Development of Autonomous Cruise Control System for Convoy Vehicle

Daniel Sim Yeat Han, Foong Chee Hin, and Hudyjaya Siswoyo Jo

***Abstract*— This paper presents the tracking and navigation techniques to enable an autonomous vehicle to navigate itself by following the car driving in front of it. The autonomous driving is achieved by tracking and following the leading vehicle based on the visual information acquired by a camera. The position and distance of the leading vehicle are extracted from the characteristics of the unique marker attached at the back of the leading vehicle. Based on the position and distance information, the vehicle will navigate itself to achieve the desired maneuver and distance with respect to the leading vehicle. The visual tracking algorithm is implemented using image acquisition and image processing toolboxes in MATLAB and the navigation algorithm is designed using model-based design approach using SIMULINK.**

***Index Terms* — Convoy Vehicle, Image processing, Autonomous Navigation, Vehicle Tracking**

I. Introduction

CAR has been one of the marvelous technologies which human has ever invented. Before 20th centuries, a car is a symbol for the rich, however nowadays car has been a salient needs in human life. Manufacturing technology has come to an extent that people are able to have an affordable and good quality car. However, no matter how pitch-perfect is the car, the car accident rate is still catching up in the run. One of the most significant causes is due to human error particularly the driver. In Malaysia, there is an average of 18 peoples who died from fatal accidents on the roads daily [1]. The probability of an accident is increasing as the driver is experiencing distraction or fatigue especially during a continuous long journey.

Car manufacturer and research institute are continuously working to improve the safety of driver and passenger by implementation of latest technology such as front collision avoidance system, adaptive headlight, land departure warning, etc [2]. In recent years, many researches have been carried out to detect the driver drowsiness for the purpose of accident prevention [3-6]. There are also products related to road accident prevention that have been introduced in the market. Products like ‘Mobileye’ and smartphone application ‘iOnRoad’ are targeted to assist and warns driver of potential hazards when an accident is about to occur [7-8]. Although it is proven to be effective in reducing the chances of accident occurrence, the problem with driver distraction and fatigue is still unsolved. Therefore, in order to tackle the issue, an active driver assistive system has to be implemented.

There are several preliminary studies in the related area but most of the implementations are only applicable in predetermined and known environment mainly in industry or railway applications. Amat *et. al.* proposed a method to virtually link the series of automated guided vehicle by using binary image marker as the identifier of the leading vehicle. This method is reliable when it is operating in controlled environment with expected path and turning radius. However, the system is only capable to detect and follow the leading marker up to a certain amount of angle due to the limitation of field of view and image distortion [9]

Henke *et. al.* introduced the convoy system dedicated for multi-cabin railway vehicle. The system will allow multiple cabins on the railway to follow the leading cabin for the purpose of enhancing the operation flexibility and improving the overall efficiency. The convoy coordination is achieved by two-way wireless communication between the connecting cabins [10].

Kita *et. al.* proposed a velocity control technique for vehicle platoon/convoy. The work focuses on minimizing the speed fluctuation of the follower vehicles during the convoy. However the maneuvering technique of the vehicle is not reported in the literature [11].

The work presented in this paper mainly focuses on the development of the driver assistive device when the vehicle is driving in a convoy. The cruise control system will work as a supplementary system which will allow the driver to have a temporary break from controlling the vehicle during the long journey. While the autonomous cruise control system is in place, the driver is still given a full control in engaging and disengaging the cruise control system in real time. Therefore, in certain circumstances, when traffic condition does not allow the cruise control to work in order, the driver is able to take full control of the vehicle.

At its final implementation, this system is intended as a supplementary system to be fitted to the existing vehicle. The system is expected to assist the driver to temporary takes control of the vehicle while the driver is expected to be in the state of distraction such as making phone call, consuming food or replying message.

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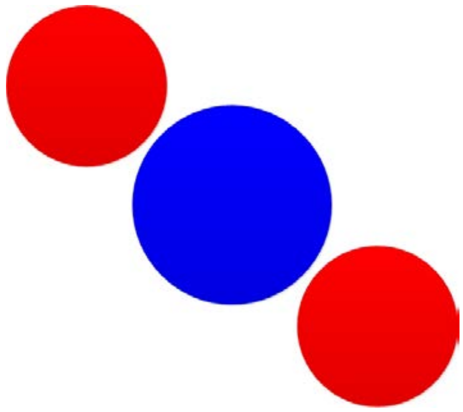

Fig. 3. Unique pattern

In order to verify the uniqueness of the pattern, the tracking algorithm is divided into three steps. The steps are further explained below.

Firstly, the captured frame of RGB image is converted to HSV image. In the HSV colormap, the value of Hue (H), Saturation (S) and Value (V) are set to extract a specific blue and red color from the image. The red and blue mask are masked together to extract both specific blue and red color at the same time. After the color extraction, the image will only process that specific region of blue and red color in order to improve the efficiency of the algorithm.

After extracting the relevant color from the image, the Circular Hough Transform (CHT) method is used to detect the circles from the masked region. The information (radius and centroid) of all the circles found in the image are stored in the memory and further processed in the next step to identify the unique pattern.

Following the previous step, each blue circles is further processed to check the existence of two surrounding red circles. The checking is performed iteratively on each detected blue circle to look for the existence of two red circles with similar size. If two red circles are detected, the centroid and radius of each red circles will be stored into a temporary variable. The value stored in the temporary variable will be computed to find out the area of the unique pattern. If no red circle is found after running through all detected blue circles, it indicates that the unique pattern is not detected. Fig. 4 shows the completed steps in pattern verification. The red box indicates the area of the detected unique pattern which reflects the distance of the unique pattern from the camera.

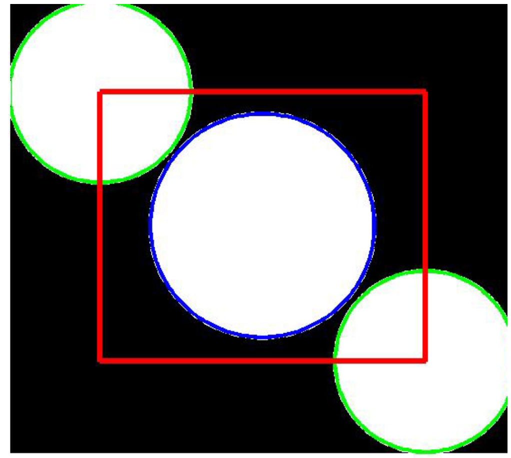

Fig. 4. Detected unique pattern

By going through the three steps of verification, it is safe to assume that the tracking algorithm has found the correct pattern. Once the valid pattern is found, the information will be transfer via serial communication to the navigation system which is running on the microcontroller.

IV. Vehicle Navigation System

In order to automatically navigate the vehicle to follow the leading vehicle, the system will determine the direction and the speed of the vehicle based on the area and centroid information obtained from the Vehicle Tracking system as discussed in the previous section. The navigation of the vehicle is divided into steering control and speed control subsystem which are implemented using PID control. The navigation algorithm is developed in SIMULINK with the model-based design approach and the completed model is converted into C code using Simulink Coder before it is programmed into the microcontroller.

A. Steering control

The steering control utilizes the centroid obtained from the image to track the object. To improve the performance, vision servo technique is used where the camera is mounted on a panning actuator to increase the camera field of view and accelerate the response of the tracking system.

The image tracking system is achieved by controlling the panning speed and direction of the camera. The panning motor is actuated based on the centroid value provided by the image processing software. If the centroid falls in the middle, the motor will stop. If the centroid value falls in the left side of the image frame, the camera will pan to the left. The panning speed is determined by the distance of the detected centroid from the middle point.

Fig. 5 shows the implementation of the steering angle control algorithm using discrete PID control technique. The control system obtains the centroid calculated by the Vehicle Tracking system and compares it with the set point value. The set point is fixed at 160 pixel which is the midpoint of the horizontal span of the image frame. The error is then fed into the PID controller to calculate the required motor speed. The applied output has to be integrated as the camera servo is receiving command in the form of motor position but on the other hand, the PID controller is giving the output of motor speed required. Similarly the output of the integrator is also fed into the steering servo after multiplying the value with a ratio. This ratio will determine the responsiveness of the steering reaction in following the camera heading.

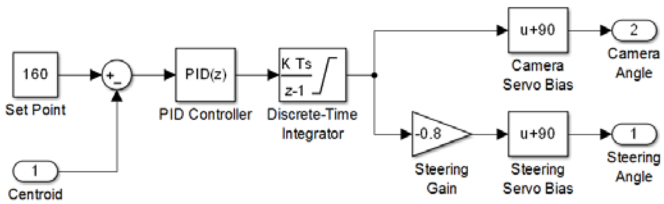

Fig. 5. SIMULINK model of the steering angle control algorithm

B. Speed control

The speed control system is designed to maintain the ideal speed for taking turns as well as following the leading vehicle. In this system, the speed of the vehicle is determined based on the steering angle as well as the distance of the vehicle to the leading vehicle. The distance of the vehicle can be deduced from the area of the detected unique pattern, where larger area means closer distance and smaller area means further distance.

Additionally, the speed of the rear wheels have to be controlled accordingly based on the turning radius. Fig. 6 illustrates the car taking a turn to the right. When steering angle θ is applied to the inner front wheel, the location of the turning pivot can be found by finding intersection of the lines which are perpendicular to the axles of the wheels. In this case, the left rear wheel should rotate faster than the right rear wheel by the ratio suggested by the distances *R*+*D* and *R*.

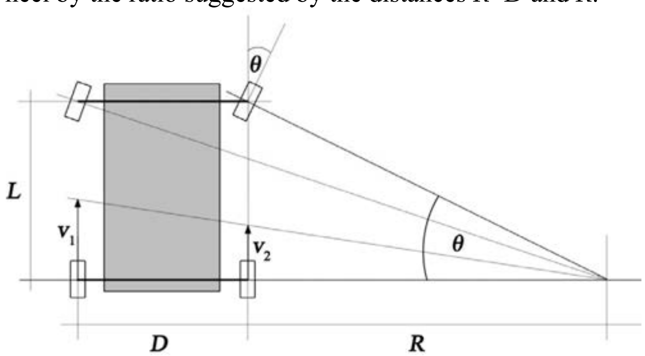

Fig. 6. Ackermann steering geometry when car is taking a right turn

The proper ratio for both inner and outer wheel speed can be estimated through turning angle as follows:

$$R = \frac{L}{\tan\theta} \quad (1)$$

$$\frac{v_2}{v_1} = \frac{R}{R+D} \quad (2)$$

Substituting (1) into (2) yields:

$$\frac{v_2}{v_1} = \frac{\frac{L}{\tan\theta}}{\frac{L}{\tan\theta}+D}$$

$$\frac{v_2}{v_1} = \frac{L}{\mathrm{L+D}\tan\theta} \quad (3)$$

Fig. 7 shows the implementation of the vehicle speed control algorithm. Two parameters are taken into account in order to decide the speed of the left and right wheel. Firstly, the area of the unique marker is calculated to gives the desired vehicle speed based on linear relationship. Large area value will result in slow speed and small area value will result in high speed. Secondly, the ratio of the left and right wheel speed is calculated based on the steering angle input following the relationship derived in (3). Lastly, the calculated desired wheel speeds are fed into the closed-loop system to ensure that the motors will run at their intended speed based on the measurement from the optical encoder. The motor speeds closed-loop control model is shown in Fig. 8. In addition, for safety measures, an ultrasonic range finder is installed at the front part of the vehicle to detect any obstacle that appears in front of the vehicle while running in autonomous mode.

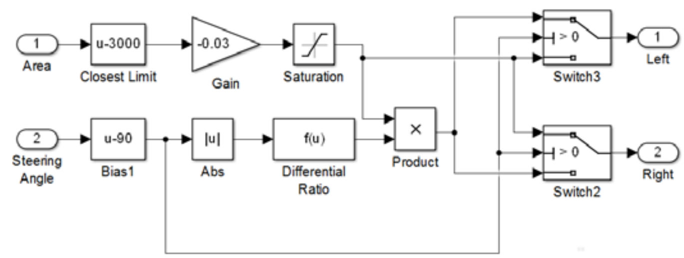

Fig. 7. SIMULINK model of the vehicle speed control algorithm

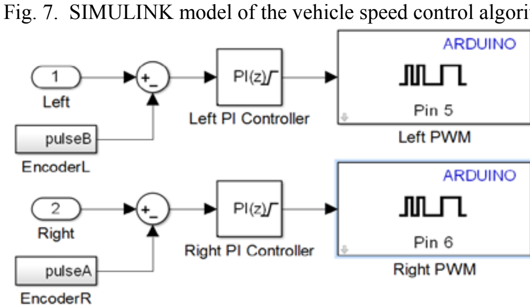

Fig. 8. Implementation of closed-loop control for rear wheels DC motor

C. Driver Interface

In order to operate the cruise control system, a Graphical User Interface (GUI) running on Google Android platform is developed. Bluetooth connection is used to form serial communication between the Android device and Arduino microcontroller. Fig. 9 shows the overall design of the cruise control user interface. The GUI provides control to activate and deactivate the cruise control system as well as providing the connection and leading vehicle detection status to the driver.

Fig. 9. Driver interface for Autonomous Cruise Control System

V. Experimental Results

The effectiveness of the proposed concept is verified by implementing the system on t he physical prototype. For the testing, a s eparate remote controlled vehicle carrying the unique pattern is used as the leading vehicle. The leading vehicle is maneuvered in a random manner which includes taking 90° turns, 180° turns, 'stop and go' and other maneuvers that are commonly executed during normal driving on the road.

Fig. 10 shows the sequential screenshots of the prototype cruise control vehicle following the leading vehicle while it is maneuvering. The screenshots are taken with the interval of two seconds per image.

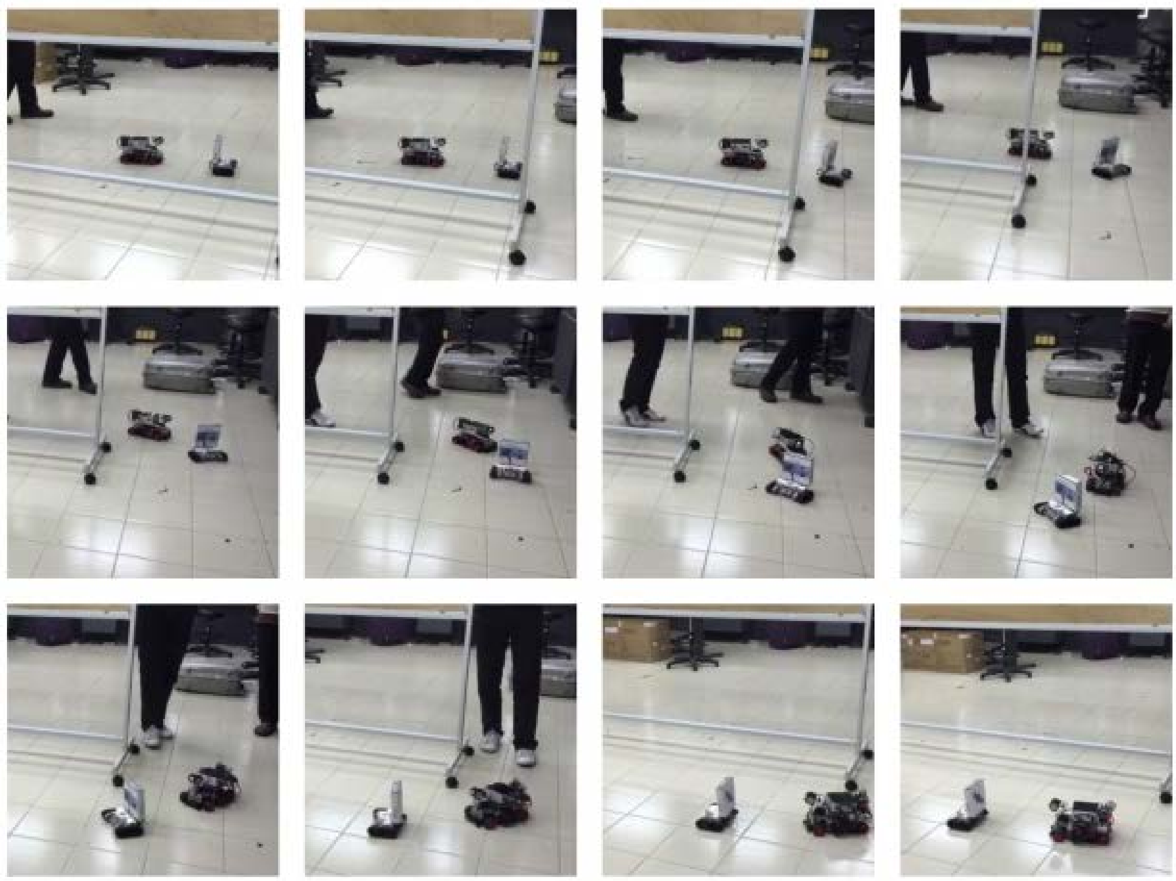

Fig. 10. Sequential snapshots of the autonomous cruise control system experiment taken at interval of 2 seconds

VI. Conclusion

The vehicle tracking and navigation control proposed in this paper are fully developed and implemented on the scaled down vehicle model for the proof-of-concept. The initial implementation and experimental result provide positive indication on the possibility of implementing such system in a convoy vehicle. The vehicle tracking system using vision servo technique is proven to be reliable and responsive in tracking the leading vehicle. The experimental result shows that the proposed concept is able to achieve accurate and continuous vehicle tracking as well as seamless navigation of the vehicle.

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