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Implementing hue-saturation-value filter and circle hough transform for object tracking on ball-wheeled robot

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ABSTRACT

The ball-wheeled robot relies on a camera for receiving information on the object to be followed. Object tracing is one of the methods that can be used for detecting object movement. In recognizing objects around it, the robot requires an image analysis process that involves visual perception. Image processing is the process of processing and analyzing images that involves visual perception, and is characterized by input data and output information in the form of images. This is how the robot can see objects around it and then be assisted by computer vision to make a decision. The object tracking method with hue-saturation-value (HSV) colour filtering and shape recognition with circle hough transform (CHT) is applied to the ball-wheeled robot. The front vision of the robot uses HSV colour filtering with various test values to determine the thresholding value, and it was found that the ball could be identified up to a distance of 1,000 cm. To further improve the performance of recognizing the ball object, CHT was applied. It was found that the ball could be identified up to a distance of 700 cm. Furthermore, the ball can be identified in obstructed conditions up to 75%.

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1. INTRODUCTION

Robot competitions are widely held in Indonesia and other countries as part of efforts to develop robotics. One example is the ball wheel robot competition [1], [2]. The ball wheel robot utilizes a camera as a means to gather information about the objects it will track [3]. One of the methods used to detect the movement of these objects is object tracing. In carrying out its task of recognizing objects in its surroundings, the robot relies on the process of image analysis, which involves visual perception. Image processing is a process wherein images are analyzed and processed to obtain information, using input data and producing output in the form of images [4], [5]. These competitions provide a platform for researchers, engineers, and robotics enthusiasts to showcase their advancements and innovations in the field of robotics. By exploring different techniques and algorithms in object tracing and image processing, participants aim to enhance the capabilities of robots and contribute to the development of robotics technology. The integration of visual perception and image processing in robot competitions not only fosters technological advancements but also encourages collaboration and knowledge sharing within the robotics community [2].

The detection of objects has been extensively studied, and various techniques have been developed to achieve high accuracy. One such approach involves the use of color detection, which can effectively identify objects based on their color properties [3]. Another commonly employed method is the circle hough transform (CHT), which has shown promising results in object detection tasks [3]. However, when it comes to detecting obstacles, the CHT has been found to have limitations in terms of its performance [6]. Despite the existing research on object detection, there is still a gap in understanding the influence of brightness, distance, and visibility on the detection of spherical objects using color filtering and CHT.

In this research, we explore an innovative method for recognizing and tracking a ball for a ball-wheeled robot. The robot relies on a camera as its primary source of information for detecting and following objects [1]–[4]. The image analysis process involves visual perception and image processing, characterised by input data and output information in the form of images [5], [7]–[9]. The object tracking method used is by applying hue-saturation-value (HSV) colour filtering and shape recognition using the CHT [6], [10]–[12]. The hypothesis of this study is that by employing HSV color filtering and CHT, the proposed method can improve the identification and tracking of a ball for ball-wheeled robots. The study aims to demonstrate that the combined use of these techniques enhances the recognition and tracking performance of objects, particularly in terms of longer distance identification and detecting the ball in obstructed conditions.

2. RESEARCH METHOD

Figure 1 depicts a block diagram of object tracking, in which a microcontroller is connected to a camera that is utilized for monitoring objects. In the system, HSV colour filtering [13]–[16] and shape recognition using the CHT [6], [10]–[12] are designed to perform ball tracking [17]–[20]. The design includes testing, testing each component of the object tracking system such as the camera [21], Raspberry Pi [22], and the object tracking [23], [24] result from the camera capture. Selecting an appropriate camera is crucial in object detection and tracking systems as it directly affects the accuracy and efficiency of the system. Figure 2 illustrates that the choice of camera will determine the field of view for observing the object to be detected. The field of view refers to the area that the camera can capture, and it is influenced by various factors such as the camera's focal length, sensor size, and resolution.

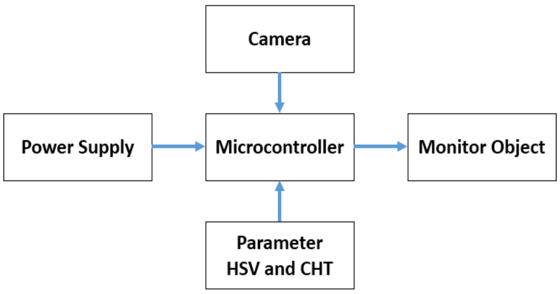


Figure 1. Diagram scheme of design system

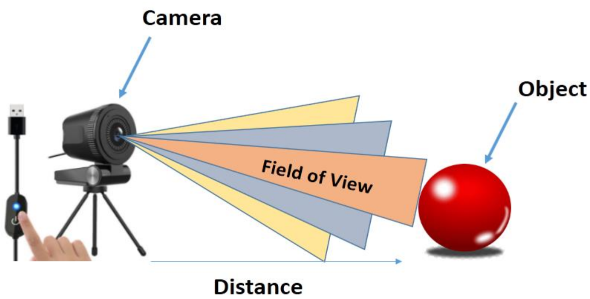


Figure 2. 3D model of object tracking

In this design stage, the camera capture on the robot is modeled and parameters used for object tracking using HSV colour filtering are specified [25], [26]. Figure 3 illustrates the preprocessing steps for object detection, which include blurring, red-green-blue (RGB) to HSV conversion, binarization, and morphology. These steps are crucial for improving the quality of the images and facilitating the detection process. The first step, blurring, is performed to reduce noise and smooth out the image. This step is particularly useful in reducing the impact of small, high-frequency details in the image that may not be relevant to the detection process. The second step involves converting the RGB color space of the image to the HSV color space, which is more suitable for object detection applications. This conversion helps to isolate the object of interest based on its color and brightness properties. After the color conversion, the image is binarized to create a binary image that only contains black and white pixels. This step is performed to enhance the contrast between the object and the background and make it easier to distinguish the object. The final step, morphology, involves applying mathematical operations to the binary image, such as erosion and dilation, to further improve the object's visibility and separate it from the background. These operations help to eliminate any small gaps or holes in the object and make it easier to detect.

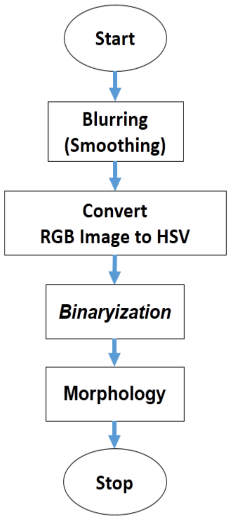


Figure 3. Object image pre-processing stages

3. RESULTS AND DISCUSSION

3.1. Hue-saturation-value colour filtering testing

A test was conducted using the Luminous C30 webcam to perform HSV color filtering with different illuminance values. The test involved taking a color sample value of 180, 100%, 70%, and comparing it with other set point values. Three conditions were used for comparison. Firstly, the maximum threshold was set to +10 and the minimum was set to -10. Secondly, the results of 10 color sample points obtained from a simulation image were calculated. Lastly, the saturation and value values were set to 100 and without S and V or with values ranging from 0 to 255. These comparisons were made to evaluate the accuracy and reliability of the HSV color filtering test.

3.2. The range testing

The test for distance was conducted in both bright and dark conditions. The distance test was performed from 100 centimeter to 10 meters as the testing limit obtained from the maximum specifications of camera used. The test was conducted to determine the limits of the ball's distance and radius that can be detected with different HSV set points. Figure 4 shows the results of the bright test with brightness 234-260.6 lux that the set point values used were able to detect the ball up to 10 meters except for the test at 15.00-16.00. Tests at 08.00-09.00 had a larger and better-detected area and radius compared to tests at 08.00-09.00 and 12.00-13.00. However, test d easily detects objects other than the ball. At a distance of 760 cm, set point at 15.00-16.00 was already struggling, and incorrectly detected at 850 cm. This error in detection was then interpreted as an inability to detect or be undetected. This was due to the lack of adjustment of S and V values so that all the brightness and concentration contrasts in the captured image could be considered as an object.

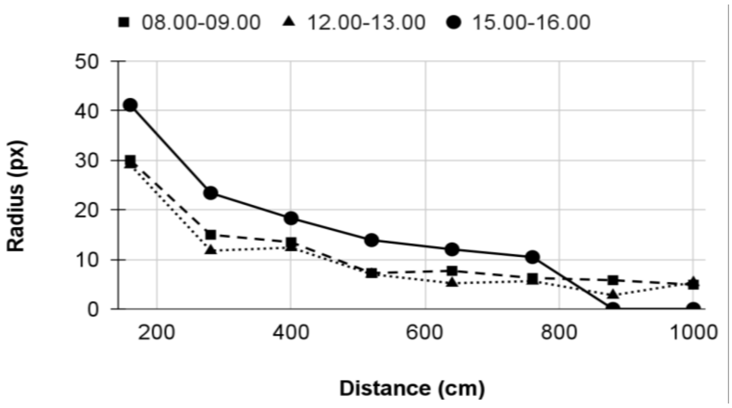


Figure 4. Detected ball radius on brightness 234-260.6 lux

3.3. Object tracking

Based on the results of the object tracking testing using colour filtering HSV, it can be concluded that the set point b used in the colour filtering process was able to successfully detect the ball object. This is a promising development for object tracking applications, as colour filtering is a widely used technique due to its simplicity and effectiveness. Furthermore, the ability to track the movement of the ball object is a crucial aspect of object tracking, and the results demonstrate that the system was able to track the ball's movement accurately. The coordinates of the ball before and after it was moved are given as (330, 344) and (300, 306) respectively, indicating that the ball was moved towards the left and slightly downwards.

These results are significant, as they demonstrate the potential of using colour filtering with set point b in object tracking applications. This technique can be applied to track other objects with distinct colours, such as traffic lights or road signs, and could be particularly useful in autonomous vehicle navigation systems. Overall, the results of this testing provide valuable insights into the effectiveness of colour filtering with set point b for object tracking, and highlight the potential applications of this technique in various industries. Even more accurate and reliable object tracking systems in the future could be achieved through further research and development, as shown in Table 1, with the HSV value results in the image.

Table 1. HSV value results in the image

R	G	B	H	S	V
223	117	94	4.95	232.815	151.98
227	187	196	172.875	45.645	226.95
210	59	50	1.675	194	209.865
179	0	3	179.57	255	179
173	108	112	178.118	95.88	172.89
152	40	20	4.515	221.595	151.98
109	89	91	177.31	46.41	108.885
100	33	51	171.84	170.595	99.45

3.4. Circle hough transform testing

A test of the CHT was performed as a shape recognition test using the determined HSV set point b and its defined parameters. The inverse ratio was tested with values of 1, 1.5, and 2. Based on the tests performed with 84 trials for each inverse ratio, the highest percentage of success was achieved using an inverse ratio of 2 with a success rate of 78.57%. The experiment conducted with the radius values of (2, 53) revealed that the ball could be read from both close and far distances. However, there was difficulty in reading the ball at close distances because the set maximum value was still too small. When the radius was not set with a far distance, object detection became incorrect.

The results of the experiment showed that using a radius is better than without a radius, but the maximum radius value needs to be readjusted for better performance. Calibration was performed using the radius values obtained from the HSV colour filtering and without a radius limit, with a minimum radius value of 2 and a maximum radius value of 68, which was obtained without adjusting the radius value. A better percentage was achieved by the radius of (2, 68), as shown in Figure 5, compared to (2, 53), with a success rate of 95.45%, as presented in Table 2. These are the inverse ratio test results.

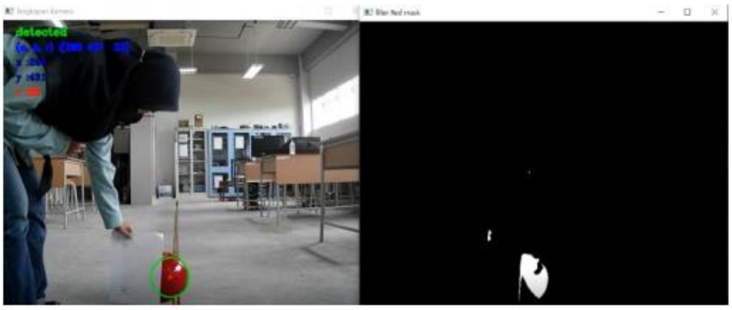
Figure 5. Detection results with radius settings (2, 68)

Table 2. Inverse ratio test results

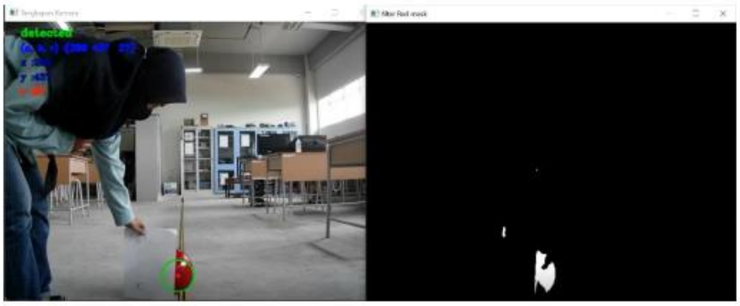
Inverse Ratio	Results	Success presentation (%)
1	14	16.67
1.5	56	66.67
2	66	78.57

3.5. The visible testing

The purpose of the visible side ball testing was to evaluate the system's ability to detect the ball accurately, even when it is partially or fully obscured by other objects or robots in real-world scenarios. The results of the 14 tests conducted, depicted in Figure 6, demonstrated that the system was able to detect the ball accurately under various visibility levels ranging from 50% (Figure 6(a)) to 25% (Figure 6(b)). The testing is essential to ensure the system's robustness and reliability in detecting and tracking objects, even in dynamic and complex environments such as industrial settings, where the visibility of the tracked object can vary. Table 3 displays the radius success percentage. The system's ability to detect the ball accurately under these conditions indicates its suitability for various industrial applications where objects being tracked could be partially or fully obstructed by other objects or robots.



(a)



(b)

Figure 6. Visible ball side test (a) 50% and (b) 25%

Table 3. Radius success percentage

Radius	Success presentation (%)
(0, 0)	27.27
(2, 53)	90.9
(2, 68)	95.45

4. CONCLUSION

The results of the HSV colour filtering test showed that the hue, saturation, and value values have an impact on object detection. The best results were obtained using the values obtained from 10 colour sample points on the object, which were (171, 45, 93) for the minimum and (180, 255, 227) for the maximum. The HSV colour filtering was able to perform object tracking and detect objects from a distance of 100 to 1,000 cm with a success rate of 100%, but a shape recognition technique was necessary to avoid misidentifying the object. Thus, CHT was used for shape recognition. The CHT values used greatly influence the object recognition results. Based on the tests, the parameters used were dp=2, mindist=100, parameter1=70, parameter2=20, minRadius=2, and maxRadius=68. The results showed that the CHT was capable of recognizing the ball object and tracking it effectively from 100 to 700 cm with a success rate of 96.45%. Further research that can be carried out is to test the movement of the wheeled ball robot, as it approaches the object.

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