Autopilot and Ground Control Station for UAV

Duarte Lopes Figueiredo
duarte.figueiredo@ist.utl.pt

Instituto Superior Técnico, Lisboa, Portugal

November 2014

Abstract

The Unmanned Air Vehicle sector has become the most dynamic growth sector in the aerospace industry. There are more and more civillian applications that greatly benefit from the use of these aircrafts. With the growing number of commercial UAVs there will be cheaper technologies that will allow for flight performances similar to more expensive ones. The objective of this work is to test and implement an autopilot and a ground control station for an UAV that is being developed in a colaborative project by IST (*Instituto Superior Técnico*), FEUP (*Faculdade de Engenharia da Universidade do Porto*) and UBI (*Universidade da Beira Interior*) under the sponsorship of LAETA (*Laboratório Associado de Energia, Transportes e Aeronáutica*). It is also expected to implement a Remote Person View system along with the autopilot. The autopilot that was chosen to be implemented is the Ardupilot APM 2.6, which is an open source, low cost autopilot. This will help reduce the total cost of the project, while also offering similar performances to commercial autopilots. This autopilot can be used in different types of vehicles, and provides an ground control station station software called Mission Planner. In order to safely test the autopilot without the risk of damaging any component it was first installed on a rover. This allowed for a complete test of the autopilot operation modes and also for an analysis of the functioning of the Remote Person View system. The autopilot operation modes performed correctly after some configurations of the autopilot parameters. The Remote Person View system also worked correctly but there were some interferences between the video transmitter and the vehicles radio receiver. The autopilot was then tested in the UAV. The first tests conducted were ground test to check how the control surfaces reacted. They responded correctly to the controller and the autopilot inputs. After the ground test, the UAV was flown in the several flight modes provided by the autopilot. The autopilot proved to be working correctly even with the default parameter settings In this work, it was analysed and implemented an autopilot solution for an UAV. It was found that an open source autopilot can be used to transform a simple commercial radio controlled vehicle into an autonomous, remotely piloted vehicle at a low cost. For future work, the autopilot should be installed and tunned in the long endurance electric UAV, once the project is finished.
Keywords: Autonomous Flight, Remotely Piloted Vehicle, Artificial Cockpit, Flight Control, Rover

1. Introduction

The UAV sector has become the most dynamic growth sector of the world aerospace world, with expectations of reaching a market value of over 8.000 million by 2018 [1].

Being initially developed for military applications due to their potential in replacing humans in high risk missions and for being a cheaper option, this market is now turning its focus to the civilian side. Applications such monitoring crops, wildlife or traffic, or even aerial photography or video, can take advantage of the numerous UAVs capabilities.

In May of 2013 there were about 4000 UAVs operating worldwide [2], with the majority being small ISR (intelligence, surveillance and reconnaissence) platforms, with only a small part being used for civil applications such as agriculture, but, within five years, FAA (*Federal Aviation Administration*) estimates that there will be 7500 commercial UAVs flying in the USA's airspace alone [3].

With the growing number of civilian UAVs that are being developed, in the foreseeable future there will be cheaper technologies that can provide a similar performance to more expensive ones. With this in mind, this project objective was to implement and test an open source autopilot, along with a ground control station, in a civilian, low cost, solar powered UAV. It was also expected to implement a RPV (Remote Person View) system in the aircraft, which allows the user to have a real time video feed transmitted from the UAV.

2. Background

This work is part of a project of a long endurance electric unmanned aircraft vehicle (LEEUAV) that is being developed in a collaborative project by IST (*Instituto Superior Técnico*), FEUP (*Faculdade de Engenharia da Universidade do Porto*) and UBI (*Universidade da Beira Interior*) under the sponsorship of LAETA (*Laboratório Associado de Energia, Transportes e Aeronáutica*). The main objective was to implement and test an autopilot and a ground control station for the UAV, which allows the aircraft to be flown autonomously and to be remotely controlled. By installing the RPV system in the aircraft, it is possible to have a real time video feed from the aircraft's point of view. The UAV's project main goal is to develop a low cost, small footprint electric UAV shown in Figure 1, that is capable of being deployed from short airfields, easy to build and maintain, and highly flexible to perform different civilian surveillance missions.

Figure 1: Long endurance electic UAV [4].

2.1. Available Autopilot Solutions

The UAV project requires that the autopilot implemented in the aircraft fullfils the following criteria:

- Small Dimensions and Weight;
- Low Price;
- Waypoint Following Capabilities;
- Auto Take-Off and Landing Capabilities;
- Configurable.

Based on this requirements several autopilots were analysed and compared in order to choose the most appropriate autopilot. There were several solutions found in this process and both commercial and open source solutions were accessed.

The classification of each autopilot is presented in Table 1. In each autopilot there is a reference link in which a detailed description can be found. The objective of this classification is to analyse which autopilot best fullfills the requirements of the UAV. Each autopilot was classified from 1 to 6 in the following decision criteria:

- Dimensions - In order to maximize the payload capability of the UAV it is important that the autopilot has small dimensions;
- Weight - Having an autopilot with lower weight is important as it will reduce the total weight of the UAV;
- Price - The UAV project will benefit from a low cost autopilot;
- Functions - It is required that the autopilot has several functions such as waypoint following and auto take-off and landing;
- Hardware - In this criteria it will be accessed the hardware capabilites of the autopilot;
- Software - The software capabilites of the autopilot are an important part of the autopilot. Being able to operate the software in different operating systems and being able to configure the autopilot will provide the UAV with greater flexibility.

	Dimensions	Weight	Price	Functions	Hardware	Software	Total
VECTOR[5]	1	1	1	6	6	5	3.33
MP2028^{g}[6]	3	5	2	5	5	4	4.00
Kestrel v2.4[7]	5	6	1	5	5	4	4.00
Piccolo SL[8]	2	2	3	5	5	4	3.50
APM 2.6[9]	5	5	6	6	6	6	**5.67**
Revolution[10]	6	6	6	3	5	6	5.33

Table 1: Evaluation of researched autopilot solutions.

The first four solutions are commercial autopilots, while APM 2.6 and Openpilot Revolution are open source solutions. Based on the comparison made the open source solutions achieved better marks as these autopilots share almost the same functions of the commercial autopilots at a very competitive price. Since the APM 2.6 offers more functions thant the Openpilot Revolution, it was chosen to be used in this thesis work.

3. Implementation

After selecting the autopilot that would be used in the UAV, it was first assembled with its components, and checked if it was working correctly. The ground control station and the RPV system were also accessed in this phase. It was then decided that it would be best to install the autopilot system on a rover, before installing it on the UAV. This would reduce the risk of damaging any component. After testing the system on the rover, it was then installed on the UAV.

3.1. Ardupilot APM 2.6

The APM 2.6, shown in Figure 2, has dedicated ports to connect the GPS module, the compass, a power module that will supply the required power to the board and a telemetry radio. The autopilot uses a telemetry radio in order to communicate with the ground control station. It also has an USB port that allows it to be connected to a computer in order to upload the desired firmware. The board has several analog ports that can be connected to different sensors. It can be connected to an RC controller through input ports, and it sends control commands to servos through the output ports.

Figure 2: Ardupilot APM 2.6 [9].

This autopilot has several flight modes that can be configured through the software. These modes vary accordingly to the type of vehicle that is being used. The primary mode is Manual, that allows for full manual control of the vehicle. Some modes provide some flight stabilization such as lateral or longitudinal stabilization or even altitude hold. This modes are only available for aircraft vehicles. The more complex mode is Auto, which allows the vehicle to perform a mission, such as waypoint following, or even auto take-off and landing (in aircrafts). The mission must be first created in the ground control station and then be uploaded to the autopilot.

The Ardupilot board needs to be supplied by a power source and this is achieved by using a 3DR Power Module [9], shown in Figure 3. This can be connected to the battery that powers the servos of the UAV while also supplying the ardupilot board with the required power. The Power Module also allows the monitoring of the battery voltage level in the Mission Planner.

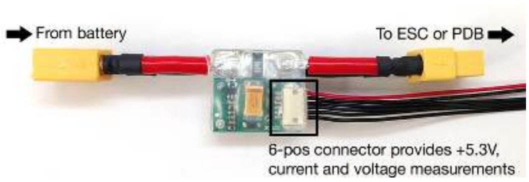


Figure 3: 3DR Power Module [9].

The GPS and Compass data are provided by the 3DR GPS Module [9], shown in Figure 4.

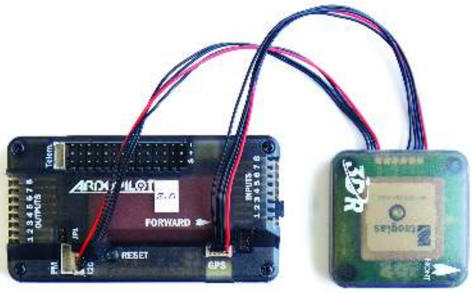


Figure 4: 3DR GPS Module [9].

The airspeed sensor, shown in Figure 5, has a pressure sensor and a pitot tube. It measures the airspeed which helps the autopilot in windy conditions, slow flight and autonomous landings. The top tube of the sensor measures the dynamic pressure of the air flow that passes through the pitot tube, and the bottom tube measures the static pressure of the air.

(a) Pressure sensor [9].

(b) Pitot tube

Figure 5: Airspeed Sensor.

The Sonar sensor [9], shown in Figure 6, provides obstacle avoidance functionality for the Ardupilot. It measures the distance between the sensor and an obstacle in front of it.

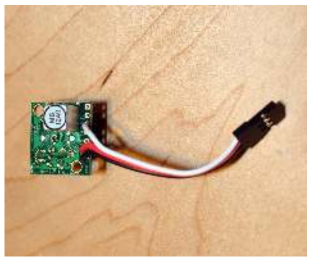


Figure 6: Sonar sensor [9].

The telemetry connection between the autopilot and the ground station is achieved by using 3DR Radios [9], shown in Figure 7. The radio with the USB cable is connected to the ground station computer, while the other is directly connected to the Ardupilot board.

Figure 7: Telemetry radios.

3.2. Ground Control Station

Ardupilot provides an open source software called Mission Planner, shown in Figure 8 that is used in the ground control station. Mission Planner provides a user-friendly interface that allows quick interactions between the ground controller and the aircraft. The ground controller can monitor several flight parameters, such as airspeed, altitude, heading, among others and can even see the current position of the vehicle in a map.

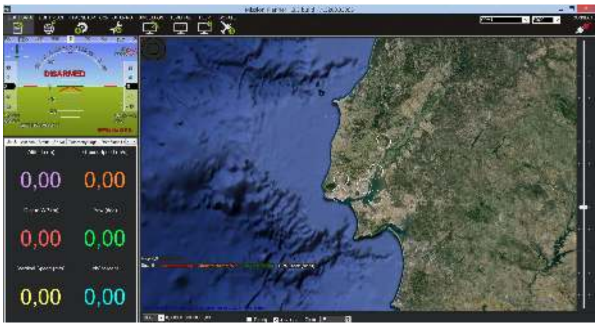


Figure 8: Mission Planner.

It is also through this software that the autopilot is configured. It allows the upload of the required firmware based on the type of vehicle that is being used.

There is a tab in the Mission Planner where a mission profile can be created. In these missions waypoints can be specified for the vehicle to follow. It can then be uploaded to the autopilot using the telemetry communication between the ground station and the vehicle.

3.3. Remote Person View

To fly the aircraft using a RPV system it was used a camera, an OSD (On Screen Display) and a video transmitter connected through the telemetry port as schematicaly shown in Figure 9. An OSD overlays the flight data to the video from the camera. This information is then transmitted to the ground through the video transmitter. The flight data that is displayed can be configured through the OSD software.

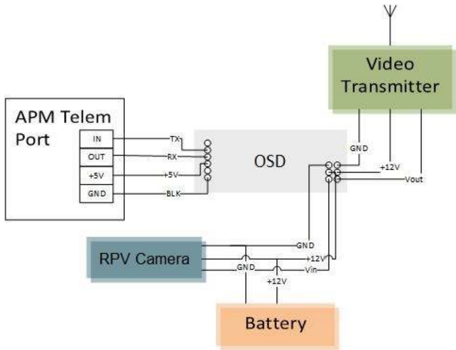


Figure 9: OSD connection.

Figure 10 shows the RPV system that is mounted on the vehicle.

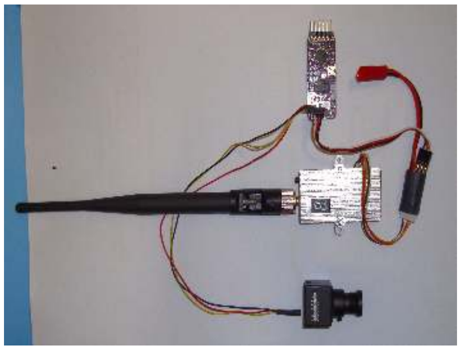


Figure 10: RPV system.

To receive the OSD data on the ground it was used a video receiver connected to a monitor, as shown in Figure 11. As the video receiver and the RPV monitor were powered by a battery it allowed the system to be mobile.

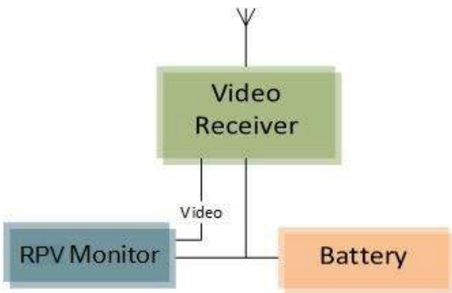


Figure 11: OSD receiver connection.

In order for the radio telemetry that connects the autopilot to the Mission Planner and the RPV system to work simultaneously, an Y cable must be used in the telemetry port. In Figure 12 it is shown the complete ground control station with the RPV system.

Figure 12: Ground station and RPV system.

3.4. Rover Implementation

The autopilot was first installed on a Radio Controlled (RC) model car, allowing it to be used as a rover. To this end it was required that the autopilot was loaded with the correct firmware which is the *ArduRover v2.45*.

The RC receiver was connected to the autopilot inputs as shown in Table 2. The autopilot outputs were connected to the car steering servo and motor speed controller (ESC) as shown in table 3.

RC Rx	**APM Input**	**Function**
1	1	Steering
2	3	Throttle
5	8	Mode
6	7	Record Waypoint

Table 2: Input channels.

APM Output	**Car**	**Function**
1	Servo	Steering
3	Motor/ESC	Throttle

Table 3: Output channels.

The RC car with the autopilot system installed onboard is shown in Figure 13.

Figure 13: Rover test platform.

The next step was to correctly calibrate the RC radio settings in the Mission Planner. Once this step was completed, it was necessary to choose the flight modes that can be switched with the selected toggle switch. The flight modes chosen were the following:

- MANUAL mode - This mode allows for total manual control of the vehicle. The rover is driven with the RC transmitter with the throttle and steering being manually controlled. It does not require a GPS lock to control the vehicle.
- LEARNING mode - The steering and throttle are also manually controled but the vehicle can record waypoints provided it has acquired GPS lock.
- AUTO mode - In this mode the vehicle will follow a mission that was previously set up in the Mission Planner, or recorded in LEARNING mode. The steering and throttle are controlled by the autopilot. If the RC connection is lost the vehicle will enter HOLD mode.
- HOLD mode - The vehicle immediately comes to a full stop.
- Return to Launch (RTL) mode - When this mode is activated the vehicle will automatically return to its HOME position. This is the location where it first had a GPS lock when the system was powered up.

Since that the rover relies on compass information for steering it was also required to calibrate the compass readings.

3.5. UAV Implementation

The procedures to install the autopilot system on an aircraft are similar to those required to install it on the RC car. The correct firmware to use an aircraft as an UAV is the *Arduplane v3.1.0*

The RC receiver channels were connected to the APM inputs as shown in Table 4. The autopilot outputs were connected to the aircraft servos as shown in Figure 14.

RC Rx	APM Input	Function
2	1	Roll/Aileron
3	2	Pitch/Elevator
1	3	Throttle
4	4	Yaw/Rudder
6	8	Aux4(Mode Switch)

Table 4: Input channels.

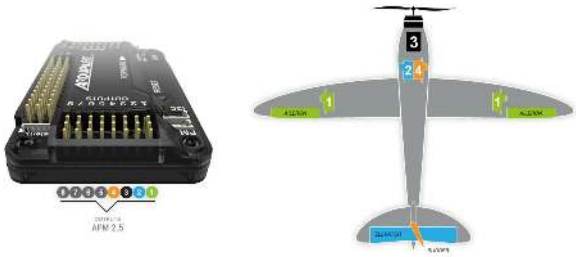


Figure 14: APM outputs [9].

The autopilot was installed on the plane with the RC inputs facing forward and the servo outputs facing back. The GPS module was installed on top of the plane so that it had a clear view of the sky and was as far way as possible from radio transmission equipment.

Figure 15: UAV test platform.

The configurations made for the autopilot to work on the UAV were similar to those made for the rover. The RC radio settings were calibrated and the following flight modes were chosen:

- MANUAL mode - The aircraft is manually driven without any stabilization provided by the autopilot.
- STABILIZE mode - This mode provides RC control with simple stabilization. If no control inputs are applied the autopilot levels the plane.
- FLY BY WIRE_A mode - The autopilot will hold the roll and pitch specified by the control inputs. The throttle is manually controlled.
- LOITER mode - In this mode the aircraft will circle around a point where it was ordered to loiter, holding its current altitude.
- GUIDED mode - This mode allows the aircraft to be flown with the ground control station without setting up a mission. Using the Mission Planner "Click to Fly" feature, the operator can click on the map to send the UAV to the desired location. It will then enter LOITER mode at that position.
- AUTO mode - It is used for the aircraft to follow missions. Besides waypoint following it also allows the aircraft to automatically take-off and land when it is set in the mission profile.

4. Results

The analysis of the autopilot system conducted before installing it on the rover proved that the system was correctly assembled. This preliminary analysis was crucial for the development of the next phases of the project. The RPV system was tested and it worked as expected. After this inital phase, the system was tested on the rover platform, and on the final phase of the project it was tested on the UAV.

4.1. Rover Ground Testing

The ground testing phase main objective was to check if the autopilot system, along with the RPV, and the rover radio receiver and servos, was correctly assembled and configured. It was also important to analyse and improve, if possible, the behaviour of the autopilot in the several flight modes and to correct any problem that was not expected.

The tests were conducted at the sports field in *Instituto Superior Técnico*, as it provided a wide flat ground with a clear view to the sky. It also provided landmarks that were helpfull to compare the vehicle current position with the position displayed on the Mission Planner map.

The system was first tested using the telemetry connection but with the RPV system disconnected. It took a couple of minutes to acquire a GPS lock, but the error of the position displayed on the ground control station was small, epecially when the GPS acquired six or more sattelites.

After analysing the GPS performance, the rover was driven in the several flight modes. The MANUAL mode worked as expected providing full manual control throught the radio controller. The rover was then driven in LEARNING mode, and several waypoints were recorded. First, it was record simple rectangular tracks and, later, tracks such as shown in Figure 16. After having some courses recorded

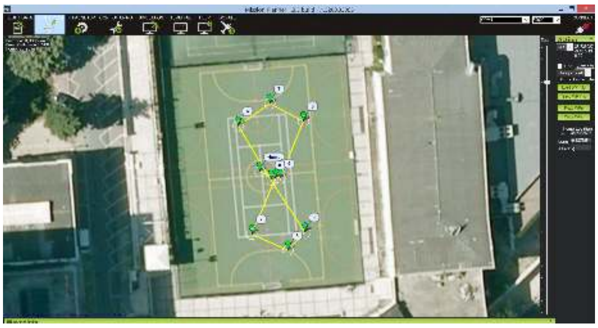


Figure 16: Figure 8 track.

for the autopilot to follow, the AUTO mode was tested. There were some difficulties at the beginning, but after manipulating some autopilot parameters, the rover followed the courses with no difficulties. The HOLD mode was also tested, and the rover would immediately come to a full stop when it was triggered. Finally, the RTL mode was tested, and it drove the rover to the Home location as expected.

After concluding the analysis of the flight modes of the rover, the RPV system was connected and its performance analysed. The video and OSD data was correctly received at the RPV monitor, as shown in Figure 17. However, there were some problems as the video transmitter signal interfered with the reception of the radion controller signal, causing the rover to lose the controller signal at a distance of around 10 meters. After moving the antenna of the radio receiver of the rover, the distance at which the rover lost the controller signal increased to around 20 meters. There was also a problem with the video transmitter as it overheated when turned on for some time, but this was corrected by installing an heat dissipation plate on it.

4.2. UAV Flight Testing

The flight testing phase was separated in two parts. The first part consisted of UAV ground tests and the objective was to check if the system was correctly assembled. The second part consisted of flight tests with the objective of analysing the autopilot behaviour and improving its performance.

The first part of the tests were conducted at *Instituto Superior Técnico*. It was made an overall check regarding the stability of the autopilot module, shown in Figure 18.

The pitot tube was initially mounted on this platform, but since it would be directly behind the propeller of the UAV, it would have erroneous readings.

Figure 17: OSD display.

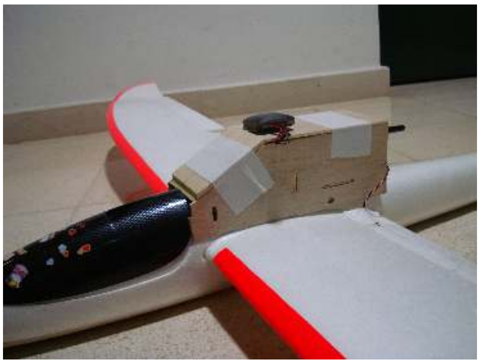


Figure 18: UAV autopilot module.

This was corrected by installing the pitot tube and the pressure sensor in the left wing of the UAV, as shown in Figure 19.

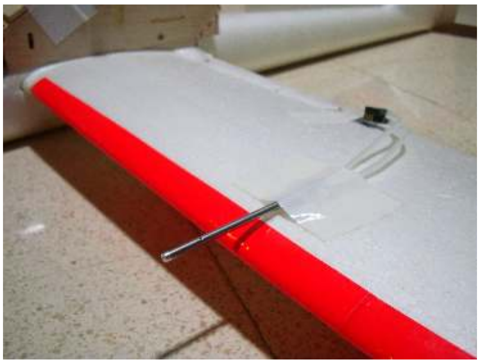


Figure 19: UAV pitot tube.

After having the system correctly installed on the aircraft, the next ground tests conducted were to check if the control surfaces responded to inputs from the radio controller. To check this, the system was connected to the Mission Planner and the autopilot flight mode was set to MANUAL. Then, all the UAV servos were individually inspected and checked to see how they responded to simple control inputs. It was verified that all the control surfaces and the throttle responded correctly to the control commands sent by the radio controller.

The last step of the ground tests were to verify how the autopilot would stabilize the plane when it was pitched or rolled. To verify this, the autopilot flight mode was set to STABILIZE and the aircraft was rolled and pitched several times. It was verified that the control surfaces would react in order to stabilize the plane. When the aircraft was rolled, the autopilot would use the ailerons to bring the plane back to the initial position. When the aircraft was pitched, the autopilot would use the elevator to correct its pitch angle. If there was any sideslip angle, the rudder would be activated.

These tests ensured that the autopilot was correctly installed and that the UAV was ready for the flight test phase. The flight test phase was conducted at *Base Area №1* in Sintra. This provided a large runway where the flight tests could be safely conducted.

The first test conducted was to check if there was any interference between the radio controller of the aircraft and the telemetry radio link. The aircraft was manually conducted to a distance of around 200 meters and the control surfaces were activated using the radio controller. It was verified that the aircraft was correctly responding to any control input and that the telemetry information was being correctly received at the ground station computer.

The aircraft was then flied for the first time. The first flight objective was to analyse the performance of the autopilot in MANUAL mode and in STABILIZE mode. The aircraft was hand lanched in MANUAL mode and it was flown for some time to check its behaviour. The autopilot provided full manual control of the aircraft as expected. The flight mode was then changed to STABILIZE. When there where no control inputs applied to the aircraft, the autopilot automatically leveled the plane. This mode provided a stable flight while also allowing manual control of the UAV. The altitude profile of this flight is shown in Figure 20.

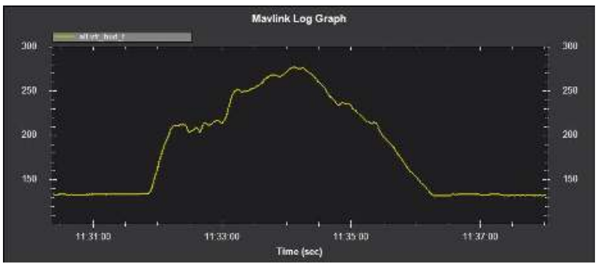


Figure 20: First flight altitude profile.

To test the autopilot AUTO mode it was created a simple rectangular mission shown in Figure 21. The aircraft would fly the waypoints at an altitude of 100 meters relative to the ground.

Figure 21: UAV flight test mission.

The UAV was hand launched in MANUAL mode and when it was at the correct altitude the flight mode was changed to AUTO. The altitude profile is shown in Figure 22. When the AUTO mode was triggered the aircraft immediately flew to the first waypoint of the mission. It then followed the mission without any issue. When the aircraft completes the mission it returns to its HOME position and it loiters above that position.

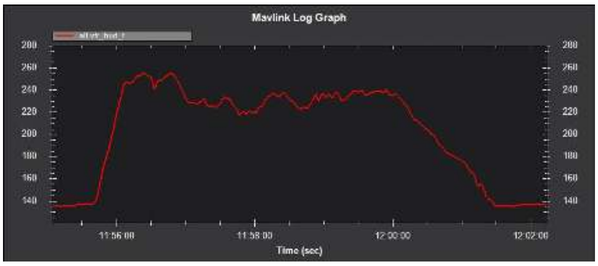
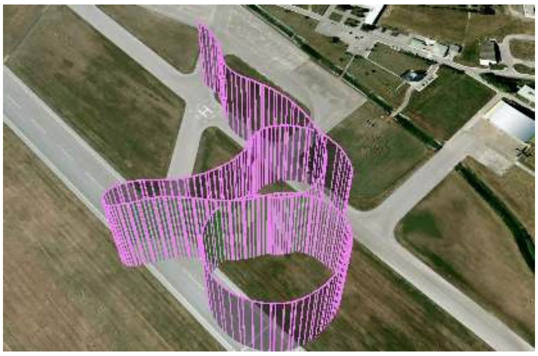


Figure 22: AUTO mode flight altitude profile.

The last test flight was to analyse the behaviour of the autopilot in LOITER and in GUIDED mode. The aircraft was hand launched in MANUAL mode and when it was at the desired altitude and at the desired location it was changed to LOITER mode. The flight path in LOITER mode is shown in Figure 23(a). The UAV loitered around the initial point where it was set to loiter. The radius of the loiter was set in the autopilot parameters to 40 meters. The flight mode was then changed to GUIDED. This mode allowed the aircraft to be controlled with the ground station computer. The aircraft was sent to a location and it was seen that it would loiter around that position as soon as it reached it. This is shown in Figure 23(b). The altitude profile of the flight is shown in Figure 24.

With the Mission Planner log playback feature, there are several parameters that can be analysed

(a) LOITER mode.



(b) GUIDED mode.

Figure 23: Flight paths - third flight.

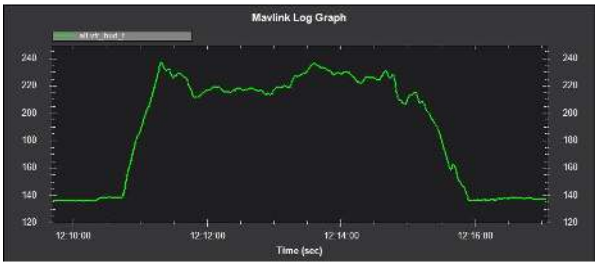
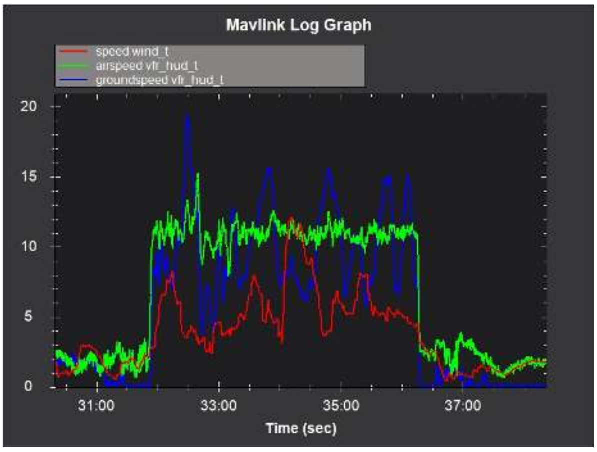
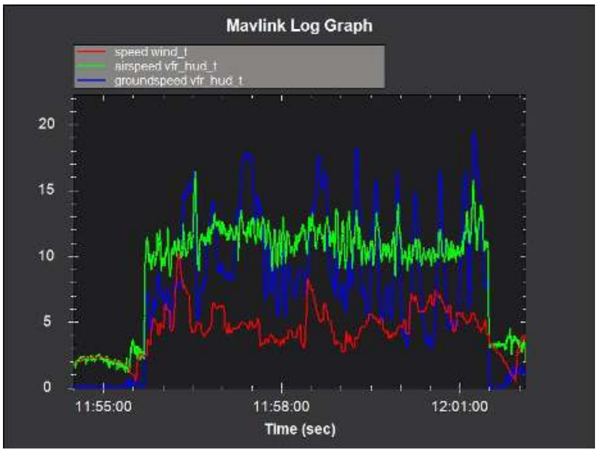


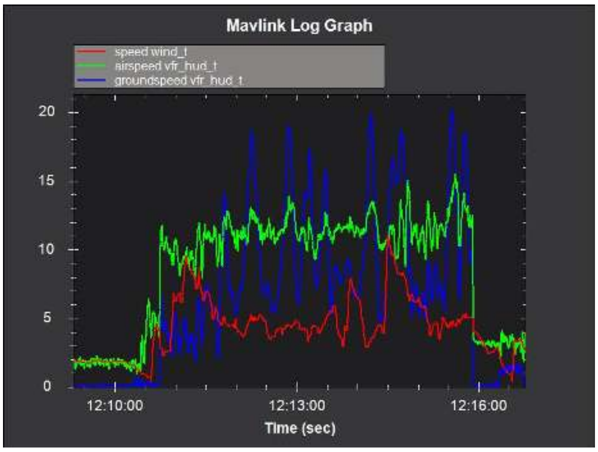
Figure 24: Third flight altitude profile.



(a) First flight.



(b) Second flight.



(c) Third flight.

Figure 25: Test flights windspeed (red), airspeed (green) and groundspeed (blue) profiles.

after the flights. Figure 25 displays the airspeed, groundspeed and windspeed profiles for each flight. The autopilot estimates the groundspeed based on the GPS information. The airspeed is measured using the pitot tube and the windspeed is then calculated based on the direction and difference of these two speeds. By analysing the three flights it can be seen that the airspeed remains relatively constant throughout each flight. The groundspeed has sudden variations due to the direction of the flight relatively to the wind.

5. Conclusions

In this work, it was analysed and implemented an autopilot solution for an UAV. It was found that an open source autopilot can be used to transform a simple commercial radio controlled vehicle into an autonomous, remotely piloted vehicle at a low cost. It was also analysed the ground control station software that is provided by this autopilot. A RPV system was successfully implemented. This system was usefull as it provides realtime video from the perspective of the vehicle.

Ardupilot APM 2.6 provides a very flexible platform that can be employed in a variety of vehicles. The change between different vehicles is easily accomplished. This allowed the autopilot to be tested in a ground vehicle, before being installed on the UAV, which proved to be a crucial step of the project. The autopilot software Mission Planner provides an interface that is easy to use with quick access to the autopilot configurations. Missions are easily created and uploaded to the autopilot, and the interaction with the vehicle is easily achieved. It also allowed the analysis of flight data by using the recorded flight logs.

The rover ground test phase proved to be an important step of the work. It provided a more detailed knowledge of how the system was set up. This was a more secure way to test the several system components before installing them on the UAV. After correctly tunning the autopilot, the rover was capable of automatically following missions that were created in the Mission Planner. This phase also showed that the RPV system interfered with the rover radio receiver.

The flight test phase showed that the autopilot was correctly configured and installed on the aircraft. It proved to be working correctly in the several flight modes even with default parameters. This test showed that the autopilot was ready to be installed in the UAV that is being developed.

Naturally, the next phase of this work, is to install and tune the autopilot on the LEEUAV, once the project is complete. It would be interesting to further develop the RPV system of the UAV. It could be either by developing a platform that integrates the video feed in the Mission Planner, or by using a gimbal that would allow the user to control the camera position. It would also be interesting to study and analyse the autopilot performance regarding other vehicle platforms such as rotorcraft.

Acknowledgements

The author would like to thank Dr. André Marta for his guidance and availability throughout the development of this work.

References

[1] C. Dubrin. UAV market worth $8.3 b by 2018. *Microwave Journal*, page 37, August 2013.

[2] J. R. Wilson. Uav roundup 2013. *Aerospace America*, pages 26–36, July 2013.

[3] Us drone flights hit technical and military turbulence, July 2014. http://rt.com/usa/169624-drones-us-faa-issues.

[4] A. C. Marta. Long Endurance Electric UAV. Technical report, Instituto Superior Tcnico, 2013.

[5] UAV Navigation. Vector Datasheet. http://www.uavnavigation.com/sites/default/files/ds/VECTOR.pdf.

[6] Micropilot. Mp2028^{g} datasheet. http://www.micropilot.com/pdf/mp2028xp.pdf.

[7] Lockheed Martin. Kestrel Flight Sytems. http://www.lockheedmartin.com/content/dam/lockheed/data/ms2/documents/procerus/Kestral_Flight_Systems_Datasheet_080513.pdf.

[8] CloudCap. Cloud Cap Technology Piccolo SL. http://www.cloudcaptech.com/Sales%20and%20Marketing%20Documents/Piccolo%20SL%20Data%20Sheet.pdf.

[9] APM Open Source Autopilot. http://ardupilot.com/.

[10] Openpilot. http://www.openpilot.org/.