ORIGINAL

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UAV Project: development of a test for the elaboration of a GPS-guided bomb in the Electronic Warfare Club of the Air Force Academy

Proyecto VANT: desarrollo de una prueba para elaborar una bomba teleguiada por GPS en el Club de Guerra Electrónica de la Academia de la Fuerza Aérea

Projeto VANT: o desenvolvimento de uma bomba teleguiada por GPS no clube de guerra eletrônica da Academia da Força Aérea

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ABSTRACT

The UAV Project of the Air Force Academy (AFA) Electronic Warfare Club (CGE) was originally designed to motivate cadets enrolled in the club to develop operating systems for an Unmanned Aerial Vehicle (UAV). Therefore, this article suggests the application of this PROJECT in an electric model aircraft controlled by a microcontroller. In this context the model aircraft used was the Hooby King BIXLER2 and the micro-controller, an ARDUINO UNO board. With these materials, it was proposed to use the model aircraft in the simulated launch of an aircraft-based artifact, guided by the Global Positioning System (GPS) for landing at a predetermined point (target). Simulating a smart bomb, the challenge of the project could be positively concluded through the results achieved by the different missions and verified by the course developed and mapped in an AFA's T-27 Tucano aircraft.

Keywords: UAV. ARDUINO UNO. GPS. Smart bomb.

RESUMEN

El proyecto VANT, del Club de Guerra Electrónica (CGE) de la Academia de la Fuerza Aérea (AFA), fue inicialmente concebido para motivar, los cadetes integrantes del club, en cuanto al desarrollo de sistemas operativos de un Vehículo Aéreo No Tripulado (VANT) . De esta forma este artículo sugiere la aplicación de este PROYECTO en un aeromodelo eléctrico controlado por un microcontrolador. En este contexto el aeromodelo utilizado fue el BIXLER2 de Hooby King y el,microcontrolador una placa ARDUINO UNO. Con estos materiales, se propuso utilizar el aeromodelo en el lanzamiento simulado de un artefacto embarcado en una aeronave, guiado por el Sistema de Posicionamiento Global (Global Positioning System - GPS) para aterrizaje en un punto predeterminado (objetivo) Simulando una bomba inteligente, se pudo completar positivamente el desafío del proyecto por los resultados obtenidos por las diferentes misiones y verificado por la ruta asignada y desarrollada en una aeronave Tucano T-27, de AFA.

Palabras-clave: *VANT. ARDUINO UNO. GPS. Bomba inteligente.*

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VANT is the acronym in Portuguese for Unmanned Aerial Vehicle, Veículo Aéreo Não Tripulado, which in English corresponds to the abbreviation UAV. The other acronyms and abbreviations contained in this article correspond to the ones used in the original article in Portuguese.

RESUMO

O Projeto VANT do Clube de Guerra Eletrônica (CGE) da Academia da Força Aérea (AFA) foi, inicialmente, concebido para motivar nos cadetes integrantes do clube o desenvolvimento de sistemas operacionais de um Veículo Aéreo Não Tripulado (VANT). Desta forma este artigo sugere a aplicação deste PROJETO em um aeromodelo elétrico controlado por um micro-controlador. Neste contexto o aeromodelo utilizado foi o BIXLER2 da Hooby King e o micro-controlador, uma placa ARDUINO UNO. Com estes materiais, esta pesquisa propôs utilizar este aeromodelo no lançamento simulado de um artefato embarcado em uma aeronave, guiado pelo Sistema de Posicionamento Global (Global Positioning System – GPS) para aterragem em um ponto pré-determinado (alvo). Caracterizando uma bomba inteligente, pôde-se concluir positivamente o desafio do projeto por meio dos resultados conseguidos pelas diferentes missões e que pôde ser verificado pelo percurso desenvolvido e mapeado em outra aeronave da AFA.

Palabras-clave: *VANT. ARDUINO UNO. GPS. Bomba inteligente.*

1 INTRODUCTION

The Electronic Warfare Club (CGE) of the Air Force Academy (AFA) was founded in 2010 with the objective of studying the concepts of Electronic Warfare and its applications in the Brazilian Air Force (FAB), as well as introducing in the training of the aviation, logistics/administration and infantry officers, knowledge about technological innovations in operations in the FAB. Among the various issues discussed, there is a lot of interest among club members in the development of Unmanned Aerial Vehicles (UAV).

With this motivation, a project was conceived in the CGE called UAV Project, with the objective of enabling the cadets to develop and apply a UAV among one of the activities of the Aeronautics Cadet Corps (CCAer).

The United States Department of Defense (DoD) defines UAV as:

> A motor air vehicle that does not carry a human operator, uses aerodynamic forces for air support, can fly autonomously or be remotely piloted, it can be disposable or retrievable and carry a lethal or non-lethal payload. (VANE, 2006, p. 9).

According to Cianflone (2011), UAV is a type of a pilotless aircraft that can fly autonomously and be remotely controlled, in actions of monitoring, recognition and surveillance, among others. Its main advantage over other vehicles is the ability to perform tactical intelligence actions without putting human lives at risk.

These two definitions express the versatility of the missions carried out by an autonomous aircraft, and the great relevance of this type of aircraft is the possibility of preserving the human resource, especially when it is a war mission.

The applicability of the UAV covers the civil and military sphere, mainly in monitoring, recognition and surveillance (ALBANO, 2008).

In the military scope, Afghanistan's campaign drew attention because there the UAVs actually started attacking targets, besides seeking for information. In the civil scope, on the triple border (Brazil, Argentina and Paraguay), in the south of the country, the Federal Police operate Israeli UAV s, acquired to combat trafficking and smuggling (CIANFLONE, 2011). Therefore, it is extremely important that the aeronautical cadet knows about systems and technologies that make it possible to balance the potential of the Brazilian Armed Forces against the others, especially considering that the FAB is based on technology, both onshore and offshore.

With the use of this type of aircraft in the FAB it will be possible to preserve human resources, expand several areas of knowledge and acquire technological independence from other countries, as well as being adapted to the new market demands.

The CGE UAV Project was not designed in a practical way, but only theoretical, and since 2010 no work or research has been developed with the purpose of making this project possible and feasible. Some researchers in the area started in 2011 works and projects that had the objective of developing this aspect at AFA.

The development of this type of aircraft requires the application of concepts of digital electronics and computing, considering that the aircraft will be a programmed robot and will perform a certain mission or task. Therefore, in addition to flying, it will have to perform a given operational function (ALBANO, 2008).

The proposal of this work is to address solutions for the development of the CGE UAV Project, complementing the knowledge already acquired in the Division of Teaching (DE)at the

Air Force Academy, in digital electronics and computing through ARDUINO open source technology and on several sensors capable of maintaining an electric model airplane in an autonomous flight glided steadily, and controlled by an embedded navigation system. With this, it is proposed to apply a test for the future development of a smart bomb guided by the Global Positioning System (GPS).

It was also sought to analyze and apply feasible means for the development of the gliding flight stability of an electric aircraft model for autonomous landing at a predetermined point (target), simulating the use of an artifact launched from an aircraft and guided by GPS.

1.2 Materials and method

> The model of an airplane is a reduced version of an airplane in its normal size. Models and objects in their normal size have the same types of relationship between the lengths of their different parts. [...] A model is only a means of transferring some relation from its actual form to another form. (BOLTON, 1993, p. 4).

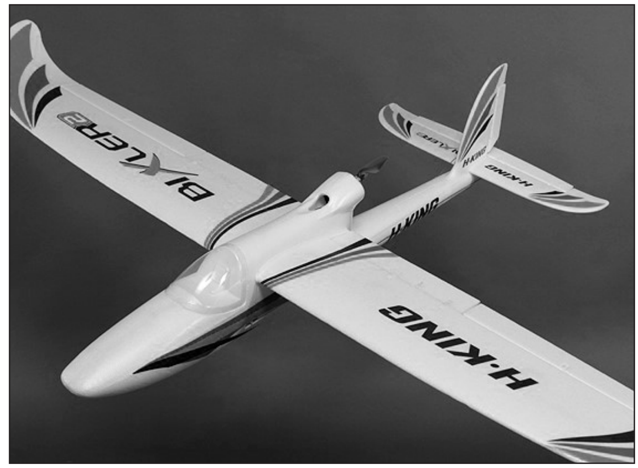
According to Bolton (1993), the difference between an aircraft model and a full-size airplane is only on the scale. It is, therefore, worth considering an aircraft model similar to an airplane that can be piloted properly, in an experimental environment.

On the weekends there are glider operations at AFA's eastern sector airstrip, airstrip 02R (Runway 02 right)/airstrip 20L (Runway 20 left), these operations are coordinated by the cadets who belong to the Gliding Club (CVV) and they are supervised by the Flight Instruction Division (DIV).

The glider model can be devoid of engine and its aerodynamic efficiency is represented by its glide ratio. This ratio is, on average, much higher than that of a conventional aircraft, and one of the advantages of a glider lies in the smooth handling and stability of the flight.

Just as there are aircraft model of conventional airplanes, there are also models of gliders. As an example, the Hooby King BIXLER2 aircraft model (Figure 1) can be mentioned. This model has the same aerodynamic characteristics of a glider. Its wings are long, and its structure is styrofoam to reduce mass, but unlike the gliders piloted by the cadets in the Gliding Club (CVV), this aircraft model is equipped with a motor to enable its ascent.

Figure 1 – BIXLER2 from HoobyKing.



Source: Toywing... (2013).

The BIXLER2 is equipped with four servomotors to control its control surfaces, one for each aileron, one for the elevator and one for the rudder, and it is also equipped with flaps, which are actuated by independent servomotors. According to this research, the operation of the engine and flaps will always be at the operator's control via radio control.

The control axes of an airplane or of an aircraft model are: longitudinal, transverse and vertical. All of them are controlled by the respective primary control surfaces ailerons, elevator and rudder. Every airplane is controlled by these surfaces and thus it has movement in all possible directions.

To better understand the axes of an aircraft, there is the specification of the movement of each axis, according to Figure 2.

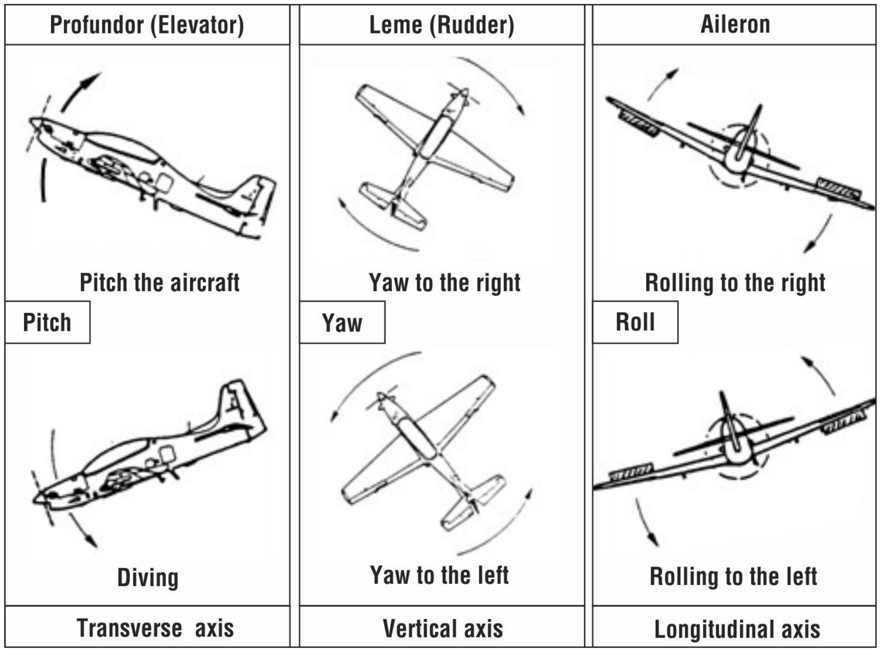
On the transverse axis, the airplane raises or lowers its nose[1] by the movement of the elevator. When it is deflected up it creates an aerodynamic downforce, shifting the nose upwards; when deflected down, the inverse occurs. This movement is called pitch and determines the attitude of the airplane in relation to the horizon. This axis changes the angle of attack of the wings, vital component of the support.

On the vertical axis, the nose of the airplane rotates horizontally, from the right to the left and vice versa. This movement occurs by the rudder. When it is deflected to the right, it creates an aerodynamic force on the tail[2] to the left, shifting the nose of the aircraft to the right, and when

[1] Front of the aircraft.

[2] Rear of the aircraft.

Figure 2 – Axes of movements of an aircraft.



Source: Toywing... (2013).

deflected to the left, the opposite occurs. This movement is called yaw. The coordination of the aircraft is corrected through the rudder due to the relative wind, as well as the surface is responsible for maintaining the bow of the aircraft.

In the longitudinal axis, the airplane rotates around the imaginary line that interconnects the nose to the tail by the alternating movement of the ailerons. The wing that deflects the aileron upwards reduces its sustentation and the wing that deflates the aileron down increases it, thus the roll movement happens.

It is worth mentioning that the ailerons, elevator and rudder are primary control surfaces, because they act directly in the result of the aerodynamic forces of the airplane, modifying its trajectory, attitude and coordination.

In the BIXLER2 aircraft model the performance of the control surfaces is carried out as explained above, however, in order to achieve the objective, this model must carry out a gliding flight.

The gliding flight is characterized when the airplane is driven by a resultant force between the support, the weight and the drag, with the sustentation being smaller than the weight (CAROLINE, 2007). This definition guides the flight analyzed in this paper.

According to instrument flight rules, the descent rate of an aircraft should be 500 ft/min to 1000 ft/min or 2.54 m/s to 5.08 m/s, which will be used in this paper. However, the ideal descent rate should be checked considering the aerodynamic aspects of the BIXLER2 aircraft model with the equipment of the embedded controller kit, which implies a larger mass of the aircraft model.

1.2.1 Steps of the test script

a) Step I: Check the code and load it in the ARDUINO

The code loaded in ARDUINO is **Piloto_1**, which has in its loop function a sequence of conditions that transform the scroll and pitch variations into digital signals to control all four servomotors (BANZI, 2011). In this code it is necessary to include the library <**Servo.h**>, responsible for the functionality of the servomotors.

b) Step II: analyze the performance of the MMA8542Q sensor.

Before mounting the aircraft model, all servomotors must be placed in the neutral position, i.e., the axis at 90 degrees (Figure 3). In this intention, so a code was developed to determine the 90-degree angle and to install the servo mechanical arm. The code used was **CALIBRAR_90**.

With the servos in the neutral position, a test was performed with the four servomotors to verify the maximum amplitude that would be used in the aircraft model. As a result, the variation suitable for use was found to be ± 55 degrees for more or less, i.e., 55 degrees upwards or downwards.

Figure 3 – Calibration[3].

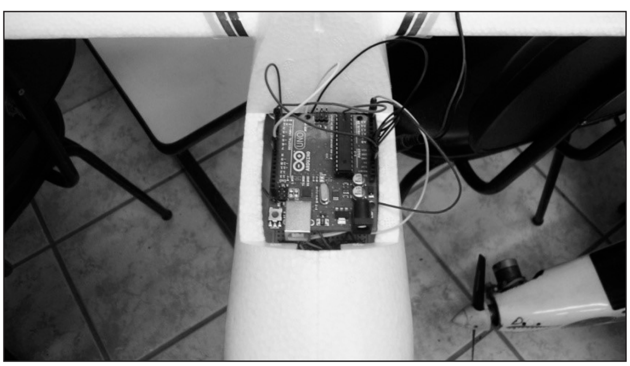
Source: O autor.

When mounting the servomotors on the control surfaces, it was verified that the motors' performance was smooth, coordinated and according to the necessary correction to maintain a flight with leveled wings. Therefore, the assembly of the aircraft model was successfully finished.

c) Step III: install the ARDUINO and the MMA8542Q sensor in the aircraft model.

During the assembly of the aircraft model Hobby King BIXLER, it was possible to adapt the protoboard inside the model in a compartment that would be used to place the battery (Figure 4). It is noteworthy that the maintenance of the Center of Gravity (CG) was taken into account. In this way, it is possible to preserve the embedded equipment in case of an unexpected fall of the aircraft model.

Figure 4 – Installation of ARDUINO/MMA8452Q in BIXLER.



Source: The author.

d) Step IV: verification, on the ground, of the tendency of the servomotor to be corrected on the control surfaces.

After assembling the aircraft model and installing the control assembly inside the BIXLER, it was verified that the control surfaces, ailerons (Figure 5) and elevator searched for stability of flight through the wings and elevator, although the rudder did not act as expected, because the Z axis of the MMA8452Q chip responsible for reading the variation around the vertical axis is the reference axis of the chip. With respect to the variation of the gravity force and the action on the rudder, it is only done when a vertical thrust is applied to the aircraft model, which is impracticable during a gliding flight.

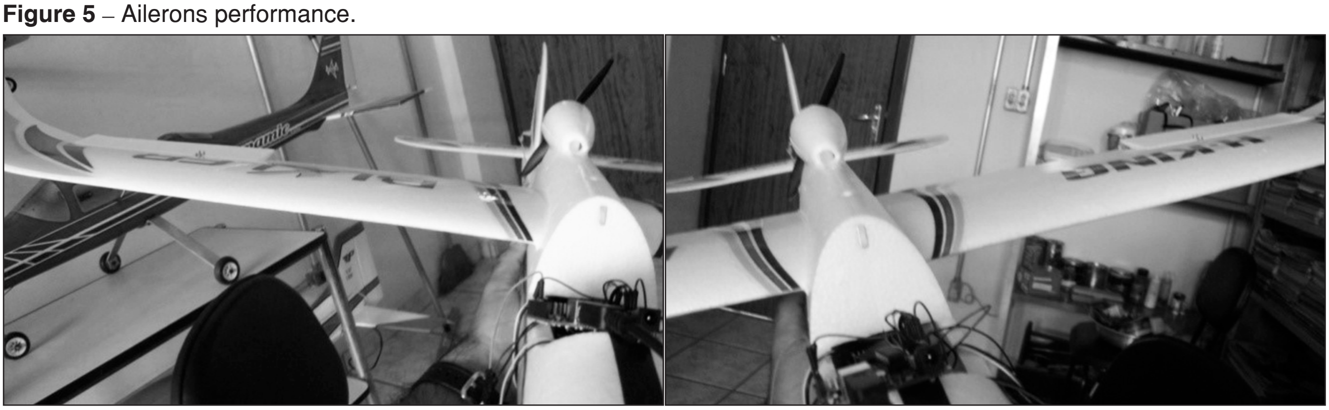
The result met the expectations satisfactorily, since the rudder can be disregarded, since the ailerons keep the aircraft with the wings leveled for the stability of the flight and the elevator acts in the angle of attack, which is indispensable for maintaining the support.

The external source used is the lithium polymer (LiPo) battery of the BIXLER aircraft model and, to convert the 11.1 V with 1800 mAh to 5.0 V with 500 mAh, an ARDUPILOT voltage regulator was installed in the ARDUINO UNO power system.

A 3-cell (3S) lithium polymer (LiPo) battery was used as the power supply for the model aircraft, which has 11.1 V nominal voltage with a current of 1800 mAh. In order to supply the ARDUINO UNO, it was necessary to use an ARDUPILOT voltage regulator.

As for the speed of the response of the command surfaces to the changes in attitude of the aircraft model,

Figure 5 – Ailerons performance.



Source: The author.

[3] Calibration, in this context, is being used to determine the neutral position of the servomotors, different from the calibration definition described in the International Vocabulary of Metrology (VIM) (BRASIL, 2012).

it was verified that it is possible to obtain corrections in a flight in the environment in a suitable and smooth way, and the performance of the servos is directly proportional to the speed of attitude change.

Analyzing the results obtained, it was noticed that the MMA8452Q really fulfilled the objective of reading the variations of the axes and that the ARDUINO performed, according to the established code, the translation of the readings in PWM, applying the respective angles in the axes of the servomotors.

As already mentioned, it was not possible to operate the rudder, since the vertical axis variation in the sensor is not angular, instead varies only in intensity due to the condition that the MMA8452Q is an accelerometer and depends on the gravity force, which is oriented in the same direction of the vertical axis. Thus, the test verified the need to use another sensor capable of acting on this axis.

As a solution, the GPS module EM-406A was chosen as the yaw control, since it is possible to maintain an ideal bow for a predetermined point by the GPS data.

1.2.2 EM-406A GPS Module

This module, which is manufactured by USGLOBALSAT based on the SIRF STARIII chipset and distributed by Sparkfun, contains a led to indicate the power status and another one to indicate the operation of reception of satellite signals, which must remain flashing to indicate the reception of these signals.

For operation with the ARDUINO UNO board, a Shield board is used as shown in Figure 6.

Figure 6 – Shield GPS EM-406A.

Source: The author.

1.2.3 Sistema GPS

The Global Positioning System (GPS) or Navigation Satellite with Time And Ranging (NAVTEAR-GPS) is a radionavigation system developed by the Department of Defense (DoD), which aims to be the main navigation system of the American army. Due to the high accuracy provided by the system and the high degree of development of the technology involved in GPS receivers, a large user community emerged in the most varied civil applications (PEREIRA, 2007).

After a plane crash in Korea in 1983 with 269 victims due to an interception and shooting down of a commercial aircraft flying in a prohibited airspace by a Soviet fighter, probably due to a navigation error, President Ronald Reagan announced that GPS would be available for civilian use. In 1996, President Bill Clinton officially declared dual-use GPS, both for civilian and military purposes, and created the GPS International Executive Management Agency.

GPS is made up of a constellation of 24 (twenty-four) satellites on the Earth's orbit. The distribution of these satellites is divided into 6 (six) orbital plans with 4 (four) satellites in each one, and this architecture allows the simultaneous reception of 7 (seven) satellite signals in any position on the planet.

In order to determine the position, the GPS receiver needs to receive electromagnetic wave signals from at least three (3) satellites in order to be able to perform a trilateration of the reception time of these signals, thus obtaining its position in space. The GPS position corresponds to the intersection of the signals of the satellites, being possible to determine it in three-dimensional form, i.e., by the latitude, longitude and altitude.

For the operation of the GPS receiver there are two protocols that encode the position information carried by the electromagnetic waves in specific characters, thus forming a language pattern. These protocols are National Marine Electronics Association's NMEA 0183 and GARMIN, which is a modification of the first.

The communication protocol is basically a language pattern among electronic components, which enables the interpretation of physical elements such as waves, pressure or temperature in electric pulses characterized by bits, due to binary language.

The NMEA 0183 communication protocol is used by most GPS devices. It is based on ASCII and transmitted serially. According to this protocol, the communication is made by messages that follow norms established by the NMEA. According to Karasinski (2009, p. 37):

ASCII is an acronym for “American Standard Code for Information Interchange”. This code was proposed by Robert W. Bemer, aiming to standardize the codes for alphanumeric characters (letters, signs, numbers and accents). So, it would be possible for computers from different manufacturers to understand the codes. ASCII is a numeric code that represents the characters using a decimal scale from 0 to 127. The computer then convert these decimal numbers into binaries and it processes as a command. Therefore, each letter you type will match one of these codes.

Currently, this system is indispensable for aerial, land or submarine navigation due to its reliability and accuracy.

2 COLLECTION OF RESULTS WITH MICRO-SD CARD

The test script included only the MMA8452Q sensor responsible for flight stability. For the EM-406A and BMP085 sensors, the test should be applied under real flight conditions. For this, the ARDUINO microcontroller was embedded with the EM-406A GPS Module in a T-27 Tucano aircraft of the Air Force Academy.

As there is no display coupled to the above-mentioned module, it was necessary to use an alternative form of GPS data recording, using a Micro-SD Shield printed board (Figure 7), thus allowing ARDUINO to record the data.

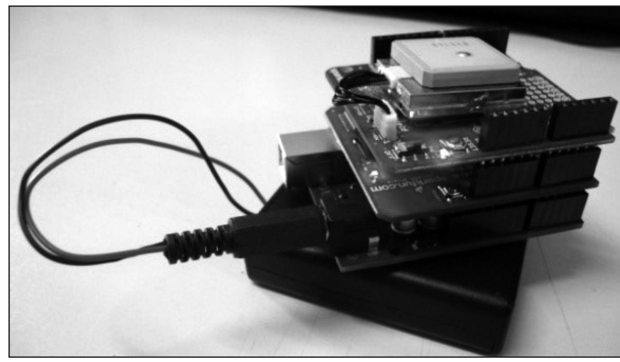
The Micro-SD Shield has the same pinning as the ARDUINO, as does the EM-406A Shield. Shields are used to couple several sensors in ARDUINO without isolating the ARDUINO pins that will be used by other sensors.

According to Pereira (2007), a route mapped in Google Earth is created through collected GPS data. Considering this publication as a reference, the GPS data was recorded using a Micro-SD memory card. To use this card, the <**SD.h**> library is required.

According to Aloi (2012), the communication protocol of this card is the ISP of ISP interface, which does not support cards with more than 4 gibabytes. To initialize the card, you must send a byte to the card and verify that it is recorded, otherwise the card will not work.

For this work a Sparkfun Micro-SD Shield was acquired, as shown in Figure 7. After assembly, ARDUINO is equipped with two Shields, Micro-SD and EM-406, as shown in Figure 8.

Figure 8 – ARDUINO with Micro-SD and EM-406A.

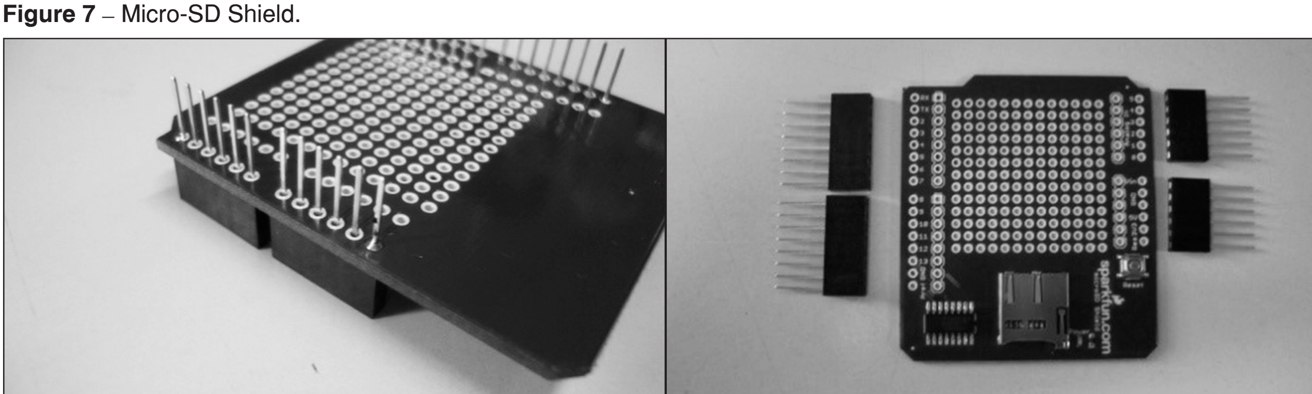


Source: The author.

The test of this kit was carried out on a flight on the T-27 Tucano aircraft on an instrument flight mission of the advanced Course of Aviators Officers in the 1st Air Instruction Squadron(1st EIA). The objective of the mission is to train the aviator cadets of the 4th AFA Squad to perform instrument approach procedures. The objective of this test was to verify the GPS data recording in the Micro-SD card through the ARDUINO, according to classification described by Gamboa (2008).

The code developed specifically for this work has the function of giving instructions to ARDUINO on how to perform the GPS signal readings and write them to a CSV file in Excel. In Table 1, it is possible to verify the data collected in flight, as well as indicators that generated the route performed.

Figure 7 – Micro-SD Shield.



Source: The author.

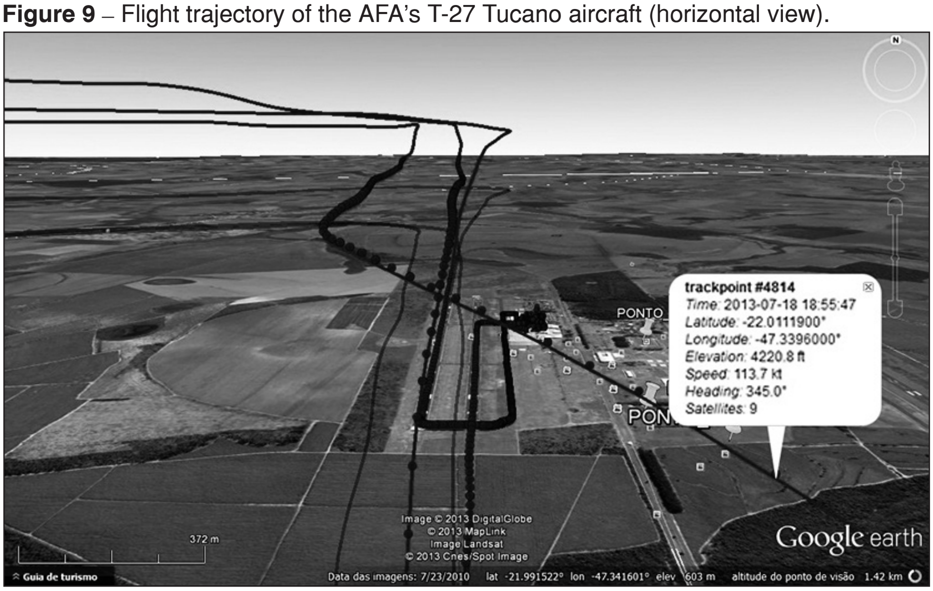
Table 1 – Flight data with the AFA T-27 Tucano aircraft.

hour	minute	second	latitude	longitude	speed	day	month	year	altitude	course	satellites
17	36	28	-21.98113	-47.33849	-1.00	0	0	2000	618.60	1000.00	4
17	36	29	-21.98112	-47.33848	-1.00	0	0	2000	619.60	1000.00	4
17	36	30	-21.98112	-47.33848	-1.00	0	0	2000	620.10	1000.00	4
17	36	31	-21.98112	-47.33848	-1.00	0	0	2000	620.60	1000.00	4
17	36	32	-21.98112	-47.33848	-1.00	0	0	2000	621.60	1000.00	4
17	36	32	-21.98112	-47.33848	0.17	18	7	2013	621.00	12.67	4
17	36	33	-21.98112	-47.33848	0.17	18	7	2013	621.40	12.67	4
17	36	34	-21.98112	-47.33849	0.17	18	7	2013	621.60	12.67	4
17	36	35	-21.98112	-47.33849	0.17	18	7	2013	621.80	12.67	4
17	36	36	-21.98112	-47.33849	0.17	18	7	2013	622.10	12.67	4
17	36	37	-21.98112	-47.33849	0.17	18	7	2013	622.20	12.67	4
17	36	37	-21.98112	-47.33849	0.20	18	7	2013	622.20	15.17	4
17	36	38	-21.98112	-47.33849	0.20	18	7	2013	622.30	15.17	4
17	36	39	-21.98112	-47.33849	0.20	18	7	2013	622.50	15.17	4
17	36	40	-21.98112	-47.33850	0.20	18	7	2013	623.90	15.17	4
17	36	42	-21.98113	-47.33850	0.80	18	7	2013	1000000.00	192.49	255
17	36	43	-21.98113	-47.33850	0.80	18	7	2013	623.00	192.49	4
17	36	44	-21.98113	-47.33850	0.80	18	7	2013	623.30	192.49	4
17	36	45	-21.98113	-47.33850	0.80	18	7	2013	623.50	192.49	4
17	36	46	-21.98113	-47.33850	0.80	18	7	2013	623.70	192.49	4
17	36	47	-21.98113	-47.33850	0.80	18	7	2013	623.80	192.49	4
17	36	47	-21.98113	-47.33851	0.07	18	7	2013	623.80	347.72	4
17	36	47	-21.98113	-47.33851	0.07	18	7	2013	624.00	347.72	4

Source: The author.

These data are handled at the specific site to obtain a KMZ extension file. When this KMZ file is queried (in) on Google Earth, it is possible to visualize the trajectory with data of geographic position, speed, bow, altitude, date and time, as can be seen in Figure 9.

Figure 9 – Flight trajectory of the AFA's T-27 Tucano aircraft (horizontal view).



Source: The author.

In Figure 10 it is also possible to follow the work developed with the system. These images show the importance of the use of a Micro-SD in the verification of the trajectory carried out by the aircraft model to analyze the maintenance of the descent ramp of the gliding flight from a 3D perspective, as well as it is possible to check, from point to point, data of speed, bow, altitude, geographic position, etc.

It is also possible to create a database with the missions performed and, thus, it is possible to improve the ARDUINO programming processes, increasing the accuracy of the flight with respect to the ramp and the landing on the target.

With these procedures and materials, it is possible to plan missions with different aspects of execution and practice, being one of them this mission proposed for mapping and reaching predefined target. Finally, it is possible to improve and apply the mission with explosive material, taking into account, for example, the application of guided bomb (CASTRO, 2013).

3 CONCLUSION

The UAV Project is a considerable initiative of the CGE in motivating the cadets to scientific development, as well as developing the possibility of putting into practice the knowledge acquired. The building of a UAV out of a simple electric model in its complete design requires research and development. This work was developed only in the landing system of a UAV applied in the simulation of an artifact launched from an aircraft, so that it can touch the ground at the predetermined point, as described.

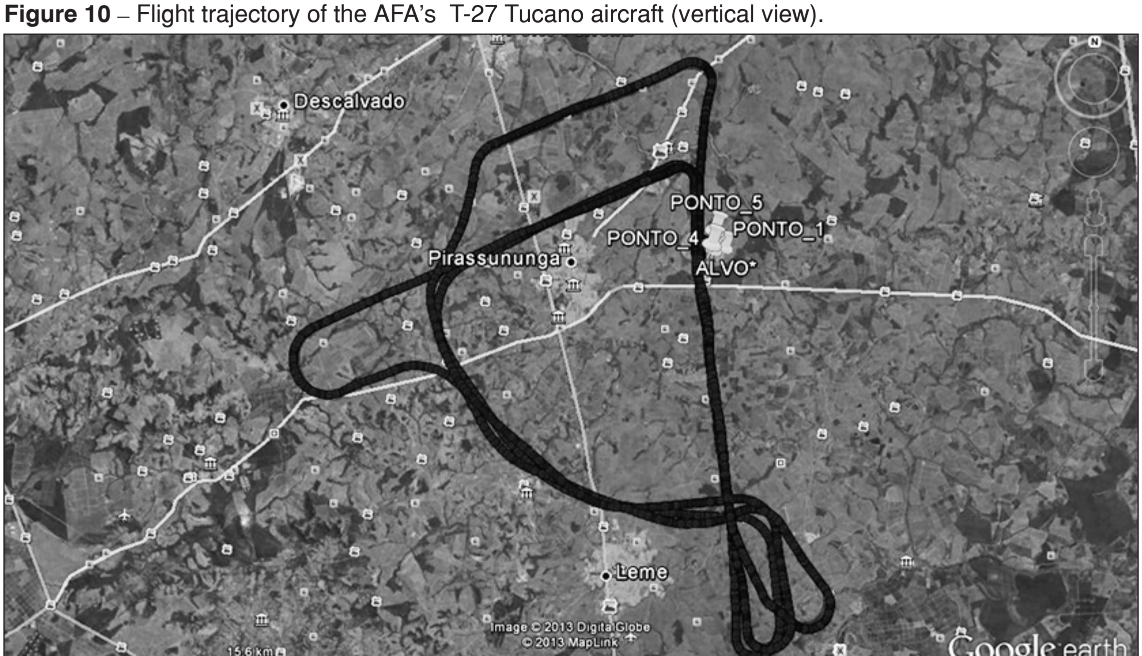
To this end, the use of microcontrollers in the process of automation is the possibility that the CGE has to apply the theoretical knowledge of the cadets. Among the various microcontrollers currently available on the market, we chose ARDUINO technology because it is a microcontroller that is open to development. When embedding this microcontroller in an electric aircraft model, it was possible to develop a UAV, even if initially for the experimental work.

To carry out the work, it was necessary to use sensors with the ability to perceive environmental variations affecting the flight, such as variations in altitude, distance, speed and bow, considered as a short navigation by the GPS system.

In this paper the sensors play a decisive role in the maintenance of the gliding flight, as well as in the navigation of the BIXLER2 aircraft model. The communication between microcontroller and sensors was developed in the C/C++ language. Thus, the results are the data collected on a Micro SD card, which allow the improvement of the methodology applied in this project, with a view to better results in future projects of the CGE.

This fieldwork is an important step for the new studies that have been developed at the Air Force Academy regarding the theme and the practical application of a UAV.

Figure 10 – Flight trajectory of the AFA's T-27 Tucano aircraft (vertical view).



Source: The author.

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