UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA

_ TELECOM ESCUELA
TÉCNICA VLC SUPERIOR
DE UPV INGENIEROS
DE TELECOMUNICACIÓN

DESIGN OF AN AERONAUTICAL DATA COLLECTOR FOR AIRPORTS BASED ON ADS-B

Author: Óscar Fuster Hernández

Supervisor: Fulgencio Montilla Meoro

Co-Supervisor: Ignacio Despujol Zabala

Bachelor's Thesis presented in Telecommunications Engineering School of Polytechnic University of Valencia, to obtain the Bachelor's Degree in Telecommunications Engineering

School Year 2016-17

Valencia, 17th August 2017

Resumen

El propósito del presente trabajo es el diseño de una estación colectora de datos aeronáuticos del tráfico aéreo de un determinado aeropuerto. Para ello se modificará un producto conocido como Piaware, basado en una Raspberry Pi Modelo 3B con software libre y software adicional que ha sido desarrollado por la compañía rastreadora de vuelos FlyAware. En dicho dispositivo la Raspberry se conecta a un receptor basado en una tarjeta de radio programable que se vende como receptor de TV digital que será utilizado para recopilar datos del ADS-B y del radar secundario (SSR) en modo-S y guardar parámetros tales como la posición, la altitud, la velocidad y la identificación de las aeronaves próximas al aeropuerto. Con la recopilación de estos datos, se podrán estudiar en detalle los procedimientos de despegue y aterrizaje. Dicha operación será realizada haciendo uso de software libre ya existente (dentro del proyecto de software definido para radio), pero adaptándolo y mejorándolo a las necesidades de nuestro trabajo.

Resum

El propòsit del present treball és el disseny d'una estació col·lectora de dades aeronàutiques del trànsit aeri d'un determinat aeroport. Aquesta tasca, serà realitzada mitjançant un producte conegut com Piaware, que es tracta d'una Raspberry Pi Model 3B que ha estat desenvolupada per la companyia rastrejadora de vols FlyAware. Aquest dispositiu, serà connectada a un receptor basat en una targeta de ràdio programable que es ven com a receptor de TV digital i serà utilitzat per recopilar dades del ADS-B i del radar secundari SSR en mode-S, per guardar paràmetres com ara la posició , l'altitud, la velocitat i la identificació de les aeronaus pròximes a l'aeroport. Amb la recopilació d'aquestes dades, es podran estudiar en detall els procediments d'enlairament i aterratge. Aquesta operació serà realitzada fent ús de software lliure ja existent (dins el projecte de programari definit per ràdio), però adaptant-lo i millorant-lo a les necessitats del nostre treball.

Abstract

The aim of this project is to design an aeronautical data collector which captures the air traffic data in a certain airport. Such task will be accomplished using a product known as Piaware, which is based in a Raspberry Pi Raspberry Pi Model 3B device, and has been develop by the flight tracker company FlyAware. The Raspberry Pi is connected to a Digital TV tuner stick, which is sold as a digital TV receiver and will be used to capture not only ADS- data but also Mode S transponder data to get nearby aircrafts parameters like position, altitude, speed and identification number. Using this data compilation, further studies related to landing and taking-off procedures could be performed. This operation will be designed by using existing open software (included in a software defined radio project) modified and enhanced for our purpose.

Index

1. Introduction

Airports are expensive and complex infrastructures. Their air-side, which is composed by runways, taxiways, aprons and nearby air space, is a critical part in airports' capacity.

Since airports are a very important infrastructure in terms of countries' transport, they should work as efficiently as possible in every process of the air navigation. Consequently, to improve their efficiency is a very important issue.

Flight delays increase exponentially when airports' capacity is close to its maximum. Therefore, small improvements in air space procedures and air side operations have a strong impact in flight delay decrease. This is why, every flight process is carefully analysed, including aspects like air separations, landing points, runway occupation times after landing or taxiways occupation time, among others.

So far, to have estimates for these parameters, it was necessary to accomplish specific statistical studies in which they measured manually and analysed, obtaining statistical data.

Nowadays, every commercial flight is equipped with an ADS-B on-board system that broadcasts the geographical parameters that define its position. That system relies on the GPS satellite system. Consequently, those geographical parameters have a satellite precision. The idea is to capture this data obtain the measurements of the take-off and landing operation and compute the statistical parameters without the need of specific manual data procedures.

This project aims to design a low cost system to automatically capture and store all these aircraft data and upload it to a server to perform further studies. Those studies will allow having a detailed knowledge of the different parameters of take-off and landing procedures in a certain airport, and by installing the system in several airports, we could get the aggregated parameters of a complete airport network.

2. Thesis Goals

2.1 What do we want to accomplish?

The aim of this project is to create a low-cost aircraft tracking data collector so that further studies about airport's efficiency can be accomplished.

The collected data will be automatically processed and uploaded to a database in order to obtain information about the take-off and landing procedures in a certain airport.

The aircraft data that will allow us to perform such task are the ADS-B data.

From now on, it will be called just a data collector based in ADS-B data.

ADS-B, that stands for automatic dependant surveillance – broadcast, is an aircraft surveillance system, which is used by commercial flights so that they can be tracked by ground-based system stations and other properly equipped aircrafts. ADS-B systems periodically send the following aircraft's geographical parameters:
* Latitude.
* Longitude.
* Velocity.
* Altitude.
* Heading.
* Aircraft code.

To collect all this data, we are going to use a system created by the flight tracking company FlyAware, called Piaware. This system is based in a Raspebrry Pi device using the open source programs dump1090 and a specially developed software called Piaware to decode the ADS-B signal, store it and feed FlyAware's Servers with ADS-B data of nearby tracked aircrafts. With this system and its different utilities, properly configured, we will be able to collect the desired data.

Once the data compilation is acquired, processed with the airport's geographical location, studies about take-off and landing procedures would be achievable.

Thanks to the collected information, the following parameters will be obtained:
* Airborne separation of arriving planes.
* Exact landing spots in the runways.
* Runway occupation times after landing.
* Taking-off runway occupation time.
* Taxiway occupation time.
* Aircraft landing distances.
* Aircraft take-off distances.

Consequently, the analysis of all those aircraft's procedures will allow to know in detail how each of those processes works and take beneficial solutions, such as:
* Problem prevention.
* Process controlling.
* Process optimization.

The last one, process optimization, is a critical issue in order to improve airports' efficiency.

By optimizing each state of the air navigation and minimizing those waiting times in an airport, further benefits will be achievable:
* Higher airports' amortization.
* Air traffic flow enhancements.
* Airports' security improvement.

- Environmental impact reduction.

Many reasons can be found to support these points:
1. If air traffic flow was improved, airports' capability would be closer to its maximum. Which means a better amortization of the airports.
2. More awareness about dangerous situations would enhance airports' security.
3. Environmental impact reduction: Since aircrafts have to wait for a taxiway before landing, lower waiting times would decrease the oil utilization. Which stands for a better utilization of the amount of oil used by an aircraft and a lower environmental impact.

In other words, we would lay the foundation stone for ADS-B data collection pointed at air processes studies by using this device, and we would allow professionals from this area to develop that field.

2.2   How are we going to develop it?

While we were researching on the topic, we found the RTL-SDR project.

This is an open source project for software defined radio that uses a cheap DVB-T TV tuner dongle based on the RTL2832U chipset. A huge number of users, who are not only amateurs, but also software defined radio field professionals, support this project. Therefore, a huge quantity of information is easily accessible.

The Piaware is based in the RTL-SDR project. As this project stands for the beginning of ADS-B data collection pointed at air processes studies by using a Piaware system, we might think that it would not be a bad idea to use software and hardware that is strongly backed up by a huge community of users. Therefore, in the future another student or researcher would dispose of the more quantity besides his own university or institution resources.

Hence, this project will be developed by using software available on the RTL-SDR that will be configured an enhanced to achieve our aim.

3. Theoretical Background

3.1 ADS-B

3.1.1 Description

ADS-B: Automatic Dependent Surveillance – Broadcast mode.

- Automatic: Messages are periodically sent without any interrogating system.
- Dependent: Position and velocity are derived from the Global Positioning System (GPS).
- Surveillance: Primary purpose for the system is aircraft tracking.
- Broadcast: Messages are broadcast to everyone, not just sent to specific receivers

This surveillance technology is used in order to perform Aircraft Tracking and Positioning. This system relies on the Global Positioning Satellite System, which acquires and provides the ADS-B data, to each ADS-B equipped aircraft. Once the aircraft receives the ADS-B data, it is broadcasted (data is updated every second).

Information can be received by air control ground stations as a replacement for secondary radar.

This system does not depend on any pilot's decision, which means that works automatically and the signal is periodically broadcast. Not only could an aircraft send its own positioning by using ADS-B out service, but also an aircraft could receive other's aircraft ADS-B data if they are properly equipped with ADS-B in. Therefore, every ADS-B equipped aircraft is able to track and be tracked in the airspace.

These are some of the ADS-B parameters:

- Aircraft identification number.
- Positioning: Latitude and longitude.
- Altitude.
- Speed.
- Heading.

3.1.2 Secondary Surveillance Radar

Radar based surveillance system used in Air Traffic Controlling (ATC) is an older technology. It is an evolution from the primary radar technology, in which ATC gets a point in the Radar display for an aircraft but no information about it. In Secondary Surveillance Radar (or SSR), the aircraft has a transponder that answers when it receives the RADAR pulse, transmitting an identity code for the aircraft, so the ATC sees the code by the point in the RADAR screen and identify it. This system has evolved with time and today it transmits at least the position and the altitude of the aircraft.

It relies on an on-board aircraft equipment, the transponder, which replies to the radar pulse.

The on-board transponder works as both receiver and transmitter. On the one hand, in receives the radar interrogation on 1030 MHz. On the other hand, it replies broadcasting the information in the 1090 MHz band.

It has different working modes:

- Mode C: It sends pressure altitude and aircraft identity. Light aircraft use it.
- Mode S: It sends information that is very similar to the one transmitted in ADS-B, the difference is that it does not broadcast the information at regular intervals; it only transmits when it receives an interrogation from the radar.

3.1.2.1 Modulation

- Mode S interrogation:
  - Pulse Position Modulation (PPM).

        o   Data Rate: 1 Mbps.
- Mode S reply:
    - Differential Phase Shift Keying Modulation (DPSK).
    - Data Rata: 4 Mbps.

3.1.3   How ADS-B works?

ADS-B is divided into two different services: ADS-B out and ADS-B in.

- ADS-B out: The part of the ADS-B system, which periodically broadcast the information to other ADS-B equipped systems. This service is mandatory for some aircraft models.
- ADS-B in: This is the reception part of the ADS-B messages from other ADS-B transmitters. This part of service is not mandatory but rather beneficial for pilots.

There are two frequency bands that are used for ADS-B purposes: Universal Access Transceiver (UAT-978 MHz) and Extended Squitter (1090 MHz).

3.1.3.1   Universal Access Transceiver - UAT-978 MHz)

Over UAT band operates not only ADS-B services, but also other services such as Flight Information Service (FIS-B) and Traffic Information Service (TIS-B).

On the one hand, ADS-B out equipped aircraft are seen in the air space by ground stations. On the other hand, ADS-B in equipped aircraft are able to see detailed data from other ADS-B out properly equipped aircrafts, like positioning, speed, heading, and identification number.

FIS-B and TIS-B are also received by ADS-B in. Therefore, an ADS-B in properly equipped aircraft will receive many reports that would enhance its Air Navigation experience.

This is a bidirectional band: While aircrafts send out their ADS-B data, ground stations send Traffic and Weather Information by using FIS-B and TIS-B services.

3.1.3.2   Extended Squitter – 1090 MHz

It is an extension of Mode-S technology. It works over the same frequency as the transponder replies.

The aircraft periodically broadcast messages with such information, as the positon or the aircraft identification number. Every properly equipped aircraft could receive this broadcast message.

The following parameters are sent:

- Aircraft position (Either landed or flying).
- Heading and speed.
- Aircraft identification number.
- Report messages (if necessary).

3.1.3.3   Other important points

Non-ADS-B aircraft are identified Secondary Surveillance Radar. In ADS-B equipped aircraft, the transponder is still required. Secondary Radar System is thought as a backup service.

Because of the use of two different ADS-B frequencies, 1090 MHz and 978 MHz, communication between different aircraft could be restricted. For instance, a 1090 MHz ADS-B equipped aircraft would be able to track just 1090 MHz equipped aircraft. That aircraft could not see neither the 978 MHz equipped aircraft nor the non-ADS-B equipped aircraft. Therefore, another service was created with such a purpose, ADS-R. This service solves the previous issue by retransmitting up to the 1090 MHz the 978 MHz ADS-B messages. It also rebroadcasts all the 1090 MHz traffic over the 978 MHz frequency.

3.1.4   Other services

ADS-B provides to both, pilots and air traffic controllers, different critical information. Those services work through ADS-in service.

3.1.4.1   Traffic Information Service – Broadcast (TIS-B)

Air Traffic Information Service, which allows pilots to see nearby aircrafts in their cockpit display. It works as a flight advisor and it is thought and as collision avoidance.

This system works over both ADS-B bands: 1090 MHz and 978 MHz.

3.1.4.2   Flight Information Service – Broadcast (FIS-B)

FIS-B is a Flight Service that reports weather information in different formats, such as text weather or graphical weather to both pilots and air controllers.

It provides 'Free Weather' to 978 MHz UAT-equipped aircraft. It is not available on 1090 MHz channel. This is a ground-based service, which may have line of sight limitations. It does not happen with current satellite-based systems.

3.1.5   Benefits

ADS-B introduces to the Air System many beneficial solutions that are going to improve both safety and efficiency all around the air space.

3.1.5.1   Benefits for the Air System

- Air Traffic Control is being transformed from Ground-Based Systems to Satellite-Based Systems. This fact improves both safety and efficiency while it reduces maintenance cost of the network.
- ADS-B has been chosen as the next generation of Air Transport Systems to increase accuracy.
- ADS-B ground stations are cheaper to install and operate compared with radar systems.
- Fight information reports could be sent thanks to FIS-B service. These reports include information such as temporary flight restrictions.

3.1.5.2   Benefits for both pilots and operators

- A pilot would be able to view nearby aircrafts position (as far as they are properly ADS-B equipped aircrafts).
- Non-ADS-B equipped nearby aircraft would also be visible for the pilot thanks to TIS-B service.
- Weather reports would also be received thanks to FIS-B service.
- Enhanced ATC systems: faster rate updates and positioning updates (comparing with radar systems).
- Improved last-position data for Search and Rescue tasks (SAR)

3.1.5.3   In terms of Safety

3.1.5.3.1   Information updates

Pilots in an ADS-B in equipped aircraft could see on their cockpit display other traffic located in their air space. Besides, other relevant information, such as detailed weather information, airport closing or temporary flight restrictions would be reported to pilots.

3.1.5.3.2   Visibility

One of the main benefits that ADS-B introduces regarding visibility is that not only ADS-B equipped aircrafts would be visible in the air space, but also non-ADS-B equipped aircrafts would be visible. With other systems, like traffic alert and collision avoidance system (TCAS), an aircraft could only see other aircrafts that are equipped with the same system.

Even ADS-B out only-equipped aircrafts will benefit from this system because air traffic controllers would be able to monitor their position more accurately.

Thanks to ADS-B system, both pilots and controllers would be able to see the same display (as far as pilots are equipped with ADS-B in). Pilots will see all the aircrafts in the air space.

To improve safety, ADS-B provides:

- Real-time cockpit air traffic display.
- Real-time cockpit weather conditions display.
- More accurate search and rescue response.
- Other aircraft avoidance assistance.
- Improved visual flight rules.
- Improved instrument flight rules.

3.1.5.4   In terms of Efficiency

Because ADS-B improves aircraft position accuracy, Air Traffic Controllers would be able to guide aircrafts through a more crowded air space with a higher precision. Besides, separation between aircrafts would be smaller while keeping safety standards. Therefore, the amount of time that Aircrafts had to be waiting before landing would smaller.

3.1.5.4.1   Environmental impact reduction

As flight time is smaller, the amount of pollution generated and oil consumption by air traffic will be reduced, generating a smaller environmental impact.

3.1.5.4.2   Higher Air Capability

ADS-B systems will enhance the following features of the Air Guidance:

- ATC traffic management.
- Reduced aircraft separation.
- Visual approaches.
- Capability operation.
- Operation capability in higher altitudes.
- Operations capability in lower visibility conditions.
- Air Traffic Control in non-radar space.
- Optimal trajectory.
- Air Traffic of the airports.

3.1.6   What are we interested in?

Because of this system development, many ADS-B tracking networks are being developed. One of the most important companies that has been working on this field is FlyAware.

FlyAware is a company which data is provided from two main sources: from Governmental institutions that provide them ADS-B and Mode-S Surveillance Secondary radar data, and from their own users.

It also operates a worldwide network of ADS-B and Mode S receivers that track ADS-B or Mode S equipped aircrafts flying around the globe.

Their users receive ADS-B data from ADS-B out equipped systems, while Mode C secondary surveillance radar position is calculated by multilateration when the aircraft is tracked by at least three receivers.

For our project, we are going to develop an ADS-B data collector based in the pre-built Piaware device. This device is going to be improved and enhanced in such a way that data can be shorten and processed for further analysis.

Therefore, our ADS-B data collector will collect ADS-B out data and Mode-S Secondary Surveillance Radar responses.

3.2 ATC

3.2.1 Introduction

Air Traffic Control, ATC, is a service whose purpose is the Air Traffic management. The organization and some points may differ depending on the country where it operates. However, it usually covers purposes such as collision prevention, flow traffic expedition or providing important information regarding the air conditions.

This service is usually provided to private, military and commercial flights operating in its airspace by traffic controllers who are placed in ground based stations. Besides, Air Traffic Controllers are responsible of directing an aircraft through the ground and controlled air space.

3.2.2 Different Services

ATC could be divided in three different services depending on its distance to the airport. Therefore, we could talk about areas. Air Traffic Controllers are responsible of the movements and locations of the different vehicles and aircrafts in these three areas.
- Ground control: At the airport.
- Air control or Local control: Next to the airport (From 10 to 20 km. Depending on the airport).
- Sector control: Further distance than the previous one.
- Fight data.

Air Traffic Controllers are also responsible for providing flight data and clearance delivery to pilots.

Air Traffic Controllers depend on some surveillance systems, such as Primary Radar, ADS-B or Secondary Radar so that they can see on their displays the aircraft location, among other parameters, to be able to execute their mission. These systems work as a flight assistance to control air traffic.

3.2.2.1 Ground Control

Firstly, Ground Control is responsible for the movement of aircrafts and vehicles inside the airport while they are in contact with the ground. People who work in this area are bound to have a communication link to communicate with the ground station (usually radio or cell phone).

This is a critical part of the airport because it directly affects the airport's efficiency and safety.

3.2.2.2 Airport Traffic Zone Control

Secondly, ATC is responsible for guiding the aircrafts through the active runway and nearby airspace in the approach, landing and taking-off procedures. Therefore, it ensures that a certain aircraft meet the time and space requirements to keep airport's security and efficiency.

What is more, Air Control service uses an extremely efficient communication process to communicate with pilots. This is because both services have to be aware about any decision and relevant information regarding Aircraft Traffic. Otherwise, it could affect and endanger the airport's capability of operation. Besides, another purpose of the Air Control is trying to optimise the runway utilisation.

3.2.2.3 Sector Control

ATC is also responsible of guiding commercial flights when they are flying from one airport to another, for which they use long range primary radars and two way radio communications with pilots.

3.2.2.4   Flight Data

Finally, Flight data is the part of Air Traffic Control that provides the aircraft with different rout clearances within its area. Its main responsibility is to ensure that each aircraft have the correct rout taking into account aspects such as Air Traffic or Weather Conditions. This information and commands are also coordinated by Ground Control and Air Control Services, so that the aircraft reaches the runway while fulfilling time restrictions.

Furthermore, flight data ensures that both pilots and air controllers have the information properly updated. So that, all of them are aware of different inconvenience like weather conditions, runway closures, flight delays or others air traffic issues.

3.2.3   Technology and relation with ADS-B

Many different technologies are used to collect information to build up the air situation. Once this information is treated and summoned by a flight data processing system, it is available for both pilots and air controllers.

Surveillance Systems are used to identify each nearby aircraft. Consequently, the system that this aircraft has installed depends on many variables, like its model or the kind of flight (civil, private or commercial).

Primary and Secondary Surveillance Radar are commonly used to improve Controller's Air Traffic Control. Besides, transponder equipped aircrafts reply to secondary radar interrogations by responding with ID and altitude or with more complex data.

ATC communications relies on many different technologies, which are related to ADS-B surveillance system:
- Flight data processing systems: This system processes all the information related to the flights. After such task, it distributes all the processed information to the rest of the Air Control subsystems.
- Mode S: Mode S transponder. It allows controllers to get extended information about nearby aircraft which are using these important systems to perform further operations such as tracking.
- ADS-B: Automatic Dependant surveillance broadcast. Many parameters are acquired by the system used in further operations.

4. Working Methodology

4.1 Project Management

4.1.1 Schedule

Research
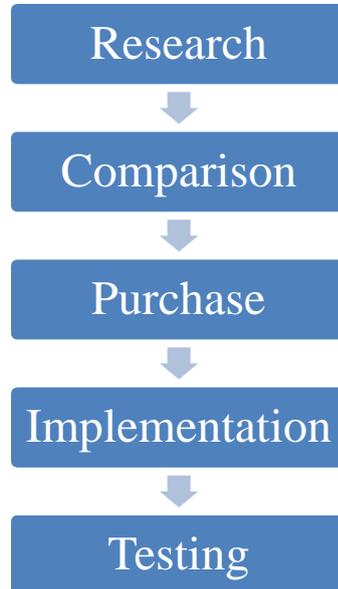
Comparison

Purchase

Implementation

Testing

Diagram 1 - Project Management

To develop our project, the previous scheduling with be followed.

4.1.2 Research

This part aims to research the low cost ADS-B market in order to target the most suitable product to achieve the aim of our project. The research will cover from which companies work on ADS-B data acquiring, to what are the products that these companies offer on ADS-B systems.

For this part, many different sources will be used, such as information available on the internet, bibliography from libraries and academic publications on science and technology magazines.

Firstly, we will have to target which companies are already established on this market. In this case, we have found two companies that are quite developed regarding ADS-B products. These companies, which are well known ADS-B suppliers all over the world, are Air Nav Systems and FlyAware.

On the one hand, AirNav System is the only company that owns a real-time tracking network in the world. On the other hand, FlyAware has been working on aircraft tracking since 2005 and owns the biggest tracking network in the world.

Secondly, we will have to select for each company the best solution offered to achieve our aim. In case of AirNav Systems, that stands for RadarBox ComStation and for FlyAware, Piaware.

4.1.3 Comparison

At this point, after all the researching process is finished, we will have to compare every aspect of each product.

Many aspects of both products will be considered to select our product:
- Functionality.
- Prize.
- Available software.

- Operating System that works on.

The point on that is to ascertain the best solution without forgetting our initial condition: We have to use a low-cost device that might be used in the future again to keep on developing that field of study.

4.1.4   Purchase

Once the decision has been taken and by using the economic resources of our university, the product will be purchased. Then, we will be ready to start developing our project.

4.1.5   Implementation

For the implementation, we will have to develop a system to collect flight-tracking data. That could be divided into two tasks:
- The development of a program that acquires the tracking data of all nearby detected aircraft and saves all this data in a file directory system. There are two sorts of tracking data:
    - ADS-B data and Mode S data (that are very similar).
    - Mode C transponder data.
- Upload all this data to a server so that could be accessed to accomplish further studies.

As it was told before, we will have to obtain the tracking data of commercial flights. The data that provides geographical position of those flights is the ADS-B data. To perform such a task, we will use a software available for Linux, which is part of the software defined for radio, also named RTL-SDR project, which is called dump1090. This program relies on the RTL2832U dongle, to not only demodulate but also decode the ADS-B signal. That program stores the ADS-B data in a specific directory of the system that will be accessed later by another program to shorten all the data.

After this task has been accomplished, we will have to store safely all those tracking data into a server. We will use a FTP server that has been provided by the university to develop our project. Therefore, the file upload will be designed as an automatic process.

Finally, one of the requirements that our project has to fulfil during its development is that our data collector system should work in an automatic and autonomous way, which means that once the device has been installed and is working properly, further configurations or installations are not required. Therefore, the device must be acquiring data indefinitely and automatically.

4.1.6   Test

In order to check that our project works as desired, we will have to place our device in a location close to the airport. For such a purpose, we will have to contact many different companies whose offices are close to the airport and ask for their permission to install our product there.

Some of the requirements that the placement of the device must have, are:
- Direct line of sight to the control tower and the runway.
- Power supply.
- Internet connection (Ethernet or Wifi).

Finally, if the device works properly, it will be installed permanently there to allow other Bachelor's thesis students or researchers on that field to keep on developing that area of study.

4.2 Task distribution

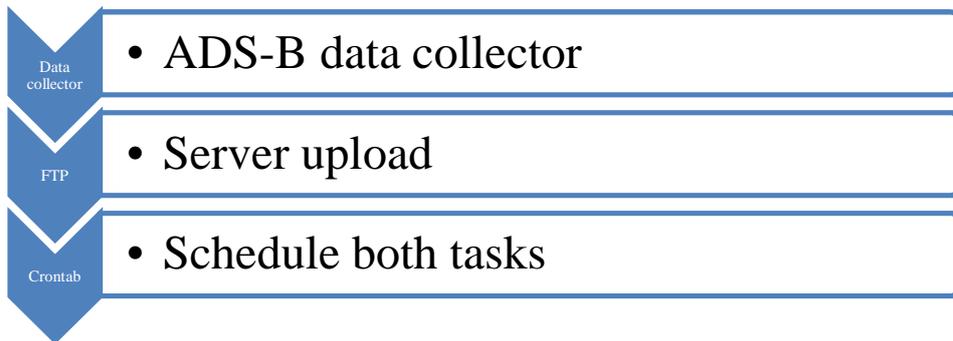The aim of the project could be split into three main tasks:

- Data collector — **• ADS-B data collector**
- FTP — **• Server upload**
- Crontab — **• Schedule both tasks**

<div align="center">**Diagram 2 - Task distribution**</div>

Each of these tasks is part of the whole data collector system and plays an important role in the working process.

4.2.1 Data collector

This is the part where the program that will capture the desired data will be developed. It will acquire three kinds of tracking data. The first two are very similar and the third is a subset of the former:

- ADS-B data.
- Mode S transponder.
- Mode C transponder.

4.2.2 Server Upload

Once the tracking data capture has been achieved, we have to design a process that uploads all those files to the server.

4.2.3 Crontab

This Linux process administrator will be very useful in order to schedule the previous program. With Crontab, we will be able to determine the moment when we want a program to be run, by setting the hour and minute of the task execution. The minimum cadence for this process administrator is one minute.

On the one hand, because we want to acquire as much tracking data as possible, all task regarding the data collection will be scheduled as often as possible which on Crontab stands for every minute of the day.

On the other hand, it will be necessary to upload the files to the server just once a day. Therefore, we will schedule Crontab to acquire such a task at the end of the day. The reason of that is that we will be able to sort our files by day.

5. Development and results

5.1 Planning

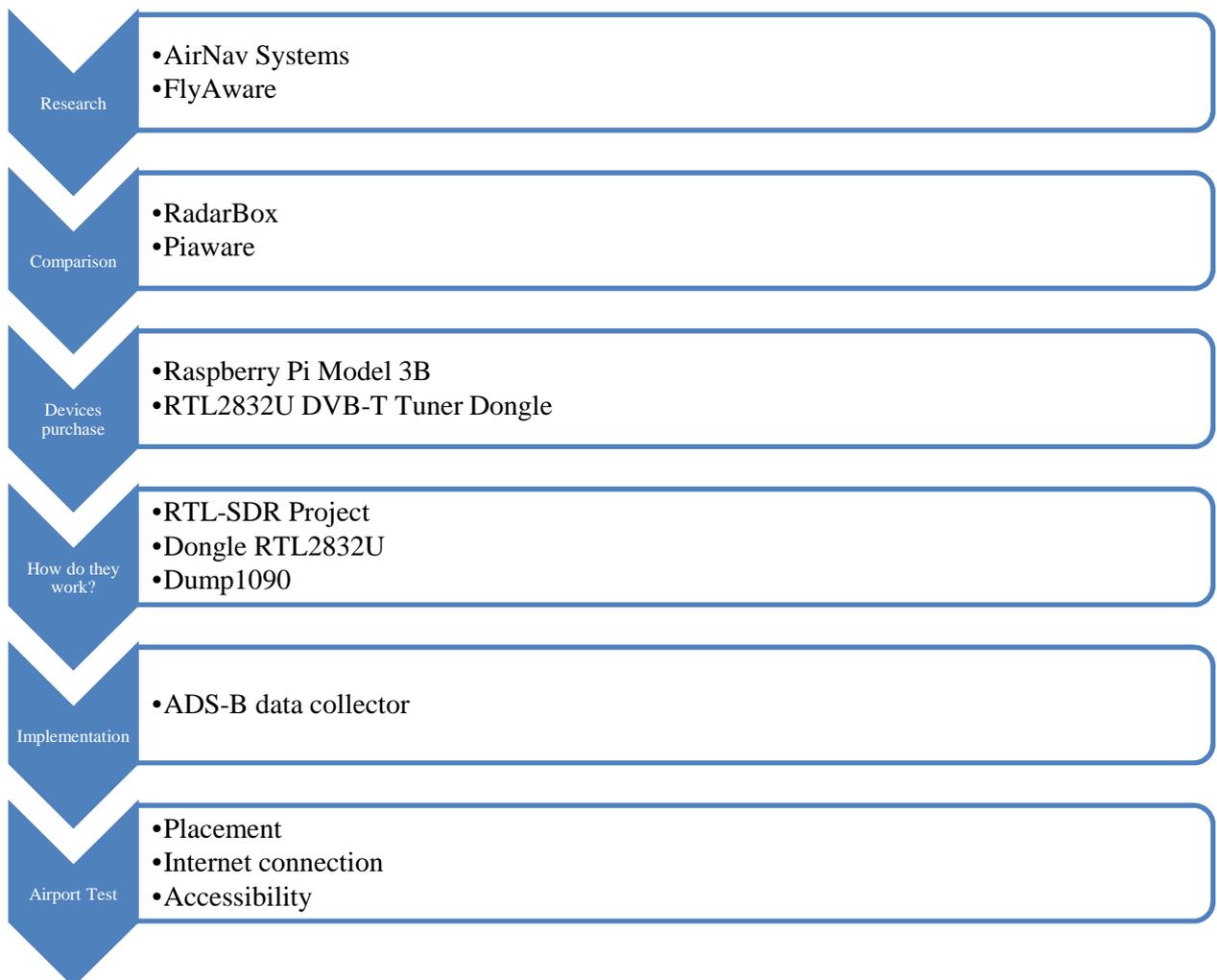|	
Research	• AirNav Systems • FlyAware
Comparison	• RadarBox • Piaware
Devices purchase	• Raspberry Pi Model 3B • RTL2832U DVB-T Tuner Dongle
How do they work?	• RTL-SDR Project • Dongle RTL2832U • Dump1090
Implementation	• ADS-B data collector
Airport Test	• Placement • Internet connection • Accessibility

Diagram 3 - Project Development

5.2 Research

The aim of this project is to design an ADS-B data collector. Therefore, our researching should be focused on finding not only hardware but also software which could be suitable to work on such task.

What is more, many variables will be considered to decide which device is going to be used on our project. Some of them are:
- Difficulty to set up.
- Difficulty to fix problems.
- Documentation available.
- Technical aspects (battery consumption, internet connection, operating system…).
- Licenses.
- Prize.

Since it is a developing field (Comparing to other tracking technologies, companies on that field have been working only for 10 years) many companies are pointing their activities at ADS-B data collection and feeding. We will highlight two of the most important tracking companies. Each of them with its product:

16

- AirNav: Radar Box.
- FlyAware: Piaware.

5.2.1   *AirNav Systems: Radar Box*

Airnav Systems is a company has a Worldwide Real-Time ADS-B Flight Positioning Network. It operates in more than 150 countries, including areas like Europe, US, Canada, Atlantic and Pacific.

As a mainstream user, you can decode ADS-B signals to track aircrafts in your computer. Besides, you would be able to display all the ADS-B parameters on your web application.

This company started with the development of simple software which purpose was to track planes over oceanic areas. Nevertheless, you can find a wide range of different applications regarding flight tracking and monitoring tools.

What is more, Airnav Systems has many different types of clients, which go from Airlines and Airports to Aviation Enthusiasts, to whom it provides unique software solutions. Nowadays, Airnav has over 15 thousand users in more than 150 countries.

5.2.2   *Flight Aware: Piaware*

FlightAware is the biggest flight tracking company in the world. FlightAware acquires air control data in more than 55 different countries. This data come from their own ground-based ADS-B stations placed in more than 150 countries, but also from the Aireon ADS-B special stations by using Global datalink. FlightAware is provided with Global data link by companies like ARNIC, SITA, Satcom Direct, Garmin, Honeywell GDC and UVdatalink. Besides, it provides global flight solutions to more than 10 thousand aeronautical companies and more than 12 million passengers.

FlightAware provides real-time data about flights, airports, delays, oil prizes, weather conditions, flight tracking and flight world news among others. It develops not only computer software, but also smartphone apps for their more than 10 million clients.

For the aim of our project, we have chosen its most suitable product, Piaware. It gives you the chance to build your own ground station so that you could receive real-time data to your computer. It can track flights within a range of 160 to 480 km depending on many factors like line of sight, antenna or weather conditions.

5.3   Comparison

5.3.1   *Radar Box*

It is an ADS-B, VHF Airband and GPS receiver that connects to RadarBox windows software.

The included software has the following features:
- Real-time flight tracking.
- Real-time retrieval of aircraft details including registration, company and aircraft type.
- Easy plug and play USB connection.
- ACARS Decoder interface.
- 5 minutes delayed flight data in port 7879.
- Data sharing output in add-on compatible format is available on Port 40004.
- Automatically Imports Outline Files.
- Real-time photos of all tracked aircrafts.
- Real-time weather information.
- Export data and generate reports.
- Shared screen shoots or send logs automatically to others.
- MyLog: log all and share with your friends all the aircraft you receive.

- Alert generation for specific aircraft or in-range flights.
- Radar player to review airspace recordings.
- Editable callsign database included: Know the origin and destination of each flight.
- 160 thousand flight number data base included.

The package includes:

Item	Num	Price
Receiver: Radio receiver (GPS, ADS-B, VHF-AM. SMA connector)	1	-
Power supply: 5V DC. 2A.	1	-
Ethernet: 10/100 Mbps (RJ45 connector)	1	-
Antenna: 3 dBi Gain.	1	-
Total (Dollars)	**-**	**649,95 $**
Total (Euros)	**-**	**551,60 €**

Table 1 - RadarBox Kit

Figure 1 - Radar Box Kit

5.3.2 Piaware

Piaware runs on Rasbian (Debian distribution for Raspberry Pi), and it allows you to track flights directly on your Raspberry Pi. Besides, you can see your statics on their website.

The pre-built kit includes two pieces of software:

- Dump1090: This is a lightweight Linux based command line program for mode S, mode C and ADS-B decoding. It also has a build in service which can display the decoded aircraft on Google Maps.
- Piaware: This is a software package from Raspberry Pi which allows data coming from dump1090 to be shared with the FlightAware.com public servers.

To build our PiAware receiver, the pre-built kit includes the following components:

Item	Num	Price
Raspberry Pi Model 3B	1	-
5V 2.5A Micro USB Power Supply for Raspberry Pi	1	-
32 GB PreLoaded MicroSD Memory Card Class 10	1	-
Case for Raspberry Pi	1	-
FlightAware Pro Stick USB ADS-B Receiver	1	-
Indoor Antenna MCX plug with a SMA adapter. 2 dBi Gain.	1	-
ADS-B 1090 MHz Band-pass SMA RF Filter. 980 MHz – 1150 MHz Pass-band	1	-
Total (Dollars)	**-**	**150 $**
Total (Euros)	**-**	**127,00 €**

<p align="center">**Table 2 - Piaware Kit**</p>

<p align="center">**Figure 2 - Piaware Kit**</p>

5.4   Devices Purchase

Due to the many benefits and features that both option have, each of them could perform quite good approaches. However, since the aim of our project could mean the beginning of the ADS-B

data collection using this Piaware device, we have though that, the cheaper and more flexible, the better solution.

On the one hand, Radar Box is a high quality product, but it might not be suitable enough for the aim of our project. The first inconvenience is its cost, which would restrict many people to purchase it. Besides, it is a one-task device. Consequently, Radar Box would force its user to use that device for that particular task.

On the other hand, Piaware can be used for as many purposes as you can think of a Linux computer and its price is quite affordable. Many students or institutions for different fields, not just ADS-B studies, could purchase it. Furthermore, if Radar Box got obsolete, the amount of money to spend would be very high. Nevertheless, if we wanted to purchase the new Raspberry Pi version, it would cost rather 30 €and the software can be upgraded easly.

Consequently, our chosen option has been Piaware device.

5.5 How does the hardware work?

5.5.1 Dongle RTL2832U

5.5.1.1 General Purpose

This integrated circuit that works as a COFDM demodulator that was produced by Realtek Corporation has as main purpose to demodulate DVB-T (digital TV) signals to be sent to a host computer through the USB bus. It has an additional mode designed to allow the reception of costume FM radio. This is performed by capturing I/Q raw samples and forwarding them to the host computer for demodulation and further treatments.

5.5.1.2 Capture Bandwidth

This chip is theoretically capable of capturing up to 3.2 MHz of the RF spectrum. However, the largest bandwidth successfully received without sample loss is 2.8 MHz.

5.5.1.3 Frequency range

The RTL2832U chip does not acquire any RF tuning itself, so it must be used with a suitable tuner to enable signal reception. The most common one is the Elonics E4000.

Tuning characteristics:
- Recommended:
  - o fmin = 64 MHz.
  - o fmax = 1700 MHz.
- Tested:
  - o fmin = 30 MHz.
  - o fmax = 2100 MHz.

5.5.1.4 Schematic

As shown below, the RTL2832U schematic. It works as follows:

1. The RF tuning chip acquires the down-frequency demodulation obtaining the intermediate frequency signal.
2. The RTL2832U chip, obtains the I/Q data.
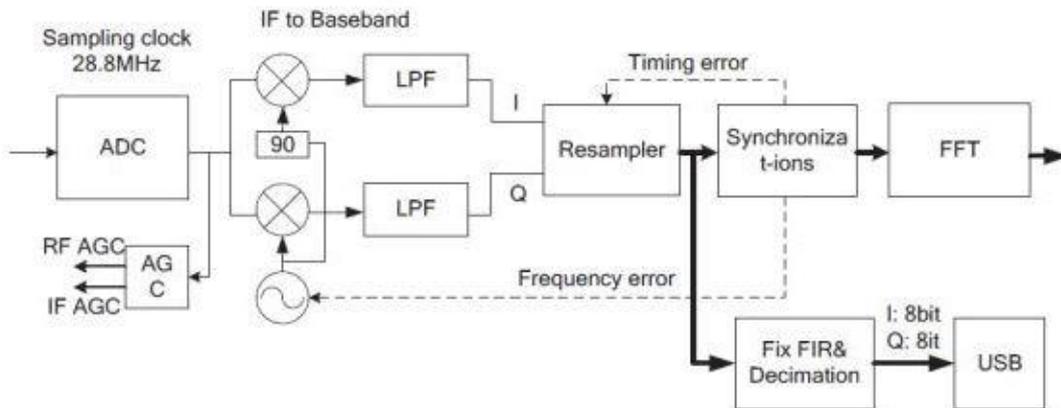3. The data is demodulated by using some certain software, such as dump1090.

Diagram 4 – RTL2832U demodulation squematic

5.5.2 RTL-SDR Project

RTL-SDR (Software Defined Radio) aims to implement many of the hardware radio components, such as, modulators, demodulators or tuners, into software instead. This enables easy signal processing and thus cheap wide band scanner radios to be produced. In other words, it uses DVB-T TV tuner dongle based on the RTL2832U chipset to access I/Q data and convert it into a wideband software defined radio via a new software driver.

5.5.3 Dump1090

Dump1090 is the program that uses the RTL2832U dongle to demodulate I/Q samples to obtain the Mode S and ADS-B data. Furthermore, this program generates a .json file named 'aircraft', which stores recent aircraft data and is updated every few milliseconds (determined by receiver.json file). Besides, aircraft.json file, dump1090 program generates up to 120 json files, which are updated every 30 seconds, storing all the .json files as historical copies of previous aircraft.json files. All this files are saved in the Linux directory **/run/dump1090-fa** The Json file is composed by the following key values:

- now: The time when this file was generated (in seconds since Jan 1 1970 00:00:00 GMT)
- messages: the total number of Mode S messages processed since dump1090 started
- aircraft: an array of JSON objects, one per aircraft. Each aircraft has the following keys. A key will be omitted if data is not available:
    - hex: the 24-bit bit ICAO identifier, as 6 hex bits.
    - squawk: the 4-digit squawk (octal format)
    - flight: the flight time/callsign
    - lat, lon: the aircraft position in decimal degrees
    - nucp: the NUCp (navigational uncertainty category) reported for the position
    - seen_pos: how long ago (in seconds before 'now') the position was last updated
    - altitude: the aircraft altitude in feet or 'ground' if it is   reporting it is on the ground
    - vert_rate: vert rate in feet/minute
    - track: true track over ground in degrees (0-359)
    - speed: reported speed in kt. This is usually speed over ground.
    - Messages: total number of Mode S messages received from this aircraft
    - Seen: how long ago (in seconds before 'now') a message was last received from this aircraft
    - Rssi: recent average RSSI (signal power), in dbFS

As shown below, dump1090's working diagram among the rest of Piaware's pre-installed software.

We can see that the RTL2832U dongle obtains the I/Q data and the dump1090 performs the demodulation.

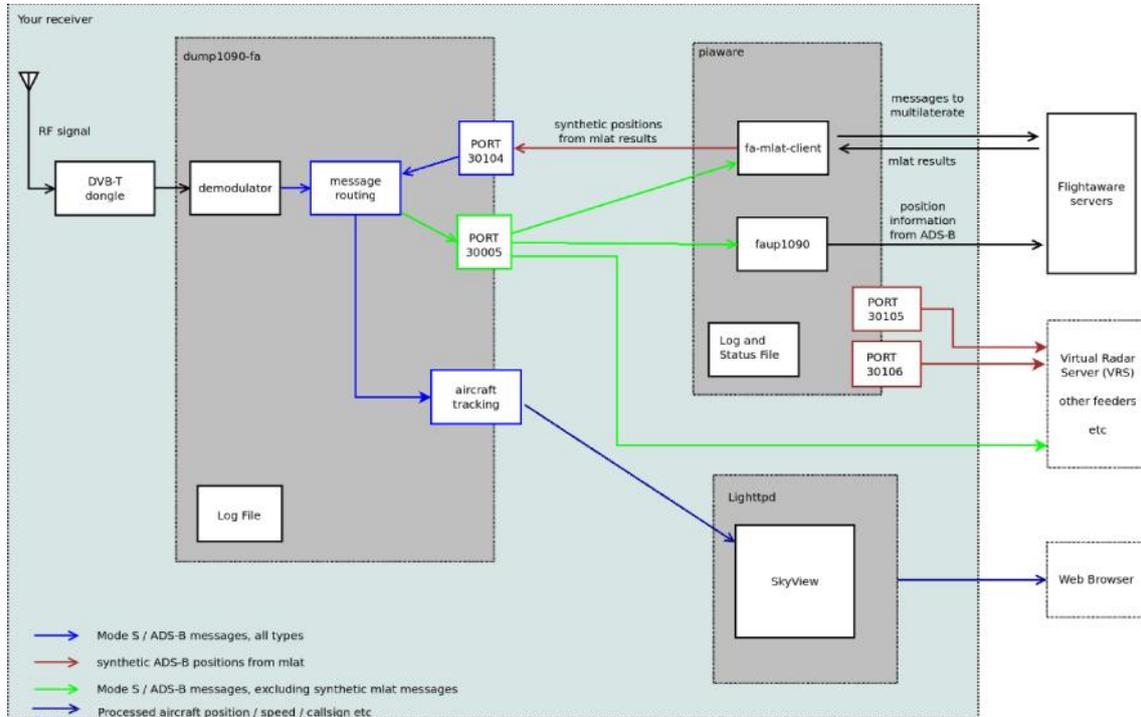What is more, we can observe how other processes, such as Piaware and mlat functionalities.

Diagram 5 - dump1090 schematic

5.6 Implementation

At this point, we will discuss about the implementation of our program. Actually, we will explain how both programs are going to work in terms of what particular task they are going to perform and if any software is going to be used.

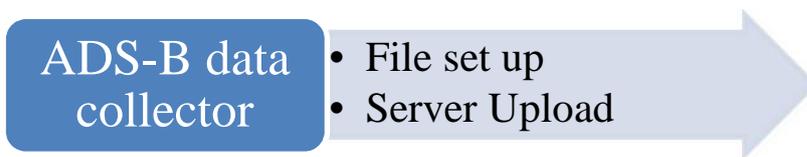### *5.6.1 ADS-B data collector*

Diagram 6 - ADS-B data collector

This entire task is performed by a bash script file named 'getdata.sh'.

In this part, we want to store the ADS-B data of all the nearby aircrafts that the RTL2832U dongle receives and sort them by day.

To perform such a task, we have to access **/run/dump1090-fa** directory and continuously copy the aircraft.json file content into another file. This other file will aggregate all the parameters available of every detected aircraft for one day, one after another (without missing the .json format). The filename will be as follows 'days in UTC format'-'day-month-year' (all refered to the date when the data is acquired). Once date changes in the system, the parameters of new tracked aircrafts will be saved in a new file respecting the previous format.

This script must run every second so that no aircraft data is missed.

Our acquired data is saved in the directory **/capturas**.

5.6.2   FTP Server Upload

This entire task is acquired by a bash script file named "serverup.sh".

As a security measure, the Raspberry Pi device which acquires ADS-B data is isolated from the internet (wlan0 interface is down) most of the time. When the file upload is going to be performed, the device is connected to the Internet. Once it has finished, the device is disconnected from the network. The security process is repeated each time that the file upload occurs.

5.6.2.1   ADS-B data upload

This process is responsible for uploading the ADS-B acquired data to the FTP server.

It works over tree folders of the system: **/capturas**, **/salida** and **/archivo**.

The script works as follows:
1. It access **/capturas** folder where all the acquired ADS-B data are saved and compress each file in a **.tar.gz** format. Afterwards, it is moved to **/salidas** folder.
2. It tries to upload all the files that are on **/salidas** folder to the FTP server. If some file upload was unsuccessful (it is checked by analysing the answer of the server), the file will remain in that folder. However, if a certain file was successfully uploaded, the .tar.gz file is moved to **/archivo** where all the files will be saved to keep historical copies of tracked flights.
3. Only unsuccessfully uploaded files and pendant uploaded files will stay on **/salidas** folder. Therefore, if there are some inconveniences, the day after, unsuccessfully files will be tried to be uploaded again.
4. The process will keep on uploading an unsuccessful file until it receives a satisfactory confirmation from the server.
5. The process runs at 2:45 h to avoid problems with the winter to summer hour change.

5.6.3   Crontab

Thanks to this Linux task administrator, we will be capable of scheduling our different scripts without the need of executing them manually.

That is achieved by selecting the certain moment (or moments) of the day when we want a file to be executed.

Figure 3 - Crontab Scheduling

As it is shown above, both processes, getdata.sh and serverup.sh have been scheduled.

- getdata.sh: Runs every minute.
- serverup.sh: Runs every day at 2:45 h.

5.6.3.1 getdata.sh

To schedule the ADS-B data acquiring, the minimum sample time will be used, that in Crontab stands for one minute. However, that is not enough to achieve our ADS-B collector requirements. That is because the ADS-B data is broadcast every second by ADS-B equipped aircrafts. Therefore, we would have to decrease our sample time down to one second. That is performed by using a for sentence (that repeats the script 60 times) combined with the sleep instruction on getdata.sh script.

What is more, we are not interested in using a sample time smaller than that, if so, we would be acquiring the same ADS-B signal data more than once, without the parameters changed. Besides, Raspberry's microprocessor would be charged with unuseful load.

5.6.3.2 serverup.sh

To schedule the ADS-B data upload to the FTP server, we have to consider a very important fact regarding the .json created files on **/capturas** folder. The point is that the server upload should not be run before the .json file containing all the ADS-B data of nearby tracked aircraft has been closed. In order to understand so, we have to explain how days (UTC format) variable, which is used to name every .json file on the previous folder, is acquired.

To obtain days in UTC format, 'now' variable inside aircraft.json file is accessed and saved. That variable (as described above) contains the seconds in GMT format. In order to the variable be smaller and, therefore, easier to work with, it was converted to days (respecting GMT format). Consequently, every new .json file on folder **/capturas** is created, and the previous one filled, at 00:00 h, GMT time. Converted to Spanish time reference, that means at 1:00 h (wintertime) or 2:00 h (summer time).

Because of the previous issue, the ADS-D data upload should not be performed until the .json file on **/capturas** has been closed.

Finally, the ADS-D data upload was set every day at 2:45 h (GMT+2 time).

5.7 Airport test

So far, we have implemented our program to do the certain task that we wanted. After thi we proceeded with the system test.

We placed our device at a suitable location to acquire the ADS-B data and the ATC voice communications.

Firstly, it was necessary that the placement met a few requirements to get the best signal possible:
1. The device must be placed within a distance to the airport not bigger than 15 km.
2. In order to obtain the best working conditions of the ADS-B receiver antenna, there should be line of sight pointed at the properly equipped ADS-B transmitter. Consequently, as far as it is possible in order to acquire better results it should be facing towards a free space (where the aircrafts are flying around).

Secondly, other requirements should met:
1. Power supply available.
2. Internet connection: To upload the acquired data to the FTP server.
3. Shelter from meteorological conditions so that our device is not damaged by the weather inconveniences.
4. Access to the device: We needed access the device if there were some problems or just to change its configuration.

To decide where we could place the ADS-B data collector, we have contacted different companies whose offices are placed next to Valencia's airport. Furthermore, we have explained to them our project aim in order to be allowed to place our device in their offices. Fortunately, a company agreed. That company is located as shown below:

Figure 4 - Device Location in Valencia's Airport. Euraservices

We thank to Euraservices Company for their collaboration.

Therefore, we moved to Valencia's airport to install our device. Then, we had to make different check-ups to ascertain that our project worked properly. For instance, we checked that there was no Firewall on the business network that blocked the file uploading.

Finally, once our device worked as desired, it was installed in that placement and is acquiring ADS-B data.

6. Budget

6.1 ADS-B data collector

Item	Num	Price
Pre-loaded Kit	**1**	**150,00 $**
Raspberry Pi Model 3B	1	-
5V 2.5A Micro USB Power Supply for Raspberry Pi	1	-
32 GB PreLoaded MicroSD Memory Card Class 10	1	-
Case for Raspberry Pi	1	-
FlightAware Pro Stick USB ADS-B Receiver	1	-
Indoor Antenna MCX plug with a SMA adapter	1	-
ADS-B 1090 MHz Band-pass SMA RF Filter	1	-
Total (Dollars)		**150 $**
Total (Euros)		**126,38 €**

Table 3 - ADS-B data collector budget

7. Conclusions and further improvements

7.1 Results

The aim of this project was to design a low cost ADS-B data collector in order to allow further studies about airports' efficiency.

This collected data should be automatically processed and uploaded to a database in order to obtain processed information about the air traffic flow in a certain airport.

7.1.1 ADS-B data collector

We wanted to design a system which stores ADS-B data on one device and automatically uploads it to a server.

This process has been performed so that the upload happens every day at 2:45 h. As we can observe in the image below from the ftp server disk, the system is working properly. Besides, the name of the tar.gz files is the value of 'day' variable in UTC format.
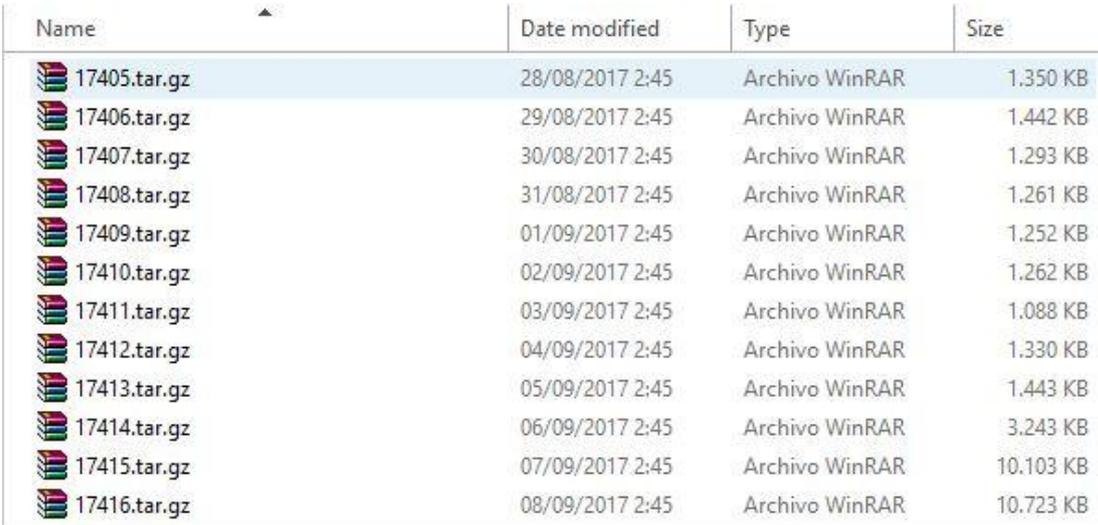
Name	Date modified	Type	Size
17405.tar.gz	28/08/2017 2:45	Archivo WinRAR	1.350 KB
17406.tar.gz	29/08/2017 2:45	Archivo WinRAR	1.442 KB
17407.tar.gz	30/08/2017 2:45	Archivo WinRAR	1.293 KB
17408.tar.gz	31/08/2017 2:45	Archivo WinRAR	1.261 KB
17409.tar.gz	01/09/2017 2:45	Archivo WinRAR	1.252 KB
17410.tar.gz	02/09/2017 2:45	Archivo WinRAR	1.262 KB
17411.tar.gz	03/09/2017 2:45	Archivo WinRAR	1.088 KB
17412.tar.gz	04/09/2017 2:45	Archivo WinRAR	1.330 KB
17413.tar.gz	05/09/2017 2:45	Archivo WinRAR	1.443 KB
17414.tar.gz	06/09/2017 2:45	Archivo WinRAR	3.243 KB
17415.tar.gz	07/09/2017 2:45	Archivo WinRAR	10.103 KB
17416.tar.gz	08/09/2017 2:45	Archivo WinRAR	10.723 KB

Figure 5 - Uploaded files

What is more, every json file within the tar.gz file is uploaded with the desired name format. It is composed by:
1. The value of 'day' variable in UTC format.
2. The date when the file is acquired (day/month/year) matches with 'day' in UTC format.

Nombre	Tamaño	Comprimido	Tipo	Modificado	CRC32
..			File folder		
17415-06-09-2017.json	171.933.650	?	JSON File	06/09/2017 23:59	

Figure 6 - File format

Another important fact about this procedure is the size of the file. As it depends on the amount of acquired data, we cannot ensure a constant file size. However, a good approach could be that each compressed file weights from 10 to 12 Mbytes. Therefore, the file system will upload every year about 4 Gigabytes of storage to the FTP server.

Consequently, as the storage of the memory card installed in the Raspberry Pi is 32 Gigabytes, we will be able to store years of flights data without the need of performing any process to delete stored files or changing the memory card. Besides, such a file deleting process has not been performed yet because as we are at the beginning of acquiring ADS-B data by using a Raspberry Pi device to allow further studies about airports' efficiency, the project needs are not fully known.

Thanks to this process, we are able to collect within each json file about 100000 different aircraft registers.

7.1.2 Result System

As shown below, the schematic about how the different components have been connected:
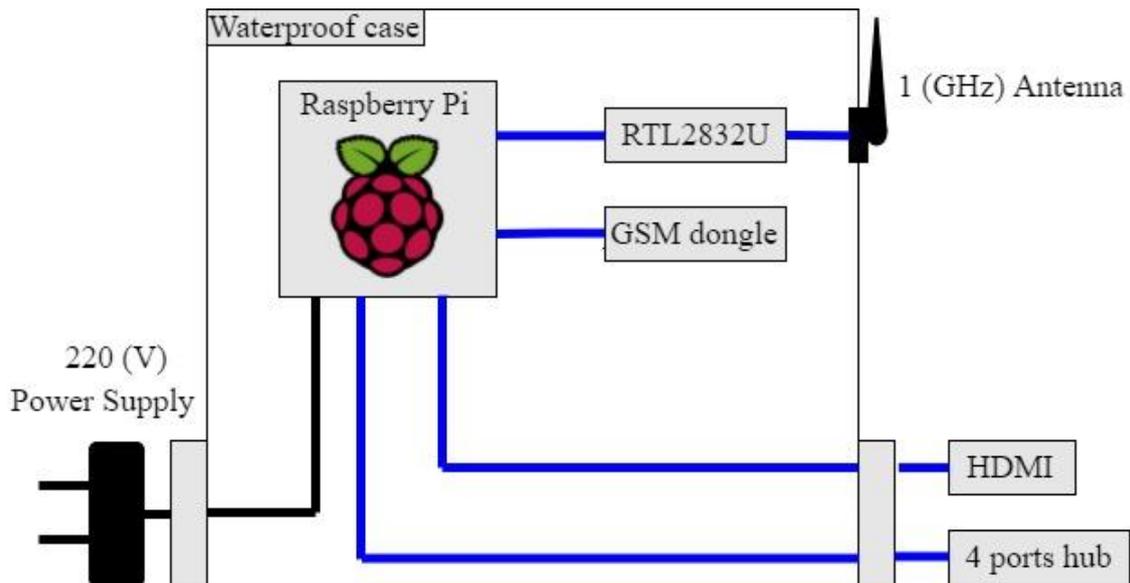

Figure 7 - Raspberry Pi System

Once the test fase is finished all the devices are already configured and placed inside a waterproof case so that it can be managed and carried easily and installed outdoors.

The Raspberry Pi has a free HDMI port for the control screen and a free USB port to connect four port USB hub to connect the keyboard and the mouse.

Room for a second RTL2832 has been reserved to allow for the capture of the ATC voice communications in the future, to see if more information about mode C equipped airplanes can be obtained from them.

The device must be placed outside a building, it would be better at the top of it, in a placement close to the airport which we want to acquire data from. Furthermore, this placement must have a plug to allow the power supply of the Raspberry Pi.

The internet connectivity is achieved by using a GSM USB dongle. Therefore, the Raspberry is able to upload the data files to the FTP server.

As a conclusion, once the device has been placed, it can be acquiring data indefinitely without any supervision and it will work automatically and upload all the ADS-B acquired data to the server.

7.2   Further Improvements

It this part, we will discuss about how the power supply of the system efficiently could be enhanced to avoid having to look for an electricity plug in the location where the system is installed.

7.2.1 Power Supply by using solar panels

Other possible enhancement regarding the device autonomy could be to connect it to a solar panel system instead of feeding it by connecting to mains electricity.

7.2.1.1 Process of calculation

1. Raspberry Pi consumption

By using a multimeter, we have measured the output current that is required by the Raspberry Pi when all the devices are connected and working (the two RTL2832U dongles, the GSM dongle and the four ports hub), the result was I_{out}=0.5 (A).

Therefore, the required power supply is:

$$E_{CC}(Wh) = I_{out} * 5(V) * 24\ (h) = 60\ (Wh) \qquad (1)$$

In order to satisfy our power requirements, our solar panel system has to be able to generate, at least such a quantity of power.

However, we will size our system in order to produce more energy and load the battery system.

2. Location and panels inclination

We have made the calculations for our placement at Valencia's Airport with the following geographical parameters:
- Latitude: 39.490403º.
- Longitude: -0.469973º.

Since we will have to satisfy the electrical power for the whole year, our calculations will be focused on the worst month of the year (Worst month in terms of solar power received). Therefore, by satisfying the power requirements of that month, the device will be able to work during the whole year.

For such purpose, the recommended inclination is the geographical latitude plus ten degrees, which in our case stands for 50º, which is the chosen inclination.

3. Worst month determination

As we have told before, our design will ensure that the device works during the whole year by ascertaining that it is working during the worst month. Using data from Surface Meterology and Solar Energy NASA's website, the solar energy received in worst month of the year has been calculated as follows:

	January	February	March	April	May	June	July	August	September	October	November	December
Consumption (Wh)	60	60	60	60	60	60	60	60	60	60	60	60
Daily solar radiation (Wh/m^2/day)	2310	3170	4360	5470	6080	6770	7070	6200	4760	3410	2380	1920
k factor for 40º latitude	1,41	1,28	1,13	0,98	0,87	0,83	0,87	0,99	1,18	1,39	1,54	1,52
Atmospheric coefficient	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Horizontal solar radiation (Wh/m^2/day)	3420	4260	5173	5629	5554	5900	6458	6445	5898	4977	3848	3064

Table 4 - Worst Month Calculation

In order to satisfy the electrical requirements for the worst month, December, we will have a horizontal solar radiation of 3064 (Wh/m^2).

4. Minimum Medium Peak Power required by our system

1) Before the power regulator:
- Days of autonomy, N=1.85 (About two days).
- Depth of Discharge, P_D=60% (To meet IDAE recommendations).
- Self-Discharge coefficient, k_A=0.001.
- Charging/discharging coefficient, k_B=0.1.

- Joule effect throughput, $_J{}^{DC}$=0.985 (To meet IDAE recommendations).
- Power Transformer throughput, $_T$=0.98.

N	P_D	k_A	k_B	$_J{}^{DC}$	$_T$	R_{DC}
1.85	0,6	0,001	0,1	0,985	0,98	**0,8661**

Table 5 - Calculations before the power regulator

The throughput factor of the installation is R_{DC}=0.86.

2) After the power regulator:
- Joule effect Efficiency from the solar panel to the power regular, $_J{}^{GF-R}$ =0.985 (To meet IDAE recommendations).
- Power regulator efficiency, $_R$=0.98.
- Solar panel efficiency: $_{GF}$=0.9.

$_J{}^{GF-R}$	$_R$	$_{GF}$	PR_{DC}
0,985	0,98	0,9	**0,7524**

Table 6 - Calculations after the power regulator

The throughput ratio of the installation is PR_{DC}=0.7524.

- Solar peak hours:

$$H_{SP} = \frac{G_{dm}(\alpha,\beta)}{I_{CEM}} = \frac{3064\ (Wh/m^2)}{1000\ (\frac{W}{m^2})} = 3.064\ (h) \qquad (2)$$

- Energy required by the photovoltaic generator:

$$E_{GF}{}^{TEO} = \frac{E_{CC}(Wh)}{PR_{DC}} = \frac{60\ (Wh)}{0.7524} = 79.7412\ (Wh) \qquad (3)$$

- Minimum Medium Peak Power:

$$P_{mp,min} = \frac{E_{GF}{}^{TEO}(Wh)}{H_{SP}\ (h)} = \frac{79.7412\ (Wh)}{3.064\ (h)} = 26.0225\ (Wp) \qquad (4)$$

5. Nominal capacity of the required batteries

$$C_N(Ah) = \frac{E_{CC}(Wh) * N}{R_{DC} * P_D * V_N(V)} = \frac{60\ (Wh) * 2}{0.8659 * 0.6 * 12(V)} = 17.8003\ (Ah) \qquad (5)$$

7.2.1.2   Results

Therefore, in order to satisfy our power requirements, we will have to purchase:

- Solar panel, which provides at least 31.227 (W). (120% of the obtained power. Due to IDAE recommendation).
- Battery with at least 18 (Ah) of nominal capacity.

However, our system will be oversized for unexpected events.

7.2.1.3 Products and brochure

Items:
- Lidersolar 45 W Model Solar Panel. 16.5 % Cell efficiency. Dimensions: 646 x 296 x 25 (mm).
- BlueSolar MPPT 75/15 Power regulator. 98 % Maximum efficiency.
- FitTek Electrical transformer 12 V, 5 V, 3A and 15W.
- U-Power Battery: UP18-12 Model. Nominal Voltage 12 V. Nominal Capacity (10HR) 18 AH.

Brochure:

Item	Num	Price
Lidersolar 45 W Model Solar Panel	1	185,86 €
BlueSolar MPPT 75/15 Power regulator	1	92,57 €
FitTek Electrical transformer	1	2,72 €
U-Power Battery: UP18-12 Model	1	34,85 €
Total (Euros)		**316,00 €**

Table 7 - Brochure of the Enhanced System
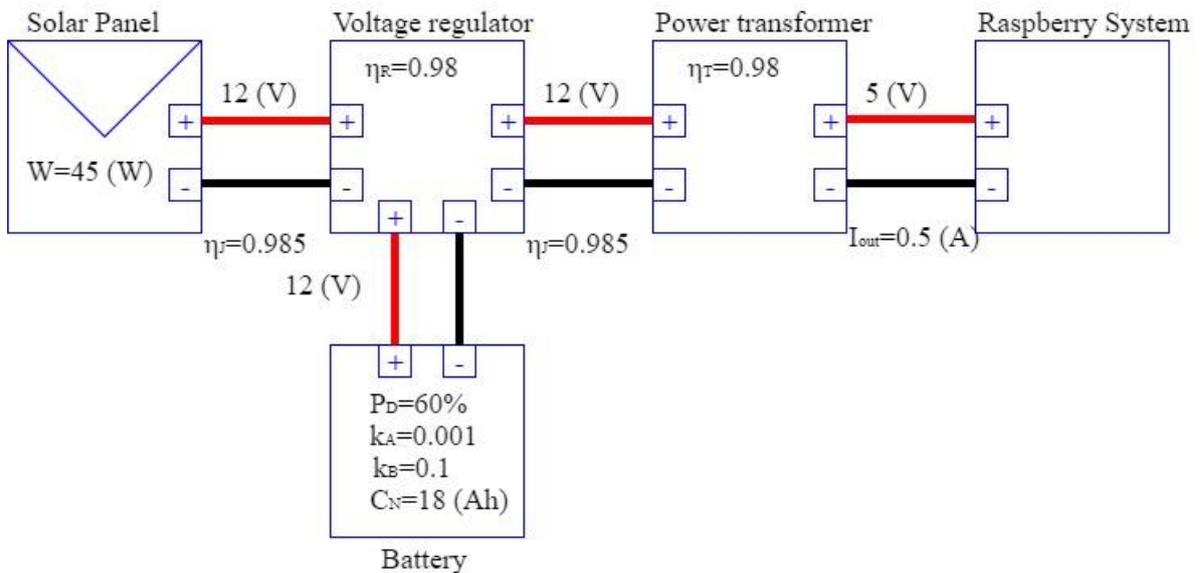
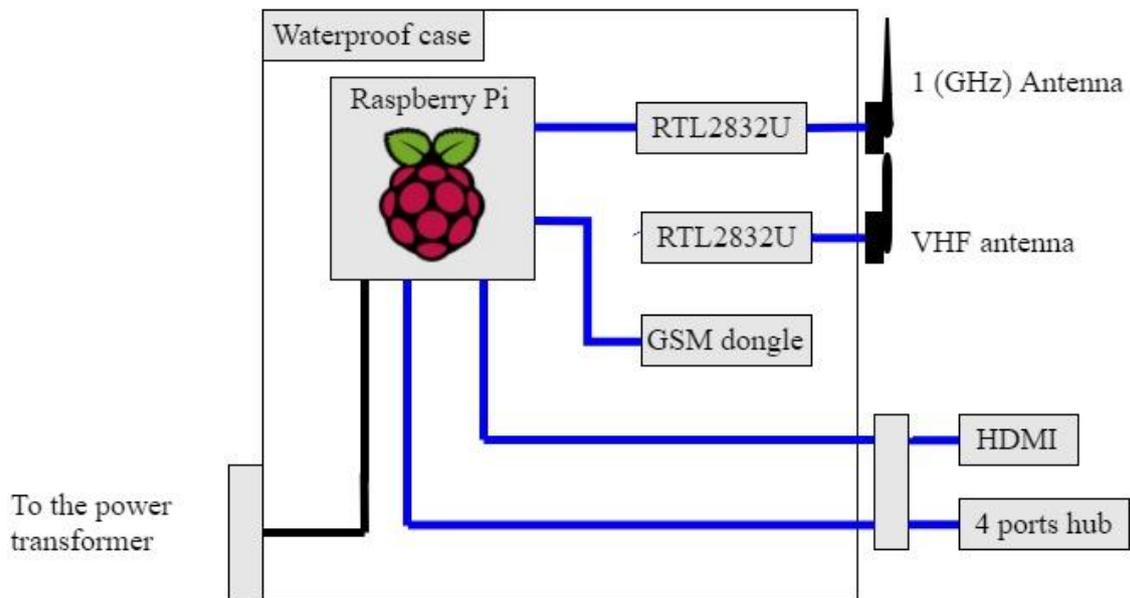### 7.2.1.4 Result System

Figure 8 - Solar Panels System

Figure 9 - Raspberry System

7.2.2 Mechanism to select the inclination of the panels

Since our system has been designed in order to work in airports placed at such a latitudes as the northern hemisphere, we will have to be able to select the inclination for our solar panels depending on the airport's location.

This will be accomplished by a using an inclinable structure that will allow the user to select between different inclinations from 10º to 70º.
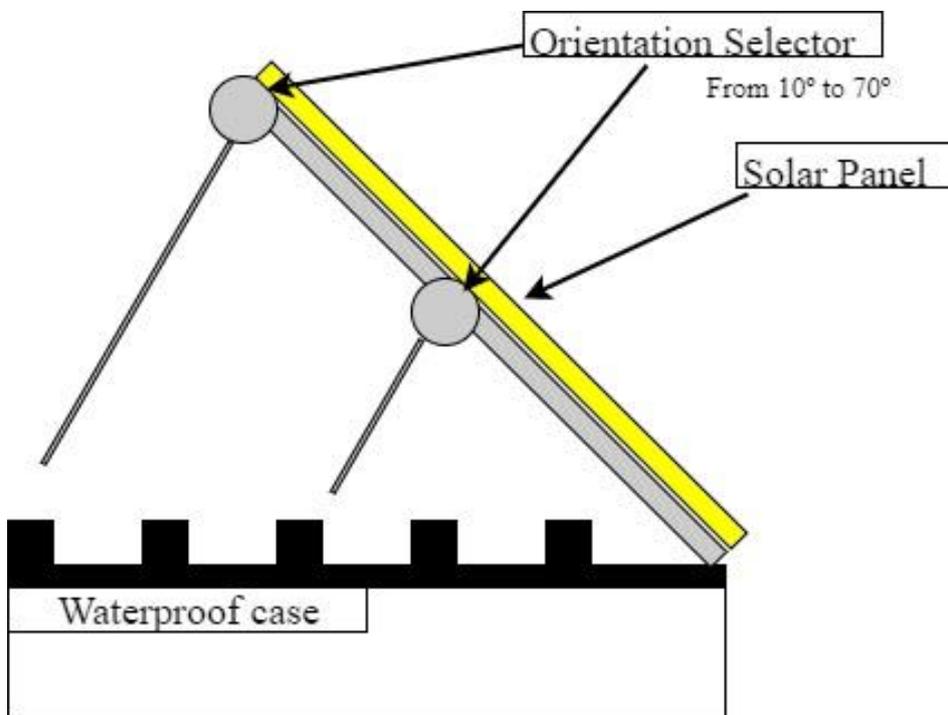
The mechanism works as shown below:

Figure 10 - Inclinable Mechanism

7.2.3   ATC communications recorder

As non-commercial flights, like light aircrafts, do not have neither ADS-B nor mode S transponder, it would be interesting to implement a system to record the voice communications of the control tower. That idea would allow us to infer other parameters for small aircrafts by listening to the voice communication recording of the control tower.

These small aircrafts use another tracking system, Mode-C transponder. This system only sends the aircraft code and its altitude, relying in a RADAR system to get the aircraft position. As we will not have the RADAR data, we will not have their geographical position, not being able to get the parameters we want to study.

Pilots communicate with the control tower during all phases of the taking-off and landing procedures. Using a voice communication radio receiver we will record the voice communications of the control tower frequency to see if we can get some additional data that help us to characterize the operation of this type of planes.

Runway entrance and take-off clearances form the ATC or information as runway vacated from the pilot could give us useful information to be able to calculate some of the operational parameters.

When control tower communicates with the light aircraft, is uses a code for it, the pilot answers via voice message through a radio link and provides that code. The identification code is usually the aircraft registration number. As far as we obtained that identification code, we would be able to search for information linked to that aircraft so we can find the model of the plain.

This procedure might not work for all the light aircrafts, because some of the identification numbers of those aircrafts are not linked to the model. Instead, they are linked to the institution which owns them like their Air Academy.

7.2.3.1   How we would obtain them

As we are using dump1090 software, we are able to receive some light aircrafts parameters, such as identification and altitude.

If we designed some software or system that used RTL2832U dongle to listen to the radio link between the aircraft and the control tower, we will be able to know when those orders are given. We could supervise the channel, and by using a squelch function, we could record the communication when it happens.

What is more, listening to the ATC communications channel might be possible since it operates over the VHF frequency band, at 108 to 137 MHz margin of frequencies.

Besides, it uses amplitude modulation, which means that the signal is not decoded. Therefore, we would be able to listen to it without the need of using a certain decoder for such communications.

7.2.4   Conclusions

Finally, due to these system enhancements, we would be able to design a device that works fully autonomously and automatically acquiring tracking data from nearby aircrafts that will allow further studies about airports' efficiency.

8. Bibliography

[1]   USA Federal Aviation Administration, Automatic Dependant Surveillance System, https://www.faa.gov/nextgen/programs/adsb/. [Online].

[2]   Sigidwiki, ADS-B, 1090 MHz Extended Squitter, https://www.sigidwiki.com/images/1/15/ADS-B_for_Dummies.pdf. [Online].

[3]   Skybrary, Mode S transponder, https://www.skybrary.aero/index.php/Mode_S. [Online].

[4]   Agencia Estatal de Seguridad Aérea, Air Traffic Control Communications, http://www.seguridadaerea.gob.es. [Online].

[5]   AirNav Systems, RadarBox, https://www.airnavsystems.com. [Online].

[6]   FlyAware, https://es.flightaware.com/. [Online].

[7]   Raspberry Pi Community, https://www.raspberrypi.org/. [Online].

[8]   Realtek, RTL2832U dongle specifications, http://www.realtek.com.tw/products/productsView.aspx?Langid=1&PFid=35&Level=4&Conn=3&ProdID=257. [Online].

[9]   DataSheetCafe, RTL2832U dongle specifications, http://www.datasheetcafe.com/rtl2832-datasheet-pdf/. [Online].

[10]   Amateur Radio, RTL2832U dongle specifications, http://www.amateur-radio-wiki.net/index.php?title=RTL2832. [Online].

 [11]   NASA, Surface Meterology and Solar Energy, https://eosweb.larc.nasa.gov/sse/RETScreen/. [Online].

[12]   LiderSolar, Solar Panels Purchase, http://www.lidersolar.es/. [Online].

[13]   Amazon, Raspberry Pi Purchase, https://www.amazon.es/. [Online].

[14]   AGM Batteries Characteristics, http://www.enernaval.es/PDF/Dossier.pdf

 [Online].