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DEVELOPMENT OF NAVIGATION SYSTEM FOR UNMANNED SURFACE VEHICLE BY IMPROVING PATH TRACKING PERFORMANCE

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Abstract

A fundamental of a fully unmanned vehicle entails the use of Global Positioning System (GPS) and sensors module that emits USV a series of a waypoint for moving towards the target. In other words, GPS provides an accurate data location longitude and latitude for monitoring purposes. However, this real-time tracking path needs to extend their application for moving in curvature motion. Based on this fact, the real-time autonomous navigation system of USV will improve in this research by implementing the mathematical equation that will communicate with the GPS sensor. The objectives of this project are developing a navigation system that will determine a real-time of an unknown target location by using GPS and focuses on validating an ability of mathematical equation for correcting the error occurred between USV heading and the target heading error path. In this project, the system is divided into two parts; target platform and USV platform. Target platform is left freely on the water surface with an unknown location. RF Transceiver module 2 in the USV platform receives the information signal from RF Transceiver module 1 in the target platform. Employment of the PP Guidance controller will be engrossed in this project for estimating the future goal point by computing the goal point coordinate and the current USV body commands. Hence, the distance between two coordinates has been computed in the controller for getting new coordinates as a new waypoint towards the Target platform. Based on this experiment, there is some error occurred due to the sensors on-board. For further research, USV platform needs to add a PID controller to overcome the interruption reading between mathematical equation heading routing to get the actual result.

Keywords: Global positioning system, Path tracking, Pure pursuit guidance. Unmanned surface vehicle.

1. Introduction

Unmanned Surface Vehicle (USV) is a watercraft that have been introduced since world war II for performing tasks in the ocean, such as water monitoring, gathering and delivering water samples or cleaning up ocean contaminants. Due to this potentiality, great attention from the researchers is focusing on the ability of USV to eliminate workforce performance in monitoring specific environmental issues. In-depth, the performances of USV highly stand on the communication with sensors to make sure the situation of USV is cognizant [1]. Besides, sensors in the autonomous vehicle consist of inertial navigation, environmental sensor, and GPS that provides velocity and the position, vision system such as radar, monocular and stereo vision, Automatic Identification System (AIS) to transmit the velocity, heading and the vessel type information to the other vessel, and Automatic Radar Plotting Aid (ARPA) for providing continuous target evaluation [2].

GPS is a crucial element in autonomous navigation for guiding USV towards correct trajectory path. The path has been designed in the USV onboard control system. A fundamental of a fully autonomous vehicle entails the use of GPS and compass module that emit USV a series of a waypoint for moving towards the target. According to Ghazi et al. [3], in other words, GPS provides an accurate data location longitude and latitude for monitoring purposes. For instance, USV platform uses the GPS trajectory data to move towards the waypoint, which has been planned in the predefined navigation map [4]. As a result, USV able to be guided by the GPS data to perform an auto-heading, as well as auto speed towards the target path [5].

Due to this circumstance, this project will develop a system that equipped USV with GPS and compass for tracking the path towards the target position on the water surface. In order to track the target, USV heading is a crucial element to make sure USV will move in the correct position. Breivik et al. [6] have done the research that contributed to straight-line target tracking without declaring the target behaviour in advance. However, this real-time tracking path is an important component in the climate system and plays a key role in moving in curvature motion. Based on this fact, recent developments in the field of the real-time autonomous navigation system of USV have led to a renewed interest in GPS with the mathematical equation.

Several researches work programmes have been undertaken to improve the reliability and accuracy of the Navigation, Guidance and Control (NGC) system. For example, Line of Sight (LOS) and Pure Pursuit (PP) [7-10] are used in the mission for reaching the target in the short period of time [7, 10, 11], Constant Bearing (CB) will be implemented in the system for communicating with the mother vessel, i.e., the motion of two vehicles [12-15]. A few papers used the backstepping method because these algorithms need to be combined with other techniques for making the USV zero of error when manoeuvring towards the target [16-19].

Jacobian task priority [20] and predictive trajectory [21, 22] planning are implemented in the controller to manoeuvre the USV in the low-level feedback controller, which are suitable for cluttered environment and Motion Goal Prediction usually will estimate the motion of the target for estimating the motion that the slave vessels need to follow [23]. Kalman filtering is usually implemented in the indoor positioning vehicle, whereby the vehicle will be guided using the GPS and the compass measurement [20]. Shamduddin et al. [24] mentioned that based on all paper, that have been revised, there are some constrain has been found, which is the implementation of the PP guidance was limited in the USV and the usage of the GPS data is limited to user monitoring only [24].

PP guidance technique is frequently used in the autonomous vehicle due to its ability for cutting the corner. Due to this condition, the popularity of PP guidance controller is the highest instead of other existing methods. Hence, this technique is implemented in the UAV, UUV, and AGV [5].

Lundgren [25] reported that the concept of PP guidance approach is to estimate the distance between the current pose of the USV towards the goal point by computing the curvature and identifying the look-ahead distance. The goal point will be determined in the same technique such as a follow-the-carrot algorithm to chase the prey. The whole point of the algorithm is to choose a goal position some distance ahead of the vehicle on the path. Next, a circle is then defined in such a way that it passes through both the goal point and the current vehicle position. Then, a control algorithm chooses a rudder angle in relation to this circle.

This paper proposes a new methodology for developing a navigation system that will determine a real-time of an unknown target location by using GPS. Besides, this paper also focuses on validating an ability of mathematical equation to compute USV heading towards the target coordinates. The implementation of GPS real-time data that associate with the PP guidance algorithm will be highlighted.

2. Sub-System Description

Three main parts will emphasize within this project that includes Identification of target, Transmission of data and Navigation Control.

2.1. Identification of target

Track identification is the process to get the position of the target that will be employed by USV platform. Besides, the target platform is the medium platform for identifying the unknown target position on the water. The status location of the target (X_G, Y_G) will be determined by satellites for getting the real-time location.

2.2. Central data observance room (CDOR)

CDOR takes a responsibility to receive information and transmission data from the target platform and USV platform. In-depth, the status of the location of the target and USV platform will be collected and appear on the Graphical User Interface (GUI) for monitoring purpose by the user. This GUI displays to the user the position of USV either receive the correct location or strays from the path. CDOR also will displays distance computation between target and USV platform that automatically calculated by USV platform.

2.3. Navigation control

Navigation control is the crucial part for performing a task, which guides USV follows the instruction between two waypoints, which designed by the controller. Besides, the USV platform is the medium platform for identifying the status of USV position (X_V, Y_V) on the water.

3. Material and Method

The following descriptions are the crucial hardware components used to communicate with the USV platform and Target platform.

Target platform

Target platform consists of two primary sensors, on-board GPS (GPS1) and onboard transceiver module (RF1). Within this project, the identification process will escort by the target platform for covering the recognition system responsibility.

Within this process, the current location of the target platform will be examined by onboard GPS1. Next, the raw data from GPS will send to Arduino Uno controller for giving the next instruction to transmit the instruction based on the output from the controller via RF1. hardware connection for Target platform was illustrated in Fig. 1.

3.2. USV platform

USV platform has equipped with several hardware components for performing a task that include SKM53 GPS module, RF(UART) Transceiver module, MPU6050 6DOF Accelerometer+ Gyro, High-Resolution Ultrasonic Range Finder, Arduino Mega 256 R3-Main Board, and motor for USV Propeller. Hardware connection for Target platform is shown in Fig. 1.

An SKM53 GPS shield is used to get the location, which acts as the target search by the USV platform in fact. Besides, SKM53 GPS was responsible for communicating with the 433 MHz RF (UART) Transceiver Module that broadcasting the commands of the position fix.

This study is associated with two Transceiver Modules for transmitting the target location commands and receives commands to compute the navigation route. Its wireless working frequency range is 433.4 to 473.0 MHz. MPU 6050 sensor module consists of three types of combination, which are three-axis gyroscope, three-axis accelerometer and digital motion control processor for balancing the vehicle position.

3.3. Hardware working principle

Figure 1 illustrates the block diagram of USV hardware architecture. The system is divided into two parts; target platform and USV platform. Target platform is left freely on the water surface with an unknown location. RF Transceiver module 2 in the USV platform receives the information signal from RF Transceiver module 1 in the target platform.

Then, the GPS module 2 get the current position of the USV and MPU6050 6DOF Accelerometer + Gyro will estimate the heading angle of the USV rigid body with the targets while High-Resolution Ultrasonic Range Finder will sense the location of the target.

After all the information of the target position and the rigid body commands have been stored and computed in the Arduino Mega 2560 R3-Main Board, the USV propeller will rotate based on the output commands.

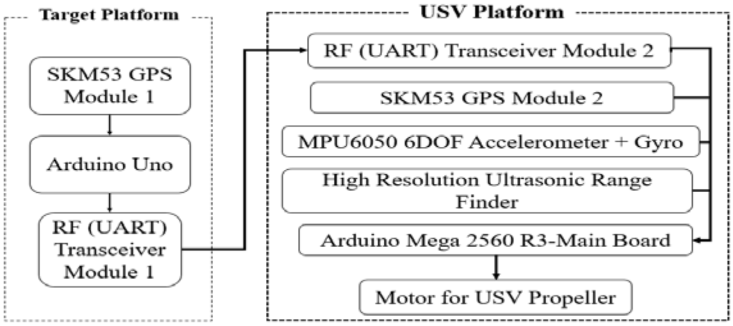

Fig. 1. Block diagram of USV hardware architecture.

4. Algorithm for Route Distance

The problem formulation of this study is divided into two parts, which are track identification and USV Heading control.

4.1. Track identification

Employment of the PP Guidance controller will engross in this part for estimating the future goal point (X_g, Y_g) by computing the goal point coordinate and the current USV body commands. Hence, the coordinate of (X_{fd}, Y_{fd}) will be computed by using Eqs. (1) and (2) [25].

$$X_{fd} = (X_g - X_C)\cos\theta + (Y_g - Y_C)\sin\theta \quad (1)$$

$$Y_{fd} = -(X_g - X_C)\sin\theta + (Y_g - Y_C)\cos\theta \quad (2)$$

4.2. Heading Control

Figure 2 shows an illustration of a PP guidance estimation approach. There are three main points are emphasized based on the illustration, which is the reference point (X_c, Y_c), (X_g, Y_g) and current position of the vehicle (X_{cg}, Y_{cg}). The value of r will be determined in Eq. (3) by estimating the line segment of d and x_L and the value of the chord line, which is looking ahead distance (la). Equation (3) will be implemented for correcting heading error occurred in the real-time.

$$\boldsymbol{r} = \frac{2x_L}{l_a} \quad (3)$$

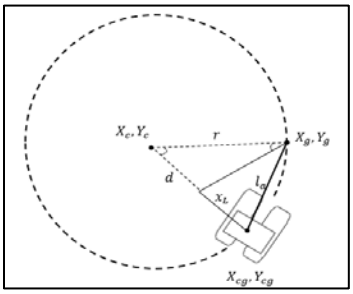

Fig. 2. PP Guidance estimation approach.

4.3. Working principle of PP guidance

In order to get the information status of the target location, the Target platform will need to receive series wireless data from USV platform for allowing the next instruction. USV platform will transmit the instruction to the target platform when these two platforms are in the range 1000 m at the open space.

The change of the USV heading angle is limited to the Eqs. (1) and (2) where X_{fd} and Y_{fd} is the distance position of the target platform and USV platform. This waypoint will be locked and converts from latitude/longitude to the northing or easting in the meter. Next, each update from GPS1 will trigger the algorithm to check either the USV platform has reached the position of the target platform. If not, GPS1 will send a new current location of the target platform to trigger the algorithm to identify a new X_{fd} and Y_{fd}. Hence, the new waypoint will convert as a current waypoint in USV.

5. Experimental Result

Full-scale experiments were carried out in UMP Lake, Pekan, where USV was, would track the target coordinates and catch the target in real-time. An output data of the target platform have been shown onto the laptop via the serial monitor. RF2 receives the position of the target platform and the data location have been transmitted via the antenna from the Arduino controller. Figure 3 shows the latitude and longitude data of the target platform that has been sent by the RF1 to the RF2. The data have been read and show on the serial monitor for every 10 seconds.

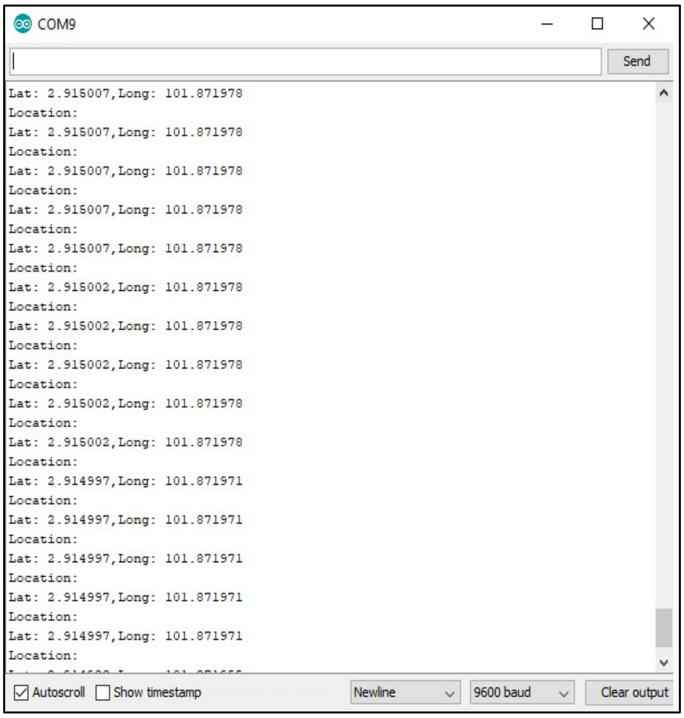

Fig. 3. Latitude and longitude reading of target platform via serial monitor.

Then, Global Navigation Satellites System (GNSS) is providing signals from space that transmit positioning and timing data to GNSS receivers. the receiver, which is GPS2 then use this data to determine the current location of the USV platform. By using this data location, the distance between two coordinates have been computed in the Arduino controller for every 10 seconds. Hence, the output data from the controller will be implemented into the GPS2 as a new waypoint towards the Target platform as shown in Fig. 4.

This new output data towards the target location is based on the computation by using PP Guidance Eqs. (1) and (2). In this situation, USV depends on the target platform location reading, which is updated in the microcontroller. In-depth, the reading of the data transmitted will give some error at a certain time due to the transmitting signal is beyond from the 1000 m on the water space. Figure 5 shows the position of USV platform interfaces in the Google Map for monitoring the actual location of this platform.

Figure 6 shows USV was proposed in the real situation for searching the target platform on the water surface. Figure 7 shows the results obtained from the preliminary analysis of USV Platform searching the Target Platform Location on the curvature path. This vehicle has been guided by itself to move towards the position based on the computation, USV platform will be stopped if the position of the target platform has been reached in around the 10 cm. Based on the comparison reading between mathematical equation reading and the compass reading, there is some error have occurred during the turning towards the target position. This is due to the interruption reading between mathematical equation heading routing for every 10 seconds.

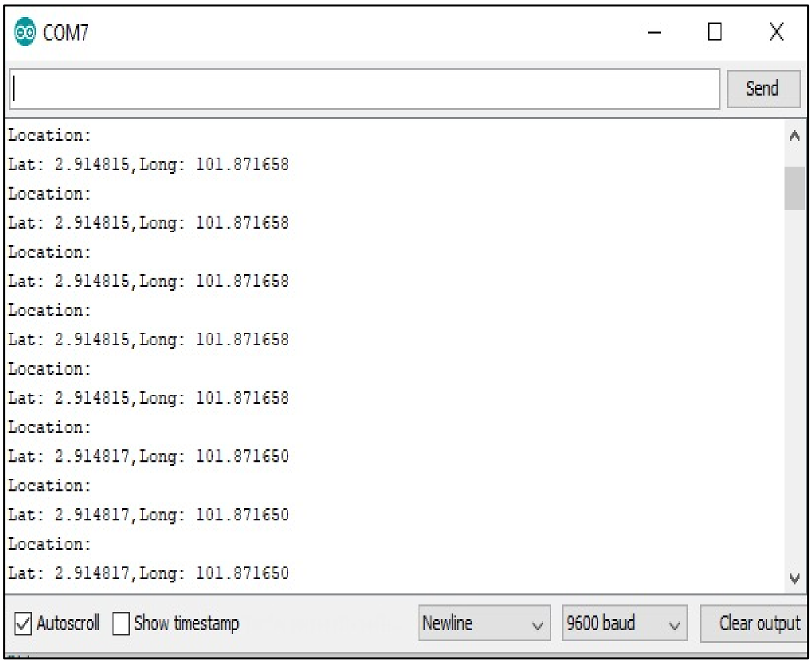

Fig. 4. New latitude and longitude reading towards target platform via serial monitor.

Fig. 5. Location on the Google Map.

Fig. 6. USV platform searching the target platform location.

Fig. 7. USV platform in the curvature path.

In the experiment, the target started about 107.50 m to the northeast of the USV, moving due north in a forward direction. USV started at rest with an initial heading 55.54 degree. It was moved to intercept the target position. However, the water flow of the USV movement during these experiments were far from the ideal conditions to intercept fast with the target. USV was stopped moved when USV position was reached the target position.

Figure 8 shows the coordinates of USV and target in the Universal Transverse Mercator Projection (UTM) coordinates system. Figure 9 shows the look-ahead distance between two points. Based on the graph, USV has followed the target coordinates by tracking every new position sent by the RF1 in 10 seconds. Figure 10 shows the difference between the desired target angle and current USV Heading. In this point, the controller will compute the differences heading angle then moves towards the desired waypoint.

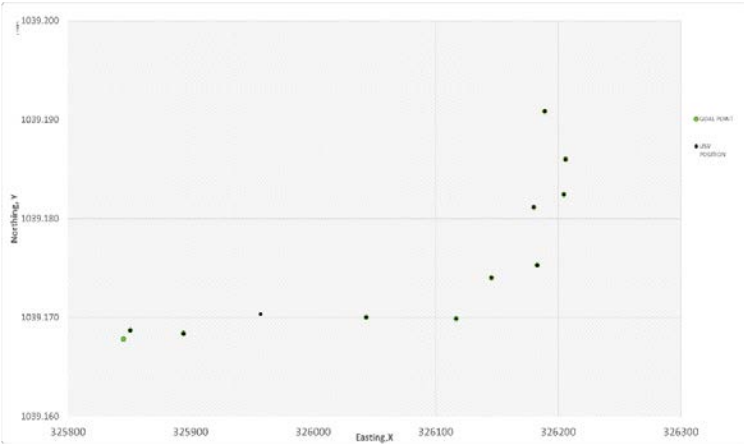

Fig. 8. USV and target waypoint navigation.

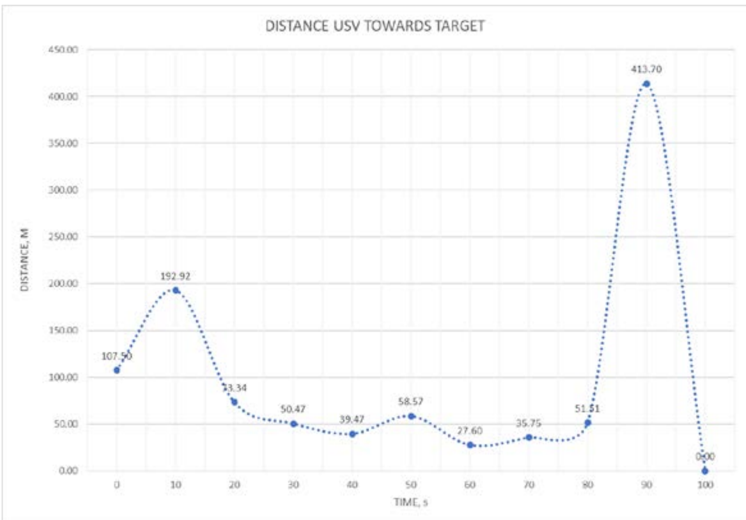

Fig. 9. Look-ahead distance USV towards target position.

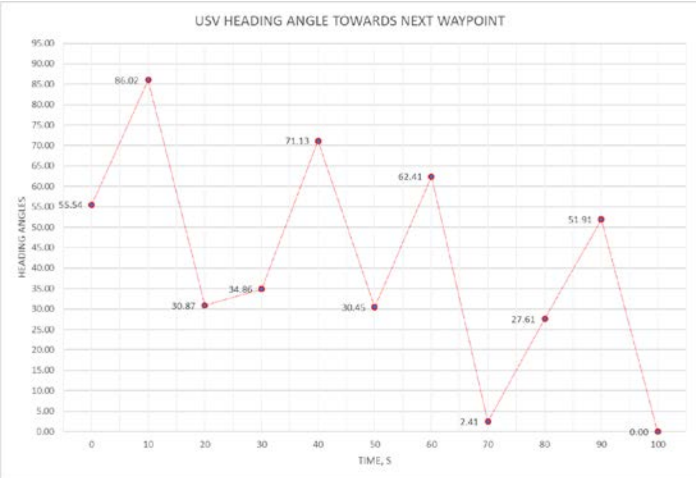

Fig. 10. USV heading angle towards waypoint.

6. Conclusions

This paper was undertaken to analyses path tracking performance for USV navigation system. The results of this research support the idea that USV platform can receive the real-time of an unknown target location on the water space whereby Both GPS is able to receive the GNSS signals from the space and store in the CDOR for every 10 seconds. The most obvious finding to emerge from this study is that the mathematical computation of PP Guidance is implemented in the USV platform for reach the target location that correcting the error occurred between USV heading and the target heading error path. Considerably more work will need to be done to determine some error occurred due to the sensors on-board. Further research is needed to develop a deeper understanding of the relationship between of USV and PID controller to overcome the interruption reading between mathematical equations heading routing to get the actual result.

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Nomenclatures

d	Distance between goal point with reference frame
l_a	Look-ahead distance
r	Radius between d to the goal point
X	x-axis in body frame
X_c	Centre point for x-coordinate
X_{fd}	New x-coordinate in USV
X_g	x-coordinate for goal point
X_0	x-axis in global frame
Y	y-axis in body frame
Y_c	Centre point for y-coordinate

Y_{fd}	New *y*-coordinate in USV
Y_g	*y*-coordinate for goal point
Y_0	*y*-axis in global frame
Abbreviations	
AGV	Autonomous Ground Vehicle
AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
DOF	Degree of Freedom
GPS	Global Positioning System
NED	North-East-Down system
NGC	Navigation Guidance and Control
PP	Pure Pursuit Guidance
RF	Radio Frequency
UART	Universal Asynchronous Receiver-Transmitter
USV	Unmanned Surface Vehicle

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