Location and Position Determination Algorithm for Humanoid Soccer Robot

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Abstract
The algorithm of location and position determination was designed for humanoid soccer robot. The robots have to be able to control the ball effectively on the field of Indonesian Robot Soccer Competition which has a size of 900 cm x 600 cm. The algorithm of location and position determination uses parameters, such as the goalpost's thickness, the compass value, and the robot's head servo value. The goalpost's thickness is detected using The Centre of Gravity method. The width of the goalpost detected is analyzed using the principles of camera geometry to determine the distance between the robot and the goalpost. The tangent value of head servo's tilt angle is used to determine the distance between the robot and the ball. The distance between robot-goalpost and the distance between robot-ball are processed with the difference of head servo's pan angle and compass value using trigonometric formulas to determine the coordinates of the robot and the ball in the Cartesian coordinates.

Keywords: *robot, soccer, location determination, robot position*

1. Introduction

There are many techniques used to determine location of the robot and the ball on the field, for example: Voronoi based strategic positioning for robot soccer [1] and Monte-Carlo localization method applied in Multi-Cue localization for soccer playing humanoid robots [2]. The robot's role on the field determination and its behavior has been researched by D.P. Playne in knowledge-based role allocation [3]. Similarly, Karen Petersen, Georg Stoll, and Oskar von Stryk developed a supporter behavior for soccer playing humanoid robots [4]. Hierarchical reactive control for humanoid soccer robot has been proposed by Sven Behnke and Jorg Stuckler [5]. The self-localization based on monocular vision for humanoid robot determines the robot's location using a CCD camera [6]. Vision Based Self Localization for Humanoid Robot Soccer was implemented by Nuryono Satya Widodo and Arif Rahman [7] to create a robot soccer localization system. In this system, the robot's location is used to take a decision whether or not the robot will kick the ball toward enemy team's goal.

A soccer robot team must be able to play using a good strategy to win the game. Each robot must know the duty as a striker or a defender. The attacker is supposed to be on the attacking region position and scoring goal, while the defender is supposed to guard the defending region. The robot location and position determination becomes the problem in humanoid soccer robot. Therefore, the location and position determination algorithm is required so that the robot can know its duty and its working region.

In this paper we proposed an idea how to determine the coordinate of the robot and the ball in the field using the combination of the Centre of Gravity method and the Camera geometry analysis. The robot's location in the Cartesian coordinate is used to create a strategy in the team. The goalpost that its coordinate has been known on the field is used as a landmark reference to determine the location of the robot on the field.

2. Research Method
2.1. Robot Control System

The robot control system shown in Figure 1 consists of three main parts: Android Smartphone as the main processor, Kondo-KHR-3HV (RCB4) as the robot's servo controller,

and ATMega324. The ATMega324 is used as the controller of the head servo. It also gives orders to the KHR-3HV to call the robot's motion [8].
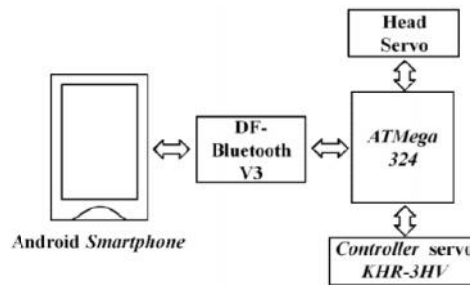
Figure 1. The robot control system

The Android Smartphone has the orientation sensor which has a yaw axis, pitch axis, and roll axis. The yaw axis is used as 360° compass as shown in Figure 2. The compass value of 0° is always set to the attack direction.
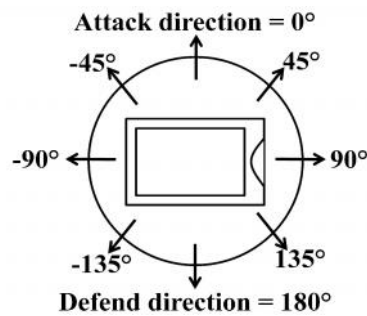
Figure 2. The Android Smartphone compass

The head servo consists of 2 servos: the pan servo and the tilt servo. The range value of pan and tilt servo is shown in Figure 3. The pan servo and the tilt servo which are used in the robot's head have 1° in precision.
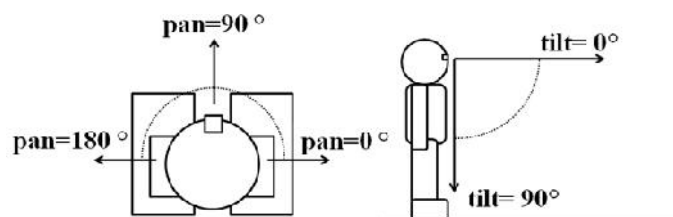
Figure 3. The robot's head servo: pan and tilt

2.2. Camera Geometry

The principle of Camera Geometry is projecting real object form the 3D dimension world to the 2D dimension image plane. The farther an object from the camera the smaller an object projected on the image plane. The pinhole camera model shown in Figure 4 is the basis in camera image processing [9-10].
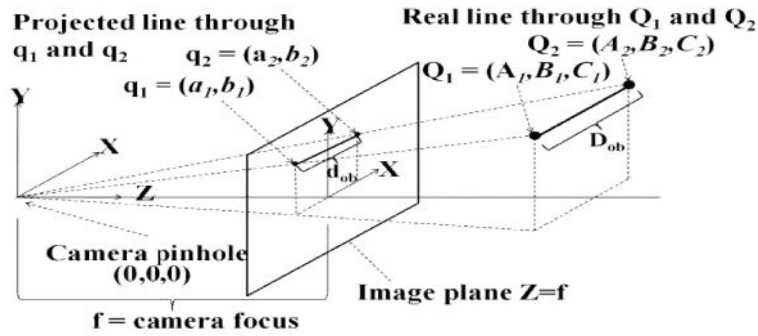
Figure 4. A line is projected to image plane using pinhole camera model

A straight line that goes through two points: $Q_1=(A_1, B_1, C_1)$ and $Q_2=(A_2, B_2, C_2)$ have the real length of D_{ob}. The following perspective equation is used to calculate the projection length of d_{ob}:

$$d_{ob} = f \frac{D_{ob}}{C}$$

(1)

Where

d_{ob} = the projection length of the line(cm)
f = the camera focus (cm)
D_{ob} = the real length of the line (cm)
C = the distance between camera focus and the line (cm)

2.3. The Robot Location on the Field
2.3.1. Goal detection

The algorithm of location and position determination uses information obtained from the image of the goalpost, the compass value, and the head pan value. The goalpost is chosen as a landmark reference because it can be seen by the robot from any position on the field. The goalpost detection is calculated using the Center of Gravity (COG) method [11-12] and Android OpenCV Library. The enemy team's goal area and its own team's goal area are determined using Android's compass. The 0° of the compass value shows the direction toward the enemy's goal area. The 180° of the compass value shows the direction toward the own team's goal area. The right and the left goalpost are determined using the COG method. Figure 5 shows the left and the right goalpost's COG value is located on the left side and the right side of the whole goalpost's COG value respectively.
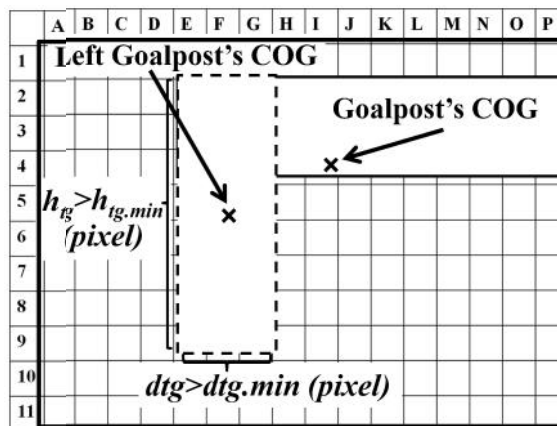

Figure 5. The detection of the goalpost

2.3.2. Robot-Goalpost Distance Measurement

A goalpost that has cylindrical shape will be projected as a rectangle on the camera's image plane as shown in Figure 6. If the distance between the robot and the goalpost has a fixed value, the rectangle will have the same width seen by the robot from every position. The rectangle's width and the distance between the robot and the goalpost can be calculated using the COG method and Android OpenCv.
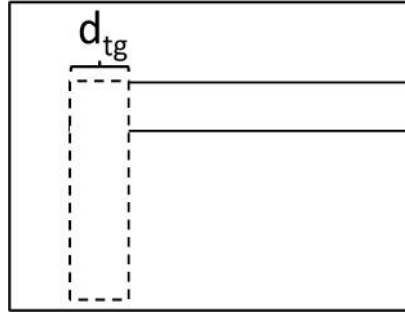

Figure 6. The detected goalpost

The distance between the robot and the goalpost can be calculated using the following equation [13]:

$$j_{rg} = f \frac{D_{tg}}{d_{tg}}$$

(2)

Where
j_{rg} = the distance between robot and goalpost (cm)
f = the camera focus (cm)
D_{tg} = the goalpost's real width (cm)
d_{tg} = the projected goalpost's width on image plane (cm)

The goalpost's detection process detects the width of the goalpost using pixel units. The projected goalpost's width on image plane in Equation 2 uses centimeter units. Therefore, the conversion value between centimeter and pixel units is necessary.

The camera resolution which is used as the robot vision is 480 pixels in width. An object detected on the screen with a length of d_{ob} will use p_{ob} pixels which can be calculated using the following formula:

$$p_{ob} = R \frac{d_{ob}}{L}$$

(3)

Where :
p_{ob} = the width of the projection of an object in the image plane (pixel)
R = the screen resolution (pixels)
d_{ob} = the width of objects detected on the screen (cm)
L = the screen's width (cm)

The camera focus of f has 7.2 cm in length. The goalpost's real width (D_{tg}) is 10 cm. The screen resolution (R) is 480 pixels. The screen width (L) is 6.4 cm. The j_{rg} value can be calculated using Equation 2 and Equation 3 by substituting d_{ob} and p_{ob} with d_{tg} and p_{tg} respectively. The following equation is the result of substituting Equation 2 and Equation 3:

$$j_{rg} = f \frac{D_{tg}}{(p_{tg} L / R)} = \frac{f D_{tg} R}{p_{tg} L} = \frac{5400}{p_{tg}}$$

(4)

The robot's Cartesian coordinate (x_{rg} and y_{rg}) relative to a goalpost as shown in Figure 7 is calculated using the trigonometric equation. The coordinate of the robot position on the field can be calculated by translating the robot's relative coordinate based on the detected goalpost.
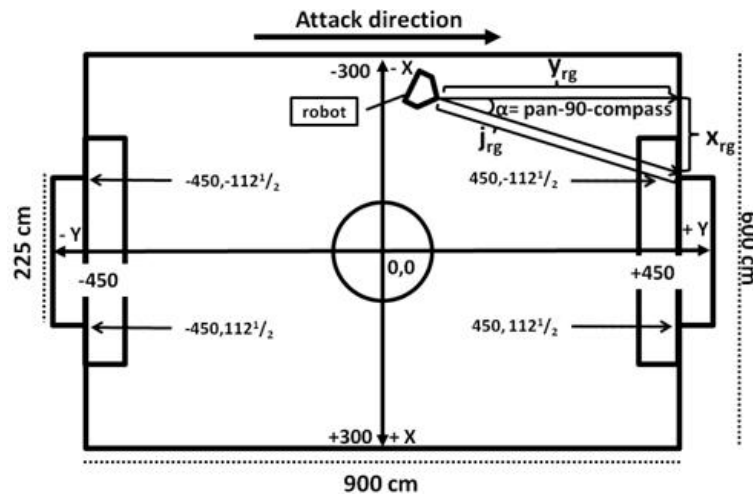

Figure 7. The distance between the ball and the robot

2.4. The Ball Location on the Field

The distance between the ball and the robot is calculated to determine the position of the ball on the field as shown in Figure 8 and Figure 9. The distance between the robot and the ball (j_{br}) is calculated using the following tangent equation:

$$j_{br} = \frac{h_r}{\tan(x)}$$ (robot's height is 47 centimeters)

$$j_{br} = \frac{47}{\tan(x)}$$

(5)

Where
j_{br} = the distance between the ball and the robot (cm)
h_r = the robot's height (cm) = (47 cm)
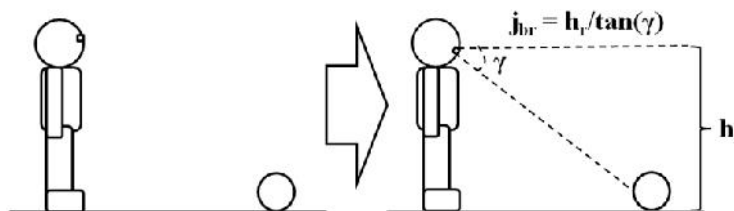x   = the tilt value (degree)

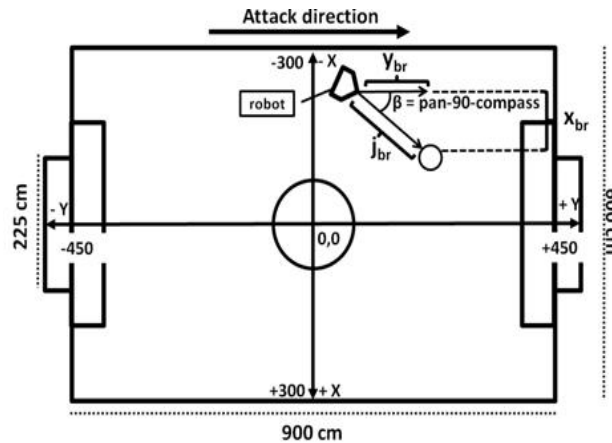Figure 8. The distance between the ball and the robot

Figure 9. The coordinate of the ball relative to the robot

The coordinate of the ball position on the field can be calculated by translating the ball's relative coordinate using robot's coordinate on the field as shown in Figure 9.

2.5. The Positioning Algorithm for Attacker and Defender Robot

The striker and the defender robots require location and position determination algorithms. The attacker robot is supposed to be on the attacking region position and scoring goal, while the defender robot is supposed to guard the defending region. This algorithm is supported by a communication process between the robots in a team which contained information about which robot is holding the ball. The attack condition is indicated when the striker robot holds the ball. The defense condition happens when the goalkeeper holds the ball.

2.5.1. The Positioning Attack Algorithm of Striker Robot

In attack condition the striker robot will move forward up to the half of the goalpost-ball distance. The robot's movement is drawn using yellow arrow as shown in Figure 10.
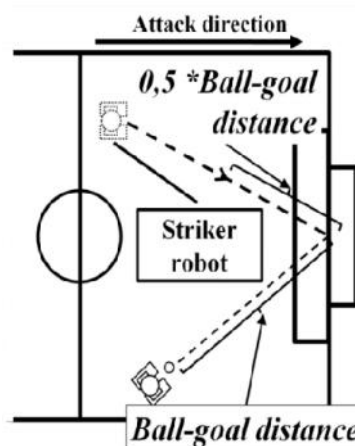

Figure 10. The Positioning Attack Algorithm of Striker Robot

2.5.2. The Positioning Algorithm of Striker Robot and Defender Robot

In defense condition the striker robot will retreat up to the center line of the field. This algorithm prevents striker robot loses the ball at the front of the field. In attack condition the defender robot will stay on the behind of the field's center line. If the defender robot surpasses the line, it will retreat backward. Figure 11 shows the robots configuration.
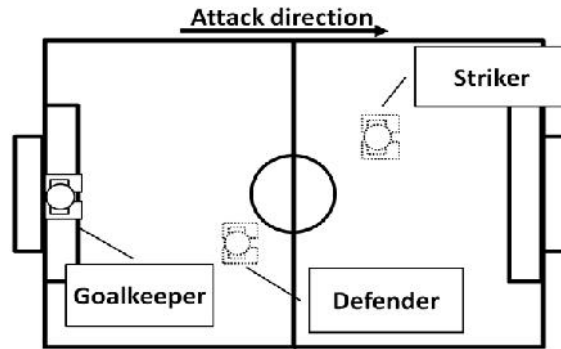
Figure 11. The Positioning Defense Algorithm of Striker Robot

3. Results and Analysis
3.1. The Location Determination Algorithm of the Robot
Table 1 shows that there are error values at coordinate determination of the robot. The integer pixel values (p_{tg}) and the error of   values cause the error of coordinate determination. Table 2 shows the robot-goalpost distance according to the pixel value calculated using Equation 4. The farther the ball from the robot the bigger error value of j_{rg} obtained.

Table 1. Robot's Coordinate on The Field

	Error value of (°)	Error value of j_{rg} (%)	Error value of coordinate (cm)	
			x_{rl}	y_{rl}
Average	5.74	15	58.31	86.83
Standard deviation	2.22	8.33	45.92	82.26

Table 2. The j_{rg} and the pixel value

Pixel value (p_{tg})	j_{rg} (cm)
6	900
8	675
10	540
12	450
14	385.71
16	337,5
18	300
20	270
22	245.45
24	225

Compared to field which has 900 cm x 600 cm in size, the error value of the robot's coordinate is about 9.72% in x coordinate and 9.65% in y coordinate.

3.2. The Location Determination Algorithm of The Ball
Table 3 shows that there are error values on coordinate determination of the ball. This is happened because of the integer value of the tilt   and the errors of   values. Table 4 shows robot-ball distance according to the tilt value calculated using Equation 8. The farther the ball from the robot the bigger error value of j_{br} obtained.

Table 3. The Ball's Coordinate on The Field

	Error value of (°)	Error value of j_{br} (%)	Error value of coordinate (cm)	
			x_{br}	y_{br}
Average	5.48	27.94	62.35	91.18
Standard deviation	1.32	14.92	48.3	67.12

Table 4. The j_{br} and the tilt value

Tilt value (X)	j_{br} (cm)
2	1345.9
4	672.13
6	447.17
8	334.42
10	266.55
12	221.11
14	188.5
16	163.9
18	144.65
20	129.13

The error value of the ball's coordinate is about 10.39% in x coordinate and 10.13% in y coordinate compared to field size.

3.3. The Positioning Algorithm for the Striker and Defender Robot

Table 5, table 6, and table 7 show the position determination algorithm error values of the striker and the defender robot. The positioning attack algorithm of the striker robot shown in Table 5 is affected by the robot location determination error values shown in Table 1 and the ball location determination error values shown in Table 3. The robot location determination error values shown in Table 1 affect the positioning attack and positioning defense algorithm of the striker and the defender robot shown in Table 6 and Table 7.

Table 5. The Positioning Attack Algorithm of Striker Robot

	Error value of coordinate (cm)	
	x	Y
Average	24.6	27.64
Standard deviation	13.45	9.91

Table 6. The Positioning Defense Algorithm of Striker

	Error value of coordinate (cm)	
	x	y
Average	26.7	54.02
Standard deviation	17.32	20.98

Table 7. The Positioning Algorithm of Defender

	Error value of coordinate (cm)	
	x	y
Average	25.94	14.08
Standard deviation	38.12	16.18

3.4. Computational Time

The computational time for executing the algorithm is measured using Android Logcat as shown in table 8 and table 9. The algorithm is run on 1 GHz processor and 512 RAM Android Smartphone.

Table 8. Computational Time for executing Robot Location Determination Algorithm

	Time (ms)
Average	85.33
Standard deviation	18.33

Table 9. Computational Time for executing Ball Location Determination Algorithm

	Time (ms)
Average	72.67
Standard deviation	14.37

4. Conclusion

The humanoid soccer robot uses the algorithm of location and position determination to determine location and position of the robot and the ball on the field. The algorithm has the error tolerance values which are caused by the integer of pixel value, the integer of tilt value, and the error values of the difference between the compass and the pan value. The farther the ball from the robot the bigger error value of j_{rg} and j_{br} obtained. The location determination's error values affect the position determination algorithm.

The location and position determination algorithm has 15% error value in average of robot-goalpost distance, while the robot-ball distance has 27.94% error value in average because the pixel values and the tilt values are integer. The average error value of robot-goalpost's pan-compass difference is 5.74°. The average error value of robot-ball's pan-compass difference is 5.48°. Compared to field size, the error value of the robot's coordinate is about 9.72% in x coordinate and 9.65% in y coordinate. The error value of the ball's coordinate is about 10.39% in x coordinate and 10.13% in y coordinate compared to field size. The computational time required to determine the location of the robot has 85.33 milliseconds in average. The average of computational time required to determine the location of the ball is 72.67 milliseconds.

The number of pixels which represent the projected goalpost's real width in image plane depends on the resolution of the camera. If the camera has high resolution then the tolerance error value of the robot and the goalpost distance will be reduced because there are many pixels used. The distance between the ball and the robot is represented by the tilt value. The servo which has higher precision of encoder will reduce the tolerance error value of the ball and the robot distance.

References

[1]   S Kaden, H Mellmann, M Scheunemann, HD Burkhard. *Voronoi Based Strategic Positioning for Robot Soccer.* Proceedings of the 22nd International Workshop on Concurrency, Specification and Programming. Warsaw, Poland. 2013; 1032: 271-282.
[2]   Hauke Strasdat, Maren Bennewitz, Sven Behnke. Multi-Cue Localization for Soccer Playing Humanoid Robots. In: Gerhard Lakemeyer, Elizabeth Sklar, Domenico G Sorrenti, Tomoichi Takahashi. RoboCup 2006: Robot Soccer World Cup X. Vol 4434. Springer Berlin Heidelberg. 2007: 245-257.
[3]   DP Playne. *Knowledge-Based Role Allocation.* 10th International Conference on Control Automation Robotics & Vision (ICARCV 2008). Hanoi. 2008; 10: 1616-1619.
[4]   Karen Petersen, Georg Stoll, Oskar von Stryk. *A Supporter Behavior for Soccer Playing Humanoid Robots.* In: Javier Ruiz-del-Solar, Eric Chown, Paul G Plöger. RoboCup 2010: Robot Soccer World Cup XIV. Vol 6556. Springer Berlin Heidelberg. 2011: 386-396.
[5]   Sven Behnke, Jorg Stuckler. Hierarchical Reactive Control For Humanoid Soccer Robot. *International Journal of Humanoid Robotics.* 2008; 5(3): 375-396.
[6]   Shih-Hung Chang, Chih-Hsien Hsia, Wei-Hsuan Chang, Jen-Shiun Chiang. Self-Localization Based on Monocular Vision for Humanoid Robot. *Tamkang Journal of Science and Engineering.* 2011; 14(4): 323-332.
[7]   Nuryono Satya Widodo, Arif Rahman. Vision Based Self Localization for Humanoid Robot Soccer. *TELKOMNIKA.* 2012; 10(4): 637-644.
[8]   Aditya Tri Sutrisno N, Yonas Aditya D, Bob William C, Ivan Kurniawan S, Choliq Budi S. *Smart Phone Berbasis Android sebagai Kontrol Utama Robot Humanoid Soccer.* The 2nd Indonesian Symposium on Robot Soccer Competition. Yogyakarta. 2014; 2: 54.
[9]   RI Hartley, A Zisserman. *Multiple View Geometry in Computer Vision.* New York: Cambridge University Press. 2000: 153-154.
[10]   Subhashis Banerjee. *Camera Models and Affine Multiple Views Geometry.* New Delhi: IIT Delhi. 2001: 2.
[11]   RD Airlangga, S Nugroho, BW Yohanes, *Optimizing Ball Detection Algorithm using Center of Gravity method and Servo Pan and Tilt Controller for Humanoid Soccer Robotic based on Android.*

Proceeding of Engineering International Conference "UNNES Conservation". Semarang. 2013; 1: 142-146.

[12] Saptadi Nugroho, Darmawan Utomo. Rotation Invariant Indexing For Image Using Zernike Moments and R–Tree. *TELKOMNIKA.* 2011; 9: 335.

[13] Ivan Kurniawan, Silvester Kristian, Kurnia Sanjaya, Kurniawan Utomo, Shandrak Lha Roy, Bangkit Meirediansyah, Evan Narendra. *Algoritma Self-Positioning Robot Humanoid Soccer R2C-R9 di Area Lapangan KRSBI.* The Indonesian Symposium on Robot Soccer Competition. Yogyakarta. 2015; 3: 121.