeper

1. INTRODUCTION

Indonesian Wheeled Robot Soccer Contest is one of division in Indonesian Robot Competition that have been introduced since 2017 (RISTEKDIKTI, 2018). 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 kick ball coming from all directions. The robot which is utilized autonomous robot which moves based on numerical analysis (Budianto, et al., 2017) (Kurniawan, et al., 2017). The movements are determined by the position of the ball in the field detected by the camera. The crucial problem that makes the goalkeeper robot's performance nonoptimal is the delay in capturing pictures by the camera from its actual condition. This caused the goalkeeper robot's response to block the ball to be too late and increase the chances of the kicking ball becoming a goal.

In this paper is discussed the ball direction prediction in the goalkeeper robot using Trigonometry Technique. The input data used is 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 trigonometry formula so that it can predict the location of the next ball. Prediction results will be a reference to determine the direction of ball movement.

The basic ability that must be possessed by the goalkeeper robot is detecting the ball in the field. In this paper, camera sensor is used to detect the object and personal computer to process digital images captured by camera (Khumaidi, et al., 2017) (Nazar, et al., 2009). The ball detection process begins with the conversion of RGB to HSV color space (Marzuqi, et al., 2017). Then the color thresholding phase according to predetermined threshold values so that it becomes a binary image (Puneet & Garg, 2013) (Mukherjee & Kanrar, 2010). Binary results are adjusted by using image morphology in the form of dilation and erosion (Beham & Gurulakshmi, 2012). In the binary phase this will be separated between the object area and the background area. The area of the object will be searched for the midpoint so that the coordinates of the location of the ball are obtained. These coordinates will be processed on the Trigonometry Technique so that it can predict the direction of movement of the ball and the coordinates of the location of the next ball.

2. METHODOLOGY

2.1. Mechanical Design

Robot mechanics are designed with dimensions of 50 x 50 x 78 centimeters. Robot construction uses iron plate 3 millimeters on the bottom base, and aluminum plate 3 millimeters on the upper base. As for the robot frame using a 0.5x1 inch aluminum pipe. Figure 1 is a mechanical construction that has been made.

Figure 1. Robot construction

Robot kinematics uses Three Omni-Directional Drive Systems which have three omni wheels arranged symmetrically (120°) apart. The three Omni-Directional Drive System is represented in Figure 2 (Al-Ammri & Ahmed, 2010).

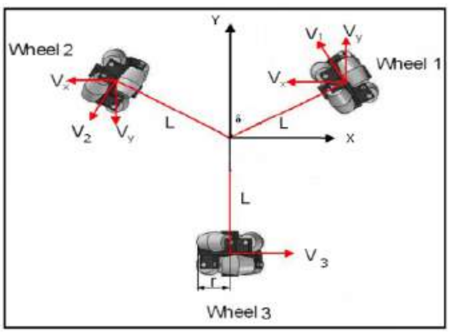

Figure 2. Kinematics representation of the Three Omni-Directional Drive System

To get the speed of each of the omni wheels equals the speed of the motor multiplied by the radius of the omni wheel which is arranged symmetrically with different angles between the wheels as in equation 1 – 3 (Al-Ammri & Ahmed, 2010).

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

$$V_y = V_1 \sin\delta - V_2 \sin\delta \quad (2)$$

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

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

a. Ball Detection Software Design

In this research, ball detection in a robot keeper uses a camera sensor with a ball segmentation method based on color parameters. The camera used is a webcam type that has 30fps framerates. Figure 2 is a flow diagram of the ball detection software.

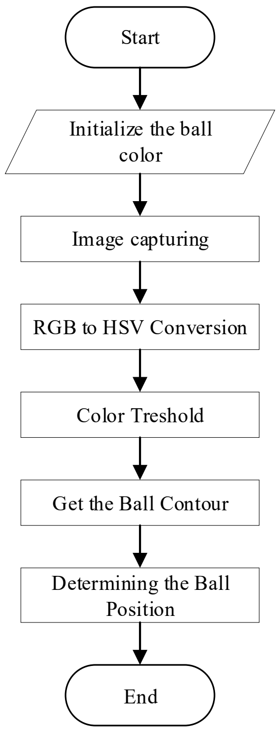

Figure 2. Flowchart of Ball Detection Software

1) Initialize the Ball Colour
   The first phase is the initialization of color parameter values Hue, Saturation, and Value also morphology parameters of the ball with manual calibration. In this research the detected ball was orange.
2) Images Capturing
   Images 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 symbolized f (x,

y), where the values of x and y are the brightness level of an image. Mathematical digital images can be seen in Figure 3 below, where image coordinates start at (0,0) and end at (M-1, N-1) (Hidayatullah, 2017).

$$f(x,y)\begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & \dots & f(1,N-1) \\ \dots & \dots & \dots & \dots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}$$

Figure 3. Mathematical digital images

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 4 is a formula for converting RGB values to HSV values (Hidayatullah, 2017).

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

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

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

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

4) Colour Threshold

Colour threshold is the simplest image processing method used to get digital images that have binary values (1 or 0) (Khumaidi, 2015). This phase aim to divide the object area (1) and background (0) in digital image. The threshold value suitable to the initialization of the colour value at the 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 noise by increasing or decreasing the size of object segmentation around the object. Thresholding can be expressed in the Equation 9.

$$g(x,y) = \begin{cases} 1, & if\ f(x,y) \geq T \\ 0, & if\ f(x,y) < T \end{cases} \tag{9}$$

5) Find the Ball Contours

After the image becomes binary, it continues with the ball contour find phase for each pixel that is indicated as an object (has 1 value). The contour find phase of the ball is done to make it easy to detect the ball based on the shape.

6) Determine the Ball Location

The initial process of determining the location of the ball by drawing a square build on the frame. This process aims to make it easier 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.

b. Trigonometry Technique 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 (Sudin, et al., 2014). The physics concept that can be implemented on Trigonometry Technique is the uniform linier motion concept that happen on the ball. Uniform linier motion is defined as the motion of an object that has a straight line and a fixed velocity (Indrasutanto & Yunitasari, 2009). Fixed velocity means the value and direction are constant. Figure 3 is a flow diagram of Trigonometry Technique software.

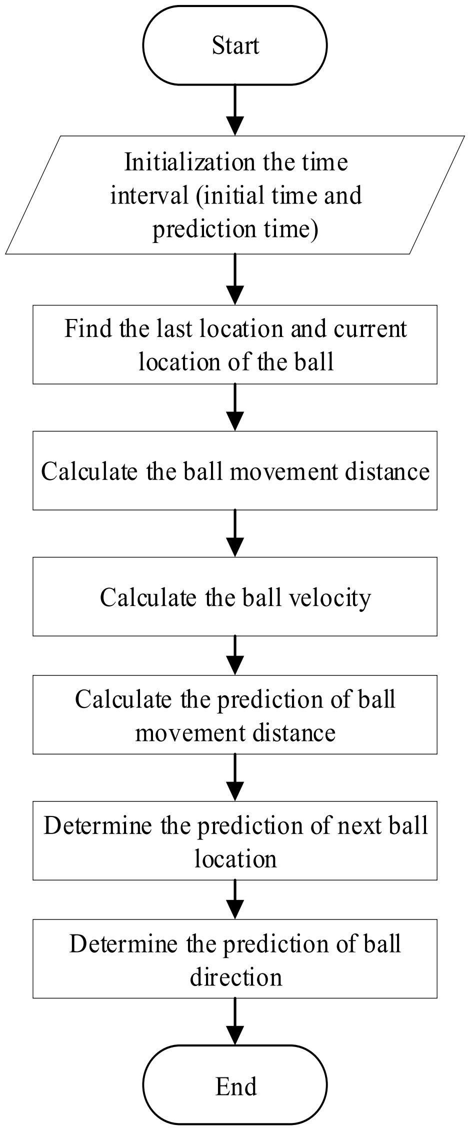

Figure 3. Flowchart of Trigonometry Technique software

1) Initialization the time interval.
   In first phase must initialize the initial interval time (t_1) and the prediction interval time (t_2). Interval times variables will be used in calculating trigonometry techniques in next phase.
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_1) whose value is determined at the initial phase. The current ball variable positions the ball coordinates on the x and y axis of the current frame, while the last ball variable positions the ball coordinates on the x and y axes of the last frame.
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.

$$dx = xcurrentball - xlastball \tag{10}$$

$$dy = ycurrentball - ylastball \tag{11}$$

From the *dx* and *dy* value, we can get the distance of the ball movement by calculating the hypotenuse of the triangle. Figure 4 illustrates the relationship between *dx*, *dy,* and hypotenuse (*s*).

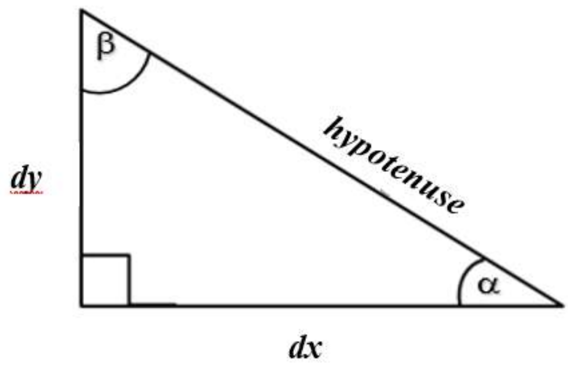

Figure 4. Relationship between *dx*, *dy,* and hypotenuse.

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.

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

4) Calculate the ball velocity
   Then, the ball distance variable can be used to calculate the velocity of ball movement based on the uniform linier concept using Equation 13.

$$velocity\ (V_1) = \frac{ball\ distance\ (S_1)}{initial\ time\ interval\ (T_1)} \tag{13}$$

5) Calculate the prediction of ball movement distance

The next phase is the calculation of ball distance predictions (S_2). By assuming the ball moves with a fixed velocity (uniform linear motion concept), the velocity in the prediction phase (V_2) is proportional to the velocity in the initial phase (V_1). With the parameter prediction time interval (T_2) that has been initialized before, we can determine the prediction of ball movement using Equation 14.

$$S_2 = \frac{velocity\ in\ prediction\ phase\ (V_2)}{prediction\ time\ interval(T_2)} \quad (14)$$

6) Determine the prediction of next ball location
This prediction estimates the location of the ball in the next frame with the prediction time interval (T_2) between each frame. The first step is dx_2 and dy_2 calculation using Equation 15 - 16.

$$dx_2 = \frac{s_2}{\sin\theta} * \sin\beta \quad (15)$$

$$dy_2 = \frac{s_2}{\sin\theta} * \sin\alpha \quad (16)$$

With dx_2 and dy_2 values, the next location of the ball can be predicted according to the rules in Figure 5:

If $dx_2 > 0$ → *x-predict = x-current ball* + dx_2
Else If $dx_2 < 0$ → *x-predict = x-current ball* - dx_2
Else → *x-predict = x-current ball*

If $dy_2 > 0$ → *y-predict = y-current ball* + dy_2
Else If $dy_2 < 0$ → *y-predict = y-current ball* - dy_2
Else → *y-predict = y-current ball*

Figure 5. The rules used to predict the next ball location

7) Determine the prediction of ball direction
There are several conditions to determine the direction of ball movement. Figure 6 is the conditioning of ball movement direction with coordinates f (0,0) in the upper left corner of the frame

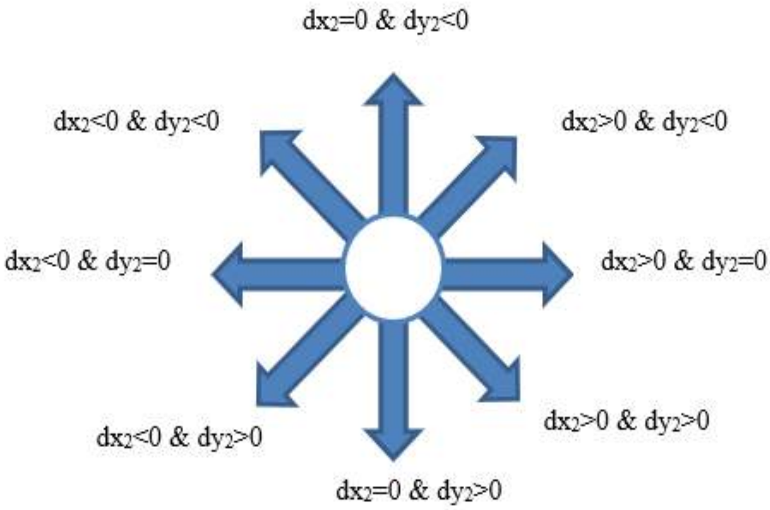

Figure 6. Conditioning of ball movement direction.

3. RESEARCH RESULT AND DISCUSSION

3.1. The Testing of Ball Detection Software

1) Image capturing test

   The purpose of image capture test is to know the view angle captured by the camera. Seen in Figure 7, the camera's viewing angle is very wide because it uses an additional fish eye lens.

Figure 7. The display of camera's view angle

2) RGB to HSV conversion test

   The purpose of this test is to know the results of the RGB to HSV colour space conversion on the frame. The results are shown in Figure 8(a) and (b).

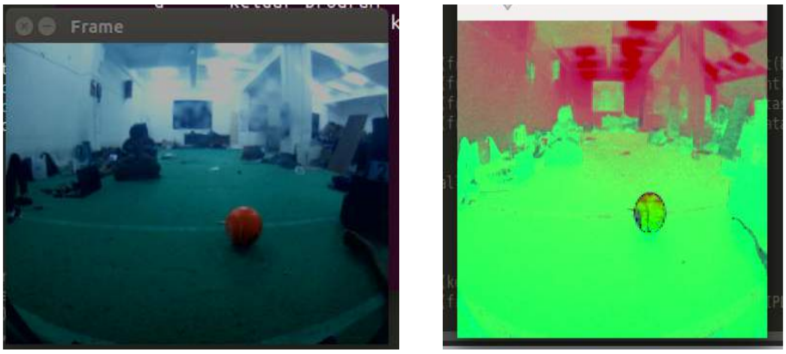

Figure 8. (a) Frame with RGB (b) HSV conversion results

3) Colour threshold test
The colour threshold test aims to know the results of colour separation on the frame into binary colour according to the ball colour initialization in initial phase. The test results are shown in Figure 79

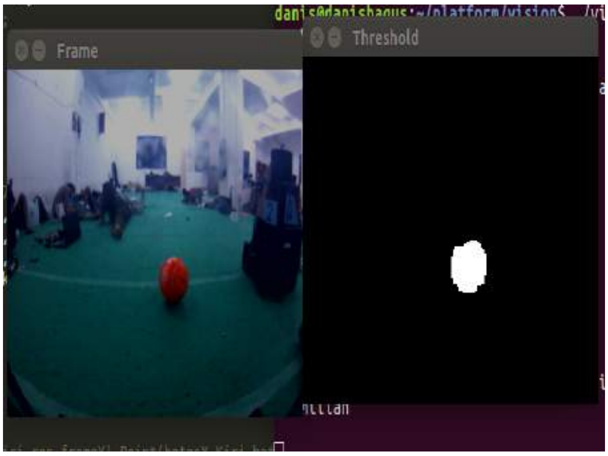

Figure 9. Color threshold results

4) Ball detection test
The purpose of this test is to find out how far the robot can detect the ball. This test is by placing the ball in front of the robot with different distances. The test results are presented in Table I.

Table 1. The Results of Ball Detection Test

No	Distance (cm)	Status
1.	50	Detected
2.	100	Detected

3.	200	Detected
4.	300	Detected
5.	400	Detected
6.	500	Detected
7.	600	Detected
8.	700	Detected
9.	800	Detected
10.	900	Not detected

3.2. The Testing of Trigonometry Technique Software

1) The testing of location ball prediction

The purpose of this test is to know the accuracy of the robot in predicting the location of the next ball. In this experiment the ball is rolled over a field with a flat surface randomly. In the Trigonometry Technique, there are several parameters that are used such as the last ball coordinates (x-last and y-last), current ball coordinates (x-current and y-current), prediction ball coordinates (x-prediction and y-prediction). The initial time interval used is 0.1 seconds, and the prediction time interval used is 0.5 seconds. The results of the predicted ball coordinates are shown in Table 2.

Table 2. The results of location ball prediction test

No	x-last	y-last	x-current	y-current	x-prediction	y-prediction
1.	423	167	423	167	423	423
2.	438	206	477	229	672	438
3.	343	214	316	232	181	343
4.	538	191	563	191	688	538
5.	384	198	366	198	276	384
6.	182	272	209	257	344	182
7.	504	249	488	241	408	504
8.	445	207	445	216	445	445
9.	420	211	420	205	420	420
10	335	192	335	192	335	192

2) The testing of ball direction prediction
The purpose of the test is to know the accuracy of the robot in predicting the movement direction the next ball. The blue line in the frame is the direction of the predicted ball that is updated every 0.1 seconds. Frame display of ball direction prediction are shown in Figure 10 While the red line is a recording of the movement of the ball at the previous time interval that is updated every 0.1 seconds. The results of the ball direction prediction test are shown in Table 3.

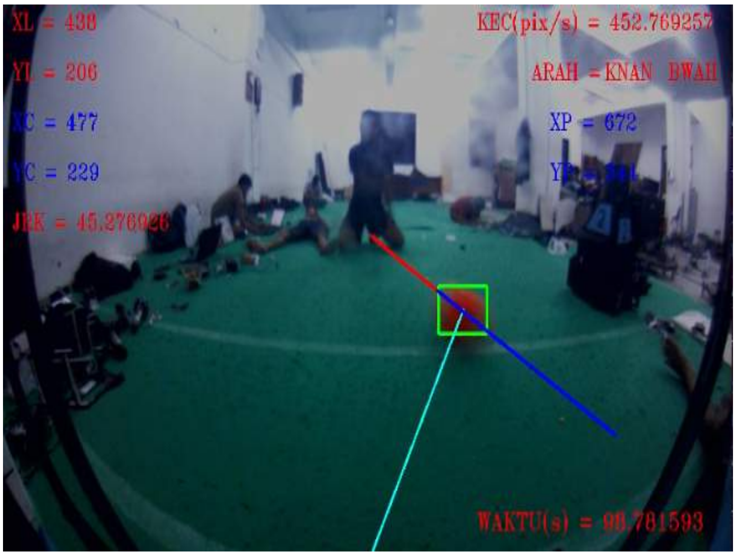

Figure 7. The display of ball direction prediction

Table 3. The results of ball direction prediction

No	Actual direction	Prediction direction	Status
1	Not moving	Not moving	True
2	Right down	Right down	True
3	Left down	Left down	True
4	Right	Right	True
5	Left	Left	True
6	Right up	Right up	True
7	Left up	Left up	True
8	Down	Down	True
9	Up	Not moving	False
10	Not moving	Not moving	True
Accuracy			**90%**

3.3. Discussion

The result of testing the ball detection software is the system can detect the ball very well. In testing ball detection, the system successfully detects the ball at a distance of 50 cm - 800 cm from the position of the robot. The system failed to detect the ball when the ball was placed at a distance of 900 cm. This is because when the distance of the ball is far away, the image of the ball captured by the camera gets smaller, making it difficult for the ball detection process.

The results of testing he Trigonometry technique software show the system successfully predicts the location of the next ball and the direction of the ball very well. In testing ball location prediction, if the prediction time interval (T_2) is long, the location of the predicted ball is far from the current location of the ball. Conversely, if the prediction time interval (T_2) is short, the location of the predicted ball is close to the current ball location. In ball direction test, the prediction was successful in experiments 1,2,3,4,5,6,7,8,10 and unsuccessful in the experiment 9. Prediction failure in experiment 9 because the ball moves too fast so the camera which only have 30 fps frame rates fails to capture the image

4. CONCLUSIONS AND RECOMMENDATIONS

The results of the next ball prediction are strongly influenced by the value of the prediction interval time (T_2) if the prediction time interval is long, the location of the predicted ball is far from the current location of the ball. Conversely, if the prediction time interval is short, the location of the predicted ball is close to the current ball location. Prediction failure of the ball movement direction because the ball moves too fast so the camera fails to capture the image.

Suggestions for further research should be to use a camera with high framerates ability so camera can capture very fast moving ball.

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