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Improvement of Auto-Tracking Mobile Robot based on HSI Color Model

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ABSTRACT

Auto tracking mobile robot is a device that able to detect and track a target. For an auto tracking device, the most crucial part of the system is the object identification and tracking of the moving targets. In order to improve the accuracy of identification of object in different illumination and background conditions, the implementation of HSI color model is used in image processing algorithm. In this project HSI-based color enhancement algorithm were used for object identification. This is because HSI parameter are more stable in different light and background conditions, so it is selected as the main parameters of this system. Pixy CMUcam5 is used as the vision sensor while Arduino Uno as the main microcontroller that controls all the input and output of the device. Moreover, two servo motors were used to control the pan-tilt movement of the vision sensor. Experimental results demonstrate that when HSI color-based filtering algorithm is applied to visual tracking it improves the accuracy and stability of tracking under the condition of varying brightness, or even in the low-light-level environment. Besides that, this algorithm also prevents tracking loss due to object color appears in the background.

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1. INTRODUCTION

The contribution of robots is rapidly increasing day by day as robots are starting to substitute humans in everyday tasks. At the same time robots can do tasks that would either be impossible for human being to do or it would take a longer time for him or her to complete it. Thus, robots make human's work easier and more productive. The function of robot can be further increased by giving vision to the robot. Color vision based mobile robot path tracking is proposed by Luo et al. [1]. In this proposed system, path following algorithm is proposed based on the data extracted from HSI (Hue, Saturation, intensity) color model using fuzzy control. As the image is captured, it will be converted into HSI color model and using segmentation method, the path is extracted from the image using optimal threshold in HSI module. The path skeleton is then extracted using skeleton extraction method. In addition, fuzzy control is used for robot path tracking control.

Soans et al. [2] used adaptive color threshold method which is equipped within a mobile robot to detect and follow a particular color of an object. As the robot equipped with mechanical arm, the mobile robot is able to pick the target object. Based on the proposed method, the captured images are transferred to a color thresholding algorithm to detect the target. The noises are filtered out and finally the colored object is detected and picked up. In addition, as mentioned by Soans et al. [2], one of the main problem in color tracking is the insignificant of current color thresholding technique which caused by e.g. reflection of smooth ground plane. This reflection results in false object detection and consequences leads to false color tracking. On the other hand, the variation of surrounding lighting conditions also leads to false color detection and tracking. These problems are the focus objectives in this paper.

People detection and tracking system based on real-time RGB-D for mobile robot is proposed by Fang et. al. [3]. In the proposed system, an open source robot operating system (ROS) is implemented to a mobile robot to track a target. In the system, the feature of the target is extracted before the depth information is collected and used to track the target based on the nearest point position information. Then, the implementation of CAM-Shift algorithm which is based on RGB information is applied to improve the anti-interference ability.

For the purpose of image contrast improvement of inhomogeneous illumination, Abdul Ghani and Mat Isa [4] have applying recursive adaptive histogram modification which focuses on applying clip-limit and gray-level mapping of the captured images. From the results, the output images show the significant output by producing a homogeneous illumination of the images. This method could reduce the noise level in the captured image of the auto-tracking mobile robot. In addition to this algorithm, unsupervised contrast correction through integrated-intensity stretched-Rayleigh Histogram [4], could become another option to address low contrast and non-homogeneous illumination images.

This auto tracking device can be used to enhance the surveillance system. For instance, it can be used to track valuable things. For example, this system can act as a moving CCTV as it not only able to observe but it also able to track things. Besides that, new technology invents an electric wheelchair where the user can control the movement of wheelchair. Now, with auto tracking technology, the electric wheelchair can be convert into an automatic wheelchair whereas the movement of the wheelchair to a certain point is done automatically based on line or moving object's color. In addition, the technology also can be applied to a luggage or shopping trolley where the system will automatically track and follow its owner.

In this project, the camera will be attached at the mobile robot as a component to move from a location to another location based on the moving target. Microcontroller with image processing implementation plays an important role. A color-based filtering algorithm is used for object tracking. Color-based filtering methods are popular because they are fast, efficient, and relatively robust.

Next, a microcontroller is also an essential part in auto tracking device. Microcontroller act as the brain of the device. Once the image has been captured by the camera, the image will be decomposed into its individual color channel. Based on these color channels, the total intensity and the maximum intensity values of each color channel are calculated. The maximum intensity values between these color channels will determine the dominant color of the object for the purpose of the device or mobile robot to identify it. Besides that, the microcontroller also sends electrical signal to the mobile robot's actuators to react to the motion of tracked object.

The direction of this project is to fabricate a simple an auto tracking mobile robot that is able to detect an object and tracks it. The main focus of this research project is to improve the detection and tracking abilities of the target color, as mentioned by Soans et al. [2]. The algorithm of image processing to detect the object is based on the color of the object. A (Hue, Saturation and Intensity) HSI color-based filtering algorithm were used in this project to detect the target. Firstly, the camera will capture the image and the microcontroller will process the information and monitor the behavior of the object. Next, when the object starts to move, this mobile robot also will follow and tracks the object. At the same time, the mobile robot always maintain distance with the object to prevent from collision with the object. Besides that, the vision of the robot is up to 180° in x-axis and y-axis as the camera is attached to a pan-tilt which is able to rotate. The rotation of the camera is control by two servo motors whereas one servo motor is used to control x-axis movement and another servo motor is used for y-axis movement.

2. RESEARCH MATERIALS AND METHODOLOGY

From the literature review, suitable components for the project were selected. The circuit design of the project is developed. This followed by software development of the project. After this, the system is tested until the system works according to the objective of this project. Figure 1 shows the methodology flowchart of the project of auto-tracking mobile robot.

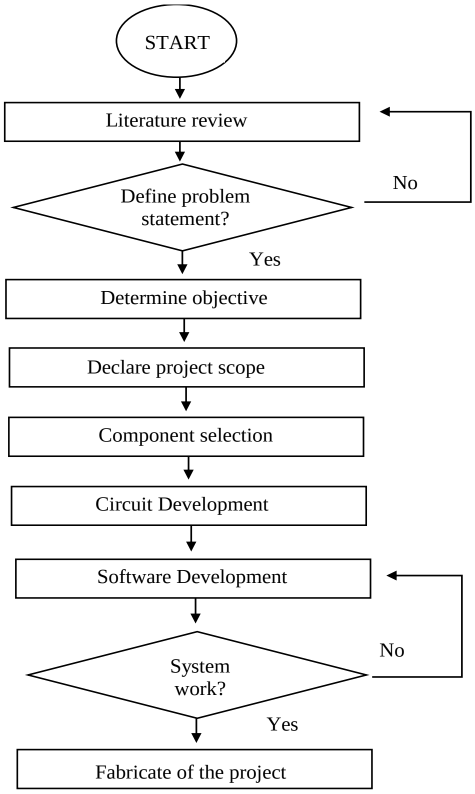

Figure 1. Methodology flowchart of auto-tracking mobile robot

a. Pixy CMUcam5

The vision sensor selected for this project is Pixy CMUcam5. The Pixy CMUcam5 vision sensor is a fast image sensor that tracks object and it can directly connect to Arduino Uno through ICSP port on Arduino Uno board. Besides that, Pixy has its own powerful processor to process the image. Since Pixy has its own processor, it will process the captured images from the sensor and extract the useful information. Besides that, Pixy come with a color algorithm to detect object's color. Normally, RGB (red, green, and blue) used to represent colors. But, Pixy calculates the hue color and saturation of each RGB pixel from the image sensor and uses these as the primary filtering parameters. Thus, conversion algorithm to convert RGB to HSI color based is not required in the programming part as the algorithm is already integrated in the Pixy CMUcam5 image sensor module. Nevertheless, Pixy processes an entire 640x400 image frame every 1/50th of a second. This means the camera detected objects' positions every 20 milliseconds.

b. Arduino Uno

In this project of developing an auto-tracking device, Arduino Uno was selected as the controller of the system. The Arduino Uno board is a microcontroller based on ATmega328. It has 14 digital input/output pins in which 6 can be used as PWM outputs, a 16 MHz ceramic resonator, an ICSP header, a USB connection, 6 analog inputs, a power jack and a reset button. The camera can be directly connected to ICSP header.

c. L293D Motor Driver

L293D motor driver is an integrated circuit chip which is usually used to control. Motor driver act as an interface between Arduino and the motors. These ICs are designed to control two DC motors simultaneously. L293D consist of two H-bridge. H-bridge is the simplest circuit for controlling a low current rated motor.

d. Circuit Design

The main hardware components selected to build the prototype for auto-tracking mobile robot are the Arduino Uno, Pixy CMUcam5 camera, Arduino Motor Shield, servo motor and DC motor. The development of circuit design for this project was started with a block diagram as shown in Figure 2. A block diagram is a diagram of a system in which the principal parts are represented by blocks and connected by lines to show the inputs and outputs of a system.

The complete schematic circuit diagram of auto-tracking mobile robot device is shown in Figure 3. The main component of the circuit is Arduino Uno as it receives data about the position of tracked object from the Pixy CMUcam5. Then, Arduino will control the movement of DC motor according to the motion of tracked object. Besides that, the servo motors are directly controlled by Pixy CMUcam5 itself.

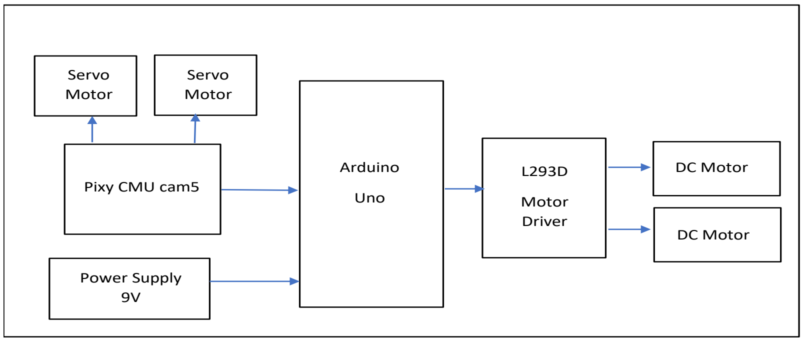

Figure 2. Block diagram of auto-tracking mobile robot

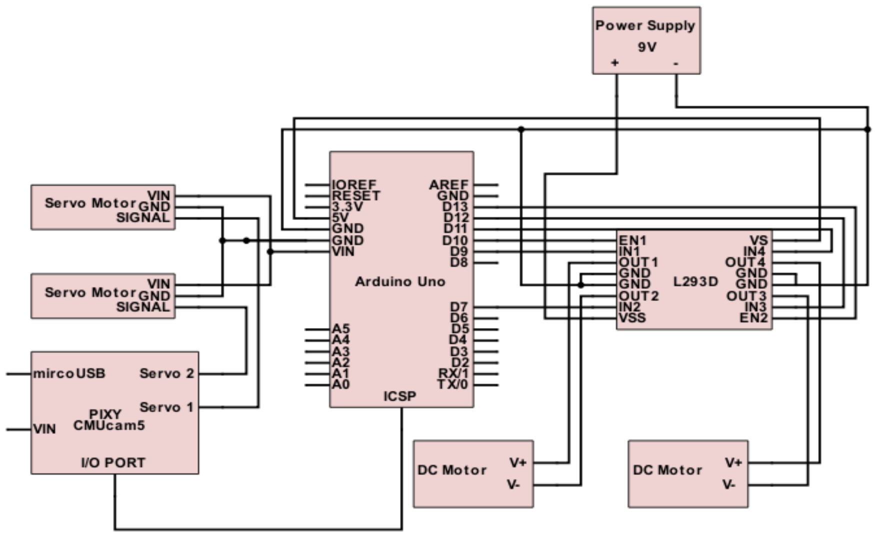

Figure 3. Schematic circuit diagram of auto-tracking mobile robot

e. Completed hardware design

The following Figure 4 shows the complete mobile robot equipped with Pixy camera for the purpose of color detection and tracking. In addition to the camera, the mobile robot is also equipeed with two DC motors, motor driver, and pan-tilt mechanism which consists of two inter-connected servo motors.

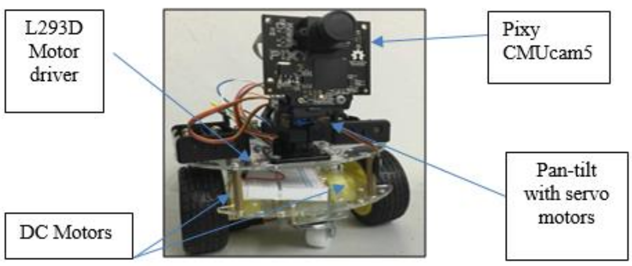

Figure 4. Final hardware design

f. Programming flowchart

Figure 5 shows the programming flowchart of auto-tracking mobile robot. Firstly, when the device is turn on, the system will be initialized. After that, the Pixy CMUcam5 vision sensor will find the signature of the tracking object. Once the object is detected the vision sensor will calculate the area and x-coordinate of the tracking object for every 20 milliseconds. To make sure the tracked object always parallel with the vision sensor an optimum area and x-coordinate are set as reference value where the reference values are defined as $A_{max}, A_{min}, X_{max}$ and X_{min} . If $Area_{object} > Area_{max}$ means the object is too near to the device. Thus, the device will move backwards to keep the device and object at optimum range. Same goes if $Area_{object} < Area_{min}$, this means the object this far from the device. Thus, the mobile robot will move forward until it is at an optimum range. Besides that, x-coordinates are used to determine the movement of the object in x-direction. If the object $X_{object} < X_{min}$ means the object is at left. Thus, the program will set the right motor on and left motor off so that the mobile robot can turn left. Same goes for $X_{object} > X_{max}$ condition where for this condition the object is to the right.

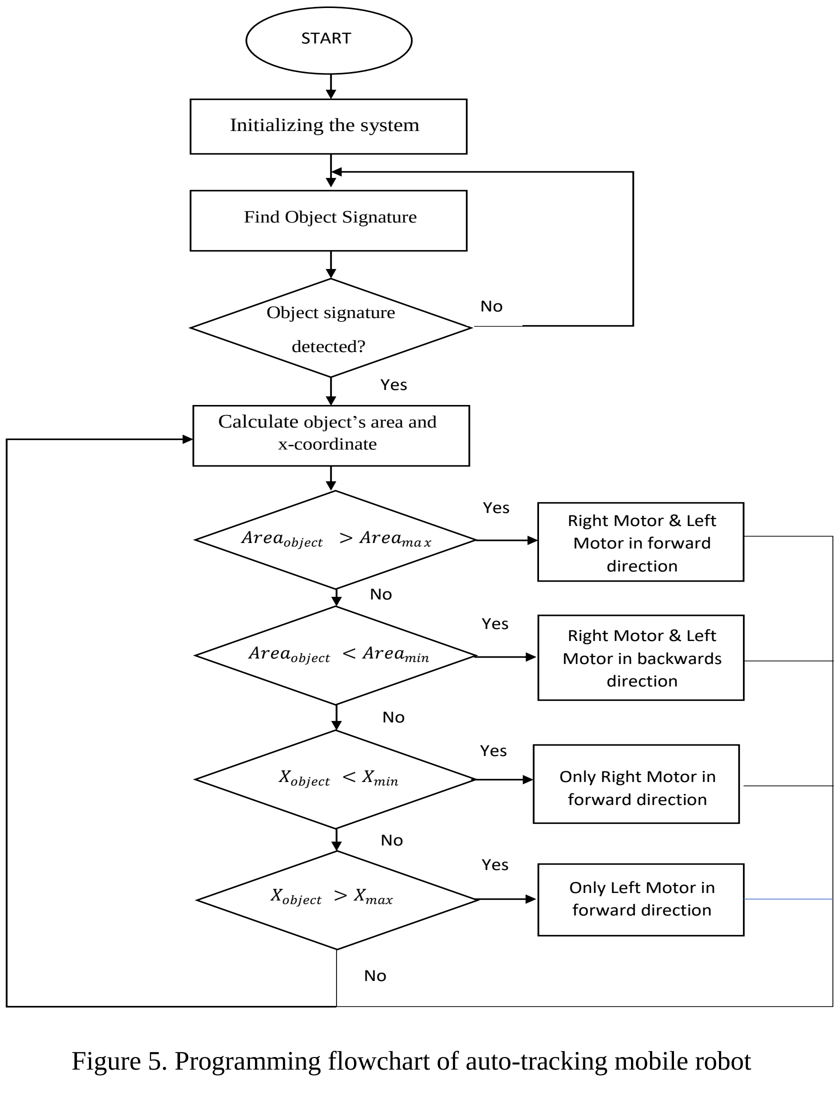

Figure 5. Programming flowchart of auto-tracking mobile robot

3. RESULTS AND DISCUSSION

The auto-tracking mobile robot able to tracking objects effectively as proposed at normal condition. Several experiments were carried out on the proposed system to ensure the objective of the project is achieved. First experiment was to determine the maximum target locking distance. Another objective of this project to evaluate the accuracy of colour identification in different illumination and background conditions, and thus improves it efficiency in tracking within various environment including low contrast and almost similar background-target color environment. Thus, the second experiment is carried out to determine the effect of background colour during object tracking. Third experiment was to exermine the effect of illumination on detection and target tracking.

a. Maximum target locking distance

The objective of this experiment is to determine the maximum distance of target from the device that gives accuracy and efficient tracking. The result of the experiment is in Table 1. Based on Table 1 it is found that when the detection range is increased as the stability of the target locking decreases. At signature range of 8.5, the vision sensor able to detect target that 240cm away from the vision sensor. However, at this range of detection the tracking loss occurs frequently due to unstable target locking as shown in Figure 8. At signature range of 1.5 the target locking is very stable as shown in Figure 6. But, the range of detection is very short. The most maximum target locking distance and the most stable target lock is given at signature range of 5.5 as shown in Figure 7 and this is the optimum setting of signature range for best detection and effective tracking.

Table 1. Result of Experiment A

Signature range	Range of Detection(cm)	Target Lock Stability
1.5	90	High
2.5	125	High
3.5	150	High
4.5	170	High
5.5	190	High
6.5	210	Moderate
7.5	225	Moderate
8.5	240	Low

Figure 6. Pixy output at singature range of 1.5

Figure 7. Pixy output at singature range of 5.5

Figure 8. Pixy output at singature range of 8.5

b. Effect of background during object tracking

The objective of this experiment was to determine the capability of vision sensor to differentiate target and background if both have almost similar color. Besides that, the accuracy of detection and tracking in this condition is studied. In this experiment a green ball is used as a tracking object and the background colour also set as green colour. This experiment is conducted by manipulating the signature range parameter. The result of the experiment is tabulated in Table 2.

Table 2. Result of Experiment B

Signature range	Noise Level	Target Lock Stability
1.5	None	High
2.5	None	High
3.5	None	High
4.5	Low	High
5.5	Moderate	Moderate
6.5	High	Low
7.5	High	Low
8.5	High	Low

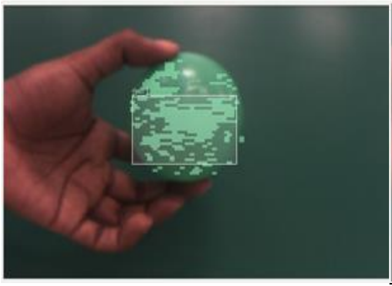

Figure 9. Pixy output at signature range of 3.5

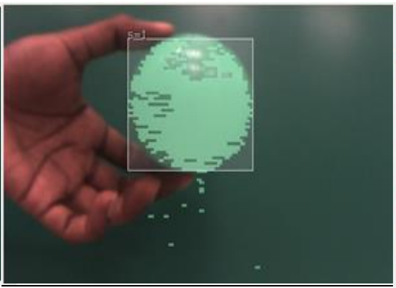

Figure 10. Pixy output at signature range of 5.5

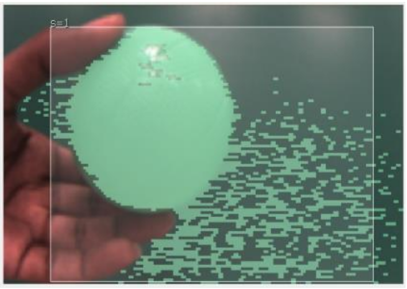

Figure 11. Pixy output at signature range of 8.5

Based on Table 2 the best setting for signature range parameter is at 3.5. This is because at this value the PixyCMUcam5 gives the best detection and target locking without any noise. At the same time, the green background also did not interrupt the tracking as shown in Figure 10. Besides that, it also gives the maximum range of detection without noise which is about 150 cm. This means the auto-tracking mobile robot able to track an object from a distance of 150 cm.At signature range of 5.5 there is very slight background interruption as shown Figure 10. Besides that , at signature range of 8.5 the Pixy CMUcam5 unable to differentiate the background and target when both are in same color as shown in Figure 11 , this will cause tracking loss due misinterpetion between target and object.Thus, signature range of 3.5 gives the best tracking when the object color appear in background.

c. Effect of illumination during object tracking

The surrounding brightness also plays an important role in performance and sensitivity of Pixy CMUcam5 vision sensor. Firstly, the auto-tracking mobile was tested in various lighting condition. It is found that the device loss tracking when there is dramatic change in lighting condition. However, the tracking was still stable when there is only slight change in illumination. Thus, an experiment was conducted at five different surrounding lighting conditions. At the same time PixyCMUcam5 camera's brightness kept constant. The result of the experiment tabulated in Table 3. At this point, we aware with the improvement proposed by Abdul Ghani (2018) and Abdul Ghani and Mat Isa (2015) for the enhancement of image contrast. This method will be implemented in our next enhancement system for a better color detection with various illuminations.

Table 3. Result of Experiment C (before calibrating)

Surrounding Brightness	Pixy Brightness	Noise Level	Target Lock Stability
Very bright	80	High	None
Bright	80	Moderate	Low
Normal	80	None	High
Less Bright	80	Less	High
Dark	80	Moderate	Low

Based on Table 2 the factors that differentiate all this condition are the stability of the target lock by Pixy vision sensor and the noise generated from the background of the tracking object. However, this problem can be overcome by calibrating the brightness of Pixy CMUcam5 vision sensor until the target lock is stable. Hence, the Pixy CMUcam5 vision sensor must be calibrated every time the mobile robot experience significant surrounding brightness change. Thus, the experiment is repeated by adjusting the brightness of Pixy camera until the target lock is stable and the noise level is reduced. The result is tabulated in Table 4.

Table 4. Result of Experiment C (after calibrating)

Surrounding Brightness	Pixy Brightness	Noise Level	Target Lock Stability
Very bright	20	Less	Moderate
Bright	50	None	High
Normal	80	None	High
Less Bright	100	None	High
Dim	120	None	Moderate

Table 3 shows the data collected after calibrating the Pixy brightness with the surrounding brightness. Results proves that the PixyCMUcam5 able to detect and track object at various illumination. This will make the auto-tracking mobile robot ineffective as it will loss tracking when the brightness changes dramatically until it is calibrated again. The results of target locking and noise level are shown in Figures 12-15.

Figure 12. Pixy output at very bright condition. (before and after calibrating)

Figure 13 Pixy output at bright condition. (before and after calibrating)

Figure 14. Pixy output at normal and less bright condition. (before and after calibrating)

Figure15. Pixy output at dark condition. (before and after calibrating)

4. CONCLUSION

The implementation of enhancement integrated with filtering methods in auto-tracking mobile robot gives a satisfactory solution to the problems that discussed in the problem statement. To improve the accuracy of identification of object color in different illumination and background conditions, the HSI color model is used in image processing algorithm. The enhancement and filtering processes in HSI color model has successfully integrated to solve the problems of loss of color tracking. Experimental results demonstrate that when HSI color-based filtering algorithm is applied to visual tracking it improves the accuracy and stability of color tracking under the condition of varying brightness, or even in the low-contrast environment, as discussed in the results. Besides that, this algorithm also prevents tracking loss due to similar background color.

Although the tracking loss issue due sudden lighting change can be solved by calibrating the vision sensor. One of the future work that can be done this project is to make high accuracy color detection of vision sensor especially when the brightness changes. Besides that, this problem also can be solved by replacing PixyCMUcam5 with a more reliable camera that able to adjust camera brightness when the surrounding illumination varies. For future improvement, the investigation on the reliable and robust algorithm for better color tracking will be included. The robust color tracking will be based on the current finding which are related to the problems of inhomogeneous illumination, various background color, and similarity of target and background color.

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