In-House Development of Unmanned Aerial Vehicle Automatic Antenna Tracking System

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Graphical abstract

Angle Calibration for Tilt
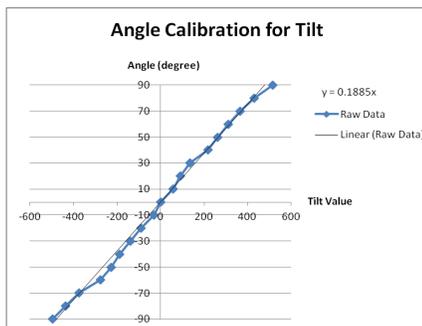
Abstract

The control of an unmanned aerial vehicle (UAV) requires a two-way radio communication between the UAV and ground control station (GCS). This radio communication is achieved through the use of antennas as medium of recital and transmission in the data-link system. This paper presents the project of an in-house low-cost development of a UAV automatic antenna tracking system. The presentation includes the control system design, hardware and software development, system integration and testing stage. The development ended with a successfully operational automatic antenna tracking system in a benchtop testing and validation.

Keywords: Antenna tracking system, closed-loop system, control system; patch antenna, unmanned aerial vehicle, aerospace engineering innovation

1.0 INTRODUCTION

Tracing the development of unmanned aerial vehicle (UAV), Fahlstrom and Gleason went back to late 19th century [1]. But some time after 1920s was when aerial vehicle first controlled remotely through radio communication [1,2]. Within this radio data-link, antennas were used as a hardware medium of communication. An efficient radio connection between antenna on-board of a UAV and the antenna on-board of ground control station (GCS) ensures the achievement of a variety of purposes:

1) Collection of telemetry data by GCS, i.e. data measured during flight e.g. environmental conditions and flight data;
2) Telecommand i.e. transmission of flight command to UAV;
3) Immediate downlink of photo and video (for UAV that is equipped with media capture technologies);

There are several choices of antennas, e.g. omni antenna and patch antenna, in the market today and these different designs provide different advantages. With the use of patch antenna, one has to direct the face of the patch to its recital-transmission path. In order to achieve this, a servo-mechanism has to be developed. Kuramoto *et al*. developed a mechanism for the control of antenna direction for land vehicle [3]. In their design, motion was controlled by signal strength against a certain threshold. Costa *et al*. also developed a steered antenna that requires scanning of signal strength [4]. The importance of providing a control mechanism for antennas in dynamic environment is further emphasized by Shimizu who used rate gyro as actuator and Haskell who provides electrical tilt to an antenna array system [5,6].

This paper presents the work that was carried out in an in-house development of a low-cost non-commercial antenna tracking system for UAV. It operates as a closed-loop system that receives

coordinate data and translates it for the directional control of 2 degree-of-freedom patch antennas. The sections include background of problem (Section 2), control system design (Section 3), methodology (Section 4) and lastly testing (Section 5). The methodology section elaborates on component selection, design and analysis, preparation of engineering drawing, system integration and assembly. Section 6 concludes the paper.

2.0 PROBLEM BACKGROUND

An automatic antenna tracking system (hereby called autotracker) was to be developed with the specification of having 1 omni antenna on-board of a medium-sized UAV and 2 patch antennas on GCS. Patch antenna falls under the class of directional antenna. Directional antennas radiate energy in patterns of lobes or beams that extend outward in one direction in a particular plane [7]. There are 2 distinctive advantages of using patch antenna over omni antenna and these advantages are as follows:

1) Patch antenna radiates signal in a directional pattern. Unlike the omni antenna that radiates in all direction, the omni antenna could not distinguish the desired signal from all other signals causing the desired signal to be weakly received.
2) Patch antenna can be directed to different directions. Therefore, it can increase the strength (gain) of the signal by changing its direction.

However, patch antenna has limited angular coverage, thus needs to be directed to the current position of UAV periodically as UAV changes position. For such a purpose, a servo-mechanism needed to be developed. Several requirements were identified during the development and an important one being the need for a closed-loop control system for an automatic servo-mechanism.

In such a system, angular bearing of UAV had to be collected from global positioning system, then transmitted through radio frequency and sent for servo motor actuation on GCS. The radio frequency was 900 MHz, 2.4 GHz or Enerlinks III. Through this actuation, the tracker shall respond by pointing the patch antenna to the position of the UAV. With a closed-loop system, the angular position error may be immediately corrected and subsequently the respond will be fast and accurate.

The servo-mechanism shall have two degrees of freedom and these were named:

1) Pan, referred to the angular direction of the antenna as seen from the sky or also known as azimuth. The data for this control was based on the latitudes and longitudes of the UAV and GCS.
2) Tilt, referred to the angular direction of the antenna as seen from the horizon or also known as elevation. The data for this control was based on the altitude and distance between the UAV and GCS. The distance was calculated from the latitudes and longitudes of the UAV and GCS.

3.0 CONTROL SYSTEM DESIGN

The purpose of sending data of the current UAV angular bearing, from time to time, to the autotracker processor is to ensure that the antennas can be directed to the UAV position. Without any check performed as to whether the alignment of direction is correct or wrong, the system is known as feedforward or open-loop control. The justification for a closed-loop autotracker control system is as follows. A closed-loop system allows the error of output from a system to be corrected by continuously adjusting the input to the system based on the difference between the targeted input and the current input. This is detected by measuring the actual position of the output (the antenna direction) and analyzes it together with the targeted input (angular bearing of UAV).
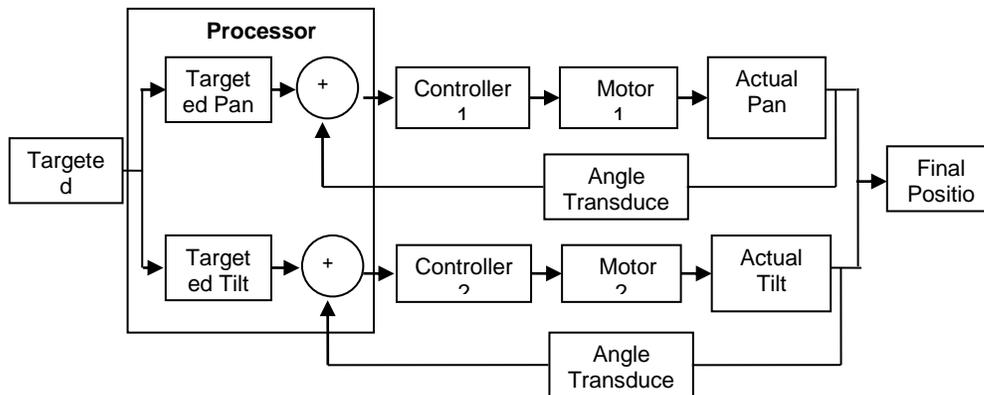
Figure 1 Closed-Loop Control System for UAV

As an addition to this correction, other aspects such as rise time, settling time and stability can be improved by providing suitable control algorithms to the calculated error. One method in achieving this is using PID algorithm. PID algorithm adjusts the error data based on the proportional, integral and derivative parameters. The values of these parameters can be set to achieve the system requirements. Advantages of PID system are well-written in many literatures (e.g. [8])

The whole control system is depicted in Figure 1. A set of components is needed which includes PID circuit boards, motors and transducers or generally referred as sensors.

4.0 METHODOLOGY

4.1 Components

4.1.1 Encoder

An encoder is a type of electrical sensor, or called transducer, that senses position and as shall be explained in Section 4.1.2, the circuit board chosen for the system needed a rotary encoder. As a requirement of the board, the encoder must have a quadrature-type feedback. Among many alternatives, AC58 quadrature encoder from Hengstler GmbH (Hengstler), based in Germany, was found to have wide applicability. It has a variety of functions and suitability. Among these choices, the encoder coded AC58 0017 A K.46 SC C was selected. The specifications of this encoder were [9]:

1) 17 bit resolution for a single turn reading;
2) 5 V DC operation;
3) Clamping-type flange, with shaft protection code IP64 (according to EN60529 and IEC529) and 9.52 mm shaft diameter;
4) Gray synchronous serial interface (+SinCos 1Vpp);
5) M23 (12 poles arranged in counter clockwise) axial connection.

These characteristics are important to achieve high accuracy, low operating voltage, adequate protection, easy assembly and wide interface capabilities. AC58 encoders were actually absolute type, as opposed to incremental, which means the reading that it makes is based on a predefined 0° starting point. This was important as it solves the need of calculating the new angular position every time data is sent from the command center of GCS. On the other hand, with an incremental encoder, a home cycle would be needed every time a new command was sent which then made it function as a pseudo-absolute encoder. Two AC58 encoders were needed for 2 motors.

4.1.2 Controller

Among the choices of PID circuit boards in the market, Gamoto board, manufactured by Gamatronix, was found to be the most suitable. Besides the fact that the price was accepted as reasonable, the operation of the board was found rather easy based on the descriptions provided in its user manual. A graphical user interface program called MotoView was also provided in the company's website where this program can be rewritten using Visual Basic 6.0 to suit the autotracker requirements [10].

However, 1 circuit board can only be used for 1 motor. Therefore, in order to control 2 motors (for pan and tilt, respectively), 2 circuit boards were needed. Only 1 of the circuit boards can be connected to a desktop personal computer or laptop. This is done through a serial level shifter, such as the RS232 9-pin connector. The boards can be connected to each other by a parallel connection as what was called serial sharing. It followed then that the communication protocol depended on the address, set by dip switches, of the boards.

4.1.3 Motor

The motor to be used for the autotracker must be suitable with the circuit board. The Gamoto circuit board functioned with a brush type DC motor with voltage within the range of 12 – 55 V. A suitable choice was the SSPS-105 motor, manufactured by Tonegawa Seiko Co. Ltd. It operates at 12 V [11]. Since there were 2 degrees of freedom for the autotracker, 2 motors were needed.

4.2 Design and Analysis

After the selection of the control system components, the autotracker mechanism was designed to suit the installment of the components. The installment of the encoders was the most crucial. Proper mechanical connection between the motor and the encoder must be achieved. The circuit boards were to be placed in a plastic box, then named control box. A number of manual analyses were made for critical components to identify suitable size with consideration of material and fabrication cost.

4.3 Engineering Drawing

Three-dimensional drawings of the encoder and motor were made using Solidworks 2007 followed by drawing of all mechanical components earlier designed with manual sketches [12]. During the designs, not only proper assembly towards the achievement of the 2 degree-of-freedom mechanism was aimed, other aspects such as aesthetics, weight balance and strength were also considered. To proceed with fabrication, orthographic engineering drawings were produced.

4.4 System Integration

Once the circuit boards had arrived, the boards were then tested for functionality. Several concerns

aroused and these were the circuit board power connection, the interface between circuit board and computer, the connection from 1 board to another board, the connection between circuit board and motor and also connection between circuit board and encoder.

4.4.1 Circuit Board Power Connection

The board required DC voltage within the range +7 to 16 V. Since the motor was functional with 12 V current, this much current was sent through 2 wires, input and output respectively, to the board through connector pinout J2 [13]. With the use of jumper JP1, motor power jumper, the current also flowed to the motor. In case separate wiring is needed, the current may be sent through connector pinout J8 [13].

4.4.2 Interface Between Circuit Board and Computer

The Gamoto circuit board only allowed RS232-to-TTL level shifter in its connection. The RS232 connector is also known as 9-pin serial-type connector. Only 3 pins needed to be attached to the computer those were ground, Rx and Tx. These same connections were needed to be wired through TTL connector to the board.

In the case that a RS232-TTL cable is not available, one may make one by connecting RS232 to TTL through a converter. One may choose to use a commercial dual converter as it saves the effort needed to connect to 2 different boards, as differed to a common single converter that can only be connected to 1 board. Such a converter may require a female-to-female 9-pin adapter and an electrical power within 7 to 18VDC. An in-house fabricated single converter was used. The converter needed at least 5 V power supply and so an additional wire was provided from Gamoto pinout J5 to the converter. Inclusive of this wire, there were 4 wires (supply power, ground, Tx and Rx) running from the converter, which operates with a MAX232 chip, to the board using a TTL connector.

4.4.3 Connection Between 2 Circuit Boards

The connection of the boards was made using a parallel connection. As one of the boards was connected to the computer with a RS232-TTL cable, 2 wires were set up to connect between pin Rx and Tx of the first board to pin Rx and Tx of the second board. The wires were soldered and connected to TTL connectors. Pins Rx and Tx were in connector pinout J5 [14].

4.4.4 Connection Between Controller Board and Motor

The connection between the controller circuit board and motor was rather simple. Only the two motor coil wires were needed to be attached to pinout J2 of the board. Different polarity would cause different rotational direction. However, since Tonegawa motor also had 3 more wires those were connected to its internal circuit board including potentiometer signal wire, the motor had to be disassembled so that the wires could be taken out. These tasks were carried out for both motors in the control system.

4.4.5 Connection Between Circuit Board and Encoder

The Hengstler AC58 encoder had an M23 Conin connector where out of 12 poles, only 4 poles were needed to be attached to the circuit board through pinout J6. These were the ground, positive voltage, A+ and B+ poles. The A+ and B+ poles form the quadrature signals that determine the angular position of the motor [9].

Based on the linkages between the encoder and the motor, different encoders transmitted data differently to the board. For the tilt operation, due to the orientation of the motor and encoder, when the motor rotated clockwise, the encoder rotated counterclockwise. Therefore, the A+ wire was connected to pin B of pinout J6. The pan operation which was assembled through a gear system had an opposite mechanism and therefore, A+ wire was connected to pin A of pinout J6.

4.5 Fabrication and Assembly

System assembly is composed of 2 activities i.e. assembly of mechanical components and assembly of electrical wiring.

4.5.1 Mechanical Component Fabrication and Assembly

The whole design needed about 20 main components. These components were fabricated from aluminium, aluminium alloy or stainless steel. Three spur gears made of stainless steel were also included. Once all the mechanical components were fabricated, the assembly was then carried out. Several fasteners and TIG welding works were required depending on the design. These fasteners include hex head screw, countersunk head screw and Phillips mushroom head screw of various sizes. No less than 170 screws and nuts were used.

Once the assembly was finished, it was then tested with the manufacturer's graphical user interface (GUI) at which point, an undesired current flow was detected on the metal frame. This caused the encoder to behave strangely. Due to this, the surface of the encoder had to be isolated from the frame. Actions were taken to redesign certain components and provide insulation by means of duct tape and nylon screws. Shown in Figure 2 is the tilt and pan mechanism of the autotracker.

Figure 2 Autotracker Tilt (left) and Pan Mechanism (right)

4.5.2 Assembly of Electrical Wiring

The circuit boards, RS232-TTL connector cable and TTL parallel cable were all placed into the control box, to ensure easy handling. This practice was also important as several switches were prepared for the boards and main power input in case of mishap. The complete control box is shown in Figure 3.

Figure 3 Autotracker control box

5.0 SYSTEM TEST AND VALIDATION

5.1 Test using Original Software

Once the system integration was completed, an initial test was made using the manufacturer's GUI software MotoView version 1.0.22. [14]. MotoView can only be used for different motors, one at a time since the transmission of command went to the board with the specified address setting. For example, if the address was set to 0, only the board with the dip switch setting 00000 reads the command. Before the encoders were integrated into

the system, the motors were only commanded to rotate either clockwise or counter clockwise and at different speeds. As the second stage of test which is after the encoders were connected, the motors were commanded to rotate to specific angles. At this stage, the encoder shafts were rotated by hand assuming a certain angle as the motor electrically rotate. Once the full assembly was achieved, the motors were tested to rotate to specific angles as the encoder shafts rotate along via mechanical linkages. These linkages were gear assemblies and flat metal linkages. The stages affirmed correct transfer of command and feedback.

An important purpose in performing these tests was to obtain the characteristics and sensitivity of the motor motion. As the slider was moved, the angle of the motor was noted. This was repeated for different values of slider positions. A characteristic that was observed was whether the motion was linearly proportional to the slider position. The sensitivity referred to how accurate the motor rotation followed the angle written in the GUI. Once these data had been obtained, the codes were ready to be modified. Figure 4 shows the relation between angle of rotation and slider position, referred as pan and tilt values respectively. Note that the motors behaviour was linear and that the pan values were half of the tilt values for the same angle because the encoder was connected through a 1:2 gear system.

5.2 Modification and Test using Modified Software

Programming work using Visual Basic 6.0 was needed to modify the original software to enable automatic transmission of UAV telemetry data (with the use of a specific software that acts as command center) to the Gamoto circuit boards. There were 2 challenges in this task:

1) To program Motoview to automatically read data from an external program;

2) To program the data in MotoView to be processed, separated and concurrently be transmitted to 2 boards.

As an early stage, MotoView was reprogrammed to read a notepad file containing a series of latitude, longitude and altitude data. These data represented the trajectory of a UAV during a flight mission. The data was read one after the other in the interval of 200ms.
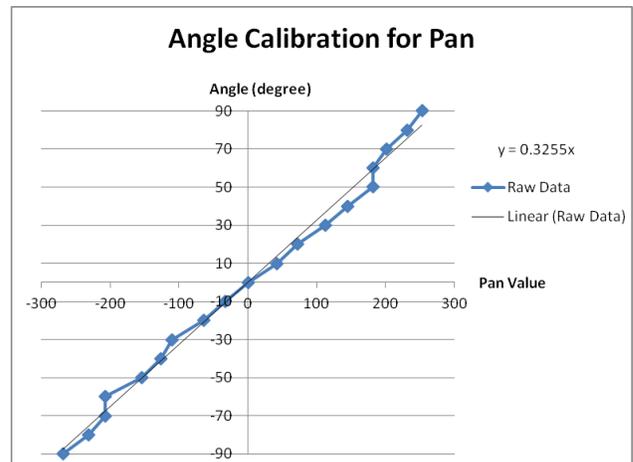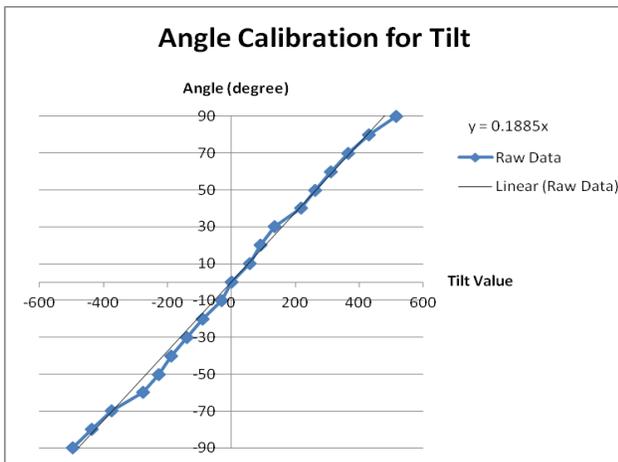
Figure 4 Angle versus Value in Tilt Calibration (left) and Pan Calibration (right)

As an early stage, MotoView was reprogrammed to read a notepad file containing a series of latitude, longitude and altitude data. These data represented the trajectory of a UAV during a flight mission. The data was read one after the other in the interval of 200ms.

Next, these data were calculated into different data i.e. range between UAV and GCS, and required pan and tilt angle using mathematical relations to an assumed GCS latitude, longitude and altitude. The angles must be between 90° to -90° for both pan and tilt. Such setting covered a hemisphere of coverage. The angles were then converted to pan and tilt values depending on the calibrated sensitivity of the motors. Since this program transferred data to 2 boards, the dip switch setting of the boards were set differently, specifically 00000 and 00001 to allow the microprocessors to differentiate the commands [13]. Among the 9 forms of MotoView, most modifications were made to frmAnalog and frmPID.
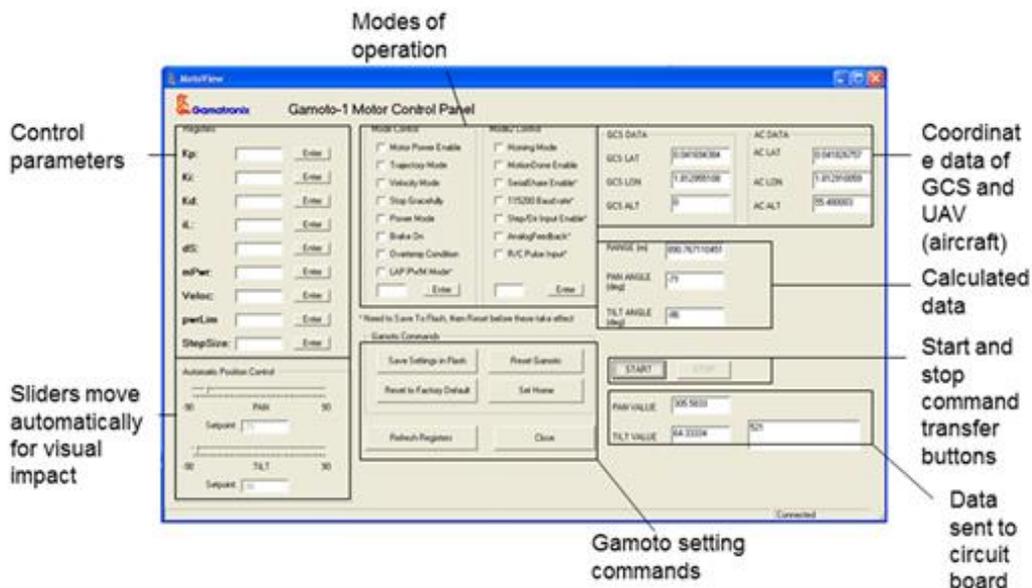
Figure 5 Modified MotoView frmPID Form in a Test

The program was successful in reading sequential latitude, longitude and altitude data from an external file and commanding the box platform and tilt platform to rotate to the required direction. These components responded to pan and tilt instructions, respectively. Shown in Figure 5 is the appearance of the GUI when a test was in progress. Note that the latitude, longitude and altitude of GCS and UAV are provided along with other calculated information. In the bottom left corner, the sliders moved according to the designated angular positions. Shown in Figure 6 is the communication log during a test. Note that in each of the TX line, the header is either "AA" or "AB". These were actually the commands sent to the boards, either board of address 0 or 1, respectively. Note also that the end protocols are different which reflects commands for different angular positions.
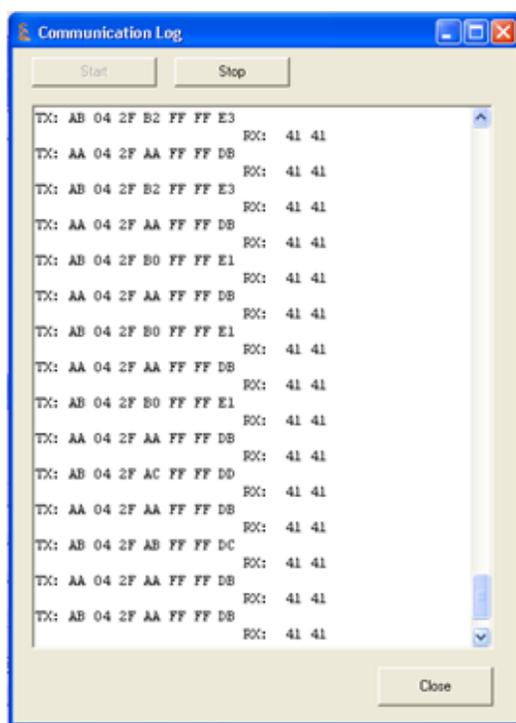
Figure 6 Communication log of autotracker test with modified motoview

6.0 CONCLUSION

The development of an automatic tracking mechanism for UAV requires thorough component search for compatibility and cost-saving. Then, the design stage took place with strength analyses of critical components. Once complete engineering drawings had been produced, fabrication followed by assembly and system integration took place.

Several initial tests with only the electronic components were made. Throughout the project, various technical problems were encountered. Among these problems were faulty electronic components, miscommunication between computer and hardware system and undesired electrical current flow. Finally a complete benchtop test was successfully completed where the autotracker was able to follow the desired direction in a closed-loop system. Future works shall be the improvement on the closed-loop system and its validation.

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