Object Tracking and Following Robot Using Color-Based Vision Recognition for Library Environment

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***Abstract*— In the current era of Industrial Revolution 4.0, many robots are expected to co-exist and assist humans, in different environments. It would be a common scene that years from now, service robots follow humans to help us in our everyday work. Researchers investigated various methods and techniques for a mobile robot to track and follow objects or humans. Our proposed method was to use a color-recognition scheme and decide on the motion of the robot based on pixel value (which represents area) of the identified object. The robot will move towards the object if the pixel value is lower than a threshold value (an indication of a distant object), move away if the pixel value is higher than a threshold value (the object too close) or stay still if the pixel value is within these two values. Implementation on a library environment shows the success of the algorithm, with only around average 4cm deviation from the 10 trials tested. The significance of the findings is that the robot is able to maintain its distance from the object, thus avoiding from colliding with the object or being too far from the object.**

***Index Terms*— Following Robot; HSV; Image Processing; Object Tracking; Vision-Based Recognition.**

I. Introduction

This digital era, especially in the Industrial Revolution 4.0, now involves a lot of robot-assisted applications for services and industrial applications, for example human-following robots which makes use of infrared sensors [1], range finders such as laser and ultrasonic sensors [2], cameras [3][4][5], depth sensors [6][7][11] or thermal vision [10]. As of now there are numerous mobile following robots which utilize various methods to find the human subject with the utilization of depth sensors and image processing. One possible execution is to track people without territory impediment or utilization of multi-sensor designs.

In past literature, several methods were used for human following or object tracking. Some of the method used is Kalman filter, Camshift, marker-based detection, colour-based detection, block matching method. Most of the method gives acceptable results and successful experimental validations. From [3], two different methods were used which is VOCUS and Camshift algorithms. Researchers used a combination of a web camera and a laser ranger finder without any obstacles in its (human and robot) path. Both of these methods successfully track and follow a person in a corridor but the detection rate is different which is 73% and 45% for each method respectively.

Other researchers in [6] (human-following robot) and [9] (leader-follower robots) show the impressive result of 100% detection and the robot was able to follow and track its target. Authors in [6] used depth sensor, RGB camera while [9] used the pan-controlled camera without any communication between the leader and follower. Researchers in [9] used multiple follower robots to track the leader robot, allowing smooth formation following, since cameras are pan-controlled.

Color-based detections for target following robots were also used by some researchers, since it is one of the feasible decent methods to identify a target, shown by researchers in [8] and [7]. Authors in [8] used red color and 3D circle shape (red ball) detection, with Kalman filter to estimate the position of the person to be followed. Although [7] also used color-based detection, it makes use of a specific marker with a unique shape that would not confuse the robot in identifying its target. The yellow color was experimented which showed a detection rate of 80%. However, [7] did not involve any obstacles in its path, as compared to [8] which avoids obstacles simultaneously using sonar sensors.

There are numerous ways to detect and follow a person by using the camera but there are a few methods that do not the camera, instead utilized infrared / ultrasonic sensors [1] and planar laser sensor [2]. In [1], by using ultrasonic sensor and IR sensor the robot will follow a person who wears a specially made vest that transmits signal and the receiver located at the robot will receive the transmitted signal. This Infrared beacon system triggers the success the tracking and the following robot although no cameras were attached to the robot. The planar laser sensor used a cluster of the leg to follow a person, but the height of the leg must be the same. This is one of the limitations by using the method mentioned in [2]. Moreover the robot can easily lose the tracked person because planar laser only works on a straight line which difficult for the robot to detect if human goes out of its line of sight. To solve this problem it used addition way which is Gradient Nearest Neighbour (GNN) method.

The kinect sensor has been used in [6] and [7]. The kinect sensor has its advantages due to the ability to sense RGB vision as well as depth. It has collision avoidance to avoid from obstacle since depth sensor is able to sense estimate obstacles distance. Both journals show different results which [7] only detect the hip of the user in the straight path but if the robot turns to the left or right the probability of the collision occurrence is 50% because the robot does not have an ultrasonic sensor on each side. Researchers in [6] it improved this concern by using two algorithm which is an adaptive person following algorithm based on depth images and mapping. Path-following shows better result because the robot can follow and track a person without collision. Authors in [7] used depth images only while [6] used depth image and mapping. The mapping algorithm is important to ensure no collision occurs during the movement of the robot.

A state-of-the-art mobile tracking was demonstrated in [12] in which researchers investigated the detection of a soccer ball by using the vision based system. Authors implemented sweeping of Hue Saturation Value (HSV) color space in hue intervals. Prior knowledge of background color (in their case, green and white of a soccer robot field) was needed and any color of the ball can be detected with their approach.

In our proposed system, we implement an object-following robot which uses circle shape HSV color-based detection with defined boundaries of the pixel to ensure a constant following of the target object. A USB camera was used attached to the Raspberry Pi controller.

II. Experimental Setup

The developed robot contains a Logitech C170 USB webcam as the sensor input, a Raspberry Pi 2 Model B as the controller/processor for the robot, L293N DC motor drivers which are attached to two DC motors for differential drive motion, fixed on a chassis for the robot, as shown in Figure 1.

Figure 1: Robot used in the experiments

As seen in Figure 1, the controller and motor driver are mounted on the base, but the camera is attached to the carrier structure. The carrier is positioned as shown to enable it to carry a light load, i.e. a small book less than 500g. The vision sensor is attached to the carrier, facing upwards to sense a certain colored object to be detected and followed. The specifications of the vision sensor, controller and motor driver are shown in Tables 1, 2 and 3. The webcam was used due to the flexibility of the structure which can be adjusted to tilt to the desired view angle. The webcam was also used to maintain a low cost and availability in the market.

Table 1
Logitech C170 Webcam Specifications

Specifications	Value
Size	5 Megapixel (MP)
Frame rate	30 fps
Resolution	1024 X 768
Interface	USB 2.0
Weight	290g
Maximum Angle of View	180 Degree

Table 2
Raspberry Pi 2 Model B Specifications

Specifications	Value
GPIO Connector	40 Pin
Memory	1 GB LPDDR2
CPU	900 MHz
Dimension	85 X 56 X 17 mm
Operating system	Linux
Core	Quad-core ARM Cortex-A7

Table 3
Motor Driver L298N specifications

Specifications	Value
Dimension	4.2 X 4.2cm
Operating Voltage	+5V to +46V
Weight	48g
Max Driver Power	25W
Working Temperature	-25ºC to +130ºC

A. Color-based detection and tracking algorithm’

The object to be tracked is a circular shape with a diameter of 10cm and red color. All the image processings were done in OpenCV Python on the Raspbian Operating System of Raspberry Pi. The idea of the algorithm is to first identify the object, whether it matches the color set by the control in Hue Saturation Value (HSV) format. This is done by acquiring the image via the vision sensor, obtaining an HSV processed image, generating the binary of the image and filtering out the image using a morphological filter to distinguish between the image and the background by using erosion technique. The value of HSV for red color detection is shown in Table 4 and the algorithm for detection and tracking is shown in Figure 2. Table 4 is obtained after experimenting with image processing with a static circular object.

Table 4 HSV for red colour detection

Hue, Saturation, Value	Value
H(min)	0
H(max)	179
S(min)	131
S(max)	255
V(min)	100
V(max)	255

Referring to Figure 2, in tracking the object, the pixel value is important for the robot to make a decision whether to follow the object or not. The robot will decide to move forward (towards the object) in the case that the pixel value of the red object is less than 900 which is approximately 82cm, indicating a large distance that the robot has to reduce. However, if the pixel value is 2000, which is approximately 15cm which indicates a distance too close, the robot has to reverse or move backwards. If a value of between 900 and 2000 is detected, it means that the robot is within the acceptable distance. The robot then does not have to move towards the object or reverse itself, instead just maintain its location (stop the motors). The advantage of this algorithm is that the robot will maintain its distance with the object tracked, will not collide or stay too far away from the object.

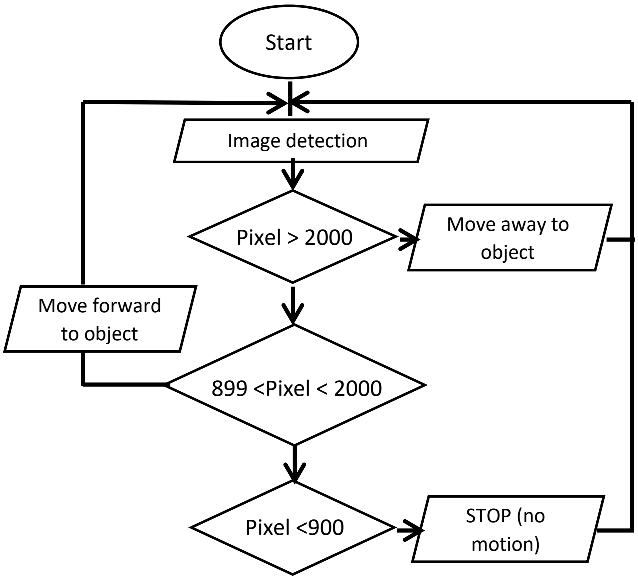


Figure 2: Detection and tracking algorithm for the robot

B. Experiments in a controlled environment

To validate the proposed algorithm, we performed field experiments in a controlled environment, which is in the library, in the open space near the racks. This is chosen due to acceptable lighting which is not influenced by day or night conditions as the outdoor environment. Thus, the HSV values read would be stable. Figure 3 shows pictures of the library environment the robot navigates in.

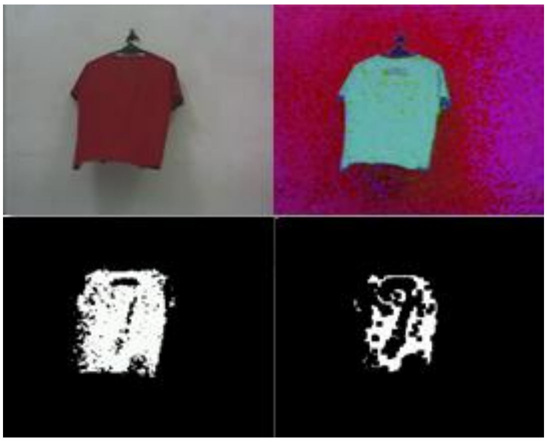
Figure 3: The robot moving towards the object (left image) and the robot moving away (reverse) from the object (right image).

To ensure the mobility of the mobile robot, the robot was equipped with a power bank as a supply for the controller and a different set of batteries for the motors. The robot is placed at a certain position in the open space at the start. The camera is tilted slightly upwards to capture the image of the object. Then, the object is placed 83cm in front of the object and the program is run. The person holding the object will move backwards at a distance of 4.2m. In addition, the tilt angles of the camera (0, 30 and 60 degrees) are also experimented, as illustrated in Figure 4. The motion (distance, speed) is recorded throughout the experiments.

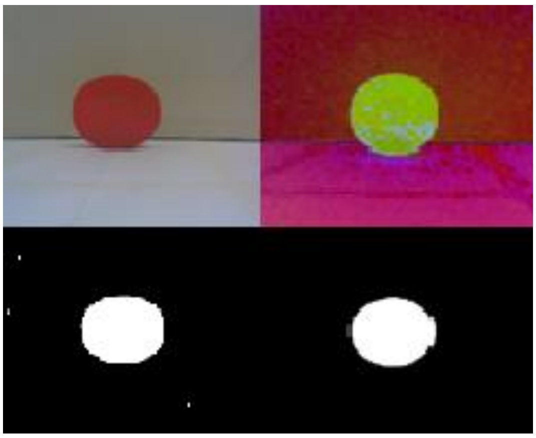
Figure 4: Different angles of the USB camera used, from above; 0, 60 and 90 degrees tilt.

III. RESULTS AND DISCUSSION

For experiment A (color-based detection and tracking algorithm), snapshots of the image detection are shown in Figure 5. Two different objects were tested, a red shirt and a red circular object.



(a)



(b)

Figure 5: Acquired and processed images of (a) red shirt and (b) red circular object.

As seen in Figure 5, the four images for each object have captured an image, HSV image, binary image and a filtered binary image. It can be seen that for the red shirt, the resulting filtered binary image shows an irregular shape which is difficult to determine what the actual detected object is. This is due to the lighting which affects the folded area or angle of the shirt. It will also give effect when the shirt is worn by a user since lighting will vary on the shirt. However, for the red circle, the results show a steady viewable image that maintains the structure of the circle. This structure is very similar to the shape of the actuals object. Thus the red circular object further experiments for the field tests.

For experiment B (field tests), measurements of speed are shown in Figures 6, 7 and 8 for different camera tilt angles (0, 30 and 60 degrees). The measurements are collected with an average planned speed of around 0.5 m/s for the object.

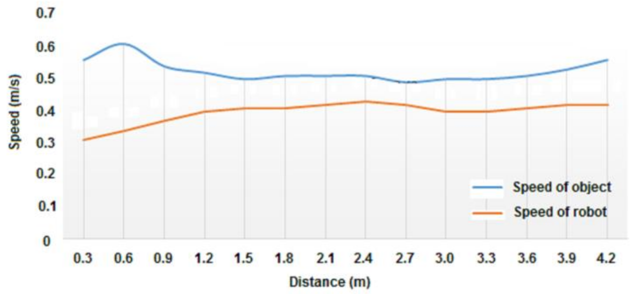


Figure 6: Speed-distance variation of robot and object at 0 degree camera tilt angle

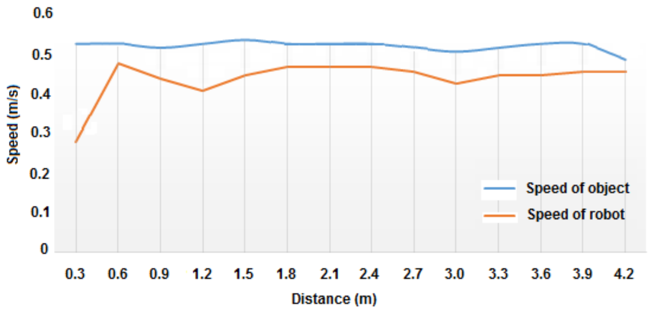


Figure 7: Speed-distance variation of robot and object at 30 degree camera tilt angle

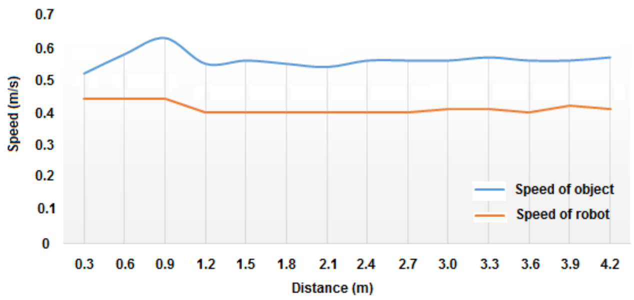


Figure 8: Speed-distance variation of robot and object at 60 degree camera tilt angle

It can be clearly seen in Figures 6 to 8 that the speed of the object is slightly higher than the robot. This is because the robot follows the object steadily and occasionally reverses or stops to maintain distance. The speed of the robot varies slightly to track the object consistently. Even with varying tilt (or pitch) angles of the camera, the robot successfully follows the object throughout the 4.2m distance. Figure 9 shows the coordinate plot of the motion of both object and robot in 10 trial experiments for 0 degrees tilt angle of the vision sensor. The human path (holding the circular object is represented as the color black while the others are represented by other colors. The average error of the 10 trials was 4.012cm. This is mainly due to the differential drive motors which vary slightly in speed, even though both were given the same directions for forwarding motion.

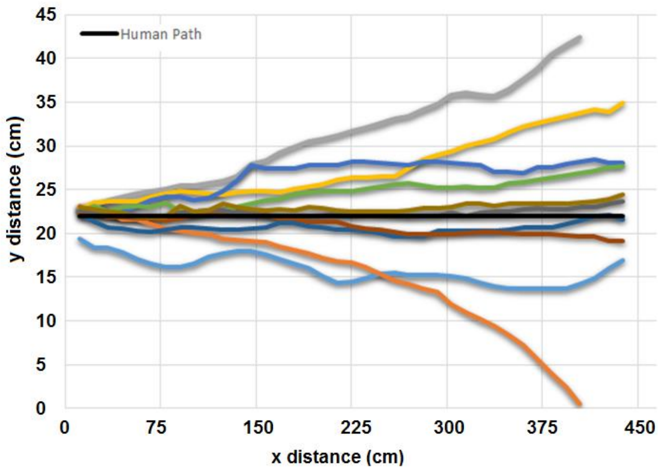


Figure 9: Plot of coordinates of motion in 10 trials of the experiment

As seen in Figure 9, although some deviations from the path occurred, most of the trials were within 15cm from the path of the object motion. This shows the success of the algorithm in the field test in the library environment.

IV. Conclusion

The object tracking and following robot using vision sensor was presented. At first, image processing was done on the acquired image to recognize the object as the target. It involved HSV, binary image conversion and filtering. Then the pixel value (area) of the identified object was calculated. To maintain the following motion within a distance, three different possibilities exists in the algorithm; to move forward if the distance is far (pixel value is smaller than a threshold value), to reverse or move away from the object if is too close (pixel value larger than a threshold value) or maintain the position (robot stop motion) if it is within the two thresholds. By using this algorithm, the robot was tested in a library environment. Experiments showed that the robot was able to track and follow the object successfully with an average error of around 4cm from the path of the robot. This proved the success of the algorithm implemented. In future, we plan to analyze and compare the accuracy of the color-based object detection with other detection methods (vision and other sensors) and conduct an investigation on larger variations of object speed and longer distance with obstacle along the path.

Acknowledgment

Authors would like to acknowledge the funding given for this research, from Universiti Teknikal Malaysia Melaka, with the short term high impact grant PJP/2017/FKE/HI8/S01524. Authors would also like to express our gratitude to Robotics and Industrial Automation Research Group under the Center for Robotics and Industrial Automation.

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