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Color-Based Segmentation and Feature Detection for Ball and Goal Post on Mobile Soccer Robot Game Field

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***Abstract* -- This study presents the real time implementation of object detection and tracking algorithm on mobile soccer robot. Object detection is considered as one of the most important task because ball and goal post are the main component in soccer. The system uses the combination of color-based segmentation and feature detection to detect the color and also the shape feature of the object used in the soccer robot game. The color segmentation uses thresholding method in Hue, Saturation, and Value (HSV) color space to differentiate the ball and goal post color from other objects in the field. Then, morphological operation is applied to the thersholded image to minimize the error. After that, Hough line transform is applied to detect the feature of the goal post. Then, ellipse detection is also applied to find the ball feature. This step is used so the desired object is correctly detected, not other object that have the same color. The final step is to calculate the image moments to determine the centroid of the objects and tracking it. Object's color, feature, and coordinate are obtained from this purposed method. In the implementation, the robot has successfully detect ball, goal post, and its position in a real time manner.**

***Index Terms*— color based segmentation, ellipse detection, feature detection, Hough line transform, image moments, mobile soccer robot, morphological operation, real time object detection**

I. INTRODUCTION

SOCCER is considered as one of the most popular sports of all time in the world. Because of its immense potential, nowadays, automation of soccer has been widely researched, especially in the robotic field.

In soccer robot, detecting objects on the field is considered as one of the most important task. However, detecting objects can be a pretty challenging task. For example, as the ball moves, its feature may vary over the time. The lighting used in the surrounding can cast shadow over the objects that could make it harder to detect. Another problem is some objects from the surrounding may also look similar to the ball [1]. In order to overcome this difficulties, the color feature of the objects need to be known and the system also have to obtain the shape feature of the objects. Several other studies already done to either detect objects using color segmentation or detect the shape feature of the objects.

In this paper, real time object detection and tracking is proposed using color-based segmentation and feature detection for detecting the objects feature on the soccer field. First, in order to filter the color of the objects, the live image source from the camera is converted from the Red, Green, and Blue (RGB) color space into Hue, Saturation, and Value (HSV) color space. Then, the converted image is thresholded by adjusting the HSV range that match the objects color, orange for ball and yellow for the goal post. Next, morphological operations such as erosion and dilation are used to remove noises and minimize the error. By this point, the color of the objects is known by the system. In addition to that, feature detection is applied to the objects. Hough line transform is applied so the feature of the goal post is known and ellipse detection is applied to the ball. This step is proposed so the detection can be more precise. After that, the objects, especially the ball movement, is tracked by finding the contour and calculating the centroid using image moments method. Finally, the result of this tracking method is displayed and the coordinates of the objects is known.

The rest of this paper is organized as follows. Section 2 presents the general framework of the proposed algorithm. In Section 3, the result of this study is presented and followed by the conclusion in Section 4.

II. PROPOSED ALGORITHM

A. Color Space

In this study, the image captured from the camera is in the RGB color space. The color components from the image are correlated with the sum of light that hit the object. Image segmentation and description of those color components will be more difficult in this situation [2]. To make the ball more distinguishable and recognizable, HSV color space is chosen. HSV color space describe color in more natural and similar way like how human eyes see color. Fig. 1 shows the representation of HSV color space that modeled in an upside down hexacone shape [3].

The top of the modeled HSV hexacone contains the maximum intensity of colors, represented by the Value at 1. The bottom part of the cone contains the darkest color, black, with the Value at 0. Saturation value is a ratio with the range of 0 (the center line of V axis), to 1 (the triangular sides). In the model above, Hue is defined as the angle around the gray/vertical axis, with Red color is at the zero point. The colors' complements measured by Hue are in opposite to one and another (in 180 degree). The color white is defined when the Saturation is 0 and the Value is 1. But, when the Saturation is 0, Hue become irrelevant and undefined.

To produce a color in HSV color space, the percentage of

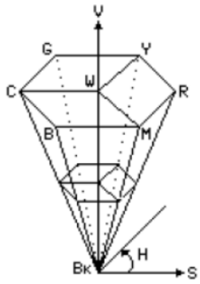


Fig. 1. HSV color space in upside down hexacone shape [3]

known color, such as blue or red is not required. Hue is adjusted to get the color, Saturation is used to change the intensity of the color, and Value is used to make the color brighter or darker [4]. With this knowledge, a color can be defined as a two dimensional field described by Hue and Saturation. The Value only need to be adjusted so the color would not be considered as black if the color brightness is too low [3].

B. *Image Thresholding*

Image thresholding is done to filter the objects color from another color in the surrounding. The method used in this process is pretty simple, it uses three arrays to be compared with. The converted HSV image from the camera is used as the input reference and defined as a set of array. Then, a set of array is made to be the minimum value of the desired color, also represented in HSV color space, and another set of array as the maximum HSV value of the desired color.

To filter the color, the minimum and maximum HSV arrays need to be adjusted to represent the objects color and the input array will check whether there are any matching values that lie between the elements of the two other arrays. This step produced a binary image that only consist of the elements that are in the range of the minimum and maximum value of HSV.

C. *Morphological Operations*

Morphological operations are essential step in filtering the objects color from the surrounding. This operations are applied to the thresholded image to minimize the noise and error in the color detection. Morphological operations used in this study are erosion and dilation.

1) *Erosion:*

Erosion is a morphological operation that set the output pixel into the minimum value of all the pixels in the input pixels neighborhood [5].

Let E be the integer grid, or Euclidean space, and A the binary image. The erosion of binary image A by a structuring element K is denoted by

$$A \ominus K = \{z \in E | K_z \subseteq A\} \tag{1}$$

Where K_z is the translation of B by vector z [7]

$$K_z = \{b + z | b \in K\}, \forall z \in E \tag{2}$$

2) *Dilation:*

Dilation is a morphological operation that set the output pixel into the maximum value of all the pixels in the input pixels neighborhood [5].

Let E be the integer grid, or Euclidean space, and A the binary image. The erosion of binary image A by a structuring element K is denoted by

$$A \oplus K = \cup_{b \in K} A_b \tag{3}$$

Dilation operation is commutative and associative

$$A \oplus K = K \oplus A = \cup_{\alpha \in A} K_\alpha \tag{4}$$

$$A \oplus (B \oplus C) = (A \oplus B) \oplus C \tag{5}$$

Dilation also have duality relation to erosion expressed below

$$A \oplus B = (A^c \oplus \widetilde{K^c})^c \tag{6}$$

Where A^c denotes the set theoretic complement of A [6].

D. *Feature Detection*

1) *Hough Line Transform*

In this study, Hough line transform is applied to detect line feature from the goal post on the field. The main principle of this method is to transform the (x,y) coordinate to (R,θ) coordinate. As shown in Fig. 2, R shows the shortest distance from the line that passes through the (x,y) point to the origin point (0,0). Theta (θ) shows the line rotation angle to the X axis. Hough transformation will produce a Hough space, a voting product from the detected pixel and the lines that pass that pixel [7].

2) *Ellipse Detection*

Ball image that captured by camera may vary over the time depending on the surrounding condition and the camera distortion. To detect the ball feature, conic fitting method is used in this study. The algorithm used in this method is Lin algorithm that uses the algebraic distance. The algebraic distance algorithm is denoted by

$$\in^2 (a) = \sum_{i=1}^{n} F(a, x_i)^2 = \|Da\|^2 \tag{7}$$

With $\|a\|^2 = 1$ and design matrix D is n x 6 matrix with x_i as the rows. This function minimize the objective function analytically to form an eigenvector.

$$E = \|Da\|^2 - \lambda(\|a\| - 1) = a^T D^T Da - \lambda(a^T a - 1) \tag{8}$$

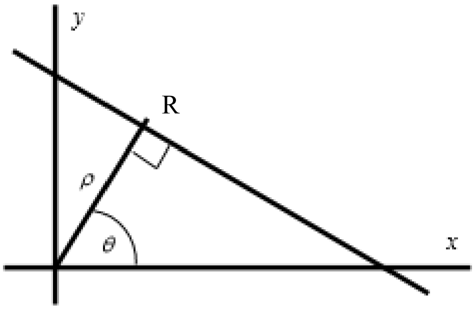


Fig. 2. Coordinate Transformation from (x,y) to (R,θ) [7]

$$\nabla_a E = 0 \Leftrightarrow 2D^T Da - 2\lambda a = 0 \tag{9}$$

Where λ is the Lagrange multiplier.

This algorithm requires minimum of 12n multiplication and 14n add. From the source [8], the total complexity of this method is about 26n + 1700 flops [8].

E. *Object Tracking*

Tracking the objects, especially the ball, is an essential feature that can help the system to locate the objects' position more efficiently. The coordinate of the centroid can be obtained by using the Image Moments method. Firstly, the system need to know the contour of the object detected. After that, the contour is used as the input for the Moments method to calculate the object's centroid. It can be calculated using the Central Moments below [9].

$$\mu_{ij} = \int \int_{\mathcal{R}} (x - x_g)^i (y - y_g)^j \, dxdy \tag{10}$$

Where

$$x_g = \frac{M_{10}}{M_{00}} \tag{11}$$

$$y_g = \frac{M_{01}}{M_{00}} \tag{12}$$

III. Result

In this section, experiment result of the proposed algorithm is presented. The first step is to obtain the image captured from the camera. The output video obtained from the camera is in a RGB color space and needs to be converted into HSV color space for further processing. The result of this process is described in Fig. 3.

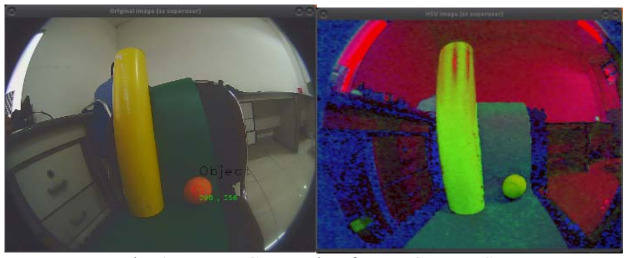


Fig. 3. Image Conversion from RGB to HSV

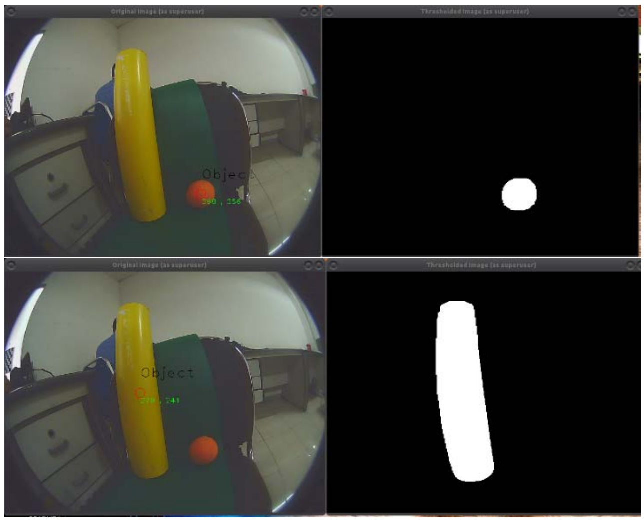
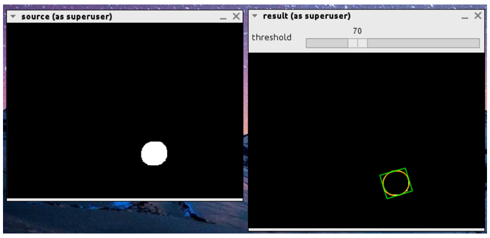


Fig. 4. Color-based Segmentation using Thresholding

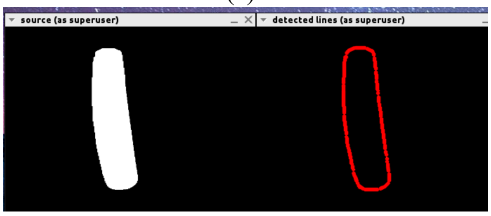
Then, detect the color of each object that is needed. In this experiment, the filtered objects are an orange ball and a yellow pole that represent the goal post. In Fig. 4, the thresholding method is used. The result is the ball and pole are separated from the other objects in the surrounding.

Next, to make sure that the detected orange color is a ball, ellipse detection is applied to isolate only orange colored ellipse object. Then the same goes to the goal post, but for this object, Hough line transformation is applied to detect the pole shape. The result of this process is presented in Fig. 5.

After the ball and pole features are obtained, those objects' centroid points are calculated and tracked using the Image Moments method. The centroid points are represented in pixel, based on the image size that displayed on the screen. This result then displayed on the screen in real time manner like presented in Fig. 6.



(a)



(b)

Fig. 5. Detected Features form the ball (a) and the goal post (b)

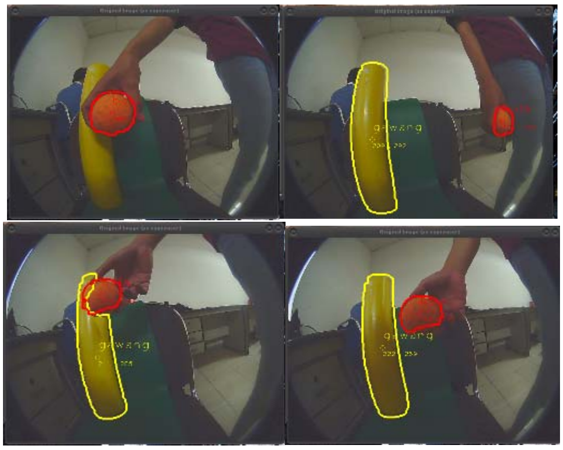


Fig. 6. Tracked Ball

The centroid points later can be used to locate the ball and goal post position on the screen for further use, such as game strategy and robot's movement.

This study is also tested in a 4 m x 6 m field with 40 cm x 80 cm goal posts based on Kontes Robot Indonesia competition rule. For this competition, the proposed method is implemented in two three wheeled mobile soccer robots with a fish-eye camera mounted on top of each robot's body (Fig.7).

IV. Conclusion

The objects are successfully detected and tracked. The coordinate of the objects are successfully obtained too. However, the feature detection that applied to the objects still have some error and sometimes the result is not really clear. Further research is needed in order to make the algorithm better.

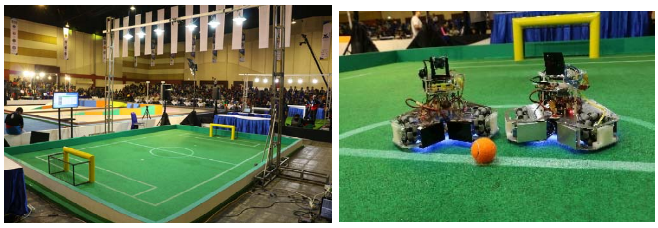


Fig. 7. Game Field and Robots

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