Design and Implementation of Autonomous Ground Control Station for Surveillance UAV

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ABSTRACT One of the world’s challenges in the contemporary time is insecurity at both national and international level. Across the globe, both governments and individuals are devising various ways to improve the security of life and properties. It has been observed that different environments and areas require different ways to resolve its insecurity issues. Unmanned Arial Vehicle (UAV) has become one of the tools being used to address some national security problems. This is particularly necessary in hostile environments or large facilities where it is not cost effective to have enough security personnel to man all the place at all times – an example is a big campus. Currently, the quest in UAV research is autonomous control of its missions. In this paper, the design and implementation of autonomous ground control station (GCS) for a micro UAV for campus surveillance is presented. The aim of this paper is to create and implement an unmanned aerial vehicle ground control station for manual and autonomous control of an UAV. The Gidan kwano campus of the Federal University of Technology Minna, was used as a case study for the implementation. The work does not entail manufacturing a UAV from scratch, but it requires selection, and modification of pre-fabricated UAV frames and then to develop and install the electronic and software controls. Works have been done on autonomous UAVs, but we are yet to have a UAV control algorithm indigenous to our environment. The autonomous control system was implemented on a Java desktop application software that drives UAVs through waypoints to surveillance missions. The type of artificial intelligence employed in this work is the expert system that uses inference engine to make decisions based on information received from the UAV telemetry circuit. The driving algorithm works by arming the UAV at a reference point, the UAV is then rotated to the direction of the mission, and it is moved forward by the GCS until it reaches its destination. The results obtained from field trials were promising, the manual control of the GCS worked efficiently, the telemetry circuit was able to send information from the UAV to the GCS for analysis and proper planning of the UAV mission, and the autonomous control of the GCS was able to arm the UAV as well as control it through waypoints to its mission. The developed system can be used for military operations such as surveillance missions and aid delivery purposes, and commercial purposes such as goods delivery services.

Keywords: Unmanned Arial Vehicle, UAV, artificial intelligence, autonomous ground control station, GCS,

1. Introduction

As early as 1920, multicopter vehicles were being designed, built, and used for experimentation with aerial vehicle projects (Anton Nakazawa, 2013). Unmanned
Aerial Vehicle (UAV) systems are aerial vehicles without on-board human pilots, which involve widespread human participation to achieve effective flight manoeuvres (F.B. da Silva, 2007). A modern UAV requires a lot of people to monitor several operations on the UAV during flight missions. Therefore, there is a significant amount of human interactions with the UAV system during flight operations, this is probably why confidence on UAVs remains to grow in military and civilian tasks. UAVs are planned from the onset to accomplish a particular task. So, all UAV systems have features that distinguish them from other air vehicles and they are usually categorised by the abilities of the UAV such as the flight-altitude, flight range and size of the UAV (Austin, 2010). They come in a variety of sizes, designs and functionalities, for example, the target and decoy, exploration, combat types, research and development, civil, and commercial UAVS. Initially, UAVs were controlled remotely but autonomous control is now becoming prevalent (Austin, 2010). It is envisioned that autonomous UAVs will be very useful in the area of security surveillance due to their ability to carry high definition cameras and their ability to operate in stealth mode at a very high altitude.

One of the world’s challenges in the contemporary time is insecurity at both national and international level. These are brought about by political unrest, religious intolerance all which has given rise to suicide bombings, kidnapping and the like. Across the globe, governments, groups, and individuals are devising various ways to improve the security of lives and properties. It has been observed that different environments and areas require different ways to resolve its insecurity issues. It is believed that refining security tools, such as UAVs, for better performance is necessary and should be a continuous exercise. Moreover, countries should design security tools that are customised to their peculiar security challenges. In this work, a ground control station for Unmanned Aerial Vehicles (UAVs) with autonomous and manual control is presented. This is designed to be used for surveillance operations in a campus environment. To achieve this the following subsystems were developed: (i) a telemetry circuit that can send control commands to a UAV and return data from the UAV’s GCS, (ii) the GCS driver software for autonomous control of the UAV was developed on a java platform, (iii) an android App for manual control of the UAV, this is necessary because manual control of the UAV may be necessary sometimes. The Gidan Kwano campus of the Federal University of Technology (FUT) Minna, was used as a case study for the implementation.

Gidan Kwano campus of the Federal University of Technology Minna is very big, covering about 10,000 hectares of land. There is yet no perimeter fence around this property, moreover, less than a quarter is currently occupied by the university. Certain security challenges like encroachment by villagers and cattle rearers, which among other ills, destroy agricultural research farms and sometimes attack students, are experienced. The encroachment of the University land, if not checked, will lead to eventual loss of such properties. It will be extremely expensive and inconvenient to employ and manage enough security operatives to patrol this expanse of land regularly, in order to check excesses. It is envisioned that the use of UAV will greatly reduce the cost of securing the campus, especially if this UAV is
locally enhanced. The enhancement done in this work is incorporation of the autono-
mous GCS with alternate manual control.

2. Related Works

Several works such as autonomous quadcopter docking system have been done on
autonomous UAVs, but the algorithm employed in these UAVs are either ineffi-
cient or not expressed clearly, moreover, to the best of our knowledge, we are yet
to have a UAV control algorithm indigenous to our environment. UAV applica-
tions have been changing from military applications to civilian uses such as aeri-
al photography, environmental surveillance, warehouse delivery, and disaster relief
operations. Most UAVs are often found to be expensive and complex. Moreover,
researches are still ongoing in micro UAVs some of which are bio-stimulated pro-
jects (Matt Parker, 2011). These designs are modelled in the form of insects and
birds, but just as the huge military UAVs are also costly. It is apparent that the mi-
cro-UAVs are too small to satisfy the essential technology (Matt Parker, 2011).
Though modern-day technology is quickly changing and improving, UAVs devel-
opments began decades ago, even before the first manned airplane flight occurred
in 1903. The initial efforts were made in France in the year 1782 by the Montgol-
fier brothers (Matt Parker, 2011).

Micro unmanned aerial vehicles are a fascinating point of study, (Matt Parker,
2011) made a research in this area and showed that there are several prototypes,
some of which are motivated by animals such as the flapping wing model. Authors
in (Andrew Gallagher, 2014) worked on surveillance UAV, the drone developed in
the work was light and able to meet the weight requirement of 1.8 kg as well as
transmitting video wirelessly. This work went beyond wireless transmission of
video as it incorporated autonomous control. In (Matt Parker, 2011), the work was
based on extending the transmission range of a UAV up to two miles radius, which
was very effective. (Mitra, 2013) tried to explore the possibilities of an autono-
mous UAV, the designed model was able to detect red surfaces and land on them
autonomously, but in this design, the UAV will also land on any red surface detect-
ed even the ones not meant for it to land on.

Though all drone models have several features that distinguish them from others,
they are frequently characterised by their functionality or magnitude of the aerial
vehicle that is needed for the execution of the mission (Anton Nakazawa, 2013).
According to (Anton Nakazawa, 2013), the terms presently in use for classification
of UAVs extend a range of models, from the high altitude long endurance (HALE),
which is an airplane of 35 m or greater wing span, down to the Nano air vehicles
(NAV) that could be just of 40 mm span. Classifications of UAVs according
(Anton Nakazawa, 2013) are as follows:

i. **HALE – High altitude long endurance.** Over 15,000 m in altitude and
   more than 24 hours fortitude. They can carry out enormously long-distance
   (trans-global) exploration and surveillance and can be equipped. They are
   frequently used by Air Forces from fixed air bases.
ii. **MALE** – *Medium altitude long endurance.* 5,000–15,000 m in altitude and 24 hours fortitude. The carry out missions that are like the HALE models but normally work at somewhat shorter distances, but still exceeds 500 km, and as well from fixed air bases.

iii. **TUAV** – *Medium Range or Tactical UAV* with range between 100 and 300 km, these UAV are smaller and operate inside simpler models than HALE or MALE and are functional also by land and naval forces.

iv. **MUAV or Mini UAV** – relates to UAV below a certain mass below 20 kg, but not as small as the MAV, these UAVs are proficient of being hand-launched and operate at distances that are up to about 30 km. These are, also, employed by mobile battle groups and predominantly for various civilian uses.

v. **Micro UAV or MAV.** The MAV was initially defined as a drone with a wing-span no greater than 150 mm. This has now been slightly relaxed but the MAV is primarily needed for missions in urban locations, predominantly inside structures. It is essential to fly gently, and preferably to hover and to ‘perch’ —i.e. to be able to stop and to sit on a wall or post. MAV are commonly anticipated to be thrown by hand and consequently winged models have very low wing loadings which ensure that they are very susceptible to atmospheric instability. This is the type of UAV employed in this work.

vi. **NAV – Nano Air Vehicles.** These are said to be of the size of sycamore seeds and used in groups for purposes such as radar misperception or imaginably, if camera, propulsion and control sub-systems can be made small enough, for ultra-short range observation.

vii. **RPH, remotely piloted helicopter or VTUAV, vertical take-off UAV.** These UAVs are proficient in vertical take-off. They are ordinarily proficient in vertical landing, and what can be sometimes are of even bigger operative importance, such as to hover flight through a task.

viii. **UCAV and UCAR.** These are UAVs which may fire weapons or even partake air-to-air battle. These are assumed the initials UCAV for drone battle air vehicle.

2. **Design Methodology**

2.1. **System Description**

The UAV used in this work comprise of: a QAV250 frame, four brushless D.C motors with two clockwise and two counter-clockwise 5030 propellers attached to them. The motors are controlled by ESCs (Electronic speed controllers) that vary
the brushless D.C motors’ speed and direction of rotation. The UAV’s primary parameters are controlled by a CC3D flight controller which is interfaced with an Arduino microcontroller. The Arduino microcontroller is responsible for the communication between the UAV’s artificial intelligence system and the ground control station. Two half-duplex transceivers of 400 MHz are used as full duplex and were used for transmitting data from the UAV to the GCS, as well as sending control commands to the UAV. At the ground control station, the RF transceivers are connected to the Java desktop application running on windows operating system via two serial ports. The Java desktop application is responsible for sending flight commands to the Arduino microcontroller residing on the UAV as well as retrieving the UAV information on the GCS. The design schematic is shown in figure 1, while the overall system flowchart is shown in figure 2.

Figure 1: System design schematic
3.2 Design Implementation

The implementation of the design was carried out in four phases which are: (i) the assemblage of the UAV chassis, (ii) the design of the UAV telemetry circuit, (iii) the design of the manual control system of the ground control station, and (iv) the design of the autonomous control phase of the ground control station.

(i) **UAV Assemblage**: the UAV chassis was selected after a thorough comparison of the available mini UAVs. The Lumenier QAV250 mini FPV Quadcopter Carbon Fibre edition chassis was the mini UAV chassis chosen, it is shown in Figure 3. Other parts of the UAV that made up the assemblage includes: Lipo Battery, Flight
controller, Brushless D.C. motors, Electronic speed controllers (ESCs), and NTSC FPV Camera.

(ii) UAV Telemetry Circuits: The telemetry circuit is the circuit responsible for sending data from the UAV to the ground control station, it sends data such as the GPS coordinates of the UAV, the number of satellites the drone’s GPS is locked onto, the yaw, pitch, and roll values of the UAV. It also receives control commands from the UAV ground control station. The telemetry circuit was separated into two parts in this work. The first part is the downlink circuit that sends the UAV’s information to the GCS, and the second part receives control messages from the GCS, both circuits transmit in the range of 400MHz – 500MHz.

Figure 3: QAV250 Chassis. Source (www.lumenier.com)

The downlink part of the telemetry circuit sends the following data to the GCS for proper planning and control of the drone when it is in autonomous mode: Number of satellites the UAV’s GPS is locked onto, the Latitude position of the UAV, the Longitude position, the Yaw value, Roll value, and pitch values, the altitude of the UAV above sea level. The uplink part of the telemetry circuit receives the following control command messages from the GCS for the manoeuvring the UAV: Yaw, Pitch, Roll, and Throttle values. These control commands are received via the uplink RF receiver that operates at 410 MHz, which is a different from the downlink frequency in order as to avoid interference between the two signals. The message received by the RF receiver is decoded by the arduino Nano that it is connected to. The message is then converted to pulse position modulation signal which is sent to the flight controller for appropriate flight action on the UAV.

Pulse position modulation is a kind of signal modulation whereby Q message bits are encoded by transmitting a single pulse in one 2Q likely needed time shifts. This reoccurs every T seconds in a way that the transmitted bit rate is Q/T bits per second. It is suitable for fast and accurate transfer of data from the GCS to the flight controller. A complete PPM frame is about 22.5 ms. The signal low state is always 0.3 ms and it normally begins with a high state of about 2 ms with each
channel (8 channels) being encoded by the time of the high state which is given by the formula

\[
PPM \text{ high state} + 0.3 \times (PPM \text{ low state} = \text{servo PWM pulse state} \, (\mu s)
\]

(iii) GCS Manual Control Design: The Ground Control Station (GCS) manual control design implementation was done by interfacing an Ebyte RF transmitter with a Bluetooth module, which is connected to an android application that can be used to send control commands to the UAV. The Graphical User Interface (GUI) of the android application is shown in Figure 4. Once the GCS transmitter receives control message from the Bluetooth module, it forwards it to the receiver residing on the UAV and the command is effected on the UAV.

(iv) GCS Autonomous Control Design: The driving algorithm works by arming the UAV at a reference point. The GPS coordinates of the drone are acquired from the UAV downlink telemetry circuit and the drone is now shown on the Map. The mission information is then fed into the GCS by the operator. The autonomous control starts by arming the UAV, rotating the UAV to the direction of the mission, and it is moved forward by the GCS until it reaches its destination. Any alteration in the path of the UAV is corrected by the flight controller and when the flight controller fails, it is corrected by the GCS autonomous control algorithm.
The GCS autonomous control was implemented with an expert system. An expert system is used to pass the knowledge of controlling the UAV to the UAV GCS java desktop application. Expert system was implemented by testing the UAV in manual mode in different locations. The latitude and longitude information received from the UAV through the downlink telemetry gives the GSC knowledge of where the drone is in space, and the distance to be travelled to execute the mission is known to the GCS. Any disorientation of the UAV is noticed by a difference in the yaw value of the UAV and it is then corrected by the GCS if the drone fails to correct it appropriately. The graphical user interface (GUI) of the Java desktop application is shown in figure 5.

3. Results

Figure 5 shows a screen shot of the designed GUI of the developed Java desktop application. Figure 6 presents a picture of the manual flight test of the UAV, while figure 7 shows a picture of the drone as it is being armed for surveillance mission. Figures 8 – 11 show the responsiveness of the java desktop application during an autonomous missions.
Figure 6: Manual Flight test (this test shows that the drone responds to the manual control)

Figure 7: Flight test
Figure 10: Mission Flight 3

Figure 11: Mission Flight 4
5. Discussion

The figures 5-11 show the results obtained during various tests of the designed system. The evaluation of the designed manual system was carried by testing the manual control of the GCS on the campus grounds. Figure 6 presents a picture of the manual flight test using the developed android application for manual controls, this means that the drone responds to the manual control system. Being on android platform, it means that with a smart phone, one could manually control the drone when necessary. The autonomous system was evaluated by using the developed Java application to carry out surveillance missions. Figure 5 shows a picture of the Java desktop application when a mission waypoints were being marked, the white dots joined by lines shows the different waypoints the UAV will be navigated to during the execution of an autonomous mission. Figure 8-11 shows different positions of the UAV on the map as an autonomous mission was being executed.

This designed model is a prototype that covered about 500 meters radius, range expansion is possible but will require an increase in the capacity of the battery for longer flight time to cover a greater distance. The range of the antenna used on the UAV will also be increased for better reception of signal to and from the GCS. The effective range of a UAV for surveillance is about 1km radius. For proper coverage of a large campus, multiple number of this micro UAVs will be deployed. Our future research will be focusing on communications between UAVs while on mission such that there could be transmission of control and mission information from one UAV to another to ensure coverage of a wider perimeter.

6. Conclusion

This paper presented the design and implementation of an unmanned aerial vehicle ground control station for campus surveillance with autonomous control, using the Federal University of Technology Minna as a case study. It explored the creation of an artificial intelligence system using an expert system approach. An alternate manual control with an android application was developed to manually control the UAV by interfacing it with a Bluetooth module. The android application could control the four basic parameters of an aerial vehicle; the roll, pitch, yaw and throttle. The Java desktop application was developed using Java Programming language. The autonomous control works by an operator marking out the waypoints the UAV will go through. Once the waypoints have been marked, the autonomous system will rotate the UAV to the direction of the waypoint and move it there, it will do this for all waypoints to the end of the mission. The system created, besides campus surveillance, can also be employed for military uses such as aid delivery purposes, surveillance, and it can also be used for commercial purposes such as goods delivery services.

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