

**International Journal of Innovative Research in Science,
Engineering and Technology**

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 11, November 2013

Color-Based Object Tracking and Following for Mobile Service Robots

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Abstract: A vision based measurement and control system is developed to enable a mobile robot to track and follow an object moving on an indoor flat terrain. A color video camera is fitted on the robot and sends the image via wireless connection to a host computer. The object image is continuously grabbed and the target color is extracted and used for target detection. The target image is processed to measure object motion parameters and then send a control signal back to drive and steer the mobile service robot. A Fuzzy Logic Controller, FLC, is designed to control the vehicle steering based on the information measured from the image. An experimental program is carried out to explore the system performance. The experimental results are evaluated and it was clearly shown that the system is robust and effective in tracking the target. The FLC is efficient and causes the system to tolerate noise and uncertainties in the target detection.

Keywords: Service Robot, Visual Navigation, Object Tracking, Color Tracking.

I. INTRODUCTION

Intelligent mobile robots are now finding numerous applications as service robots to be used in home and office environments. However, the robotics application domain is increasing and the need for intelligent behavior in such robots is also increasing. Therefore, developing techniques for autonomous navigation of mobile service robots is both important and needed. Since, data available from sensory information contains a considerable amounts of uncertainty due to the sensor itself or the techniques used to extract data from the sensors, fuzzy logic techniques lends itself as a plausible tool for solving this problem. Fuzzy logic techniques had been used for navigation research and still an active research domain, [1],[2],[3],[4], [5] and [6]. The literature of the mobile robot navigation is huge; see good reviews in [7] and [8]. It was realized in the literature, during the 1980s, that the complex behavior of a mobile robot can be built using a set of primitives or simple behaviors and combining their outputs in a way to reach final motion commands, [8] and [9]. This approach was proposed in opposition to the early serial strategy in which the inherent computational complexities would have slowed down the speed of robot reactions. One simple behavior is tracking of a moving object, which is gaining interest in robot navigation,[1],[10] and [11].

In this work, an object tracking control system is developed using fuzzy logic control. The tracked object is colored to facilitate its tracking in the image. The uncertainties associated with object detection are handled through the fuzzy set representation rather than using crisp representation. Color cues had been successfully used for navigation in the literature, [12].The target displacement in the image is used along with the target image velocity to control the vehicle so that object appears inside avisible zone. The object is detected in the image by its color and its size. Motion parameters are measured and represented by fuzzy sets. We designed a fuzzy logic controller for controlling the steering command. The control system was implemented and tested to navigate a small wireless mobile robot so that it can track and follow an object moving on flat terrains.

The paper is arranged as follows, the next section presents the model of imaging and measurements from the color image. In Section III, we describe the design of fuzzy logic controller responsible for robot steering and the system algorithm. Experiments are described in Section IV and conclusions are finally given in Section V.

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II. IMAGE-BASED MEASUREMENTS

A. Imaging Model

When the illumination light hits surfaces of the scene, the CCD camera collects the scene reflection through the lens. The color image is formed on the camera plane and the incident radiation is integrated both spatially and spectrally through the elements of its CCD sensor elements as shown schematically in Fig.1.

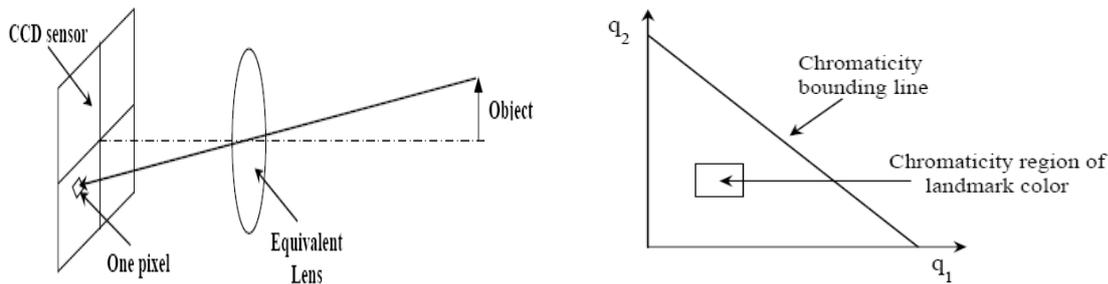


Fig.1 Imaging system. Fig.2. The color chromaticity diagram.

The color responses measured at each pixel can be described by the following equation

$$I(x, y, c) = \iiint E(X, Y, \lambda) F_c(\lambda) dX.dY.d\lambda \tag{1}$$

Where: $I(x, y, c)$ is the intensity of the image observation corresponding to (x, y) location in the image. $c \equiv (r, g, b)$ is the conventional vector representation of color attributes corresponding to (red, green, blue). $E(X, Y, \lambda)$ is the scene incident radiation. x, y , are the image coordinates measured in pixels, X, Y are the world coordinates, λ is the wave length of light and $F_c(\lambda)$ is the spectral response function of the camera optics and sampling filters giving the color $c \equiv (r, g, b)$. Equation 1, is the imaging model and shows that every pixel in the image provide a color vector of three integrals in response to the scene reflection over three different spectral bands of the visible spectrum. A digitizer interface for the video signal of eight bit resolution is used. The color vector is thus $(0,0,0)$ for completely dark locations, and $(255, 255, 255)$ for the brightest objects of the scene. The camera electronics will sample the video signal according to the following equation

$$k_r(x, y, c) = a. I^\gamma(x, y, c) + f \tag{2}$$

The camera radiometric calibration is performed to estimate the offset f in each pixel and then discounting it from the raw image. The global photo-electric conversion exponent, γ is also calculated for the whole image. The calibration is done according to the following equation

$$k(x, y, c) = (k_r(x, y, c) - f)^{1/\gamma} \tag{3}$$

B. Image smoothing

The image is spatially smoothed by convolving the input image matrix with a smoothing kernel to reduce the effect of the camera and the electronic digitizer noise. The smoothed image matrix $k_s(x, y, c)$ is calculated using the following equation,

$$k_s(x, y, c) = k(x, y, c) \otimes w(x, y) \tag{4}$$

Where $w(x, y)$ is the weight function of the convolution window, and the symbol \otimes denotes spatial convolution operation. The original image is smoothed by applying the convolution using unity window weights which reduces the effect of image noise significantly. This spatial integration is an important image filtering step that eliminates spurious pixels that result from the electronics-induced noise and is usually a necessary pre-processing operation usually

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performed for images that will be subject to quantitative measures.

The target is detected in the image by a selection criterion based on the target color chromaticity. The chromaticity space is a two dimensional space as shown in Fig.2 and it is used to define the color of the target object. The figure shows a representation between red and green chromaticities described by:

$$q_1(x, y) = \frac{k_s(x, y, r)}{\sum_{c=r}^{c=b} k_s(x, y, c)} \quad (5) \quad q_2(x, y) = \frac{k_s(x, y, g)}{\sum_{c=r}^{c=b} k_s(x, y, c)} \quad (6)$$

The chromaticity space is useful to define the landmark color since the chromaticity, being a ratio, is not affected by the illumination intensity. The chromaticity space converts the three dimensional color representation (r,g,b) into a two dimensional space described by (q1,q2). Description of color becomes therefore unique by using only two descriptors, namely the red and green chromaticities. The object color is defined within ranges of red and green chromaticities as shown in Fig.2, and the boundaries of chromaticity zone are described by the following constraints:

$$q_1 \in (q_1^l \approx q_1^h), \quad q_2 \in (q_2^l \approx q_2^h) \quad (7)$$

The segmentation process is then based on the color chromaticity as follows

$$seg(x, y) \begin{cases} = 255 & \text{if } [q_1 \in (q_1^l \approx q_1^h) \text{ and } q_2 \in (q_2^l \approx q_2^h)] \\ = 0 & [else] \end{cases} \quad (8)$$

The matrix seg (x ,y) is written to a monochromatic image, in which the target area color is written as white pixels and the background is written as dark pixels. We use the algorithm implemented in [12] for the color image segmentation.

III. DESIGN OF THE FUZZY LOGIC CONTROLLER

The decision of the motion is based on the conventional fuzzy logic inference stages shown in Fig.3. The goal of the fuzzy logic controller is to enable the mobile robot to represent the target motion attributes, namely the image displacement and image velocity of the target object. We design a FLC to control the mobile robot steering commands. The output of the controller is responsible for steering the vehicle such that the target object appears continually in the middle of the image.

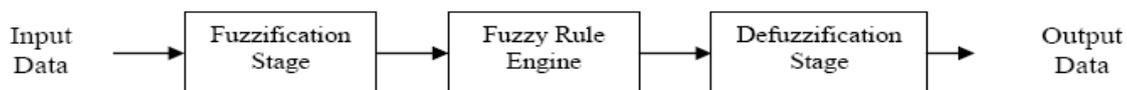


Fig. 3 The fuzzy logic control processes.

Since the camera has fixed focal length and the target size is the same through the experiments, the target area in the image is used as an indicator for the distance between the robot and the target. These rules are based on heuristic knowledge of the behavior and limitations of the experimental platform. When these rules are applied, they result in the output fuzzy variables responsible for vehicle steering commands. The sensory information available for the steering command is the target position in the image. The horizontal component of motion is only selected since the vehicle and target are both assumed to move on an indoor flat terrain and the camera orientation relative to the floor is fixed. The steering changes the target image position and hence, the motion attributes chosen as the input fuzzy linguistic inference layers for the FLC are selected to be the image horizontal displacement and image horizontal velocity.

The membership functions for these two layers are shown in Fig.4. The fuzzy logic controller used to control the mobile robot uses conventional triangular membership functions to fuzzify the data measured by the vision system. The input fuzzy variables are divided into three overlapping fuzzy set functions. In our implementation, the linguistic descriptors for the image horizontal displacement in the fuzzification step are defined as : 1) Left (L) , 2) Middle (M), and 3) Right (R). The target image horizontal velocity is described by three fuzzy variables defined as : 1) Getting Left

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(GL), 2) Getting Middle (GM), and 3) Getting Right (GR). The shape and relative overlap of the fuzzy variables (that is tuning), are determined from our early experiments with the control system. The two fuzzy variables are then used to derive three output states for steering. The three output states for steering are selected to be 1) Turn right, SR, 2) Go straight, STR and 3) Turn Left, SL. For each fuzzy linguistic interference process we define 3*3 fuzzy rule matrix as shown in Fig.5. The motion decision for the tracking behavior is calculated through the fusion of the image displacement and image velocity through the fuzzy logic inference matrix shown in figure 5. The values of matrix entry is calculated by finding the minimum of the two input variables, for example

$$SL_i = \text{minimum}(G, L) \tag{9}$$

The three output variables are then computed using the root of sum squared of contributing variables as described by the following equations

$$SL = \sqrt{SL_1^2 + SL_2^2 + SL_3^2} \tag{10}, \quad STR = \sqrt{STR_1^2 + STR_2^2 + STR_3^2} \tag{11}$$

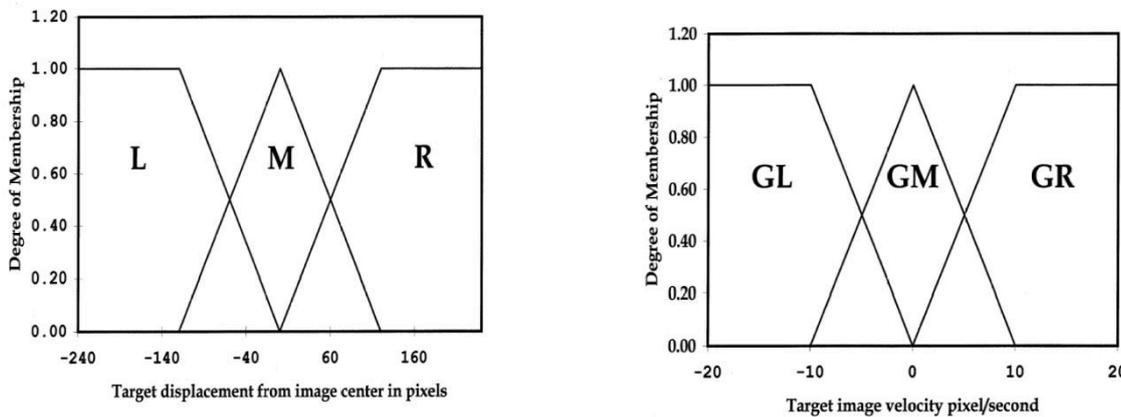


Fig. 4 Membership functions for the input variables of the steering FLC.

	GL	GM	GR
L	SL_1	SL_2	STR_1
M	SL_3	STR_2	SR_1
R	STR_3	SR_2	SR_3

Fig. 5 The Fuzzy Rule Matrix for the Steering FLC.

$$SR = \sqrt{SR_1^2 + SR_2^2 + SR_3^2} \tag{12}$$

Finally, the normalized control command are calculated by the de-fuzzification computations that are based on the center of gravity (or centroid) method and can be described by the following equation

$$SCmd = \frac{(SL \times -1 + STR \times 0 + SR \times 1)}{(SL + STR + SR)} \tag{13}$$

Where -1 is the center value for left steering, 0 is center for the straight steering and +1 is the center for right steering. The steering command, *SCmd*, is evaluated from Equation 13 and then directly sent to the steering motor subject to a no change zone in the range (-0.2 : +0.2), and steer left if the value is negative and outside the no change zone, and steer right if the value is positive. The final control algorithm is implemented in C-code and the flow chart for the whole control system is shown in Figure 6. It should be noted that the target area is used as indicator for the distance from the target. If the area is too large, that means close target and if the area exceeds a threshold, the vehicle is stopped and report "Target Reached" message. If the target area is below a minimum threshold, the vehicle is also stopped and report "Missing Target" message. It should also be noted that the vehicle stops for a short time in each measuring cycle before grabbing a new image. The experiments shows motion blurring effects with our camera so that grabbing while

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moving fast will result in an image that is difficult to segment and hence the target measurements are then prone to errors.

IV. EXPERIMENTS

The control system hardware is schematically shown in Fig.7. A small vehicle is used to test the color tracking control system. The vehicle is an on the shelf radio-frequency controlled vehicle which is modified by installing a 10 mm thick acrylic sheet which is fixed with the chassis. The vehicle actuation system consists of the driving motor and the steering motor. The vehicle main specifications are listed in Table.1, and a photograph of the mobile robot is shown in Fig. 8 a. The vehicle can move forward and backward and can also steer to the left and to the right according to commands from the radio frequency controller. A color CCD camera, with a horizontal viewing angle of 24 degrees, is mounted on top of the vehicle board. The video camera delivers an analogue signal output that is transmitted via a wireless UHF transmitter to a receiver unit connected to the host PC. The video signal is then digitized using a real-time frame grabber connected to the PCI bus of the host computer. The CCD camera image is monitored on an external TV monitor for user convenience during the experimentation stage. An external camcorder is also used to register the vehicle real trajectory in the workspace.

The frame grabber (video digitizer) delivers a video-rate digitized image every 40 millisecond, since the camera is PAL and delivers 25 frames per second. The image is then stored in an image buffer and ready for access by the control program. Image processing and control algorithms are executed in the host computer by specially devised C++ code program implementing our algorithm. The actuating signals for steering and driving the vehicle are then sent back via the R/F controller. The radio control circuit is modified so that the input signals are fed from the terminals of a data acquisition card installed and connected to the host computer. A sample of the images captured by the on-board camera is shown in Fig. 8 b, c, showing the raw captured image and the segmented image. The segmentation of more complex and real environment may require the employments of further shape and geometrical constraints that will be considered in further studies. Simplifying the segmentation gives us the opportunity to build up the control system for color tracking and explore its features without the computational complexity that may retard the tracking speed of the control system. The segmentation in this work is quite fast, since the computation is done on a pixel by pixel basis and does not involve pixel connections that can take much longer processing time. But the disadvantage is that segmentation may suffer from noise induction in the form of scattered pixels in the image.

Fig.9, shows a sample experiment of the color tracking control system. The vehicle is adjusted at first to view the target in the right side of the image. The vehicle starts to move as shown in the vehicle path and keeps moving forward. During the vehicle motion, the target continuously approaches the image center and consequently the landmark area increases in the segmented image. The vehicle stops when the landmark area in the image exceeds a certain threshold, experimentally adjusted, so that the vehicle stops at about 25 cm in front of the landmark. It can be observed that, the vertical coordinate of the target in the image is not used by the control program. The vertical coordinate can be used in some other applications, such as a red traffic signal in the roadway. In such case, the vertical coordinate can be used to distinguish the higher elevation signal mark from objects on the ground. Figure 9 shows that the control system succeeded to track the color target and enabled the vehicle to follow the target. When the target is moved, the vehicle followed its route given that the target moves with a speed comparable to the vehicle speed.

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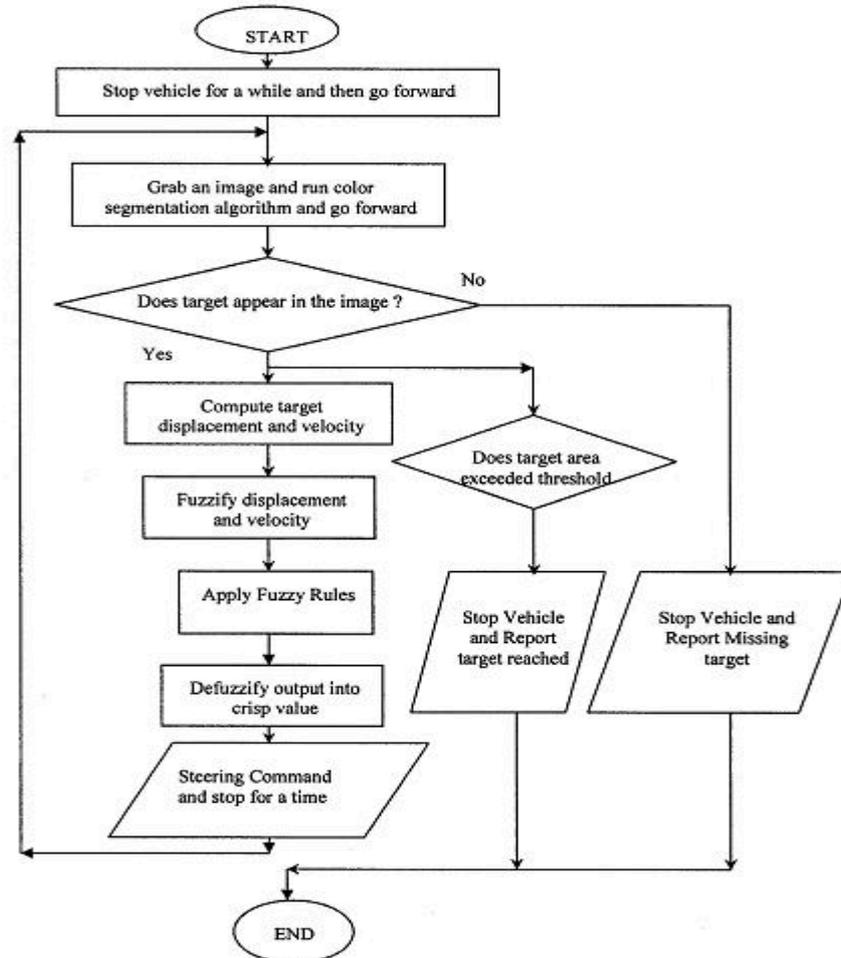


Fig.6 The mobile robot control algorithm.

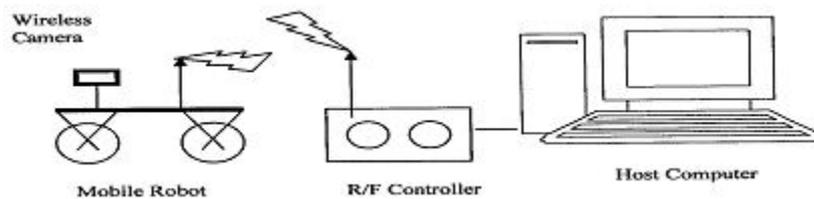


Fig.7 Mobile robot control system.

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Fig.8 The robot image, (a) the images captured by the onboard camera, (b) and color-segmented image, (c) during one run of the vehicle.

V. CONCLUSIONS

A robot control system had been implemented in order to track and follow a moving object. The system was tested using a small vehicle equipped with a wireless color camera and radio frequency controller for driving and steering the vehicle. The algorithms for color image processing and target extraction and measurement of target features have been developed. A fuzzy logic controller had been used for controlling the steering command of the robot, and the driving command have been decided based on target size in the segmented image. Membership functions for the target position in the image had been designed based on our experience in running the mobile robot. The robot reliably followed the target in our experiments and kept a distance between them that ensures the visibility of the target in the camera. Further improvements will be made in the future to reach more complicated behaviors.

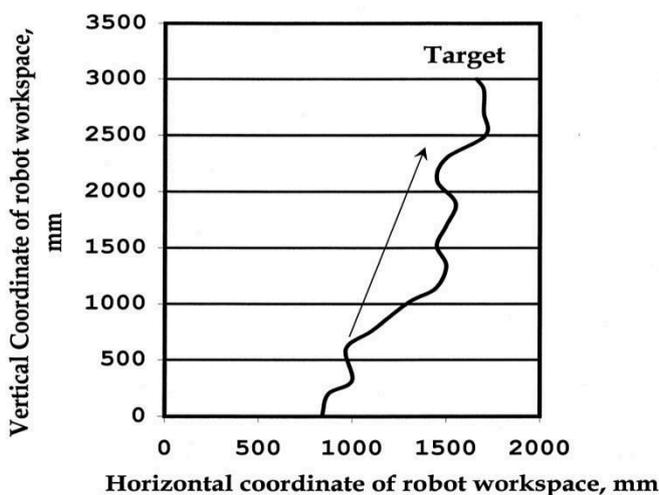


Table 1. Specification of the vehicle

Item	Description
Size	410 L, 270 W, 150 H mm.
Weight	4.5 kg
Power	Single 7.2 V battery
No. of wheels	4
Steering type	Front wheel steering
Camera type	Wireless Color CCD camera
Frame rate	25 frames per second
Image standard	PAL
Image size	640×480 pixel × pixel
Vehicle speed	25 cm/s

Fig.9 The real track of the vehicle while following the colored target.

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BIOGRAPHY



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