Development of Low-Cost Automatic Flight Control System for Unmanned Target Drone

Jang-Ho Lee*, Hyeok Ryu*, Jae-Eun Kim* and Iee-Ki Ahn*
* Department of Navigation and Control, Korea Aerospace Research Institute, Daejeon, Korea
(Tel : +82-42-860-2296; E-mail: jh7677@kari.re.kr)

Abstract: This paper describes development of automatic flight control system for an unmanned target drone which is operated by Korean army as for anti-air gun shooting training. Current target drone is operated by pilot control of on-board servo motor via remote control system. Automatic flight control system for the target drone greatly reduces work load of ground pilot and can increase application area of the drone. Most UAVs being operated nowadays use high-priced sensors as AHRS and IMU to measure the attitude, but those are costly. This paper introduces the development of low-cost automatic flight control system with low-cost sensors. The integrated automatic flight control system has been developed by integrating combining power module, switching module, monitoring module and RC receiver as an one module. The performance of automatic flight control system is verified by flight test.

Keywords: Unmanned Aerial Vehicle, Integrated Automatic Flight Control System, Flight Test

1. INTRODUCTION

This paper describes the development of automatic flight control system for an unmanned target drone which is used for anti-air gun training by Korean Army. The target drone is controlled manually, which means that ground pilot controls on-board servo motor via remote control system. Therefore, the ground pilot has to look at current aircraft state all flight time. This operational concept makes flight region very narrow, so application area of the drone is seriously limited. A great deal of work load is burden to the ground pilot on long range training such as over 2 km. For this operation, the ground pilot obtains aircraft state information thru a binocular telescope. In that case, there are high probabilities of the stress of the pilot and the danger of the aircraft crash. There has been in demand to develop automatic flight control system to operate the target drone at long range training or a night training.

Most UAVs which are developed until today use high-cost sensors as AHRS and IMU to measure the attitude, but those are contradictory for the reduction of budget. This paper says the development of low-cost automatic flight control system which makes possible of automatic flight with low-cost sensors. The integrated automatic flight control system(I-AFCS) has been developed by combining power module, switching module, monitoring module and RC receiver. The I-AFCS decreases the number of on-board cables required for system integration, and system reliability is seriously enhanced compare to previous modular AFCS. Fig 1. shows operation concept of the unmanned target drone and ground control system.

2. DEVELOPMENT OF INTEGRATED AUTOMATIC FLIGHT CONTROL SYSTEM

2.1 Needs of integration of modular AFCS

Development process of automatic flight control system is divided into many tasks like as requirement generation, architecture design, selection of components, performance verification of the components, system integration, and verification of overall performance via hardware-in-the-loop simulation test. And final performance of the system is evaluated by flight test. The on-board system of the target drone is composed of flight control computer, power module, switching module, monitoring module, R/C receiver, sensor(rate gyro, pressure altimeter, air speedometer, GPS), RF modem which are modular types. Fig. 2 shows you automatic flight control system which is composed of several modules. That is already developed in KARI[1].

Fig. 1 Operation concept of the unmanned target drone & ground control system.

Fig. 2 Modular type automatic flight control system

Most of faults detected in system integration using the M-AFCS resulted from complicated cables used to interconnect on-board modules. Also there are difficulties in maintenance and repair of M-AFCS. For the purpose of solving this problem and improving the performance of automatic flight, the I-AFCS has been developed by combining several modules into one box. One box configuration not only decreases probability of fault, but also enhances environmental characteristics, which is seriously
important for the target drone landed by parachute. Also it is convenience of using more on-board space compare with M-AFCS and easy to maintain and repair the devices.

2.2 Composition of I-AFCS and external connection

I-AFCS is composed of low-cost flight control computer(LCFCC), aircraft states monitoring module, power supply module, switching module used for operation mode change between manual mode and automatic mode, R/C receiver and several sensors. On-board sensor is composed of two pressure altimeter, airspeed meter, four one-axis rate gyro and three-axis accelerometer. As only 3 rate gyros and a pressure altimeter are necessary for automatic flight, additional 1 rate gyro and 1 altimeter are used for sensor redundancy. Fig 3. shows composition of I-AFCS and connection of device between on board systems.

2.3 Function of Internal Components

Flight Control Computer(FCC) performs acquisition of sensor signal, processing of command from GCS, calculation of auto flight algorithm and generation of PWM signal for servo motor control. It uses DSP TMS320C31 and offers 12 bit-16 channel A/D converter, 8 bit discrete I/O, 4 channel RS-232c, 8 channel PWM output, 128K byte NVRAM and two 128K bytes Flash ROM. Switching module is a device which connects to aircraft servo motor by choosing just one in PWM signal output from FCC or R/C receiver. Switching between manual mode and automatic mode is controlled by 1 channel PWM from R/C receiver or 4 bits of discrete output from FCC. Switching signal from FCC can override that of R/C receiver, and this function protects unintentional switching by PWM signal from anonymous source. Switching by R/C receiver signal makes it possible for the safety pilot to choose manual flight/auto flight of the aircraft and that by FCC is used to prevent it from abnormal behavior. Switching module uses relay and is designed to use signal from R/C receiver when the source of power is cut off. In this case safety pilot acquires the aircraft control authority and can make it recover safely by operating it manually. R/C receiver is a device which generates PWM signal for control the servo motor by transforming radio signal from remote control transmitter and used when the aircraft is operated manual mode on the ground. R/C receiver is supplied power directly from the external battery and this improves the confidence of manual flight control. Monitoring module offers the data for on-board system monitoring. This module transforms signals from battery, temperature sensor, and RPM transducer to analog signal with range of 0–5 volt, and the output signals used by FCC thru A/D converter. Power module generates 5V and 12V power signal from 12V battery output, and the outputs used in I-AFCS. The module adopts 15 watts DC/DC converter for voltage conversion, and output of the module is connected to switching module, on board sensor, monitoring module and GPS. FCC uses battery power directly because there is a power safety circuit inside.

2.4 Integration and development of I-AFCS components

The number of components installed in I-AFCS, installation requirement, overall size limitation and easy maintenance make internal architecture design of I-AFCS very difficult. The size limitation of I-AFCS has to be regarded, axis arrangement of rate gyros and accelerometers, tube path of air sensor, the simplification of cable connection and maintenance/repair to arrange on board components. FCC is located very close to the front board of I-AFCS because there are lots of connections with I-AFCS components and external connector. Case of FCC is newly developed to decrease the overall weight of I-AFCS. Installation of rate gyro and accelerometer is designed to satisfy axis alignment requirement. No internal damper is used for installation of components on I-AFCS, so installation brackets are designed to prevent the secondary vibration.

The power module has been made as a type of loading PS15-1212 and PS15-1205 DC/DC converter to PCB. Power module is placed to load at the top of the case because there's heat while it moves, and also frame earth.

The temperature sensor of monitoring module is AD22199 TO-92. The temperature measurement range is from -50° to 150° and the generating voltage is from 0.25V to 4.75V. The temperature sensor is placed near the rate gyro which
needs to measure the temperature. RPM sensing part deals with RPM sensor signal by LM2917 which is frequency/voltage converter, and the measurement range is from 0 to 15,300. Battery voltage monitoring module converts the input voltage to 0–5V DC so that three 0–12V voltage, one 0–5V voltage can be used at the flight control computer. 12V voltage battery monitoring module converts 9–15V voltage to 0.6–4.3V by using OP amp. LMC6402, and 5V voltage battery monitoring module is designed to minimize an electric current which is used as a battery voltage monitoring. The monitoring module is placed at the bottom of the inside of the I-AFCS. It was used to relay that G6A-474P, 4CH from Omron company as a switching module, and switch PWM signal five channels. 74LS04 is used to convert the PWM signal voltage which is for SSPS serve motor operation, and 74LS688 is for FCC overriding. Switching module is designed to be connected to the top of monitoring module.

Rate gyro which is among the loading sensor is CRS-03-01 from Silicon Sensing System company. It’s measurement range is -100~+100deg/sec, and it changes 20mV per 1deg/sec. Four rate gyros are loaded at the I-AFCS, each for three axis respectively, and one is added to yaw axis, which are loaded at the side of the case.

Three axis CXL04M3 from the Crossbow company is used as a rate gyro, and the measurement range of this sensor is -4~+4G and it changes 500mV per 1G. Accelerometers are loaded at the side of the case by standing in line on the aircraft body axis respectively. NS-ALM01 and NS-VEL01 from National Star company is used as pressure altimeter and air speedometer. The measurement range of pressure altimeter is 0–1800m, and that of air speedometer is 0–270km/h. Pressure altimeter and air speedometer is loaded at the side of rate gyro.

The final shape of I-AFCS is decided by considering the loading space of the aircraft body which is supposed to load this equipment. Especially cable connection line of inside of the aircraft is considered when deciding the shape. A shield plate also has been attached at the connection part of the case to prevent EMI, and use oil to prevent getting humidified when combining the case.

It is designed by considering the condition of environment such as wiring inside equipments and the vibration of the cable, and so on. Molex connector has been used about the connection of module and sensor by considering the maintaining and the repairing. Fig. 4 and Fig. 5 show you the final shape of the inside/outside of the I-AFCS through this planning process.

### 2.5 Selection of GPS sensor

In the low cost automatic flight control system, GPS is used for navigation sensor and heading data is derived from position information of the GPS. As described earlier, objective of this research is to develop low cost AFCS as cheap as possible with reasonable performance and system reliability. That is why unmanned target drone is consumable. The GPS sensor cost is more expensive as its frequency high. So Axiom GPS with 1Hz was adopted. Simulation of automatic flight control performance was performed with varying GPS frequency from 0.5Hz to 5.0Hz as shown in Fig. 6~Fig. 8. Flight mode is waypoint navigation mode with no wind effect. Aircraft stated at (0, 0) position. The location of waypoints is as below.

<table>
<thead>
<tr>
<th>Waypoint</th>
<th>East(m)</th>
<th>North(m)</th>
<th>Altitude(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1600</td>
<td>5000</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
<td>4000</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>0</td>
<td>500</td>
</tr>
</tbody>
</table>

![Fig. 4 External shape of I-AFCS.](image1)

![Fig. 5 Internal shape of I-AFCS.](image2)

![Fig. 6 Flight trajectory with 0.5Hz GPS frequency.](image3)

![Fig. 7 Flight trajectory with 1.0Hz GPS frequency.](image4)
Simulation results show that trajectory following performance is proportional to the output rate of GPS, and the system with 1Hz GPS provides reasonable performance for target drone mission. In our system, GPS used for car navigation is adopted with price $200.

3. FLIGHT TEST

Flight test is performed at the "Aircraft Performance Test Center" located in Go-Heung, which is the most southern part of Korean Peninsula.

The flight test was performed with setting up an on-board equipment on the unmanned target drone to verify performance of the automatic flight control system in Go-Hung Aeronautic Center. Pneumatic launcher for take-off was prepared. After the test equipment set up, various flight tests are performed following to test schedule in this site. In the first flight test, flight characteristics of aircraft with dummy mass simulating on-board system should be examined. This is a lesson learned obtained from a crash of aircraft with full on-board system.

3.1 Analysis of flight test

Launcher is set up for the take off of unmanned target drone in shown Fig 9.

Fig. 9 Unmanned target drone launcher for flight test.

Trim state of aircraft control surface was decided by manual flight which was using R/C transmitter after taking off, and in the auto flight mode, the FCC calculate the deflection of control surface in a basis of this trim state.

Semi auto mode was performed which was altitude hold and bank angle hold in 0 degree in the first flight test.

After entering the auto flight or semi auto flight mode, the efficiency of automatic flight control system was improved by changing the control gain of I-AFCS on unmanned target drone with monitoring the specific characteristics of flight.

Fig 10. shows aircraft trajectory after sending command form GCS to aircraft that bank angle hold in 0 degree after setting control surface trim state, the result of the flight is shown which is maintaining level flight with the constant altitude.

Fig. 10 Aircraft trajectory in level flight

The performance of semi auto flight is shown in Fig. 11 and Fig. 12. The heading angle hold mode was performed with altitude holding at 250 meters. In the first flight, heading angle was 140 degree. Flight trajectory was not exactly straight line. As expected, it is because of the GPS frequency. The heading angle is updated every seconds.

Fig. 11 Semi-auto flight trajectories.

Trajectory in Fig. 12 is obtained from a flight test with altitude hold and bank angle hold mode. In the flight, bank angle command is 3 and altitude command is 200m. In current I-AFCS system, the aircraft can not get commanded bank angle due to no attitude measurement of the aircraft. Instead of bank angle, I-AFCS is trying to hold constant yaw-rate. In small bank angle, yaw-angle hold provides bank angle hold.
like performance. Fig 13 shows time history of commanded altitude.

![Fig. 12 Semi-auto flight trajectory. (bank angle hold & altitude hold mode)](image)

**Fig. 12 Semi-auto flight trajectory. (bank angle hold & altitude hold mode)**

![Fig. 13 Time history of altitude. (bank angle hold & altitude hold mode)](image)

**Fig. 13 Time history of altitude. (bank angle hold & altitude hold mode)**

For performance evaluation of way point navigation mode, 4 way points are selected as Table 2. Fig. 14 shows aircraft trajectory obtained from flight test.

<table>
<thead>
<tr>
<th>Waypoint</th>
<th>East(m)</th>
<th>North(m)</th>
<th>Altitude(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>420</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
<td>450</td>
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<tr>
<td>3</td>
<td>100</td>
<td>-430</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>1100</td>
<td>-400</td>
<td>300</td>
</tr>
</tbody>
</table>

**Table 2 Position of waypoints from GCS.**

The target drone fly through prescribed waypoints with the sequence of pt.1→pt.2→pt.3→pt.4.

![Fig. 14 Waypoint navigation of unmanned target drone.](image)

**Fig. 14 Waypoint navigation of unmanned target drone.**

### 4. CONCLUSION

Low cost automatic flight control system for unmanned target drone was developed and various flight test was performed to verify the performance of I-AFCS successfully. It's expected to develop unmanned automatic flight control system for commercial use by improving automatic flight algorithm and on-board hardware.

### ACKNOWLEDGMENTS

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### REFERENCES


