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A Micro-Robot with Camera to Track and Follow Objects

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Abstract

A lot of work has been done to track a moving object with the aid of a camera. This paper describes one such technique, which can constantly track and follow moving objects. Most of the work done in this paper was referred from the work done by Nazim. The camera is used as a feedback sensor to help the robot follow the object. The robot system is truncated into two sub-systems: vision and motion. The vision system comprises of a two-motor pan-tilt camera driving mechanism with embedded potentiometer sensor, PCI image acquisition board and PWM based DC motor driver board. The motion system is made up of a two-wheel and two-castor platform driven by servomotors with amplifiers. The system tries to demonstrate the eye tracking ability of a human when a moving object is in focus. The robot used for this purpose is Alice, the most recent model that was developed in the year 2002 has been chosen.

Keywords: Direct current motor; Potentiometer; Robot; Stereo imagers

Introduction

Many interesting work has been done in the past in order to achieve a robot that could track and follow an object. Work has even been done in tracking multiple objects, and several tasks that varies in complexity. Some algorithms recommend the use of particle filters [1], sophisticated stereo imagers [2], or even vision-based navigation techniques [2]. Active Approach Model (AAM) is one such visual tracking task. The contour modeling has been exploited by the Denzler and Paulus [3], describing a two stage active vision system for tracking a moving object. The target is being detected and a close-up view is obtained by varying the parameters of the frame grabber and by positioning the 'end-effectors' camera appropriately. An active contour has been initialized on the first image sequence. A robust algorithm has been developed for arbitrary object tracking in long image sequences. Extending the dynamic Hough to detect arbitrary object shapes that undergoes affine motion, this algorithm requires the whole image sequence to be processed globally.

In this project, a camera-based vision system mounted on a robot has been designed. The vision system acquires gray-scale images at a rate of 25frames/ second (continuous mode). The centre of mass of the object is found in pixels and the centre of the camera image plane is aligned to the centre of mass of the target object. The motion of the camera is sensed by a potentiometer that directs the wheels of the robot and commands them to keep track of the object. A pulley and belt system connects the potentiometer and the camera drive, this way, speed is controlled using analog signals. With the high speed PCI image acquisition method, a not-so-complex image processing and measuring algorithm with no calibration requirement for the camera in real time, with fast interfacing and quick system time response has been achieved.

Object Allocation and Identification

The algorithm imitates the ability of human eye to track moving objects. A dark colored car has been chosen as a sample image.

Image enhancement and processing

Image acquisition and processing is the first step in tracking process. The gray-scale image of the original image (Figure 1) is obtained. The gray-scale image of the original image is obtained to better differentiate the contrast and the intensity level. MATLAB software has been used extensively to do the entire image processing, once the gray-scale image (Figure 2) is obtained; the program converts the gray-scale to a binary scale. The resulting image is a monochrome which makes the job much easier. Every image is represented as a matrix in Matlab, with m rows and n columns, m and n being the resolution or the pixel size of the image. The conversion of the image to its binary image can be done in several ways, simplest being the reduction to the gray-scale and then converting it to binary, and this looks well suited for this applications. Figure 1 shows the original image.

The process of converting the gray-scale image to the binary image involves a sequence of steps. The image from the camera is first reduced to a standard resolution of 250 × 250 pixels. With that, the same set of

Figure 1: The original image.

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Figure 2: The gray-scale image.

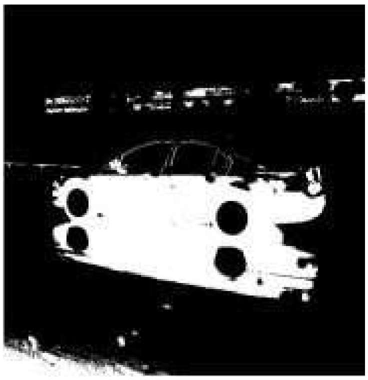

Figure 3: The preliminary binary image.

calculations can be performed for any given image and it works just like a generic image processing algorithm.

Few assumptions are worth mentioning in the context of acquiring the binary image. A threshold intensity level has to be set before the object is identified. The intensity level of the object has to be approximated. Some work is still being carried out in having a pre-defined intensity range for several objects. The outcome expected is to have the intensities well defined for any given object, irrespective of the resolution of the image.

Figure 3 shows the resultant binary image after the preliminary stage of conversion. The image is a raw binary image; it might contain some amount of noise, and without proper borders for the object. The next step is to reduce the noise level and to have a well-defined border between the object and its surroundings.

The noise reduction is done by simply exploiting the property that an object is continuous in its shape, and that its intensity does not vary across the pixel range of the object. The algorithm reads through the intensity matrix and finds the pixel range up to which the object extends. Those lying in that range is set as '1' and the rest all are considered as noise and set to be equal to '0'. By doing this, even the boundary of the object is clearly identified. Such resultant image is shown in Figure 4.

By varying the threshold level of the intensity, the object identification can be varied according to the vigilance and the environment. This counts for the object identification process and this step plays a major role in the working of the entire system.

Tracking strategy: Quadrant approach

The human eye is an excellent example for this approach and it's the best example one can quote for a system capable of tracking a moving object. With the calculated centroid of the object, the quadrant approach changes the orientation of the camera such that the centroid is always aligned to the center of the image plane of the camera. Any mismatch in locating the centroid is taken as an error, and the errors can be along the four different quadrants, resulting in four different combinations of *dx* and *dy*. These are the measures of the relative error between the image plane center and the centroid and thus the errors have to be compensated by moving the camera accordingly.

Figure 5 shows the 'field-of-view' of the camera with four quadrants from which the error signals can be computed [4]. The system has a two degree of freedom pan-tilt mechanism controlled by two individual motors. The system controller controls the motors after making a choice from the four possible combinations. This shows how the camera imitates the human eye in tracking a moving object. If more than one object is identified, the system temporarily halts as this algorithm is not designed to track multiple objects, but it can be extended to do so in the future, and several algorithms are available to do the same task.

The speed with which the object moves is an important factor. If the speed of the object is more than that of the speed of the pan and tilt motor, the camera will not be able to detect the object and it might lose the object from its vicinity. Assuming that the speeds are within the limit, the controller system assures tremendous stability and avoids spontaneous motion. The camera also acts as a feedback sensor for the entire system.

Camera Motion Subsystem Design

The speed control of the DC motors employed for the pan and tilt

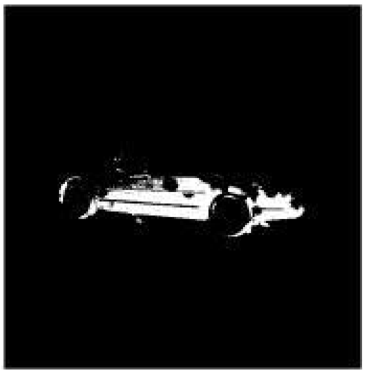

Figure 4: The final binary image.

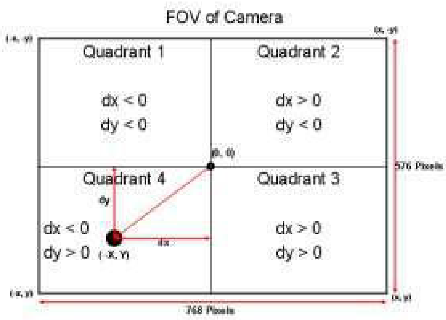

Figure 5: Quadrants of the image plane. **Source:** Mir-Nasiri et al. (2005) [4].

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function determines how smooth the motion of the camera will be and henceforth the performance of the entire system. The most important condition here is that the speed of the tracking system should match with the speed of the moving object [4].

Speed control of the strategies for the camera motion

The PWM approach has been adopted for speed control of the motors by varying the duty cycle. By varying the polarity of the supplied voltage the direction is varied as well. The supplied voltage is proportional to the absolute values of the error signals dx and dy. The *cycloidal* and *ramp* functions control the acceleration and deceleration of the motors.

The above function is used to control the speed of the pan motor [4]. This has three characteristics speeds for the pan motor. Figure 6 shows a plot of the PWN as against the pixels. It can be noticed that for objects closer than 2 pixels to the center of the image plane, the ramp function proves to be effective. The cycloidal function is effective when the object lies between 2 pixel and 50 pixel to the center of the image plane. A constant full speed run is effective when the object is located more than 50 pixels away from the center.

The speed control of the tilt motor is obtained by the above equation. A similar plot can be obtained for the PWM as a function against the pixel [4]. When the object is in the range of 2 to 15 pixels, the cycloidal function takes control of the motion. A constant full speed control is obtained if the value is more than 15 pixels (Figure 7).

These two plots for the two different functions summarize the speed control of the pan and tilt motors and a smooth control can be observed from the plots.

Components setup

The vision-based system comprises of three major parts. The first one being an analog monochrome camera. The next one is the pan-tilt mechanism driven by two different DC motors and their speed controls.

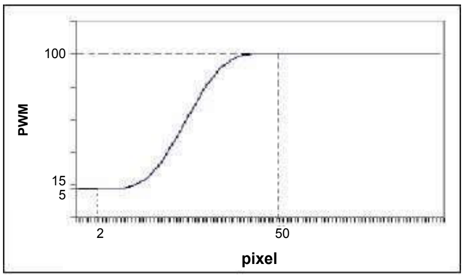

Figure 6: Speed control of pan motor. **Source:** Mir-Nasiri et al. (2005).

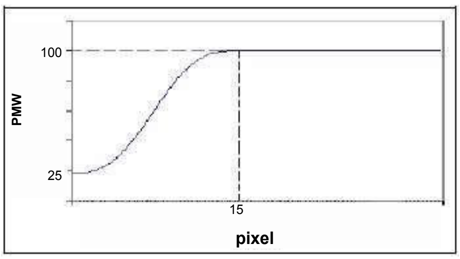

Figure 7: Speed control of tilt motor. **Source:** Mir-Nasiri et al. (2005).

Alice in Action

The micro-robot *Alice* has been assigned the job of carrying the entire navigation system and to follow the object. To put in a nut shell, the robot acts as the mobile platform for the vision-system.

Description of *Alice*

The most recent version of *Alice* was developed in the year 2002, also known as a sugar cube robot [5].

Figure 8 shows an image of the *Alice* 2002, whose dimensions are 2 × 2 × 2 cm^3. Some of the features of *Alice* are listed in Table 1.

The size of this robot makes it suitable for covert operations and work is still being carried out on how exactly the vision-based navigation system can be mounted on the mobile platform. With technology reaching new limits every day, this task is certainly feasible and similar designs have been successful implemented [6].

Alice has a remarkable autonomy of up to 10 hour, which can be exploited in this project the entire system can function autonomously as far as *Alice* can take care of herself. A simulation of the *Alice* robot has been made which demonstrates the mobility and modularity of *Alice*.

Figure 9 shows a snapshot of the 3-D simulation of *Alice* integrated with a camera model. The simulation was done using the Webots software, and the coding was done with the Virtual Reality Modeling Language (VRML). The work in the simulation is still in progress and

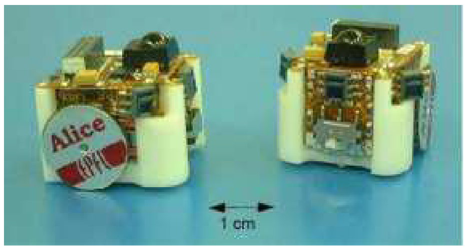

Figure 8: The sugar cube *Alice* robot. **Source:** Caprari et al. (2003) [8].

Feature	Units
Dimensions	21 × 21 × 12 mm
Weight	5 g
Velocity	40 mm/s
Power consumption	4 mW-10mW
System autonomy	Up to 10 hour
Infrared remote communication	6 m, 500 bps
Infrared local communication	4 cm, 500 bps
Radio communication	10 m, 1000 bps

Table 1: Features of *Alice*. **Source:** Caprari et al. (2001) [7].

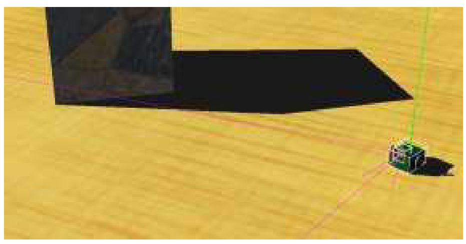

Figure 9: *Alice* in the 3-D virtual world.

the fabrication of this model and showing any kind of experimental result is out of scope for this paper.

Speed control strategies for robot motion

The 3-D object tracking camera and the tracking strategies completely guides *Alice*. Every movement of the camera is sensed by a potentiometer and the readings from the potentiometer are converted to a suitable form that could drive the robot. The independent speed controls of the two wheels essentially control the orientation of *Alice* [4]. The voltage reading from the potentiometer is directly used to control the input voltage of the motor servo amplifiers.

Conclusion

An effective approach for the object tracking system using camera as a feedback has been discussed. The controller is designed such that the camera imitates the human eye while tracking a moving object. This paper uniquely integrates image acquisition and processing techniques for object identification and mobile robot controls with a camera. The highlight of this work is the camera need not be calibrated in real world units. Smooth motion of the robot is achieved using the navigation techniques.

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