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Development of Waypoint Navigation System for Autonomous Vehicle

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***Abstract* – Autonomous vehicle can be used for various kinds of surveillance and data collection missions. The navigation and control system of the vehicle is the key to a successful mission. This paper emphasizes on the waypoint navigation system with Global Positioning System (GPS). The vehicle position in terms of latitude, longitude and heading is extracted from GPS NMEA protocol. The destination waypoints are predefined and the flight plan is preprogrammed in the Microchip PIC18F452 microcontroller. In this paper, rudder control navigation system is used while the elevator and aileron are being controlled by the FMA copilot. Through grounded tests the navigation system qualitatively proved to be able to complete levels.**

***Keywords* – GPS, Navigation System, waypoints, NMEA protocol, latitude, longitude.**

I. INTRODUCTION

There has been a great amount of research devoted to the global positioning system based navigation for mobile robot platforms and intelligent vehicles. The major navigational features of the GPS unit used in the solution of the GPS navigational problem are the ability to input/output NMEA (National Marine Electronics Association) messages, set target waypoints, and calculate bearing/range information to the target waypoint.

This research describes the development of the waypoint navigation system for autonomous vehicle using Global Positioning System. There are three main portions. The first portion is data acquisition system from GPS receiver. The second portion is flight control system which calculates the flight path angle. The third portion is servo control system which controls rudder servo whilst aileron and elevator servos are controlled by FMA copilot. The system was tested with the vehicle designed and constructed in Myanmar Aerospace and Engineering University. The purpose of this research work is to develop and implement fully autonomous vehicle. This research paper is the first step to achieve the desired mission.

II. OVERVIEW OF THE SYSTEM

The overall system block diagram is shown in Fig. 1. Two microcontrollers, PIC18F452 and PIC 16F628A are used as flight control unit and servo control unit respectively. GPS receiver is used to acquire the vehicle position and heading information. The switching system is used to change manual and autopilot control. Modems in the onboard control system and ground control station are used to receive the real time information of vehicle's position and heading from the GPS receiver. The real time data is displayed on computer at the ground control station. The transmitter at the ground control station is used for manual control in take off and landing state. It also sends command to switch on the autopilot control to the receiver. The receiver used in the onboard control system receives the command from the transmitter and sends the control signal to the servo motors.

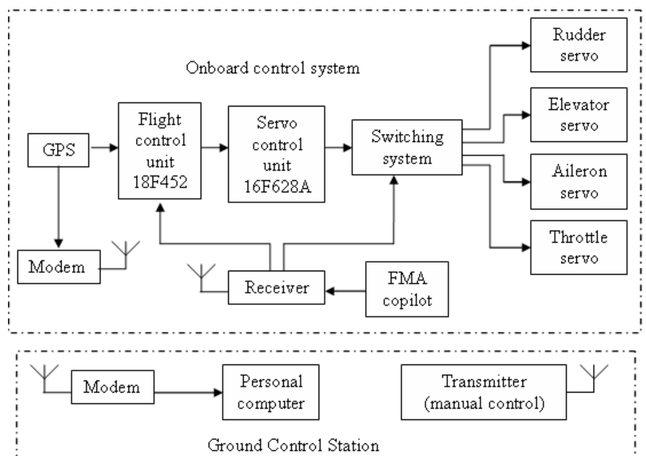

Fig. 1 Overall system block diagram

When the autopilot "switch on" command is received from the transmitter, the receiver passes this command to the flight control unit. The vehicle's take off and landing is done manually using the transmitter and receiver in the system. When the vehicle is in trimming condition, transmitter switches on the autopilot control. As soon as the autopilot on command is received from the receiver, the flight control unit starts data acquisition from the GPS receiver and calculates the flight path.

The current vehicle position is obtained from the GPS receiver. The flight control unit waits until the latitude, longitude and true heading of the current position is received. The received position and heading are in ASCII format. These are converted to hexadecimal form. The flight control unit compares the received location with predefined waypoints stored in the microcontroller. If the current location is not coincided with any of the predefined waypoint, the bearing angle to the waypoint is calculated. Then the calculated angle is sent to the servo controller. Servo controller generates the PWM signal with respect to the bearing angle to derive the servo motor.

III. Hardware Descriptions

Hardware used for waypoint navigation system of this research are GPS receiver, FMA copilot, microcontrollers, transmitter and receiver for remote control, Maxstream modem and servo motors.

A. GPS Receiver

Megallen Sport Trak GPS receiver is used in this research. This unit is an 11-channel GPS receiver, transmitting NMEA update messages at 1Hz through a local serial port.

B. FMA Copilot.

FMA copilot is a two-axis, four-sensor control-stabilization system that plugs into vehicle's Remote Control system.

C. Transmitter and Receiver for Remote Control

Radio receiver is a *Futaba FP-R148OP* which is a 7 channel PCM receiver. The receiver is controlled by a *Futaba T10CAP 10 channel* 2.4 GHz transmitter.

D. Wireless Data Communication Unit

For wireless data communication, Maxstream RF modems are used in this research work. They are used for GPS telemetry.

E. Servo Motors

Precision fixed-wing aerial vehicle and helicopters requires precise, high-tech servo motors. Most of the moving parts of an autonomous vehicle are controlled by these servos and these servos are controlled by either control unit in onboard system or a transmitter from the ground. Futaba digital servo motors are used in this research work.

F. Microcontrollers

PIC 18F452 and PIC 16F628A microcontrollers are used in this research. PIC 18F452 microcontroller is used as flight control unit. PIC 16F628A microcontroller is used as servo control unit.

IV. Flight Control Unit

The heart of the waypoint navigation system is the flight control unit. PIC 18F452 microcontroller is used as flight control unit in this research.

Flight control unit carries out three main tasks;

- data acquisition from NMEA sentences of the GPS
- calculation of flight path angle to reach the predefined destination waypoints
- sending the calculated angle to the servo control unit

G. Data Acquisition Process

The microcontroller listens out for RMC sentences sent by the GPS receiver in every second.

GPS receiver is capable of outputting various kinds of NMEA sentences. The only sentence that pertains to our needs is the GPRMC sentence. This sentence contains the data that is needed to our system. The GPRMC sentence format can be found in Table 1.

The information extract from RMC sentence is position (latitude and longitude) and heading angle. These data correspond to field number 3,4,5,6 and 8. Each field is separated by a comma. GPS baud rate is set to 9600 bps in this case. The received position and heading angle are in ASCII format. These ASCII characters are converted to hexadecimal form and stored in the registers of the flight control unit.

```
           1   2     3     4     5      6   7    8
$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,
230394,003.1,W*6A
   9      10   11  12
```

TABLE I
GPRMC Sentence Description (Magellan GPS)

1	Time, UTC of the position fix
2	Status, A = active or V= void
3-4	Latitude (N/S)
5-6	Longitude (E/W)
7	Speed over ground (knots)
8	Course over ground (degrees)
9	Date (ddmmyy)
10	Magnetic variation (degrees)
11	Magnetic variation (sense, E/W)
12	checksum

H. Calculation of Flight Path Angle

The target waypoints have been predefined to be navigated by the vehicle. They are then stored in the microcontroller memory. Each target waypoint is sequentially selected from memory.

There are some basic trigonometries to solve the equation of getting from one set of latitude and longitude, to another, or from waypoint to waypoint. This equation needed to solve the bearing to the next waypoint, as well as the distance to the destination waypoint [7]. In this research, the simplified waypoint navigation equations are used to make it easier for the PIC chip to process the equations. The latitude and longitude differences between two waypoints are calculated and the flight path angle is approximately calculated making the tangent inverse of latitude to longitude difference.

Four destination waypoints are used in this research. The received position and heading values are compared with the predefined waypoints. If the received position values coincide with one of the four waypoints, the microcontroller will give alarm signal and prepare to navigate the next waypoint. If the received position values coincide with none of the predefined waypoints, the flight control unit calculates the flight path angle to the nearest waypoint. The calculated flight path angle is then sent to the servo control unit using the USART module in the microcontroller. The microcontroller function algorithm is shown in Fig. 2.

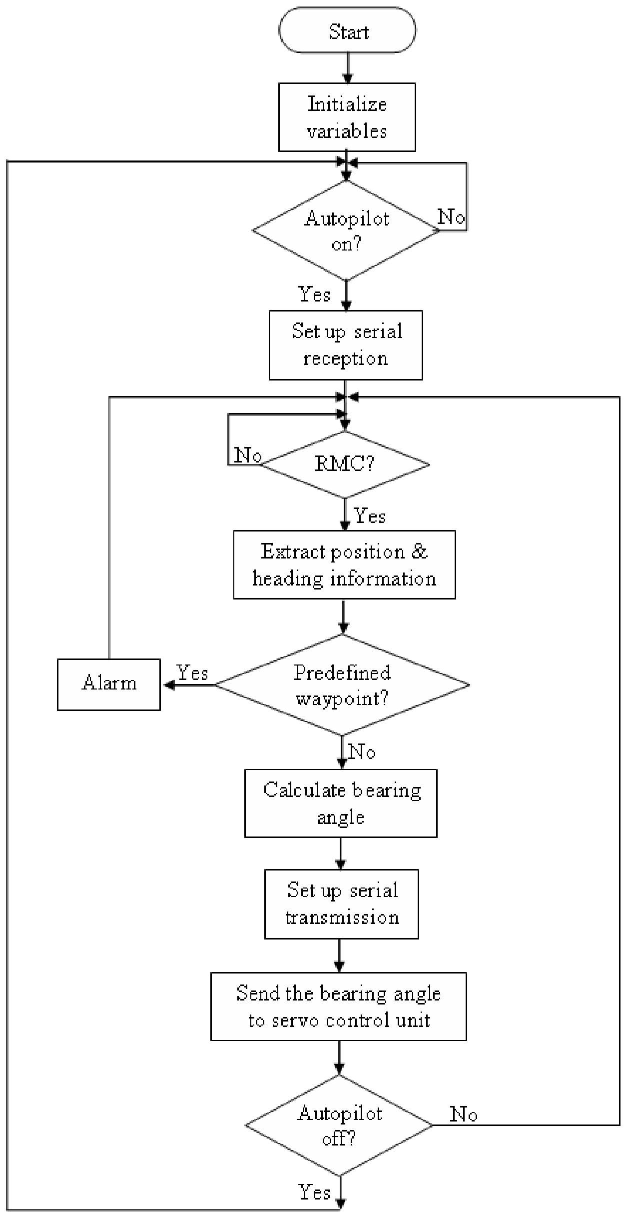

Fig. 2 Microcontroller function algorithm for waypoint navigation system

V. Servo Control Unit

PIC 16F628A is used as servo control unit. It is the interface between the flight control unit and the actuator of the system. It is used to generate PWM signals to the servos based on the flight path angle supplied by the flight control unit. This PWM signal controls a servo, shown in Fig 3, which in turn controls the rudder of the aircraft. This control unit has been implemented by another research candidate of our group.

When flying manually, all the servo control signals run directly from radio receiver through switching system to each servo. When flying autonomously, the servo signals are all generated by servo control unit based on the flight path angle received from flight control unit.

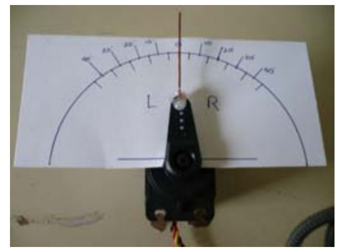

Fig. 3 Servo motor at central position (0 degree)

VI. Software Description

Both flight algorithm for waypoint navigation of flight control unit and PWM signal generation algorithm of servo control unit are written in assembly language. These algorithms are developed and compiled using MPLAB IDE version 8.36, and hex files are produced. HyperTerminal and GPS Track Maker software are used to display the real time data. GPS track maker software is used as the ground station control software in this research. It can be free downloaded from the internet.

VII. Tests and Results

A. Data acquisition

The data acquisition system is developed first with the PIC18F452 microcontroller. Only latitude and longitude of the vehicle position is extracted from NMEA sentence and displayed on personal computer using HyperTerminal. Then the heading data from NMEA sentence is also extracted to calculated the flight path angle.

B. Communication between flight and servo control unit

The serial communication between the flight control unit and servo control unit has been set up in the software and the servo deflection is tested in lab first. Fig 4 shows the tested photo of servo deflection.

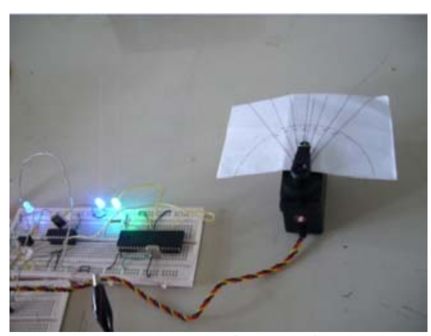

Fig. 4 Tested photo of servo deflection.

In this research work, servo deflection angle has been limited to ±10 deg to prevent losing stabilization.

The servo control unit in the system controls the rudder deflection which gives yawing condition of the vehicle. The servo motor mounted on the rudder control surface is shown in Fig. 5.

Fig. 5 Servo motor mounted on rudder control surface

C. Overall system implementation

The program has been tested and modified several times until the satisfactory results are obtained. The control algorithm in the microcontroller can also be simulated with the MPLAB Sim in the MPLAB IDE software. The overall control system is shown in Fig. 6.

Then FMA copilot is mounted on the vehicle, shown in Fig.7, to provide the control command to the aileron and elevator control surfaces for stabilization. This copilot is needed to calibrate to read the ambient IR heat; this is a two-step procedure. First, the vehicle's nose is placed on the ground with its tail sticking straight up and the sensor head facing away from human. Transmitter and receiver are turned on and then the push-button IR calibration switch is pressed. The control surfaces quickly deflected several times. After step one, the servos begins to cycle slowly. During this time, the airframe is placed on the ground in a level flight attitude. The unit then calibrates itself for level flight.

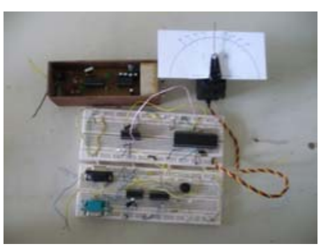

Fig. 6 Overall control system of waypoint navigation system

Fig. 7 FMA copilot mounted on the vehicle

Fig. 8 shows the circuit schematics of the waypoint navigation system. GPS receiver outputs its location data via its female DB9 connector. The pins in the connector are spliced using a male DB9 connector to hook up only transmit and ground pins to the Max 232. These pin are pin number 2 and 5 respectively. The pin number 12 of the max 232 is connected to the receive pin (pin number 26) of the flight control unit (PIC 18F452). The calculated flight path angle is transmitted via pin number 25 to the receive pin (pin number 7) of the PIC16F628A. The PWM signal with respect to the flight path angle is then generated in the microcontroller and output at pin number 6.

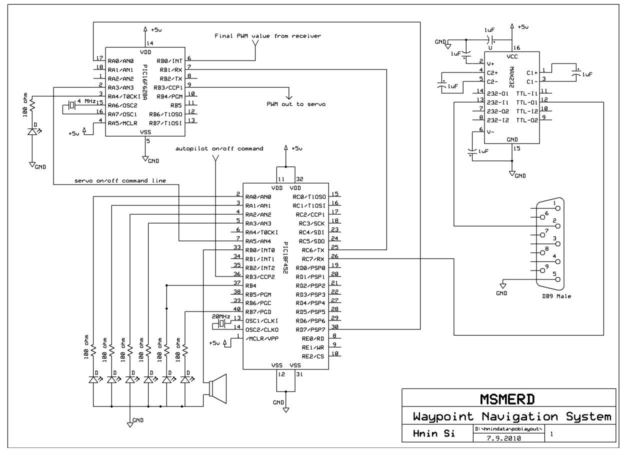

Fig. 8 Circuit schematic of the waypoint navigation system

D. Taxiing and ground test

Then the taxiing test of the waypoint navigation system is done with the experimental airframe shown in Fig. 9.

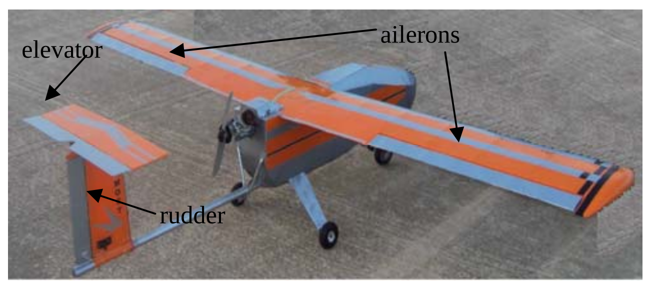

Fig. 9 Photograph of the airframe used in this research

For the flight path setting, the outdoor test is done first. Four waypoints are gathered and predefined in the microcontroller. The flight path set for testing is shown in Fig. 10. The value of GPS coordinates for these waypoints are shown in Table II.

TABLE II
DEFINITION OF TESTED WAYPOINTS

Waypoint Name	GPS coordinates
Point 1	2053.6935, N and 9553.8857, E
Point 2	2053.8282, N and 9553.8294, E
Point 3	2053.8302, N and 9553.7550, E
Point 4	2053.6963, N and 9553.8200, E

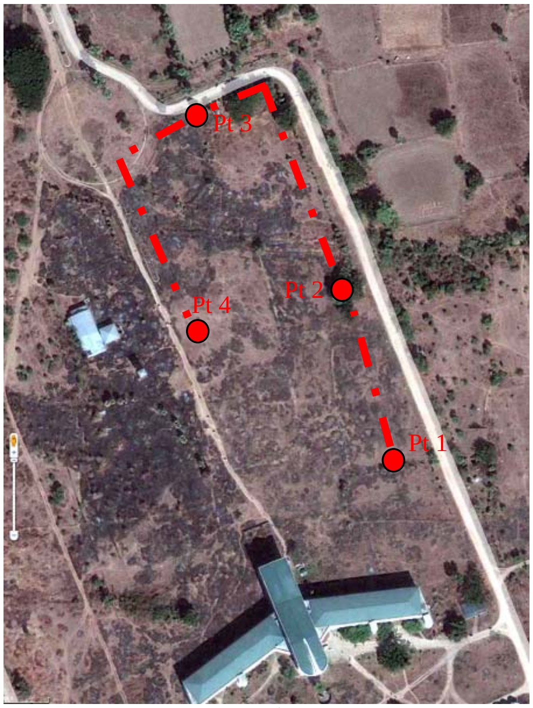

Fig. 10 Flight path set for testing in MAEU

As the servo deflection angle is limited within the range ±10 deg, the vehicle motion is zigzag instead of straight line. This draw back will be compensated in further development.

The real time data from GPS receiver is displayed on computer using GPS TrackMaker® software. The altitude profile, speed, heading, the vehicle position (latitude and longitude) can be seen in real time. The simulation window with GPS TrackMaker® is shown in Fig. 11.

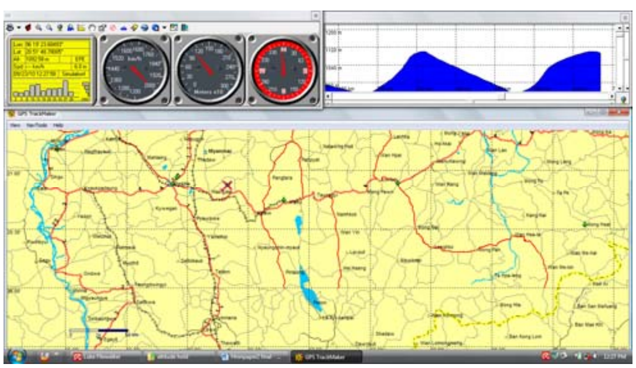
Fig. 11 Simulation window with GPS TrackMaker®

VIII. Conclusion

A number of experiments have been conducted to prove the quality of waypoint navigation algorithm. The test results show that our approach is applicable for autonomous vehicle. Through the research work, we gained experiences with autonomous vehicle control and autonomous navigation.

Only ground taxing is described in this research work as this research paper is the first step to achieve the desired mission.

The Global Positioning System (GPS) can provide long-term stability with high accuracy and worldwide coverage. Since the performance of the low cost GPS receiver can be easily degraded in high maneuvering environments, fusing the navigation data with other sensors such as accelerometers, gyroscope, altimeter, magnetometer or barometer is necessary. So GPS/INS system is considered for further research.

To reach the desired level of full autonomy, the vehicle has to be able to take off, navigate, and land without the direct control of a human operator. To achieve full autonomy, smarter airplanes need to be developed.

In the current condition, the UAV needs a ground station that receives and processes the GPS data and images from the onboard camera, runs the PID control loop and generates the necessary motion commands.

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