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Automatic Parking Vehicle System

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Automatic Parking Vehicle System

Abstract

Vehicle automation, autonomy and connectivity is a subject of mechatronics integrating many engineering disciplines including electrical, mechanical, control, and computer engineering (and technology). It is fundamentally changing the concept of automobile transportation and manufacturing. Therefore, developing new, technologically progressive curricula and hands-on lab as well as student project materials is desired to prepare for the future workforce needs of autonomous cars in the automotive industry. This "Automatic Vehicle Parking System" is a research and concept-proving project that will be prepared and extended to develop teaching materials for courses and students project on the subject of vehicle automation, autonomy and connectivity. In this project, an RC (remote-controlled) toy car is modified by integrating ultrasound sensors and Arduino with a high current shield to control the vehicle movements and the parking processes. Parking strategies and the corresponding algorithms are explored and programed through Arduino. During testing, the car is able to move to detect the imitated "road-side" environment, judge a space suitable for parking or not, and then drive to park automatically. A 3D printer is utilized to build the parts needed for modification. Student working processes of design, hardware modification, as well as the algorithm and coding procedures are observed and evaluated for systematic course material development.

Introduction

The introduction of vehicle automation, autonomy and connectivity is fundamentally changing the concept of automobile transportation. Although many automated, autonomous and connected vehicle technologies are still in development in lab, some of these technologies are already available and demonstrated by the prototypes such as Google and Toyota self-driving cars. Therefore, developing new, technologically progressive curricula and hands-on lab as well as student project materials is desired to prepare for the future workforce needs of autonomous cars in the automotive industry.

According to the U.S. Department of Transportation, automated and autonomous vehicles refer to the vehicles with safety-critical control functions that do not need direct driver inputs, including steering and braking[1]. They can also be connected to communicate with infrastructures or other vehicles wirelessly. In the United States, there are over 5 million crashes each year, killing over 30 thousand people and causing more than 2 million injuries[2, 3]. It has been reported that 94% of all traffic accidents involve human errors, which would be favorably influenced by collision warning systems that rely on vehicle automation and connection[4]. Toward this end, the understanding of vehicle automation, autonomy, and connectivity will have a broad impact on improving driver safety and reducing the number of casualties in road accidents even further. We look forward to building curricula with courses and projects providing the students hands-on experience of mechatronics on automotive sensors and control modules building, as well as system integration.

The U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) defines five levels for vehicle automation[1]:

Automation Level	**Definition**
No-Automation **(Level 0)**	The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.
Function-specific Automation **(Level 1)**	Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone.
Combined Function Automation **(Level 2)**	This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering.
Limited Self-Driving Automation **(Level 3)**	Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time.
Full Self-Driving Automation **(Level 4)**	The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles.

The curriculum of vehicle automation, autonomy and connectivity under development will mainly cover the functions Level 1 to 3, while targeting Level 4. For the Level 1 to Level 3 work, students will set up the modules of sensors, communication and control units, install and integrate these modules into a man drivable car and model vehicles, and develop on-road control strategies and algorithm for self-driving testing. Particularly, students will utilize 3-D printers to assist creating the parts for modifications. The automatic parking system in this paper is the first step of the curriculum development, covering Level 1 and partially Level 2 vehicle automation.

Many parking strategies and route planning have been studied. For instance, fuzzy control is applied to the automatic parking process[5]. Another work demonstrated that the feasible controls of motion (steering and backward/forward) approximately following a feasible parking path regulated by trigonometric functions are iteratively generated and applied during the automatic parking process. Between iterative motions, the real-time vehicle location data from the sensor feedbacks monitor the parking maneuver to correct the following motion and avoid collision[6]. There are other works emphasizing on optimizing the parking path to either the shortest time or route by studying the generic non-holonomic constraints of the vehicle routes with various mathematical functions, such as circular, trigonometric, and polynomial functions[7, 8]. These paths have non-constant curvatures and usually require lengthy periods of orbit planning and continuous wheel steering for path tracking, resulting shortening tire lifetime. In addition, Global Positioning System (GPS) is introduced to assist the automatic parking control[9]. To simplify the control process, a straight forward algorithm with fixed turning curvature was proposed[10] and is partially adopted in the setup of this project.

In this paper, a modified RC toy car performing automatic parking for course and student project development is demonstrated. The project is an application of mechatronics that integrate sensors, actuators (the DC and servo motor of the toy car) and the control unit (Arduino). An undergraduate senior level student (graduated now) is assigned to work part time (10 hours a week) on the hardware modification, algorithm coding, and testing. The working procedure and the time frame are recorded and evaluated for the development of curriculum. The built platform (toy car) will be also used to develop the teaching material of other functions of vehicle automation in the future.

Current Automatic Parking Systems in the Market

Many automobile manufacturers provide optional automatic parking assistant systems including Toyota, Ford, BMW, Audi, Mercedes-Benz, and Chrysler. However these systems need human monitoring and accelerating/braking inputs and are not completely automatic. Bosch[11] is developing a fully automated parking system by calculating a parking maneuver and monitoring the surroundings, and it allows the driver to leave the car and activate an autonomous parking from a smartphone. All these systems have similar parking strategies and maneuvers with just different levels of automation. Take Toyota's Intelligent Parking Assist[12] for parallel parking as example, the vehicle moves forward by a certain distance (around 5 meters) after detecting a suitable parking space, then the system assists steering the wheel monitored by sensors while the driver controls the accelerating and braking, as shown in Figure 1. The system demonstrated in this paper is fully automatic similar to the one of Bosch with a parking space finding function. After the parking procedure is started on a street, the vehicle moves slowly keeping an appropriate distance from the road side parked cars. Once a suitable space has been detected, the car moves forward with a certain distance and then drives backward to park the car automatically. The whole procedure is monitored by ultrasound sensors.

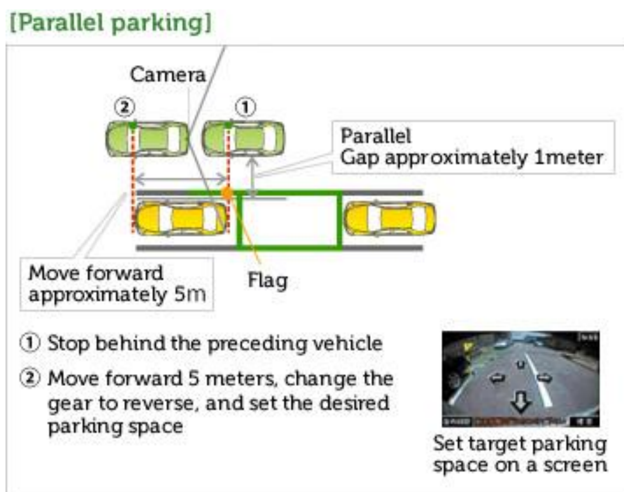

Figure 1. Toyota's Intelligent Parking Assist for parallel parking

Project Description

The project is focused on achieving a single task (automatic parking) by integration of sensors and actuators controlled by microcontroller and strategy planning/coding, therefore the vehicle platform is not built from the parts but from modifying a RC toy car instead for saving the time. There are generally three kinds of parking patterns: parallel, front/back-in perpendicular, and with an angle (usually 45 degrees), and this project is just focused on the parallel parking. The modified toy car is expected to do the following tasks in a complete automatic parking process:

1. Drive along an imitated road-side environment and detect the distance from the car to the road-side obstacles such as parked cars or just curb on the right hand side.

2. Once the length of a parking space larger than the length of the car plus a buffering distance is detected, the car will stop automatically.
3. Perform a smooth and efficient parking behavior according to the relative positions of the car and the parking space.

The automatic car parking system has the following major components:

1. The RC toy car. The toy car consists of a 7V DC motor in the back and a servo motor in the front. The length of this car is 35 cm and the width is 30 cm.
2. Arduino Mega Controller. Arduino Mega replaces the toy car's original control system to control the car's driving DC motor and turning servo motor. The sensors are connected to the Arduino board and integrated in the system, therefore the parking strategy and algorithm can be programed and uploaded to Arduino.
3. HC-SR04 ultrasonic sensors, shown in Figure 2. Currently four ultrasonic sensors are mounted on the car. Two sensors are setup on the right side to measure the distance between the car and the road-side objects. The other two sensors are mounted on the front and the back bumpers of the car in order to prevent collisions during the parking process.
4. L298N H-bridge high current motor drive shield. Arduino's maximum DC current from VCC and GND pins is merely 200 mA. This shield provides up to 2 A current to drive the car's motors. See Figure 2.
5. 3D printed frame. A 3D printed frame is used to support the ultrasonic sensors. It keeps the sensors stable in order to obtain the most accurate measurement data. The frame is modulus with many mounting spots for future research tasks with additional sensors and devices.

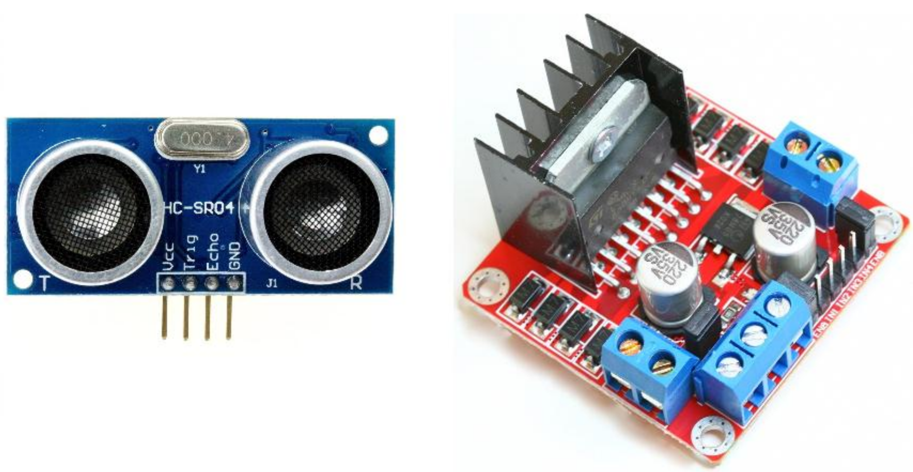

Figure 2. HC-SR04 (left) and L298N (right).

Parking Strategy Description

1. Detecting a proper size parking space

   After the switch is turned on, the car starts moving in a constant speed along the “road” with a fixed distance from the other “parked cars”. Once the car passes an empty space, the two side sensors will judge if the “depth” of the space larger than the car width for parking. If the parking space is not wide enough, the car will continue moving; while even if the space width is large enough, the car will still keep on moving to measure the space length. The ultrasonic sensors collect real-time distance measurements and record the moments of sudden distance changes. The information will be sent to the Arduino micro controller to calculate the length of the empty parking space. If the parking space is longer than the length of car by a distance l_b, for instance, 10 cm in our example, the car will automatically stop, usually overshoot by a distance from the front end of the space. Otherwise, the car keeps running until finding the next available parking spot.

   Once the car finds a suitable parking space and stops, it either starts the parking process or waits until the “driver” pushing a switch to start the parking process.

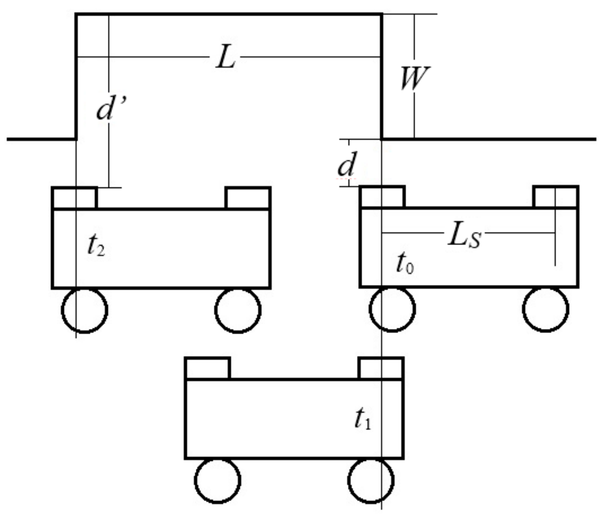

Figure 3. The moments the car pass the parking space edges where the sensors detect significant distance differences.

Figure 3 demonstrates the picture of the setup and strategy of this space finding process. Two ultrasonic detectors are mounted on the right hand side of the car by a distance L_S, one is located around the front wheel and the other is near the rear wheel. Since no speedometer is installed in this toy car, the distance between the front and rear sensors must be utilized to decide the parking space length. The ultrasonic sensors can collect real-time distance measurements from the car to the road-side objects. Once the sensors detect significant distance changes, the corresponding time is recorded and sent to the Arduino microcontroller to calculate the empty parking spot length L, which is given by

$$L = \frac{t_2 - t_0}{t_1 - t_0} L_S, \tag{1}$$

where L_S is the distance between the front sensor and the rear sensor, t_0 is the time that the front sensor detects the first significant distance change, t_1 is the time that the rear sensor detects its first significant distance change, and t_2 is the time that the front sensor detects its second significant distance change. Meanwhile, the average speed of the car v can be obtained by

$$v = \frac{L}{t_2 - t_0} = \frac{L_S}{t_1 - t_0}. \tag{2}$$

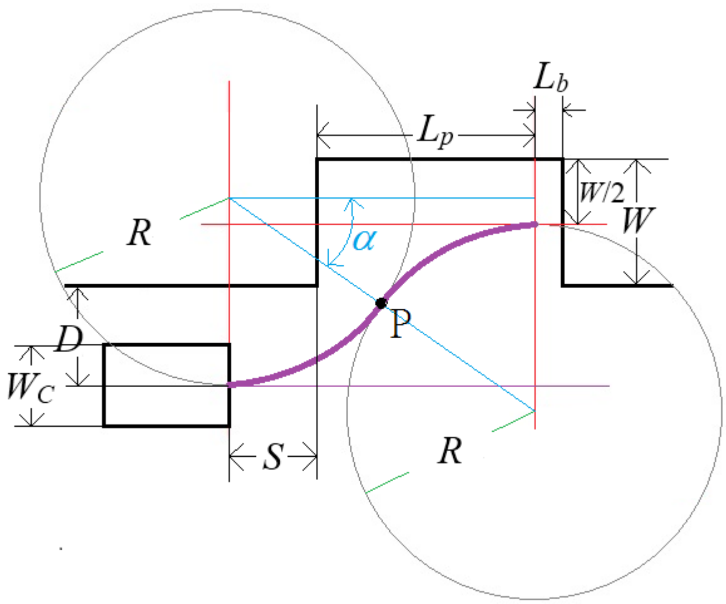

Figure 4. The parking curve and parameters.

2. Driving in the parking spot

One of the simple parking paths is along the curve composed of arcs from two circles with radius of the minimum circle the car can turn[10]. Ultrasound sensor data feedbacks are used for more accurate controlling in this parking process. The parking curve and parameters are demonstrated in Figure 4. The purple curve is the trajectory of the rear center of the car, and L_b is the rear buffering space. The angle α can be expressed as[10]

$$\alpha = \sin^{-1}\left(\frac{2R - D - W/2}{2R}\right), \tag{3}$$

$$D = d + \frac{W_C}{2}. \tag{4}$$

In addition,

$$L_p = L - L_b\ , \tag{5}$$

$$(S + L_p) = 2R\cos\alpha. \tag{6}$$

At point P, the front wheels have to turn to the other side. One way to judge if the car has reached point P is making the car moves the distance of the arc $R\beta$ where $\beta = \pi/2\text{-}\alpha$ with the assumption that it performs a constant backup speed v_b. A more accurate judgement to see if the car reaches point P is using the rear sensor when it reads the distance d_r after the minimum value when passing the corner, as shown in Figure 4. In such case,

$$d_r = R - \frac{W_C}{2} - \frac{S}{\cos\alpha}\,. \tag{7}$$

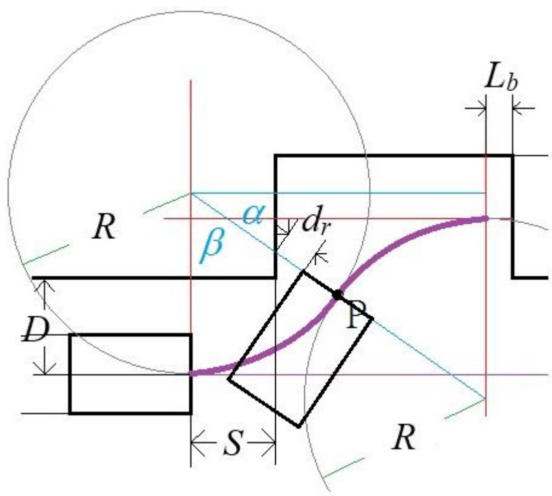

Figure 5. At the turning point P the rear sensor detects the distance d_r.

The possibility exists that the front edge of the vehicle crashing the front external corner of the parking space. To avoid this collision, the length of the parking space must be large enough. Figure 6 shows that in the limit condition, the tips of the parking space corner and the car front corner touch. Then the minimum parking space length L_{min} (or L_{pmin}) has to satisfy the equation

$$L_{pmin} = L_{min} - L_b = L_C\cos\theta + \left(R + \frac{W_C}{2}\right)\sin\theta\ , \tag{8}$$

where θ satisfies the condition

$$W - L_C\sin\theta = R + \frac{W}{2} - \left(R + \frac{W_C}{2}\right)\cos\theta\ . \tag{9}$$

Therefore, L must be larger than L_{min} to avoid collision, which is the criteria of parking space detecting.

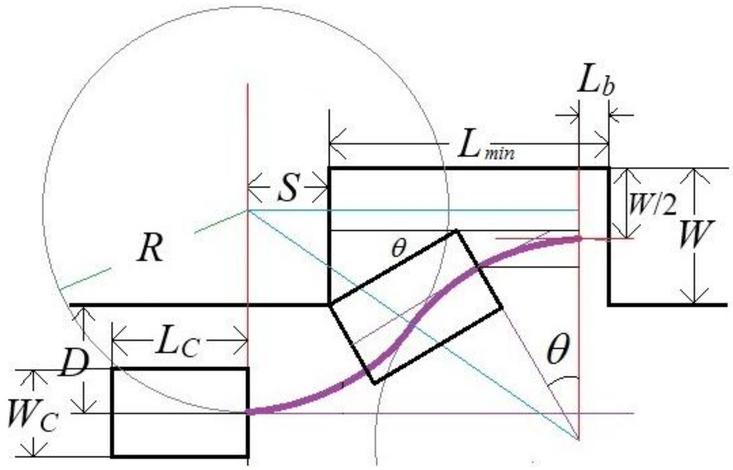

Figure 6. The limit condition that the parking space length is minimum.

This parking strategy is simple and straight forward with the price of large parking space required. Students in the course or project later will be encouraged to study and test other parking strategies.

Parameters	Physical values
Car length L_C	35cm
Car Width W_C	30cm
Car turning radius R	100cm
Parking space width W	50cm
Parking space length L	110cm (set)

Table 1. The dimensions of the car and the parking space

Experiment Results

The picture of the modified RC car used in this project in shown in Figure 7, and the dimensions of the car and the parking space are listed in Table 1. During the test, the average distance between the car and the road-side obstacles d was d = 15cm while the buffering distance was L_b = 10 cm. From the above equations one can obtain D = 30 cm and $\alpha = 46.5^o$. The minimum parking space length can be obtained from the solution of θ, which is L_{min} = 104 cm. L_{pmin} then has to be 94cm. From the result that S+ L_p = 138 cm, and choosing L_p =100 cm > 94 cm, one can obtain S = 38 cm. The rear sensor should read a distance around d_r = 30 cm at the turning point P. To avoid accident, the parking space length is set as L = 110 cm > 104 cm and is then used in the criteria for parking space finding in Eq. (1).

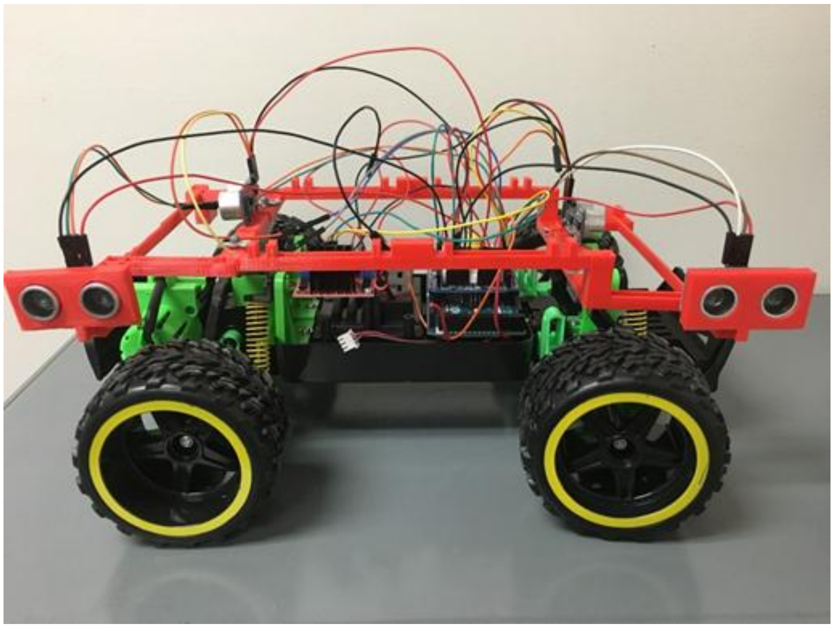

Figure 7. The picture of the modified RC toy car.

The toy car does stops after finding a proper parking space and start backing up to park. However the parked positions are not at the theoretical location and are also not identical after several tests. One of the reasons could be that the car cannot drive in an exactly constant low speed because of the torque limit of the DC motor. It also does not have a braking system that makes it difficult to stop at a position accurately. In addition, the distance detected by the ultrasonic sensor has error. Some fine tunings have to be performed and the work is still under process.

Conclusion

The major object of this project is to evaluate the work load and time frame of implementation a similar or equivalent project on the topic of autonomous vehicles in student senior project and final project of instrumentation/mechatronics courses. It took seven months for one student to modify the vehicle and achieve the functions of automatic parking mentioned above, including several weeks planning and discussion in the beginning. The result shows that it is a suitable project with proper work load to implement in a course or a student project on mechatronics and vehicle automation in a single semester. This course/project is designed for senior students who have taken courses such as Instrumentation, Electrical Machines and Power Systems, Micro and Programmable Controllers, and Control Systems as prerequisites. The student outcomes, in terms of the capabilities defined by ABET, include

General engineering technology (Bachelor):

a. an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly- defined engineering technology activities;

b. an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;

d. an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives;

e. an ability to function effectively as a member or leader on a technical team;

f. an ability to identify, analyze, and solve broadly-defined engineering technology problems;

Electrical Engineering Technology:

a. the application of circuit analysis and design, computer programming, associated software, analog and digital electronics, and microcomputers, and engineering standards to the building, testing, operation, and maintenance of electrical/electronic(s) systems;

c. the ability to analyze, design, and implement control systems, instrumentation systems, communications systems, computer systems, or power systems;

d. the ability to apply project management techniques to electrical/electronic(s) systems.

In addition, students will benefit from hands-on practice and strategy analysis/coding, and most important of all, prepare for the potential career in the future automotive industry.

Acknowledgements

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