A Proposed Controller for an Autonomous Vehicles Embedded System

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Abstract:- Many research have observable development in the automated vehicle driving field during the last few decades. This research proposed a simple optimum Intelligent PID (SO PID) controller to simplify the automated vehicle motion control. Control of an autonomous vehicle's steering routines plays an essential key role. Several steering control procedures are proposed that improve automated vehicle performance. The design of secure embedded control systems must overcome the difficulties associated with designing both computing and control systems. Also, this research introduces a model of the autonomous car prototype controlled via an Arduino microcontroller board and the GPS Module to receive the car coordinates. The car moves safely, and autonomously consequently avoiding the risk of human faults. Several algorithms such as angle and distance calculations to the waypoint and obstacle detection are combined to control the car movement.

Key-Words:- Automated Vehicle, Simplified Optimum PID, Angle calculation, Distance calculation, Optimum PID, Simplified PID.

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1 Introduction

Excluding human interaction, an autonomous vehicle can be created that can distinguish its surroundings. An autonomous vehicle is sometimes called a self-driving vehicle, or driverless vehicle. Various sensors, algorithms, and motors are used to control the vehicle's movement and move from one place to another without a human driver. The Internet is used to supply sensors with data on the surrounding environment and the vehicle's coordinates, speed, direction, and obstacles that the vehicle may encounter. Autonomous vehicles have been created to increase the safety of transportation users. These vehicles can sense their surrounding environment and make decisions without external aid to produce an optimal path to reach a destination. Even though the concept seems futuristic and, if successfully implemented, will address many existing transportation-related problems, caution must be exercised before putting it into practice, [1].

The autonomous vehicle is defined as an autonomous robot that combines navigation and positioning using multiple sensors, as well as a control algorithm and intelligent decision-making. The "Intelligent Pioneer" which indicates the autonomous vehicle's control system design is examined, as well as path tracking and motion stability for successful navigation in uncharted territory, [2]. The path-tracking is translated as a state space with a 2D of freedom dynamic motion model. Traditional controllers struggle to ensure performance and stability for regulating the path error besides a large variety of parameter variations and external disturbances. So, a recently created adaptive PID controller will be employed. The planned system is primarily intended to prevent accidents and warn drivers about the recommended speed for safe driving. The creation of an intelligent vehicle that travels at the safest speed in dangerous areas and continuously monitors a variety of vehicle parameters before sending the information to the base unit is addressed in, [3]. A few systems perform the counting and speed measurement using an image processing code as a moving object detector such as a car. These systems include vehicle counting systems and video processing-based vehicle speed measurement. The Intelligent Transportation System is still in its early stages of development with this system. Blob identification and background subtraction using the Gaussian Mixture Model (GMM) algorithm are the techniques used in this system, [4], [5]. Numerous studies, [6], [7], [8], [9], [10], [11], [12], [13] presented vehicle tracking systems, which use a GPS module and a GSM module to locate a vehicle and provide a variety of control capabilities.

A robust controller design using a parameter space approach to control the autonomous vehicle is studied. This approach takes into consideration variables vehicle characteristics variables such as vehicle mass, vehicle speed, and road-tire friction coefficient. The created multi-objective robust PID controller simultaneously satisfies the constraints on D-stability, phase margin, and mixed sensitivity. The model predictive control-based autonomous vehicle path is Investigated, [14], [15]. For autonomous vehicle route following, numerous different steering control techniques have been proposed by researchers. However, a variety of real-world issues, including model uncertainty, outside disturbances, and steering system time delays, might impair the path following the performance. In this dissertation, a methodical way to resolve these issues is suggested. First, the parameter space method-based robust PID controller is investigated. It takes into account differences in the vehicle's mass, speed, and road-tire friction coefficient. Two free PID parameters are chosen as free design parameters, and an uncertainty box is constructed to depict parameter changes. The predicted vehicle motion in the future has been anticipated using communication with the internal and external data gathered by the onboard sensors. The danger of a collision and the automatic drive mode are calculated with precisely predicted movements of a distant vehicle, [16], [17], [18].

Many researchers pay attention to modifying the PID controller to improve the controller response. A few researchers try to simplify the PID designing techniques, [19], [20], [21], [22].

This article presents a proposed autonomous vehicle PID controller called Simplified Optimum PID (SO PID) controller, this vehicle can sense its environment and make decisions without any external aid to produce an optimal route to reach a destination. A model of the autonomous car prototype controlled by the Arduino microcontroller board and the GPS Module to receive the car coordinates.

2 Embedded System Design and implementation

The embedded system (as illustrated in Fig.1) is quite a complex expression. Simply it is a gathering of both software hardware and to perform as a component of a larger system. The hardware of the embedded systems is customized to implement the required application as Computers on chips are embedded to control electronics and achieve the product's functionality. Embedded systems become an incentive for change in computing processes, data communications, telecommunications, industrial control, and entertainment area. Modern innovative applications in this area such as home networking and car information will roll out in the near future.

The microcontroller-based control system is created and implemented to execute a function or multiple functions and is not provide the capability to be programmed by the user. Generally, the users do not allow replacing a different code on the embedded system devices. The embedded systems are constructed to perform a specific function accomplished with several alternatives and various choices.

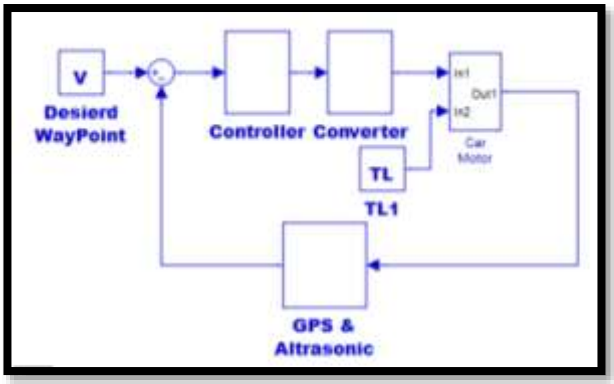


Fig. 1: Block Diagram of the System.

Due to the implanted intelligence code, a vehicle can operate without human involvement. The Global Positional System (GPS), which uses satellites to transmit positioning information, proves to be an incredibly useful tool for this purpose. Wide area DGPS offers a reliable technology that deals with satellite clock errors and selective availability errors with ease to maintain higher accuracy.

3 System Modeling

The dc motor armature control model used for controlling the car position is illustrated in Fig.2. Many models can be used to represent the Dc motor, [23]. Finally, the motor model can be simplified as in equation (1).

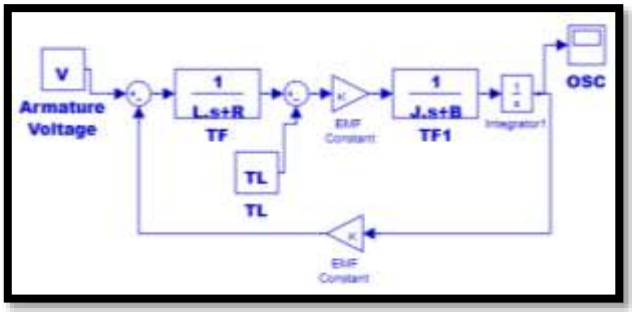


Fig. 2: DC Motor armature control Model

$$\frac{\theta}{v} = \frac{k}{S((R+LS)(B+JS)+k^2)} \quad (1)$$

3.1 A Proposed Simplified Optimum (SO) Controller

The simple Optimum SO PID design formula proposed is based on the process transfer function to determine the optimum PID controller coefficient. Figure 3 illustrates a general 2nd order system with a controller deduced based on the optimum response depending on the process transfer function as the following equations, [24], [25].

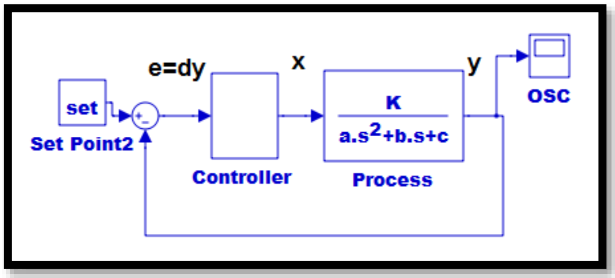


Fig. 3: PID controller in the closed-loop system

The process transfer function

$$\frac{y}{x} = \frac{k}{a.s^2+b.s+c} \quad (2)$$

$$y(a.s^2 + b.s + c) = k.x \quad (3)$$

$$a.\frac{d^2y}{dt^2} + b.\frac{dy}{dx} + c.y = k.x \quad (4)$$

Substituting

$$\frac{dy}{dt} = \frac{\Delta y}{T} \quad (5)$$

$$a\frac{dy}{dx}\left(\frac{\Delta y}{T}\right) + b\frac{\Delta y}{T} + c\int \Delta y\, dt = kx \quad (6)$$

$$a\frac{dy}{dt}\left(\frac{e}{T}\right) + b\frac{e}{T} + c\int e\, dt = kx \quad (7)$$

$$x = \frac{b}{kT}e + \frac{c}{kt}\int e\, dt + \frac{a}{kT}\frac{dy}{dt}(e) \quad (8)$$

Equaling coefficient of equation (8) with its corresponding equation (9).

$$x = K_p e + K_i \int e\, dt + K_d \frac{dy}{dx}(e) \quad (9)$$

The controller constant

$$K_p = \frac{b}{kT} \quad (10)$$

$$K_i = \frac{c}{kT} \quad (11)$$

$$K_d = \frac{a}{kT} \quad (12)$$

Where T is chosen as a control program sampling time or multiple of the control program sampling time. Applying the above PID Controller design technique with the following system parameters illustrated in Table (1) results in the following controller constants. The parameters for the electrical motor were taken from the datasheet. For a system model of a higher order than second order, use only the second order terms. The dc motor position control can be simplified as illustrated in the following block diagram (as shown in Fig.4. By substituting from Table (1) into equation (1) results from the following equation. Also, Fig. 5 shows the control system using a traditional fuzzy controller.

$$\frac{\theta}{v} = \frac{0.0235}{S(0.001(2.06+0.000238.S)(1.06+10.6.S)+0.00055)} \quad (13)$$

$$\frac{\theta}{v} = \frac{23.5}{S(\ 10.600238.S^2+21.83625228.S+2.7336)} \quad (14)$$

Table 1. The System Parameters

Parameter	Values
Armature Resistance (Ω)	2.06
Armature Inductance (mH)	0.238
EMF Constant (mNm/rad/sec)	23.5
Car and motor Inertia (m Nm/A)	10.6
Car and motor friction Coefficient (mNm/rad/sec)	1.06
Sampling Time	0.0001

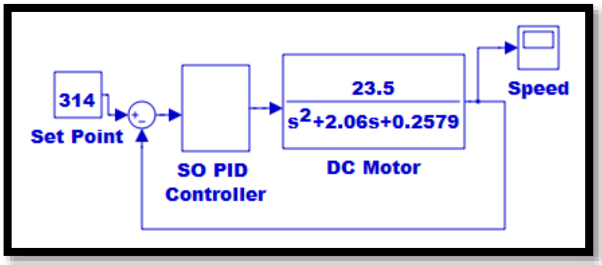


Fig. 4: Proposed SO PID controller in the Speed loop

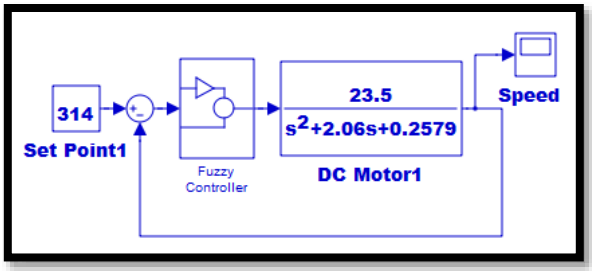


Fig. 5: Proposed Fuzzy controller in Speed loop

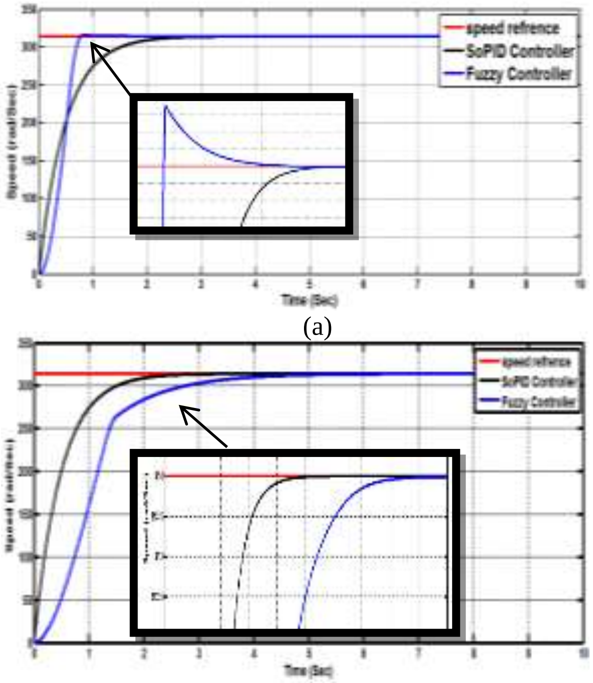
The response can be accelerated by using T equal half sampling time.

$$K_p = \frac{2.06}{23.5 * 0.0001 * 0.5} = 1753$$

$$K_i = \frac{0.2579}{23.5} = 0.01097$$

$$K_d = \frac{1}{23.5 * 0.0001 * 0.5} = 851$$

Fig. 6 shows the response of the proposed SO PID controller against a traditional fuzzy controller in individual tow cases. Figure 6 (a) is utilizing a fast fuzzy controller while Fig. 6 (b) uses a slow fuzzy controller. The comparison between the SO PID and fuzzy controller leads to using the SO PID controller to avoid overshoot and slow response



(a)

(b)

Fig. 6: The system response under SO PID and fast and slow Fuzzy controller

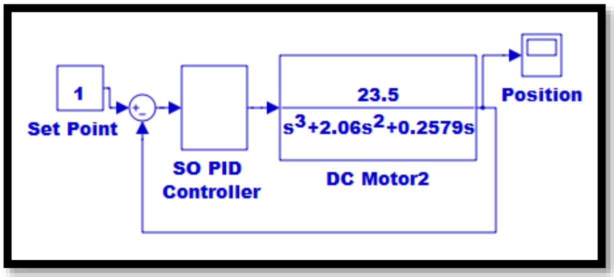


Fig-7: Proposed SO PID position Controller Motor

The position loop illustrated in Fig. 7 is used to design SO PID controller based on the 2nd order transfer function and neglecting the higher order Laplace operator which leads to applying a PD Controller for the resultant transfer function of equation (15)

$$G = \frac{23.5}{0.0001*(S^3+2.06.S^2+0.2579S)} \quad (15)$$

In the case of 2nd order system, the coefficient of the S^2 should be normalized, and apply the previous method to the 2nd order equation

$$K_p = \frac{0.2579}{23.5 * 0.0001 * 0.5} = 219.5$$

$$K_i = 0$$

$$K_d = \frac{2.06}{23.5 * 0.0001 * 0.5} = 1753$$

The performance of controlled output is shown in Fig.8.

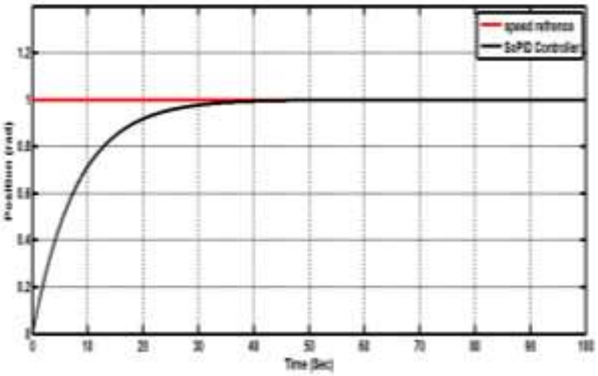


Fig. 8: PID controller performance

The designed position and speed controllers are inserted in the speed and position loops. The inner loop controller is modified with a slow execution time (at least 10 sampling time). Figure 9 shows the SimuLink block diagram while Fig. 12 illustrates the system speed and position response.

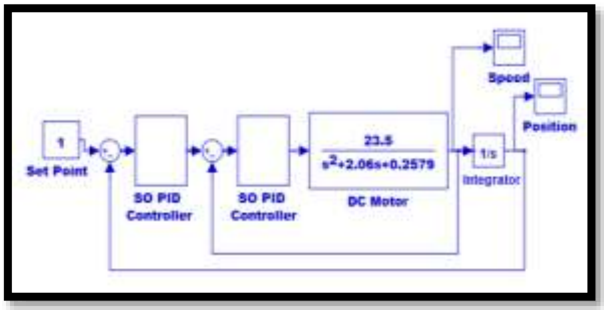


Fig. 9: Position and speed loop of the car motor

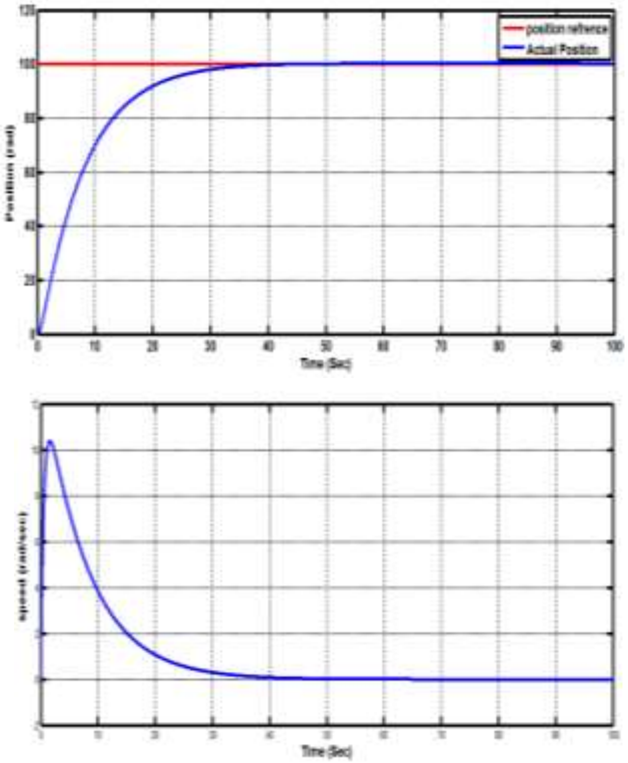


Fig. 10: The motor response under SO PID

3.2 Determines Position utilizes GPS Model

The GPS utilizes a trilateration analytical technique to perform the positioning algorithm. The position is determined using the measured distance from satellites and user position as illustrated in Fig.11 through four satellites used to locate the position of the receiver on the earth's surface. Three of these four satellites are used to track the position while the 4th satellite confirms the target position for each of those space vehicles. GPS is composed of satellites, control stations, monitor stations, and receivers. The GPS receiver collects the information from the satellites and uses the triangulation technique to determine the user position, [26], [27], [28].

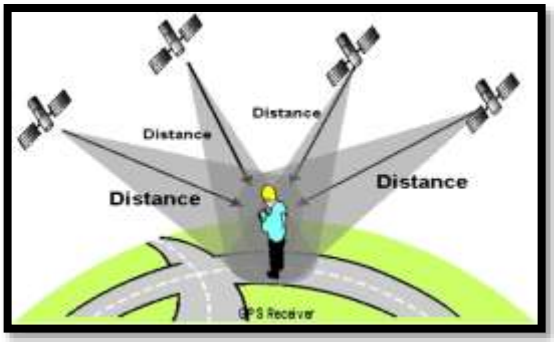


Fig. 11: Positioning of the User.

A GPS receiver must be locked on to the signal of at least three satellites in order to calculate a 2D position (latitude and longitude) and track movement. When four or more satellites are visible, the receiver can determine your three-dimensional position (latitude, longitude, and altitude). A GPS receiver will generally track 8 or more satellites, but this depends on the time of day and where you are on the planet.

GPS satellites orbit the Earth every twelve hours in a precise orbit. Each satellite transmits a unique signal and orbital parameters that allow GPS to calculate the precise location of the satellite via the decoding process. GPS receiver devices use this data and trilateration technique to allocate a user position. Essentially, the GPS receiver measures the distance to each satellite using the period between the transmitted signal and receiving it. The receiver can calculate a user position based on the distance measurements from a few more satellites and display it.

There are numerous error sources that can degrade the accuracy of positions computed by a GPS receiver. The time it takes for GPS satellite signals to travel between each other can be affected by atmospheric conditions. A GPS signal is refracted as it travels through the ionosphere and troposphere, resulting in differences in the speed of the signal and the speed of a GPS signal in space. Another source of error is noise; additionally, signal distortion causes electrical interference or errors in the GPS receiver itself. The information about satellite orbits will also cause errors in determining position because the satellites are not where the GPS receiver "thought" they were based on the information it received when determining position. Small variations in the satellite's atomic clocks cause large position errors. When signals transmitted from satellites bounce off a reflective surface before reaching the receiver antenna, the receiver receives the signal in a straight-line pathway, similar to a delayed path.

3.3 Control Algorithm

The challenge of determining a car's position in relation to its surroundings via sensor readings is known as position localization in Fig. 12. Successful autonomous robot systems must be able to localize their positions, which is referred to as the most fundamental difficulty of equipping a mobile robot with autonomous capabilities. The robot needs to keep a precise understanding of its position and orientation in order to perform autonomous navigation. The ability of a robot to precisely determine its position and orientation is necessary for the completion of all other navigational tasks. For position localization, this system makes use of GPS and inertial-specific sensors. By accurately timing the signals supplied by GPS satellites located far above the Earth, a GPS receiver determines its location. Every satellite sends out messages on a regular basis that include the time the message was sent and the satellite's position at that moment. The receiver uses the information message it has received to calculate the speed of light to calculate the distance to each satellite and the duration of each communication. A sphere is defined by each of these distances and the positions of the satellites. The coordinates of the receiver on the surface of each of these spheres are utilized to determine the receiver's location and position using the navigation equations.

When the orientation of the car on an inclined plane with the waypoint the car moving to it will start to calculate the angle needed for the car to rotate with the following equation:

$$\Psi n = \tan^{-1}\frac{(latcar - latwp1)}{(longcar - longwp1)} \tag{16}$$

Then it will calculate the distance required to move the car by the following equation:

$$d = \sqrt{(longcar - longwp1)^{2} + (latcar - latwp1)^{2}} \tag{17}$$

Where;

Ψn: angle needed for the car to rotate
d: distance required for the car to move
$longcar$: longitude of the car
$longwp1$: longitude of the waypoint
$latcar$: latitude of the car
$latwp1$: latitude of the waypoint

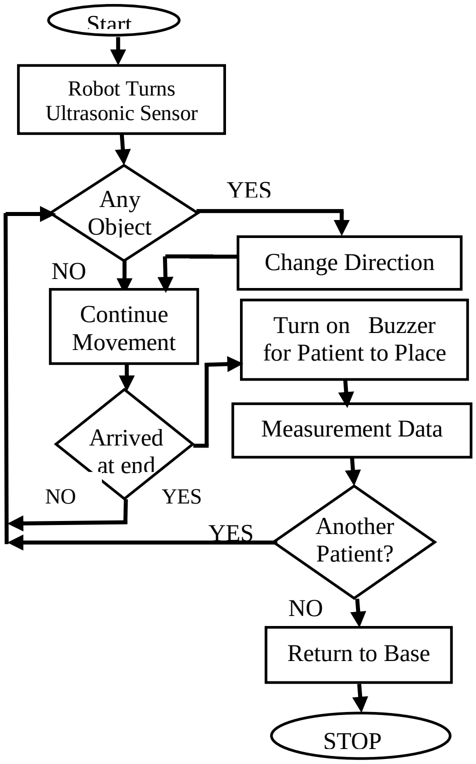


Fig. 12: Flow Chart of Control System.

4 Experimental Work

The car illustrated in Fig.13 started moving from the location that it is at where the GPS reads the coordinates of this location first thing in the code. Then, it takes the input which is the desired waypoint, and works out the equations (3) and (4), to know the distance between the current position and the intended waypoint, [29], [30], [31]. This area was chosen for a lot of short buildings area rather than the tall buildings that would affect the receiving information of the GPS.

The main problem that we faced is that the servo needed so much power to work properly without glitches and while carrying the weight of the car. Many types of batteries were used, but they did not work as they drew a very high current and all the batteries used supplied a low current. A 1.5 kg battery that uses 7.5 V and generates 3A current which is more than enough to power the servo which that car is heavy and works very efficiently without any glitches.

Ultrasonic sensors enable the car to virtual imagination and recognize obstacles and measure the separation distance. The ultrasonic transducer generates waves continuously from the transmitter part of the sensor head. The information about the obstacle is passed to the microcontroller, which controls the car's movement direction.

Fig. 13: Implementation of the System Components.

As the code is executed and the car starts to move forward, the GPS will continue giving out readings of the new current location coordinates as it is changing results from the movement of the car. All the movement and coordinates are illustrated on the PC monitor through Bluetooth connected to the microcontroller. It is decided that the motor should stop immediately, and all the components would shut down. This means that there is no error that the car could move by mistake or anything. Only the serial monitor will notify the message that the vehicle has reached the desired waypoint.

5 Work Results

The presence of buildings as an obstacle to receiving signals from satellites leads to weak signals received, which causes instability in the readings of longitude and latitude antenna numbers, as it was not perfectly connected due to the weak signal of the antenna with satellites, [32], [33]. Therefore, GPS readings are inaccurate and change every second when working around tall buildings, so it is recommended that the work area is at a sufficient distance from the buildings.

From a set of points to another point. Fig.12 shows a comparative plot of actual and measured distances. The measured path is represented by a red path while the blue path is the actual one. The figure shows the accuracy of the controller for adjusting the path of the car is more than 90%.

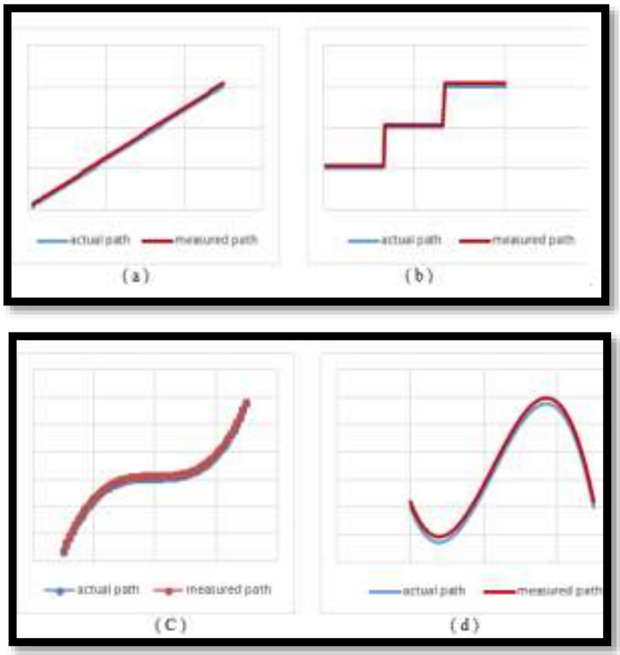


Fig. 14: Comparison between reference path and actual path

Fig. 14 shows four assumption paths of the car movement, where the actual path was compared with the reference values in the car path experimental model. The speed loop and position loop are performed utilizing the SO PID designed in simulation work. It is noticed in all the assumed paths that there is a small amount of error because of using the proposed control model. In all paths, the path in the practical model is higher than the actual path Due to the delayed response time of the controller. In the first figure (a), a path was assumed in the form of a straight line, while in the other paths, a zigzag path was considered either in the form of a straight line as in the second figure (b) or in the form of a curve as in the two paths (c), (d). An increase in the error is observed due to the curvature of the path by a small amount, which indicates the quick response of the controller in adjusting the car path.

6 Conclusion

A proposed simple optimum PID (SO PID) Controller is derived and applied to the autonomous car system. This proposed PID Controller calculates the controller constant by inspection through a simplified technique. The proposed controller performance actually has an ideal response in a transient (peak overshoot and rise time) and steady state. The human error problem in driving a car to specified position coordinates is almost eliminated by developing a car that can move autonomously from any location position to any given location coordinates. Also, it can avoid obstacles that come in its path without colliding with them. This research was successfully implemented and developed the outdoor tracking location unit using GPS. As a result, location latitude, location longitude, and the short distance between two different points on the earth are measured with an average accuracy of more than 90% of the actual value.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

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