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Design and Implementation of Autonomous Wireless Vehicle

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Abstract— Autonomous vehicles gains increasing importance in various growing application areas. The navigation, guidance and control of an autonomous vehicle is a highly complex task. Making a vehicle intelligent and able to operate unmanned requires extensive theoretical as well as practical knowledge. This paper focuses on designing and implementation of GPS based autonomous guided vehicle navigation, guidance and control system. The designed system is able to reach the desired coordinates with minimum drift, high performance, and high stability. In particular, the inertial sensors were used to support the autopilot with the required navigation states required for estimating the error between the desired and actual trajectory. The idea of the algorithm that steering the vehicle till reaching the desired position is based on the modified PI-D classical controller that prevent differentiating the input signal in order not to obtain impulse chock to the actuators; the physical limitations and constraints that might be encountered while building an autonomous vehicle are taken into consideration. Experimental results for the designed PI-D algorithm are given to illustrate the effectiveness of the proposed technique.

Keywords—Navigation; Control; Arduino; Autonomous

I. INTRODUCTION

An autonomous vehicle, also known as a driverless vehicle, self-driving vehicle is a vehicle capable of fulfilling the human transportation capabilities of a traditional vehicle [1], [2]. An autonomous vehicle must be able to make decisions [2], [3] and respond to situations completely on its own Navigation and control serves as the major limitation of the overall performance accuracy and robustness of an autonomous vehicle [2], [3], [4].

As an autonomous vehicle, it is capable of sensing its environment and navigating without human input [1]. Navigation ,Guidance and control is a branch of engineering dealing with the design of systems to control the movement of vehicles [5], especially, automobiles, ships, aircraft, and spacecraft. In many cases these functions can be performed by trained humans. However, because of the speed of, for example, a rocket's dynamics, human reaction time is too slow to control this movement [5], [6], [7]. Therefore, systems (now almost exclusively digital electronic) are used for such control [7]. Even in cases where humans can perform these functions, it is often the case that navigation, guidance, control (NGC) systems provide benefits such as alleviating operator work load, smoothing turbulence, fuel savings, etc [9]. In addition, sophisticated applications of NGC enable automatic or remote control [9], [10]. Navigation refers to the determination, at a given time, of the vehicle's location and velocity (the state vector) as well as its attitude [10].

Guidance refers to the determination of the desired path of travel (the trajectory) from the vehicle's current location to a designated the target [9], as well as desired changes in velocity, rotation and acceleration for following that path [11].

Control refers to the manipulation of the forces [10], by way of steering controls, thrusters, etc., needed to track guidance commands while maintaining vehicle stability [10], [12].

NGC systems are found in essentially all autonomous or semi-autonomous systems [6]. These include: Autopilots, Driverless cars like Mars rovers or those participating in the missiles, precision-guided airdrop systems, Reaction for spacecraft, Spacecraft launch vehicles.

The design of an autonomous vehicle requires the integration of many sensors, actuators, and controllers [11]. Software serves as the glue to fuse all these devices together.

The potential application areas of the autonomous navigation of mobile robots include automatic driving, guidance for the blind and disabled [12], exploration of Dangerous regions, transporting objects in factory or office environments, collecting geographical information in unknown terrains like unmanned exploration of a new planetary surface, etc [13].

The objectives of this paper is based on an autonomous vehicle which receives wirelessly a GPS coordinates of a certain position. After that, the vehicle determines the bearing of the desired path and the traveled distance relative to the recent coordinate's position. The proposed guidance and control techniques used include designing a feedback system which able to detect the path instantaneously for correction to the drift path through traveling to reach the desired position.

The structure of this paper is as follow, section II presents a general introduction about the navigation, different navigation systems, and the difference between the GPS system and the INS system, section III discusses an experimental setup for the proposed autopilot integrated with the whole vehicle's actuators and sensors, section IV describes the technical algorithm flow chart and finally the conclusion of this paper are presented in section V.

II. THE NAVIGATION SYSTEM

Navigation is a key aspect when designing an autonomous vehicle [6]. An autonomous vehicle must be able to sense its location, navigate its way toward its destination. Navigate in its environment is one of the most important capabilities. In general, the navigation task can be defined as the combination of three basic competences: localization, path planning and vehicle control [10], [11], [12].

GPS is used to determine the vehicle location. The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S.A as shown in Fig. 1 [2].

Fig. 1. *GPS Satellite System*

GPS satellites circle the earth twice a day in a very precise orbit and transmit signal information to earth [2]. GPS receivers take this information and use trilateration to calculate the user's exact location. Essentially, the GPS receiver compares the time a signal was transmitted by a satellite with the time it was received. The time difference tells the GPS receiver how far away the satellite is. Now, with distance measurements from a few more satellites, the receiver can determine the user's position [11].

A GPS receiver must be locked on to the signal of at least 3 satellites to calculate a 2-D position (latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user's 3-D position (latitude, longitude and altitude). Once the user's position has been determined, the GPS unit can calculate other information, such as speed, bearing, track, trip distance, distance to destination, sunrise and sunset time and more [10], [13].

another location detection method commonly used is the INS system, the inertial navigation system (INS) is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object [14] without the need for external references. It is used on vehicles such as ships, aircraft, submarines, guided missiles, and spacecraft [6]. Other terms used to refer to inertial navigation systems or closely related devices include inertial guidance system, inertial instrument, inertial measurement units (IMU) and many other variations. Older INS systems generally used an inertial platform as their mounting point to the vehicle, and the terms are sometimes considered synonymous [6], [14].

Inertial navigation is a self-contained navigation technique in which measurements provided by accelerometers and gyroscopes are used to track the position and orientation of an object relative to a known starting point, orientation, and velocity. Inertial measurement units (IMU) typically contain three orthogonal rate-gyroscopes and three orthogonal accelerometers [12], measuring angular velocity and linear acceleration respectively. By processing signals from these devices it is possible to track the position and orientation of a device [13].

Inertial navigation is used in a wide range of applications including the navigation of aircraft, tactical and strategic missiles, spacecraft, submarines and ships. Recent advances in the construction of microelectromechanical systems (MEMS) have made it possible to manufacture small and light inertial navigation systems [14]. These advances have widened the range of possible applications to include areas such as human and animal motion capture [12], [14], [15].

An inertial navigation system includes at least a computer and a platform or module containing accelerometers, gyroscopes, or other motion-sensing devices. The INS is initially provided with its position and velocity from another source [11] (a human operator, a GPS satellite receiver, etc.), and thereafter computes its own updated position and velocity by integrating information received from the motion sensors [15]. The advantage of an INS is that it requires no external references in order to determine its position, orientation, or velocity once it has been initialized. INS block diagram is shown in Fig. 2.

An INS can detect a change in its geographic position (a move east or north, for example), a change in its velocity (speed and direction of movement), and a change in its orientation (rotation about an axis). It does this by measuring the linear acceleration and angular velocity applied to the system [13]. Since it requires no external reference (after initialization), it is immune to jamming and deception.

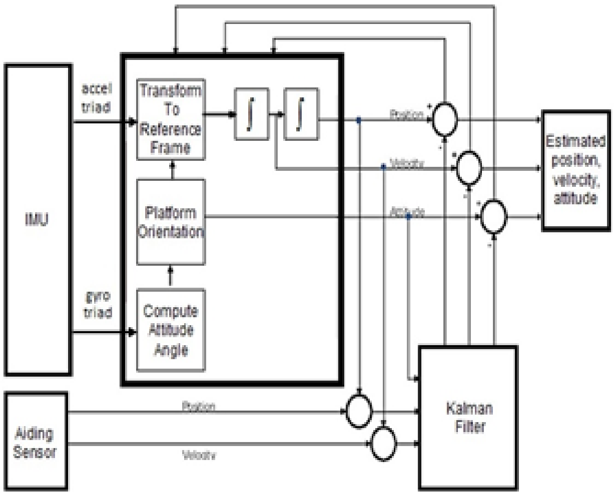

Fig. 2. *INS Block Diagram*

Inertial-navigation systems are used in many different moving objects, including vehicles—such as aircraft, submarines, spacecraft—and guided missiles. However, their cost and complexity place constraints on the environments in which they are practical for use [9], [15].

The combination of the global positioning system (GPS) and inertial navigation system (INS) has become increasingly common in the past few years, because the Characteristics of GPS and INS are complementary [17].

GPS/INS is the use of GPS satellite signals to correct or calibrate a solution from an inertial navigation system (INS). Inertial navigation systems usually can provide an accurate solution only for a short period of time [15]. The INS accelerometers produce an unknown bias signal that appears as a genuine specific force. This is integrated twice and produces an error in position. Additionally, the INS software must use an estimate of the angular position of the accelerometers when conducting this integration. Typically, the angular position is tracked through an integration of the angular rate from the gyro sensors. These also produce unknown biases that affect the integration to get the position of the unit [14], [23]. The GPS gives an absolute drift-free position value that can be used to reset the INS solution or can be blended with it by use of a mathematical algorithm, such as a Kalman filter. The angular orientation of the unit can be inferred from the series of position updates from the GPS. The change in the error in position relative to the GPS can be used to estimate the unknown angle error [10], [17], [26].

The benefits of using GPS with an INS are that the INS may be calibrated by the GPS signals and that the INS can provide position and angle updates at a quicker rate than GPS. For high dynamic vehicles, such as missiles and aircraft, INS fills in the gaps between GPS positions. Additionally, GPS may lose its signal and the INS can continue to compute the position and angle during the period of lost GPS signal. The two systems are complementary and are often employed together. GPS / INS integration is shown if Fig. 3. [11], [19].

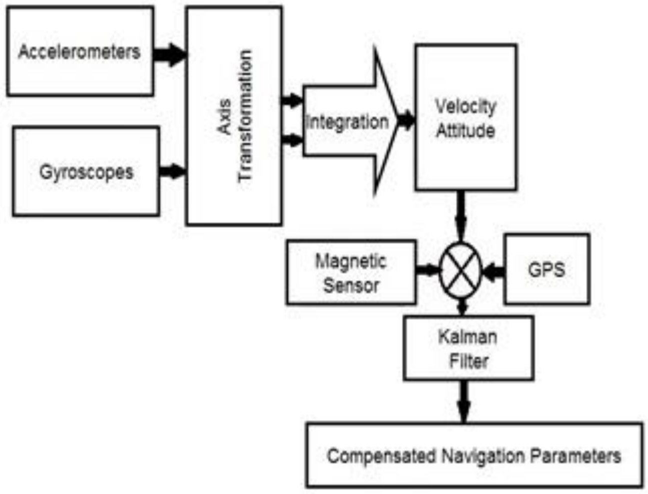

Fig. 3. *GPS with INS system*

Since the using of ground vehicle with limited sped, the navigation using GPS only is sufficient [15]; in case of the requirement of very high accuracy in position detection, another inertial navigation.

In order to complete the acquiring of navigation states, a digital compass is used to detect the heading of the vehicle, the compass detects the heading through a magnetic sensor [12] that alters its resistance proportional to the magnetic field in a particular direction. Circuitry on the chip detects the magnetic field strength and makes the field and its direction available as digital data.

One of the most recommended step in designing of an autonomous vehicle is the calibration of the digital compass; there are many ways of compass calibration, but all methods are associated with a specified physical movement of the compass platform in order to sample the magnetic space surrounding the compass. The Hard and Soft iron distortions will vary from location to location within the same platform [13]. The compass has to be mounted permanently to its platform to get a valid calibration. A particular calibration is only valid for that location of the compass. If the compass is re-oriented in the same location, then a new calibration is required. It is possible to use a compass without any calibration if the need is only for repeatability and not accuracy [10], [12], [13].

III. EXPERIMENTAL SETUP

Embedded system represented by Arduino microcontroller development kit is used as an on board computer for processing the received signal, estimating the heading error and generating the guidance command to steer the vehicle to reach the desired position. The telemetry dated is sent to the ground station through using Xbee RF module. The vehicle used 4 motors, dual channel motor driver and 12V battery for motor supply. Fig.4 show block diagram of the vehicle.

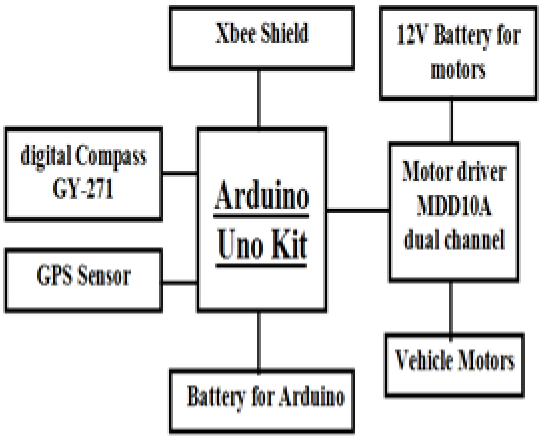

Fig. 4. *Vehicle Block Diagram*

The desired trajectory is either predetermined on the on board computer by saving the waypoints coordinated or online change through the telemetry link using the RF module.

The mechanical dimension of the vehicle is of 25 cm in length, 20 cm in width and 13 cm hight.fig.5 show an elevation view of the vehicle.

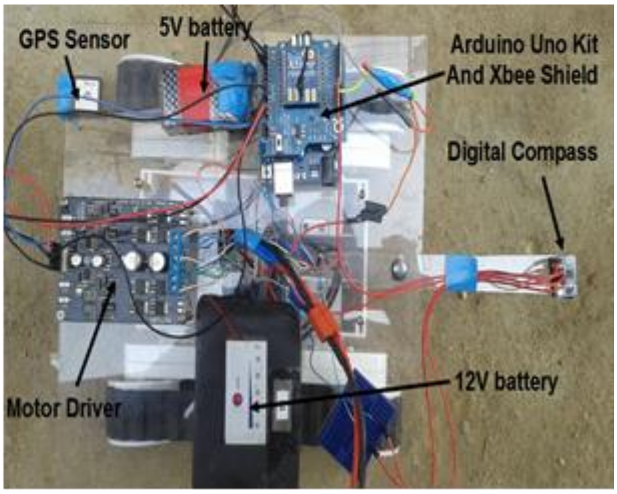

Fig. 5. *Vehicle Elevation View*

IV. METHODOLOGY

The methodology of the designed algorithm is to achieve the requirement of tracking with high accuracy, reject the disturbance, decrease the noise and overcome the modeled dynamics. The main idea of the algorithm is to calculate the travelling distance between the desired and the actual positions and the heading angle which is the angle between the north-south line of earth or meridian and the line connecting the desired coordinates and the actual position through this formula.

Denote point A and B as two different points, where 'La' is point A longitude and 'Ta' is point A latitude, similarly assume for point B. Using haversine formula to calculate the great-circle distance between two points – that is, the shortest distance over the earth's surface giving an "as-the-crow-flies" distance between the points (ignoring any hills they fly over, of course!) [12], [14], [16], [19]. Haversine formula:

Where R is earth's radius (mean radius = 6371km). The heading angle measured from North direction i.e. 0° bearing means north, 90° bearing is east, 180° bearing is measured to be South, and 270° to be west. If the bearing is denoted with positive or negative initials whose values lies between 0° to 180°, consequently, the negative is denoted for South and West sides. The bearing from point A to B, can be calculated as,

Based on the calculated errors in distance and heading the designed modified PI-D Controller generate the control command to the actuators, therefor, the vehicle will be steering.

The closed loop control with feedback signal from the compass continue supporting the controller with the required data till reaching the desired bearing. The vehicle dynamic motion is shown in Fig. 6.

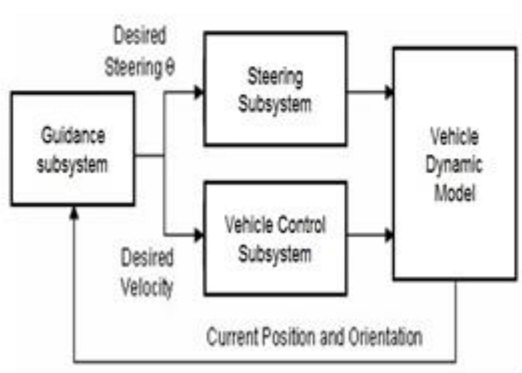

Fig. 6. *Vehicle Dynamic Motion*

During the whole trajectory, the scenario of obtaining the actual position and comparing with the desired one continue till getting zero error; at this moment the autopilot engenders stopping command to the actuators. The overall navigation, guidance and control flowchart is shown in Fig. 7.

Firstly, the desired waypoints' coordinates are sent wirelessly through the RF Xbee module from the ground control station to the onboard controller. At the same time the GPS sensor determine the actual position coordinates of the recent position. Then the coordinates of the two position are the input to a certain equation which will output the required traveled distance and the initial bearing. So the control system generate signal to the motors to steer clockwise or counter clockwise depend on the difference between the heading of the vehicle and the required angle, if the difference is less than 180 degree, it will steer clockwise and if the difference greater than 180 degree it will steer counter clockwise, the mechanical mechanism which is used to make the vehicle steering is the rotation of the motors which in the right hand side in direction opposite to the rotation of the motors which in the left hand side, it means to make the vehicle steer clockwise the right hand side motors will

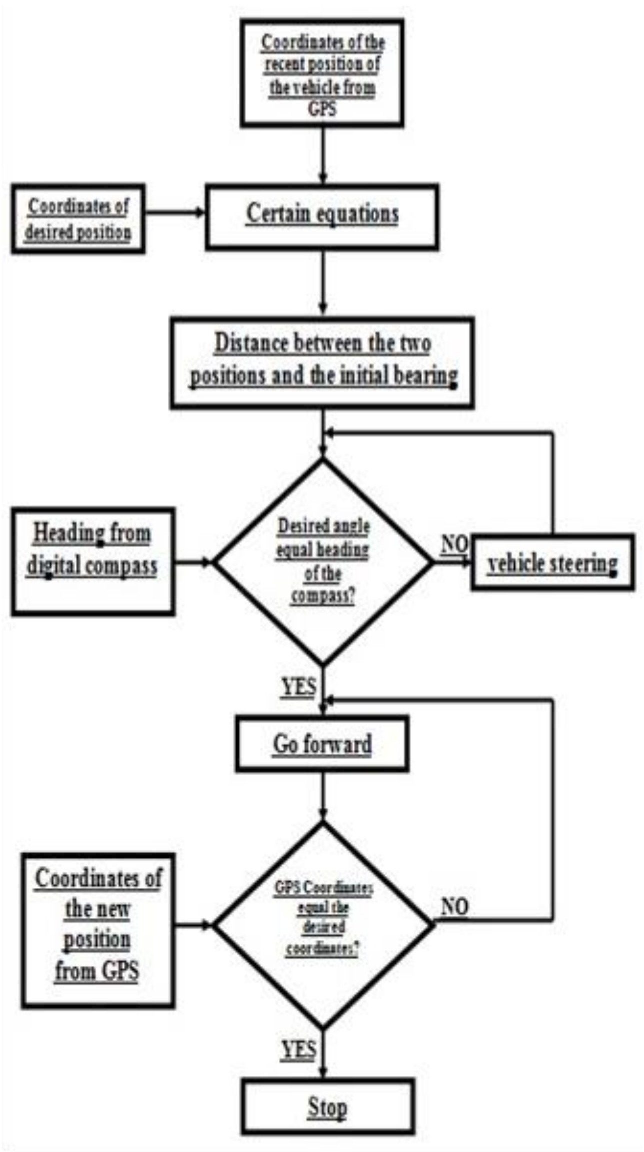

Fig. 7. *Navigation, Guidance and Control System*

rotate backward and the left hand side motors will rotate forward and to make the vehicle steer counterclockwise the right hand side motors will rotate forward and the left hand side motors will rotate backward. During the vehicle steering, a digital compass measures the heading of the vehicle. When the heading of the vehicle reaches the desired angle the control system generate signal to the motors to go forward. During the travel of the vehicle the GPS supply the control system by the new coordinates. The system uses this coordinates to estimate the new bearing from the new position to use it in the correction of the vehicle. When the vehicle reaches the desired region, the control system generate signal to the motors to stop and send message to the control station to tell the operator.

Before the vehicle travel, we can determine the required velocity for steering and the required velocity for traveling through the PWM.

because of the low accuracy of the compass and the low repeatability, we can make tolerance for the vehicle to steer, this mean it is not important for the vehicle to go forward at the exact angle but it can go forward when the heading reach a value within a certain range. Also for GPS, we give the vehicle range from coordinates to stop when it reaches a certain coordinate within this range, this mean the vehicle will stop when it reaches any position in the region surrounding the desired coordinates by 2 meters.

The interface of the command is deigned to be friendly with the user and to be self-explaining the recent step requirements.

CONCULOTION

The overall goal of this paper is to design a GPS Based Autonomous Guided vehicle; the trajectory of the vehicle will be compared with the trajectory of the vehicle with and without steering; there are two experiments that represent the effect of the designed algorithm with two different desired waypoints. The trajectories of the two experiments are shown in Fig. 8. And Fig. 9. The vehicle path without correction the path is drifted from the desired path by divergent error which ensure that the vehicle will not reach to the desired position. However, the vehicle trajectory with path correction ensure that the vehicle track the desired waypoints with high accuracy.

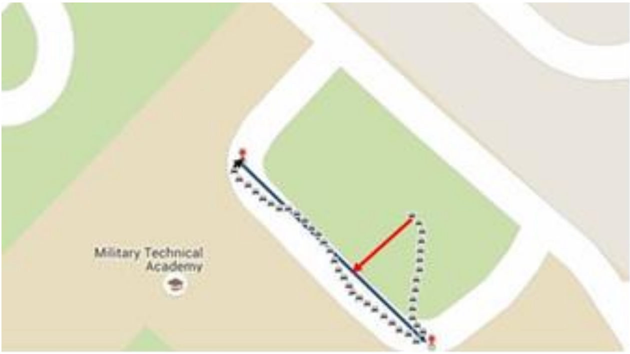

Fig. 8. *Experimental Test 1*

The convergent error in the case of correction using the designed algorithm guarantees that the vehicle follows the designed path and the vertical distance between the corrected trajectory and the ideal one is approximately half meter. The accuracy of the trajectory depends on the kind of GPS Sensor, its accuracy, its performance and its reliability. Moreover, it depends on the same parameters of the used compass.

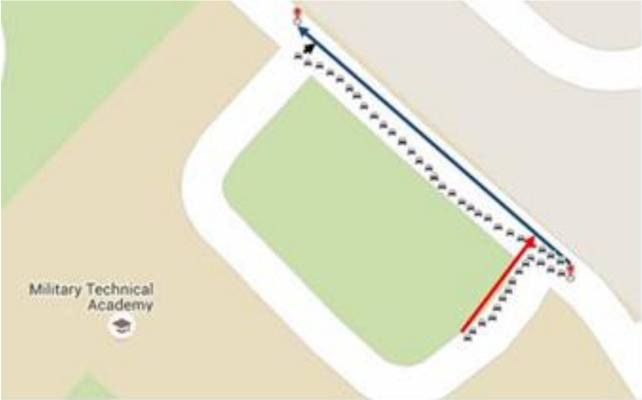

Fig. 9. *Experimental Test 2*

The compass calibration is very critical in order to ensure obtaining an accurate measurement as output value Approaching to zero when it refers to the north, but, unfortunately due to the used compass is commercial, there is a shift from the north by approximately 20 degrees that must be added to the reading of the compass to compensate the leading angle error of the used compass; which clearly confirm the important of compass calibration.

As shown in the previous figure the two corrected paths are done by making the control system calculate the angle relative to the newer position and steer the motor to change the drifted path direction to the desired position, this operation is repeated along the traveled distance to make sure the vehicle travel through the required path.

Because the relative accuracy, the vehicle doesn't reach the exact position but it reaches region which is away from the desired position at most 1 meters.

As shown in Fig.10 and Fig.11 it is a graph which represent the drift from the desired pass against the time.

The common factors which is effect on the performance of the project is the accuracy of the compass, the GPS, the time delay between each correction operation and finally the used code.

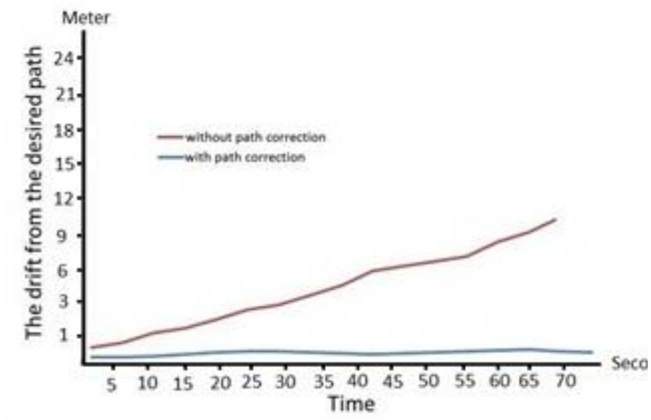

Fig. 10. *Drift Distance versus Time for experiment 1*

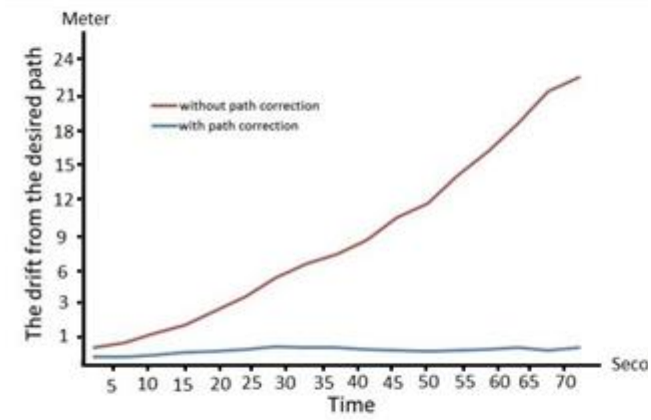

Fig. 11. *Drift Distance versus time for experiment 2*

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