An Overview of Development GPS Navigation for Autonomous Car

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***Abstract*—An autonomous car navigation system based on Global Positioning System (GPS) is a new and promising technology, which uses real time geographical data received from several GPS satellites to calculate longitude, latitude, speed and course to help navigate a car. The goal of the project is to make an auto-navigational car model that can route through known or pre-programmed co-ordinates autonomously without any control by human. It is designed to demonstrate the feasibility of using a low-cost strap-down inertial measurement unit (IMU) to navigate between intermittent GPS fixes. The present hardware consists of a GPS receiver, IMU, compass and a data processing computer. This research paper demonstrates a prototype development of autonomous car to enable the aerial vehicle accomplish the required autonomy and maintain satisfactory automated driving operation. Design objectives include simplicity, robustness, versatility and improved operational utility. The driverless car features an advanced, highly autonomous drive control system with an anti-drift from its course algorithms. The discovery of interacting hardware and software had led to breakthrough improvements in the efficiency of maintaining planned route on the track.**

I. Introduction

Autonomous navigation broadly refers to any technique, approach or method, which can be utilised to safely navigate a vehicle (terrestrial, marine, airborne or deep space), on its own in a static or dynamic environment without any intervention by a human controller. Autonomous navigation is a way to help achieve better route planning, path prediction, smoother manoeuvrability in dynamic environments and thereby achieving optimised fuel efficiency and enhanced human comfort [1]. The approach of GPS based autonomous navigation utilises a GPS receiver that receives signals from a constellation of GPS satellites. The receiver then computes its position on the earth surface and a navigation algorithm will computes other parameters such as direction and distances in order to aid autonomous navigation.

Generally, the problem of positioning (localisation) the car consists of answering the question *Where am I?* from the robots perspective. If a robot does not know where it is, it becomes difficult for it to determine what to do next. Dead reckoning is a type of localisation that determines new position based on previous position by computing or directly obtaining the distance and direction moved. A compass can be easily used to indicate direction while distance is usually determined indirectly by measurement of speed and time, but it may also be measured directly. A simple example of this type of navigation is the use of odometers with wheel encoders [2][3]. This technique allows for direction and velocity to be measured based on vehicle dimension and knowledge of the time between encoder pulses. Therefore if rotational speed of a shaft can be obtained from the encoder, angular and linear velocity of the vehicle can be calculated along with heading and distance travelled. However, odometers system suffer from accumulation of error over the course of time and cannot be used without periodically updating its current positioning with a know reference frame. Due to this drawback, it is common to integrate these systems with GPS in a manner to provide continuous positioning information.

GPS based autonomous navigation is a very rapidly developing technology. Researchers have developed several techniques for navigation under a variety of external environments. This system has been extensively used in land vehicle navigation applications. The main advantage of using GPS is that the data gathered does not depend on previous readings and therefore errors in localisation do not grow over the course of time. The disadvantage is its accuracy and precision, which is dependent on its surroundings and the number of satellites it reads.

Studies have been done in order to tackle the limitations of GPS technology. Ohno et al, use map-based navigation for an outdoor environment [4]. The robots positioning are obtained using odometers and differential GPS (DGPS) measurements and an extended Kalman filtering framework is used to correct positioning data. Through testing the authors found that even when DGPS position measurements were highly inaccurate, however, the heading data was still reliable. From the output of these measurements, the authors proposed two separate correction techniques of heading and positioning for the mobile robot. However testing of the system was only done in areas with walk ways amongst buildings and testing of the DGPS data still has to be done around areas with large natural obstructions like trees [5].

A. GPS Overview

GPS is a constellation of satellites that provides a user with an accurate position on the surface of the earth. This satellite based navigation system was developed by the U.S. Department of Defense (DoD) in early 1970s. It was first intended for military use but later it was made available to civilian users. GPS can provide precise position and time information to a user anywhere in the world. It is a one way system i.e. a user can only receive signals but cannot send signals to the satellite. This type of configuration is needed due to security reasons as wells as to serve unlimited number of users.

The GPS system consists of three main segments:

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1) Space segment
2) Control segment
3) User segment

The space segment consists of a constellation of 24 satellites in fixed orbits around the earth. Each satellite continuously transmits GPS signals to the earth, which consist of two carrier frequencies, digital codes, and navigation message. The carrier frequency and codes are used in determining distance of the satellite from the receiver. The navigation message consists of information like satellite location and clock compensation [6][7].

The control segment includes a network of tracking stations. These tracking stations continuously monitor the satellite orbit; checks satellite clock, atmospheric conditions, satellite almanac, provide necessary compensation for clock error, and upload data to satellites. The OCS (Operational Control System) consists of one master control station (MCS), several monitor stations, and ground control stations. The MCS is located in the United States at Shriever Air Force Base, Colorado Springs, Colorado [8].

The user segment consists of all civilian and military users. A GPS receiver can lock on to any visible satellites and determines its location on earths surface. GPS system was first conceived for military usage such as navigating in remote terrains and coordinating military activities. With addition of civilian access to GPS signals, it is used in various applications such as surveying, mapping, hiking, and vehicular navigation.

II. Project description

The purpose of the project is to build and develop an algorithm that takes in inputs from a GPS receiver and using those inputs to successfully navigate a car through a set of known points and called it as waypoints. The overall process is divided into three parts. In the first part, the car is set at the start waypoint where GPS receiver tries to get a fix on visible GPS satellites and compute current latitude and longitude. In the second part, the algorithm in the microcontroller computes the direction of the destination waypoint from the current waypoint and drives the car. In the third step, the algorithm steers the car to direction of point heading. This step repeats after reaching the destination and navigates to next waypoint. This project summarise for objectives were as below:

1) Setup and collect NMEA fix visible GPS data and stores into data logger
2) Computes the direction of waypoint destination using compass module
3) Steer the car heading to destination and display on LCD

The main objectives of this project are to find an appropriate technique of terrestrial navigation as to learn about GPS receivers, its signals, understanding how such data can help to navigate a car, and then interface all components together. It will help in understanding general GPS satellite system and standard GPS protocols. Developing such a technique is useful towards researching new domains of navigation applications. Electronics and software based control systems of the servos are introduced and documented in providing positioning and directional while performing the driving tasks.

III. Problem statement

There are several major and minor risks that need be view while doing this project. In order to build the GPS navigation system for autonomous car, we need to consider and discuss the entire problems that might be occurred during project completion. Below are listed of risk need to be considers:

1) Motor-Control Circuit: by using a pre assembled RC car, it takes to experiment with the motors to find out exactly how they are controlled. Once system can control them it will be able to build an H-bridge circuit compatible with the processor.
2) Interfacing the GPS chip to the processor: the chip comes with sufficient documentation, and experience needed to working with the standard TTL serial interface. Check compatibility of the GPS and microcontroller.
3) The GPS needs to compute on the collected data and use the data to control the car direction by using microcontroller.
4) The car should be able to store and read data into data logger from microcontroller. Then, the algorithm of the process is used to control the movement of the car so that it can achieve the objectives.
5) Arduino software be able to operate each component of the car, i.e. motor driver board, servo motor and DC motor. Integrating all of the software into one operational module will be a little more complicated and will potentially require a lot of debugging, testing, and redesigning.

IV. Distance and direction calculation

This project assumed to use of a concept of spherical model of earth surface. As the trajectory for navigation was limited to few hundreds of meters, there is a very less chance of a positional error. In general, Equation 1 give the distance between two coordinates (Φ_1, λ_1) and (Φ_2, λ_2) in meters. Here, R is radius of the earth, which is assumed to be constant as the spherical model of earth surface is under consideration. Also, it is assumed that the positional accuracy of a waypoint achieved would be equal to or less than 1 meter. Hence, if the car reached anywhere in 1 meter radius circle, it is assumed that the waypoint is achieved. The spherical earth equation would be

$$\begin{aligned} d &= R \cdot \cos^{-1}(\sin\phi_1 \cdot \sin\phi_2 \\ &\quad + \cos\phi_1 \cdot \cos\phi_2 \cdot \cos(\lambda_2 - \lambda_1)) \end{aligned} \tag{1}$$

where d is distance between two points and R is radius of earth 6371000 m.

The direction of next waypoint at coordinate (Φ_2, λ_2) from current position (Φ_1, λ_1) is given by

$$\begin{aligned} \theta &= \text{atan2}(\sin(\Delta\lambda) \cdot \cos(\phi 2) \cdot \cos(\phi 1) \cdot \sin(\phi 2) \\ &\quad - \sin(\phi 1) \cdot \cos(\phi 2) \cdot \cos(\Delta\lambda)) \end{aligned} \tag{2}$$

The formula of Equation 2 gives the direction in range from $-\pi$ to $+\pi$, with 0 degrees set in north direction. While, Equation 3 gives angle summarise for each quadrants and calculation done [9].

$$\text{atan2}(y,x)=\begin{pmatrix} \arctan\frac{y}{x} & x>0 \\ \pi+\arctan\frac{y}{x} & y\geq 0, x<0 \\ -\pi+\arctan\frac{y}{x} & y<0, x<0 \\ \frac{\pi}{2} & y>0, x=0 \\ -\frac{\pi}{2} & y<0, x=0 \\ \textit{undefined} & y=0, x=0 \end{pmatrix} \quad (3)$$

To drive the car follow the correct path, system need to determine the car route that needs to be followed. The main component of the car is used to drive the motor servo which control the car direction. In order to accomplish this, the angle distance between each point has to calculate such that the car can navigate correctly to the path. The calculation of the angle between points is given by

$$r=\sqrt{\text{long}^2+\text{lat}^2} \quad (4)$$

where r is distance from first and second point, $long$ is Cartesian longitude-coordinate and lat is Cartesian latitude-coordinate. Using the relation

$$\theta = atan\left(\frac{long}{lat}\right) \quad (5)$$

where is angle relative to latitude axis (degrees). Cartesian can be divided into four quadrants which I, II, III and IV. Each quadrant contains 90 degree, thus total overall quadrants is 360 degree. By using Equations 4 and 5, angle can be obtained between each point and then navigate the car into the direction. Figure 1 shows Cartesian quadrants and angle calculated for those two points.

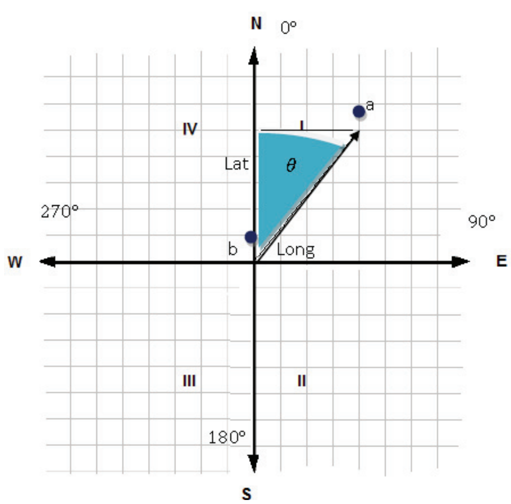

Fig. 1. Cartesian quadrants and angle between point 'a' and 'b'

The GPS receiver computes fresh latitude, longitude, course and speed readings at a rate of 1 sec. Hence the values of direction and angle θ are constantly updated. Due to uneven track surface and constantly changing GPS readings, the car tends to deviate from its set course towards destination waypoint. The algorithm measured such deviation and if the deviation goes above or below $+45$ and -45 respectively, the car be likely to turn to 45 degree either left or a right. The deviation is measured as the numeric difference of angle θ and the course of travel obtained from GPS receiver. The algorithm also updated the deviation with new values of θ and course of heading. Figure 2 illustrates the scenario

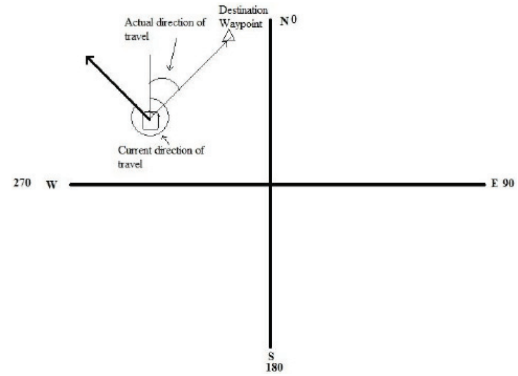

Fig. 2. Deviation Calculation

V. Hardware and circuit construction

The GPS-controlled car consists of couples major components and the system is operated by integrating GPS, data logger, compass, buttons, LCD, motor and servo motor in order to perform an autonomous car system, in which it can be controlled by Arduino Microcontrololer. Based on the Figure 3, data logger can read and write data into microcontroller. Thus, it has two ways of interaction with the controller and synchronised the information by displaying on LCD panel. LCD panel is used to display data such longitude, latitude, deviation and system operation. Servo deviation and motor speed will be controlled by Arduino. GPS module is a main component and it used to send longitude and latitude data for coordinate and car operational. Digital compass use to perform correction for angle deviated and operation buttons is to use to switch mode of collecting data waypoints. Figure 3 shows the overall consolidation of components.

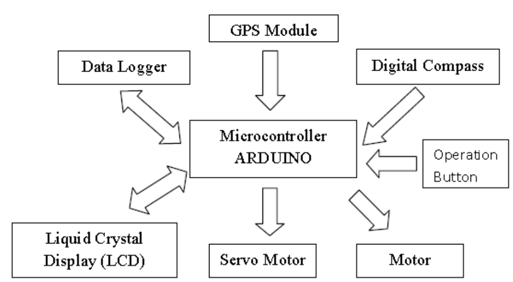

Fig. 3. Block diagram architecture of GPS autonomous car system

VI. Result and discussion

This section discusses the research finding and techniques used in this development of the project. There are a lot of trouble-shoots and analyses need to be done in order to find errors within the system and to achieve project's objectives.

A. GPS module

The GPS module is a main component of the autonomous system. Particularly in this system, the car receives the data from this module and GPS will sends the data in bytes that contains longitude, latitude, altitude, velocity, time and heading. All of these data are useful, but most importantly are longitude and latitude in which they are used to control the car navigation. According to the GPS PMB-688 data sheet, one of GPS features is it can receive up to 20 parallel satellites where all the data are sent in NMEA protocol [10]. Thus, test has been made to found how accurate and consistent the GPS coordinate data being received from the module. As a result, the data are highly accurate and consistent to change of placement. This to confirm the calculation of angle will derive the correct navigation of servo motor. Fig. 4 shows the result of longitude and latitude for different places.

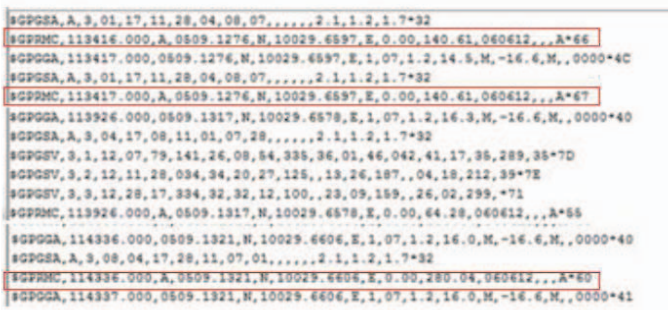

Fig. 4. Longitude and latitude results

Based on GPS module specification, it shown that data navigation update rate will be once per second. This might become a problem to the designed system since the movement of the car is a significantly fast and thus the system need to be updating the data a bit faster such that the data collection can be in better data accuracy. When addressing accuracy of collected data, varied speed of the car has been tested and it found that the lower speed of the car obtained the better accuracy data collected. Resulting to this matter, decision has been made on collecting data for each coordinate will be using low motor speed. Fig. 5 show the result for two different speed data collection.

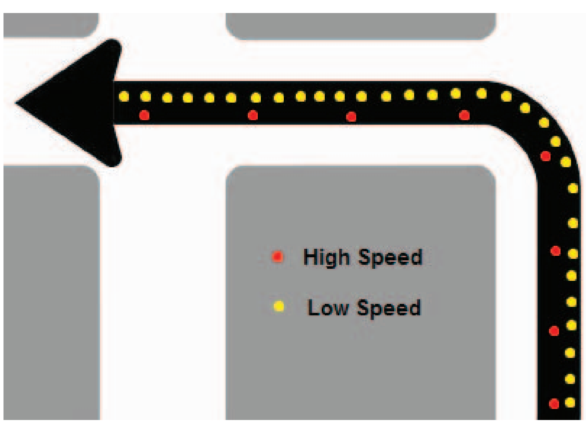

Fig. 5. Coordinate data collection in different speeds

B. Compass module

A compass is navigational instrument that been used to measured directions in a frame of reference defines the cardinal direction; north, south, east, and west. In this project, compass has been used to initialise the initial position of the car such that it used to assist car drive into correct path. As a result, this compass value will perform angle correction to previous angle received from two calculated coordinate points. Based on the car pre-testing, result found that car was not turned into correct direction even calculated values are correct for angle between those two points. During troubleshooting, the problem occurs due to initial car position was not located in north direction. In the calculation, it assumes that car only facing to north direction. Therefore, by using compass has helped the navigation of the system to facilitate countermeasure for determining true initial condition and turn the car into correct angle and path. Fig. 6 shows the corrective turning angle made compass module.

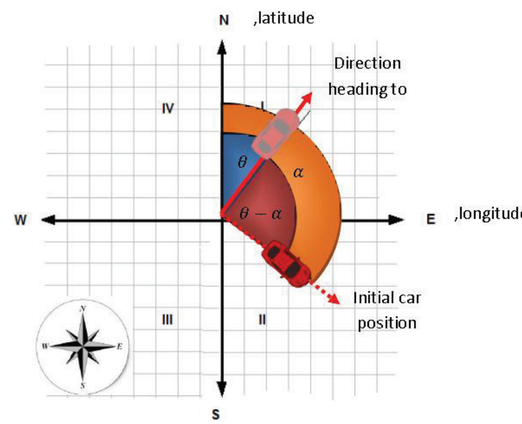

Fig. 6. Corrective operation

Based on Table I, its shown that angle calculated will be equal to angle direction. However, this condition is not considered the initial direction because it always assumes that the car will initialise heading to north direction. Testing result shows that this theory is absolutely wrong because there is another condition where the car initial heading to a certain angle. As computed in Table I, the direction of angle by using compass module is actually the real angle. It was proven that using compass gives different value of angle and work out angle correction to car navigation system.

TABLE I
RESULT COMPARISON BETWEEN USING COMPASS AND WITHOUT COMPASS

Trial	Initial post, α (Degree °)	Calculated angle, θ	Angle dir, θ (no compass)	Angle dir, $\theta - \alpha$ (use compass)
1	30	100	>100°	>70°
2	60	100	>100°	>40°
3	90	100	>100°	>10°
4	120	100	>100°	<20°
5	150	100	>100°	<50°
6	180	100	>100°	<80°
7	210	100	>100°	<110°
8	250	100	>100°	<150°
9	280	100	>100°	<180°
10	330	100	>100°	<230°

$\therefore$ *Symbols > means turn right and ; < means turn left to certain degrees*

C. Servo Motor

Servo motor is controlled by receiving pulse-width-modulation (PWM) signal, a series of repeating pulses of variable width. Normal servo can be rotating turning up to 360 degrees. However, in this system, servo motor Futaba S3010 is attached to the car steering in order to control direction of the car. Several testing have been made to determine the car steering turning limit. As a result, maximum angle of the steering can be turned 40 degrees in both direction; right and left. This is because the chassis design of the car only limits for servo to deviate only on certain angles. In addition to this, 100 degrees is determined the location of the servo is in center position or in other word car heading to straight position. At this point car will move straight and continuous to direction if there is no interference to deviate current direction. Table II below shows steering control result based on testing.

TABLE II
SERVO ANGLE DISTRIBUTION

Servo Angle (Degrees, °)																
			Left					Centre				Right				
Hard			*Mid*			*Soft*			*Soft*		*Mid*			*Hard*		
60	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*100*	*105*	*110*	*115*	*120*	*125*	*130*	*135*	*140*

D. Liquid Crystal Display (LCD)

LCD panels typically use thinly-coated metallic conductive pathways on glass substrate to form the cell circuitry to operate the panel. LCD is used to read and display data for user viewed. In this project, data can be displayed in serial com which is located in microcontroller Arduino software panel and also display in LCD panel. LCD panel is easier to use because it is compatible to display the data while car is running and not connected to serial port wired. This project have used LCD panel as a function to display varies data such longitude, latitude, speed, time, angle and speed. By using LCD, user easier to see the update for each data through the screen and make some modification. Figure 7 shows varies of LCD displays during project running such (a) Initialisation; (b) longitude and latitude; (c) GPS update; (d) angle and speed.

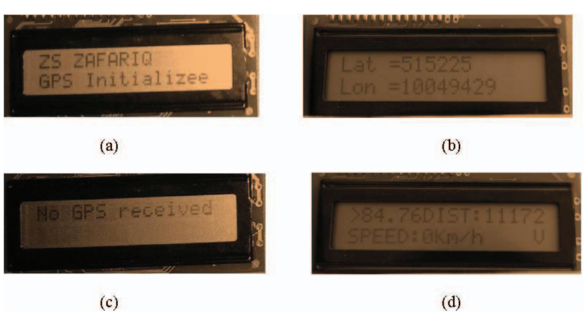

Fig. 7. LCD displays (a) Initialisation (b) Longitude and latitude (c) GPS update (d) Angle and speed

E. Software overview

Based on the pre-testing, problem was found that GPS module did not working or obtained any signals inside buildings or in blocking condition. At first, the problem is assumed that it comes from the module itself, but it was found out to receive GPS signals the antenna must have a view of the sky. From the GPS data results, data received from GPS in one row information including longitude, latitude, time, speed, validity and types. Therefore, data have to separates and arranges accordingly to obtain the specific values that are needed in this project. One of problem is that microcontroller cannot upload the program into the system while GPS receiver connects to the pin. This happened because data transferred into microcontroller being interfered by GPS module that continuously sending data into microcontroller. Data receive GPS module is in byte and take once per second for every data send.

The most important thing to bear in mind is to know types of GPS output message coded in NMEA. NMEA have several output messages such GGA, GLL, GSV, RMC and VTG. Options that been chosen is Recommended Minimum Specific Data (RMC) type, this data contains time, date, position, course and data speed in which all of these information are needed in this project. Data received from GPS module in bytes and take once per second for every data send. Fig. 8 shows GPRMC data arrangement into their specification by programming.

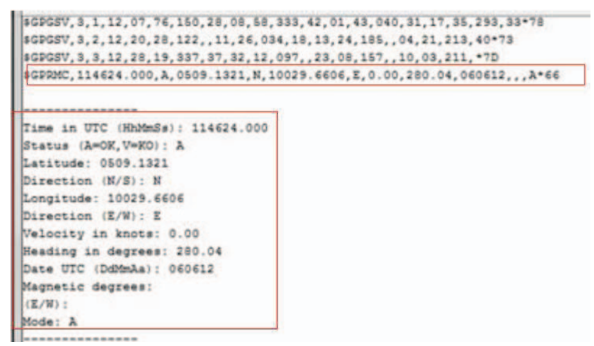

Fig. 8. GPRMC data arrangement

F. Write and read data logger system

The parallax memory stick data logger is a USB host bridge which allows connection on USB mass storage device such thumb drive. This device is important in order to store current coordinate for longitude and latitude, and other important data. There are two functions of this device which are writing and read data from microcontroller unit. In this project, command function for input number in ASCII code. Therefore, to initialise the program is by sending 'IPA' bytes into the microcontroller. 'RDF' command is used to read data and only after opening the file to read or by activating 'OPR' command. When open-file-for-write command is activated, 'WRF' command will starts the operation to write data from microcontroller into data logger. Then the file will be closed by receiving command 'CLF'. File format is used in The Comma Separated Value (CSV)is compatible with Microsoft Excel or notepad software. In notepad, whenever bytes data being separated, it will use comma symbols. Instead, Excel will move the separated bytes data into second column. Figure 9 shows the data stored in memory storage device for Excel and notepad software.

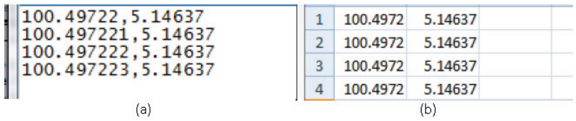

Fig. 9. (a) Notepad storage data (b) Microsoft Excel storage data

VII. PRE-TEST AUTONOMOUS SYSTEM

All the components have been integrated into a complete system, experiment has been made based on try and error method. Experimental and testing proves that existing theories was not exactly equal to practical result. While compile all the programs together, error have been found, modification and improvement need to be done in order to satisfied project requirements. There are a lot of influencing factors from the hardware to the software issues that need to be tackled in appropriate manner to obtain the best result.

GPS data received by the signal need to be calculated first in order to determine the angle of direction. Then, information data have to store into data logger which act as memory storages. Two buttons will control the system to log the data and read the data into microcontroller. The Microcontroller Arduino is used as main controller to all system operations. The data logger will log and write the data in byte. Push button write, will control the operation to store the data from GPS such longitude, latitude and time. Longitude and latitude data need to be converted from degree and minutes into degree only by doing some mathematical calculation.

When button read is activated, the microcontroller will read all the data stores. Next step, calculation has been made to determine the angle between those points. Angle calculated will be correcting using compass value which shows the initial car direction. The exact angle value will send to control the servo movement. Speed of car will be depending on servo directions. LCD is used to display longitude, latitude, servo deviation and operation have been made. As result, all the data have been plotted into table below to shows longitude, latitude, calculated angle, initial car position, angle correction value, servo direction and motor speed. All of this data have been collected for overall operations of autonomous car system. Table III shows the result for overall autonomous system. Figure 10 shows the graph longitude against latitude values according to coordinate GPS data.

Based on the graph longitude against latitude, the car is moving from coordinate 1 till coordinate 29 following order. Car is moved in circle direction and initially or constantly assumed to be heading to north direction. Based on the Table III, when value is zeros from calculated value of longitude and latitude coordinate, the car has no change on angle and continuously moves with 100 percents of speed. However, when there is some angle values change, say 45 degree from calculation, speed of car will reduce till 50 percents. The strategy is applied because the car moves to fast in the corner, it will make car overshoot from the track.

VIII. CONCLUSION

In conclusion, the objectives of the project are achieved. Development of the GPS-based project proposed for autonomous car system embedded with compass module and data logger has achieved the objectives. The car able to use real time geographical data received from satellites data such longitude and latitude to implement autonomous car controlled.

There is no human involved during car running, and system has pre programmed coordinates which successfully stored into data logger. Car navigate route based on coordinates stores from data logger and steer the car into waypoint from corrected calculation value made by compass module. LCD used to display current position of longitude and latitude coordinate, and also servo angle deviated and system operations. Integrated of all modules such GPS module, compass, data logger, LCD, button and microcontroller Arduino have yielded a result of autonomous GPS car system.

Angle calculated from longitude and latitude yielded a car deviation, however it was not correct angle value. Compass needed to do correction to the angle calculated. Angle car deviate will contribute to car speed. As more deviation of angle will result lower car speed. Integrating of overall software into

TABLE III
RESULT FOR OVERALL AUTONOMOUS SYSTEM

Point (i)	Longitude, X	Latitude, Y	Calculated Angle, θ	Initial post, α	Corrective Angle, $(\theta - \alpha)$	Servo Dir	Speed PWM (%)
1	100.497220	5.146370	0	0	0	0°	100%
2	100.497221	5.146370	0	0	0	0°	100%
3	100.497222	5.146370	0	0	0	0°	100%
4	100.497223	5.146370	0	0	0	0°	100%
5	100.497224	5.146370	0	0	0	0°	100%
6	100.497225	5.146371	45	90	-45	<45°	50%
7	100.497226	5.146372	45	90	-45	<45°	50%
8	100.497227	5.146373	45	90	-45	<45°	50%
9	100.497227	5.146374	0	0	0	0°	`100%
10	100.497227	5.146375	0	0	0	0°	100%
11	100.497227	5.146376	0	0	0	0°	100%
12	100.497227	5.146377	0	0	0	0°	100%
13	100.497226	5.146378	315	360	-45	<45°	50%
14	100.497225	5.146379	315	360	-45	<45°	50%
15	100.497224	5.146380	315	360	-45	<45°	50%
16	100.497223	5.146380	0	0	0	0°	100%
17	100.497222	5.146380	0	0	0	0°	100%
18	100.497221	5.146380	0	0	0	0°	100%
19	100.497220	5.146380	0	0	0	0°	100%
20	100.497219	5.146379	225	270	-45	<45°	50%
21	100.497218	5.146378	225	270	-45	<45°	50%
22	100.497217	5.146377	225	270	-45	<45°	50%
23	100.497217	5.146376	0	0	0	0°	100%
24	100.497217	5.146375	0	0	0	0°	100%
25	100.497217	5.146374	0	0	0	0°	100%
26	100.497217	5.146373	0	0	0	0°	100%
27	100.497218	5.146372	135	180	-45	<45°	50%
28	100.497219	5.146371	135	180	-45	<45°	50%
29	100.497220	5.146370	135	180	-45	<45°	50%

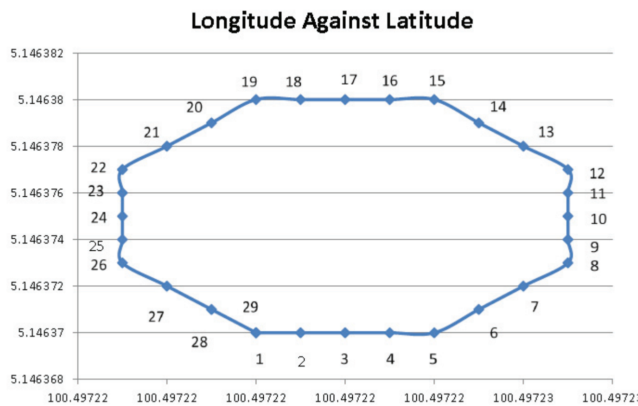

Fig. 10. Longitudes against latitude

one operational module were resulted a complicated design and a lot of errors and debug to tests the program and design improvement in order to achieve project objectives.

IX. Acknowledgement

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