Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels
UNIVERSITAT POLITÈCNICA DE CATALUNYA

TREBALL FINAL DE GRAU

TÍTOL DEL TFG: Development of a system for detection, control and prevention of locust pests using UAV platforms

TITULACIÓ: Grau en Enginyeria d'Aeroports

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Resum

El present document i projecte té la finalitat de desenvolupar un sistema basat amb l'actual tecnologia UAV (*Unnamed aerial vehicle)* amb la qual oferir una eina actualitzada per la lluita contra les plagues de llagosta.

Les plagues de llagosta amenacen els recursos agrícoles que són la base de la subsistència humana i animal com els cultius, camps de pastura, i muntanyes. És una de les plagues més crítiques i nocives ja que tenen la capacitat de desplaçar-se per aire fins a 150 km per dia a més de travessar oceans com l'Atlàntic.

La metodologia emprada és l'ús de plataformes *drone.* Aquesta tecnologia està demostrant ser una de les puntes de llança a nivell tecnològic en moltes àrees, disciplines i indústries gràcies a la seva versatilitat i accessibilitat.

El plantejament d'aquest projecte és la continuació dels anterior treballs duts a terme per el present co-director i supervisor del treball per a obtenir una solució més eficaç i avantguardista que els actuals mètodes per a combatre les plagues de llagosta a nivell estatal i oferir una tecnologia amb 3 nivells de servei: detecció, prevenció i finalment control.

Tots els recursos emprats que engloben el desenvolupament de les plataformes a nivell tècnic i operacional han estat prestades per l'empresa HEMAV, l'operadora nº1 de drones a Espanya.

Finalment es pot confirmar que després de l'actualització de l'estat de l'art i l'anàlisi de resultats hi ha un salt considerable tant a nivell tecnològic com a nivell de recursos humans en els mètodes emprats actualment i la solució proposada. S'obre una nova línia de treball i negoci per a combatre les plagues de llagosta que només el marc legal i les limitacions tecnològiques són factors limitants.

Title: Development of a system for detection, control and prevention of locust pests using UAV platforms

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Date: February 8 th 2018

Overview

The present document and project has the purpose of developing a system based on the current UAV (Unnamed Aerial Vehicle) technology with which to offer an updated tool for the fight against locust pests.

Locust pests threaten agricultural resources that are the base of human and animal subsistence such as crops, grassland, and mountains. It is one of the most critical and harmful pests since they have the capacity to travel by air up to 150 km per day in addition to crossing oceans like the Atlantic.

The methodology used is the use of drone platforms. This technology is proving to be one of the spearheads at the technological level in many areas, disciplines and industries thanks to its versatility and accessibility.

The approach of this project is the continuation of the previous work carried out by the current co-director and supervisor of the work to obtain a more effective and vanguardist solution than the current methods to fight locust pest at the state level and offer a technology with 3 levels of service: detection, prevention and finally control.

All the resources employed that encompass the development of the platforms at the technical and operational level have been provided by the company HEMAV, the operator nº1 of drones in Spain.

Finally, it can be confirmed that after the update of the state of the art and the analysis of results there is a considerable leap both at the technological level and at the level of human resources in the methods currently used and the proposed solution. A new line of work and business is opened to combat pest plagues that only the legal framework and technological limitations are limiting factors

Acknowledgment

I deeply appreciate the support, dedication and help given to Mr. Marc Aicart Ramírez, director and mentor of this project. I also thank Hemav for welcoming me and giving me total freedom to carry out my studies in his engineering workshop as well as the material provided.

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LIST OF ACRONYMS

Acronym	Meaning
CSR	Corporate Social Responsibility
DISPATCH	DISaggregation based on Physical And Theoretical scale Change
DLIS	Desert Locust Information Service
ECMWF	European Centre for Medium-Range Weather Forecasts
EKF	Extended Kalman Filter
EMI	ElectroMagnetic Interference
ESA	European Space Agency
ESD	ElectroStatic Discharge
FAO	Food and Agriculture Organization of the United Nations
FMU	Flight Management Unit
GNSS	Global Navigation Satellite System
GSD	Ground Sampling Distance
HEMAV	High Endurance Multipurpose Aerial Vehicles
IMU	Inertial Measurement Unit
IRI	International Research Institute for Climate and Society
MEMS	MicroElectroMechanical Systems
MODIS	MODerate-resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NLCC	National Locust Control Centre
PAN	PhenylAcetoNitrile
RTK	Real Time Kinematic
SAR	Synthetic Aperture Radar
SM	Soil Moisture
SMELLS	Soil Moisture for dEsert Locust earLy Survey
SMOS	Soil Moisture and Ocean Salinity
TVS	Transient Voltage Suppression
UAV	Unmanned Aerial Vehicle

INTRODUCTION

The main objective of this project is to offer a **technologically innovative solution** to the current methods of detection and control of locust pests. This document is the continuation of years of work and research against the tireless struggle **to prevent the spread of desert locust** to Europe through the use of **UAV technology.**

This solution must offer different levels of alert, among them a **quick detection** of the locusts in their most vulnerable biological phases for greater ease in their eradication, an **effective control** of their presence in the field and with all this suppose a much more **effective prevention** methodology than the current methods.

This new structure of work must provide an improvement in the **three fundamental pillars of good service**. That is, an **environmental, social and economic improvement.**

The document is divided into the following chapters:

Chapter 1 is dedicated to a detailed **biological study of desert locusts**, the problem and the **impact that it has on the environmental framework** and finally **its evolution to the present** to put into context what is the environmental, operational and technical problems that we must face.

Chapter 2 is intended to explain the actual methodology on high level remote sensing and its limitations and the **advances and updates** that have been made over the last few years in terms of **research and previous monitoring on high level remote sensing** for forecasting locust presence.

Chapter 3 includes the **technical aspects** regarding the **fixed-wing platform**. It details the improvements with respect to its predecessor, **its assembly and configuration**. It also **contains the flight tests** carried out in the test field to validate its implementation in the solution.

Chapter 4 proposes the **new architecture of the solution**. It exposes the phases of operation and its details. It also justifies **Phenylacetonitrile as a pesticide** in the form of a pheromone and finally the most **notable differences between the architects** designed to date are summarized.

Chapter 5 contains **the conclusions reached** throughout the entire project and makes a **global reflection** of how the solution has been designed.

CHAPTER 1. INTRODUCTION TO THE DESERT LOCUST AND THE ENVIRONMENTAL FRAMEWORK

1.1 Problem definition

Vast areas of remote desert within approximately 16 million sq. km. that stretch from West Africa to India and include some of the world's poorest countries are regularly monitored for Desert Locust by national ground teams. Similar activities are carried out in Caucasian and Central Asian countries as well as in Madagascar where it is difficult to survey in remote or inaccessible areas. Monitoring constitutes the primary activity in any locust early warning and preventive control system. Although satellite-based estimates of rainfall and green vegetation are utilised to reduce and prioritize these large and potentially suitable areas, imagery suffer from omission errors and are often not available in time. Consequently, there is a need to supplement these tools with additional technologies to guide ground teams to green vegetation and locust infestations. This concept aims to introduce the use of drones with the goal of improving the quality of surveys and early treatment.

Desert Locust is considered as one of the most dangerous migratory pests in the world and can cause serious damage to agro-pastoral resources. It presents a threat to agriculture in a vast area of the world stretching from the Atlantic coast of West Africa through the Near East to the Indian subcontinent. Due to its migratory ability to traverse thousands of kilometres in a matter of weeks, Desert Locust is an international transboundary concern with major economic, social and environmental implications.

The Desert Locust distribution area is divided into three regions: Western, Central and Eastern. The Western Region (WR) includes countries in West and Northwest Africa (Algeria, Burkina Faso, Libya, Mali, Mauritania, Morocco, Niger, Senegal, Chad and Tunisia). The 2003-2005 Desert Locust regional plague required control operations supported both by the countries concerned and the international community that treated nearly 13 million hectares. The cost of the regional plague was estimated at USD 570 million. Damage to agro-pastoral resources ranged from 30% to 100%, depending on type of crop. More than eight million people were directly affected by this crisis.

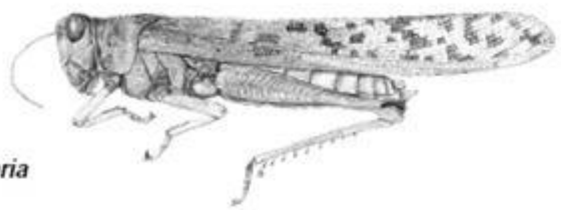
This demonstrates the relevance and importance of the preventive control strategy and its effective implementation by the concerned countries and international partners in order to minimize costs as well as economic, social and environmental consequences.

1.1.1 Desert Locust study

Locusts are members of the grasshopper family *Acrididae*, which includes most of the short-horned grasshoppers. Locusts differ from grasshoppers because they have the ability to change their behaviour and physiology, in particular their colour and shape (morphology) in response to changes in density.

Adult locusts can form swarms which may contain thousands of millions of individuals and which behave as a unit. The non-flying nymphal or hopper stage can form bands. A band is a cohesive mass of hoppers that persists and moves as a unit. In general, most grasshoppers do not form bands or true swarms. However, the distinction between locusts and grasshoppers is not clear-cut since some of the latter do form bands or small loose swarms.

This project but is based on the study and fight against the desert locust (*Schistocerca gregaria)*.



Schistocerca gregaria
(Forskål, 1775)

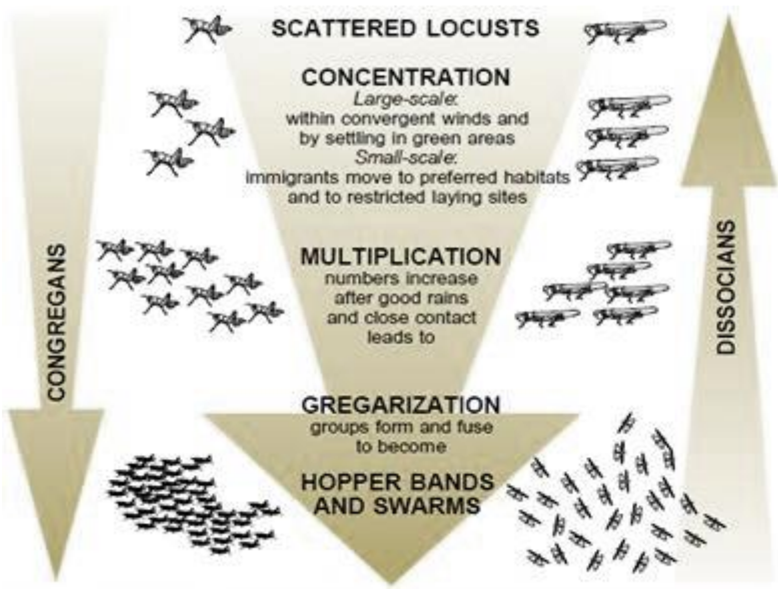
CLASS	INSECTA	
ORDER	ORTHOPTERA	Grasshoppers (about 20 000 species worldwide)
SUBORDER	CAELIFERA	Short-horned grasshoppers (about 10 000 species worldwide)
SUPERFAMILY	ACRIDOIDEA	
FAMILY	ACRIDIDAE	Grasshoppers and locusts
SUBFAMILY	CYRTACANTHACRIDINAE	
GENUS	*Schistocerca*	
SPECIES	*gregaria*	

Fig. 1.1. Scientific classification of desert locust

1.1.2 Locust phases and behaviour

Locusts have two different states called phases: solitarious and gregarious. When locusts are present at low densities, the individuals are solitarious. As locust numbers increase, they cluster into dense groups and they become gregarious (see Fig.1.2). The transition from the solitarious phase to the gregarious and vice versa is called the transient phase, and the locusts are referred to as transiens. If locusts are on the increase, they are referred to as congregans and, if they are on the decrease, they are called dissocians.

To sum up, desert locusts have the ability to change their behaviour, physiology, colour and shape in response to a change in locust numbers. At low numbers, locusts behave as individuals (solitarious phase); at high numbers, they behave as a single mass (gregarious phase). Precise thresholds at which these changes occur are not established. Three processes are involved in phase transformation: concentration, multiplication and gregarization.



Phase terminology

Solitarious	Phase when individuals live mostly separate from each other.
Gregarious	Phase when large numbers of individuals gather together.
Transiens	Intermediate phase when locusts are grouping and starting to act as a single mass and are either changing from solitarious to gregarious (gregarization) or from gregarious to solitarious (dissociation).
Congregans	Part of the transiens phase during which locusts are congregating and are in transition from the solitarious to the gregarious phase. Often used for nymphs.
Dissocians	Part of the transiens phase during which locusts are in transition from the gregarious to the solitarious phase. Often used for nymphs.
Solitaricolour	Showing types of colour associated with solitarious behaviour.
Gregaricolour	Showing types of colour associated with gregarious behaviour.

Fig. 1.2. Desert Locust phases scheme

Behavioural changes can take place rapidly. For example, Desert Locusts that have been reared in isolation in the laboratory try to avoid each other when first put into a cage, but in trying to avoid one locust they come into contact with another. Being touched by others, especially on the outer surfaces of the hind femora (thighs), results in locusts being attracted rather than repelled by others, and so they form groups. This switch from repulsion (the solitarious state) to attraction (the gregarious state) only takes an hour or so. If crowded insects become isolated they revert to behaving solitariously. The longer they are kept in a crowd before being isolated, the slower the reversion to the solitarious state. It may take several generations to complete the transition from gregarious to solitarious behaviour. Females can influence the phase of their offspring by adding a gregarizing chemical to the egg pod foam if they have recently experienced crowding, including at the oviposition site. In the field, it can take several generations before crowding occurs and solitary individuals behave fully gregariously. This is often seen during upsurges when bands and swarms become progressively larger and more cohesive.

Morphological changes (changes in colour and shape) take more time. The full gregarious colour takes one crowded generation to develop and shape takes two or more days. The differing rates of colour and shape change associated with phase changes often lead to confusion. For example, it is possible to find swarms of solitary (colour) locusts. In these guidelines, the terms gregarious and solitary (or solitarious) refer to behaviour, gregaricolour (and solitaricolour) are used to indicate coloration, and gregariform (and solitariform) indicate shape.

The change in locust colour and shape occurs after the behavioural change. Colour and shape are an indication of how the Desert Locusts have been behaving but may not be a reliable guide as to how the locusts will behave in the future. Therefore, behaviour is the best and most useful phase characteristic to use in locust control work.

Fig. 1.3. Colour differences between swarming (black and orange) and solitary (green) desert locust.

1.1.3 Presence of the desert locust

During quiet periods (known as recessions) Desert Locusts are usually restricted to the semi-arid and arid deserts of Africa, the Near East and South-West Asia that receive less than 200 mm of rain annually. This is an area of about 16 million square kilometres, consisting of about 30 countries.

During plagues, Desert Locusts may spread over an enormous area of some 29 million square kilometres, extending over or into parts of 60 countries. This is more than 20% of the total land surface of the world.

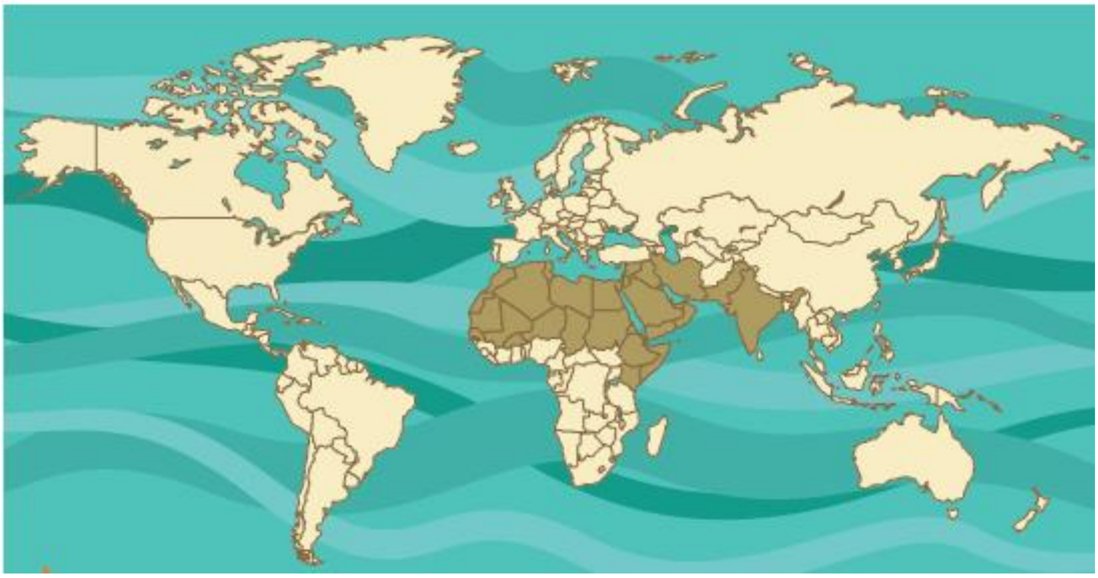


Fig. 1.4. Earth's land surface affected by Desert Locust

Desert Locusts usually fly with the wind at a speed of about 16-19 km/h depending on the wind. Swarms can travel about 5-130 km or more in a day. Locusts can stay in the air for long periods of time. For example, locusts regularly cross the Red Sea, a distance of 300 km. In the past there have been some spectacular and very long distance swarm migrations, for example from North-West Africa to the British Isles in 1954 and from West Africa to the Caribbean, a distance of 5,000 km in about ten days in 1988.

There is no evidence that Desert Locust plagues occur after a specific number of years. Instead, plagues develop intermittently. So, the lack of predictability due to locust infestations occurs irregularly is another problem to face.

1.1.4 Present problems to face off and the role of FAO

There are many reasons as to why it is difficult to successfully combat the Desert Locust. Some of these are:

- The extremely large area (16-30 million sq. km) within which locusts can be found.
- The remoteness and difficult access of such areas.
- The insecurity or lack of safety (such as land mines) in some areas.
- The limited resources for locust monitoring and control in some of the affected countries.
- The undeveloped basic infrastructure (roads, communications, water and food) in many countries.
- The difficulty in maintaining a sufficient number of trained staff and functioning resources during the long periods of recession in which there is little or no locust activity.
- Political relations amongst affected countries.
- The difficulty in organizing and implementing control operations in which the pesticide must be applied directly onto the locusts.
- The difficulty in predicting outbreaks given the lack of periodicity of such incidents and the uncertainty of rainfall in locust areas.

To face of these problems the Food and Agriculture Organization (FAO) of the United Nations was founded in 1945. One of the mandates is to provide information on the general locust situation to all interested countries and to give timely warnings and forecasts to those countries in danger of invasion.

Therefore, FAO operates a centralized Desert Locust information service within the Locust Group at FAO Headquarters, Rome, Italy. All locust affected countries transmit locust data to FAO who in turn analyse this information in conjunction with weather and habitat data and satellite imagery in order to assess the current locust situation, provide forecasts up to six weeks in advance and issue warnings on an ad-hoc basis. FAO prepares monthly bulletins and periodic updates summarizing the locust situation and forecasting migration and breeding on a country by country basis. These are distributed by email, fax, and post. All locust information is archived at FAO Headquarters and some of this is available on the Internet.

Furthermore, FAO provides training and prepares publications on various aspects of locusts. FAO undertakes field assessment missions and coordinates survey and control operations as well as assistance during locust plagues.

1.2 State of the art

Current methodologies and tools are insufficient in determining with any precision the scale of a "Desert Locust problem" that may require prevention and control. Without knowing how big the problem is, it is very difficult to deal with it in a sensible and effective manner. Too often, field teams stop and control the first Desert Locust hopper band or swarm that they come across, having no idea the magnitude of the problem. This crossroads made us look at the preventive control since prevention is the basis of the solution.

The general purpose of preventive control is to reduce the risk and impact of Desert Locust invasions and thus contribute to the fight against hunger and poverty while safeguarding the environment. To achieve this goal, the preventive control strategy is based on three pillars:

- Early warning by improving monitoring and forecasting capacities that utilize the latest technologies to delimit and prioritize survey areas, ensure reliable data collection and transmission in near real time, and provide timely and precise alerts;

- Rapid response implemented by a continuously well trained, well equipped and well financed national locust control unit that utilizes contingency planning and standard methodologies for effective, timely and safe control operations;

- Operational research to address operational difficulties encountered by locust survey and control officers in the field and other challenges of implementing the preventive control strategy.

The phases for the detection and control of desert locust pests are described below. These practices are those currently carried out by the teams assigned and deployed by FAO around the countries affected by these insects.

These practices, as has already been mentioned throughout this report, have a lack of technological support to overcome the difficulties mentioned above. What slows down the fight against locusts and moves the whole of the solution away from the fundamental pillar which is prevention.

1.2.1 Actual method

As explained above, it was identified that these insects move to areas where it has rained recently and where there is present vegetation. Concerning these data, current prevention measures are based on identifying the green zones and act in those where there is presence of these insects. Following is the process followed today divided into 4 phases.

The following image summarizes the processes carried out by the current pest control teams around the world.

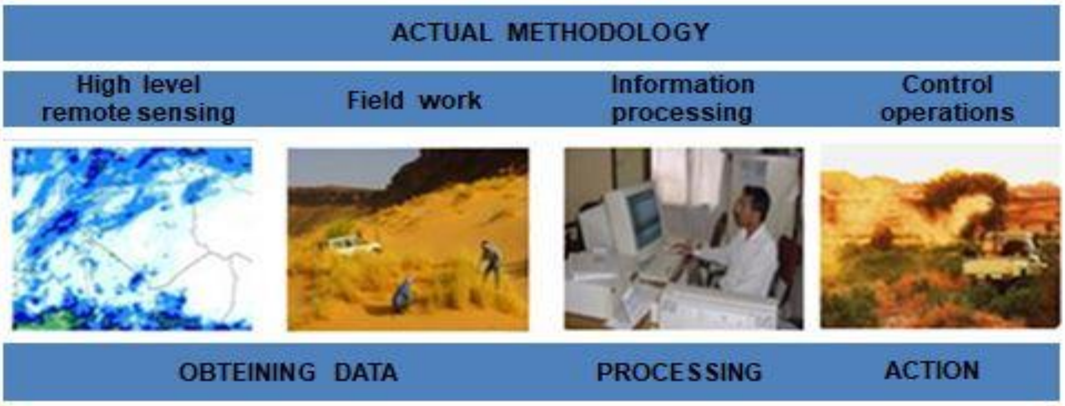


Fig. 1.5. Actual methodology scheme

1.2.1.1 High-level remote sensing

The first step, after selecting the area or country where is expected to work, is to make a first filtering to find where the green areas are susceptible of locusts breeding.

To achieve this, the teams use the help of satellite data. Specifically, the satellite information used is to estimate of rainfall, the presence of vegetation and the detection of the dynamics of vegetation by using MODIS[1].

[1] Moderate Resolution Imaging Spectroradiometer

1.2.1.2 Field work

Once the area of study is quoted, the data collection phase is followed.

This phase consists in knowing whether green zones determined in phase 1 contains locusts or not. In practice, the search is carried out by land teams that are going through the country with vehicles and are inspecting all areas. While inspecting, they use the tablet eLocust3.

Fig. 1.6. FAO officers using eLocust3 Kit

The eLocust system is the tool used by national survey and control officers in all locust affected countries for recording field observations during survey and control operations. eLocust3 is based on a hand-held tablet, into which users log details about habitat, vegetation, soil, rainfall, locusts, control and safety before transmitting the data in real time by satellite to that country's National Locust Control Centre (NLCC). All frontline countries affected by Desert Locusts have a centralized NLCC, responsible for monitoring their territory. Data from each country is collated into a single file and sent by email on a daily basis to the Desert Locust Information Service (DLIS) at FAO Headquarters in Rome.

DLIS maintains a global perspective and keeps countries regularly informed, providing assessments, forecasts, updates, alerts and warnings to prevent Desert Locust outbreaks from escalating. At FAO Headquarters, the data are checked and corrected before being imported into a custom designed global GIS, called SWARMS. This is used to analyse the field data in combination with satellite imagery, indicating rainfall and green vegetation, locust development and trajectory models, and historical records d ating from 1930.

Also, is obtained help from shepherds in areas that, if they detect a swarm of locusts, they should immediately alert the authorities to act accordingly.

As can be appreciated, this phase is completely inefficient and, above all, very slow to carry out. This is where a great possibility of improvement is foreseen that allows making this process totally necessary to streamline and make more reliable to discretize the zones where it must act.

1.2.1.3 Information processing

This phase will be carried out from the "National Locust Center" in each country or zone.
After having obtained the data from the two previous phases, all the information is taken and an exhaustive analysis of the same is carried out, in Fig. 1.7. The process information flow can be viewed. It is finished generating, in a collaborative way between all the affected countries, a report that identifies the most critical zones, the prevention of migration of locusts and other relevant data from the growth status of the resident locust and of the climatic characteristics of each affected area.

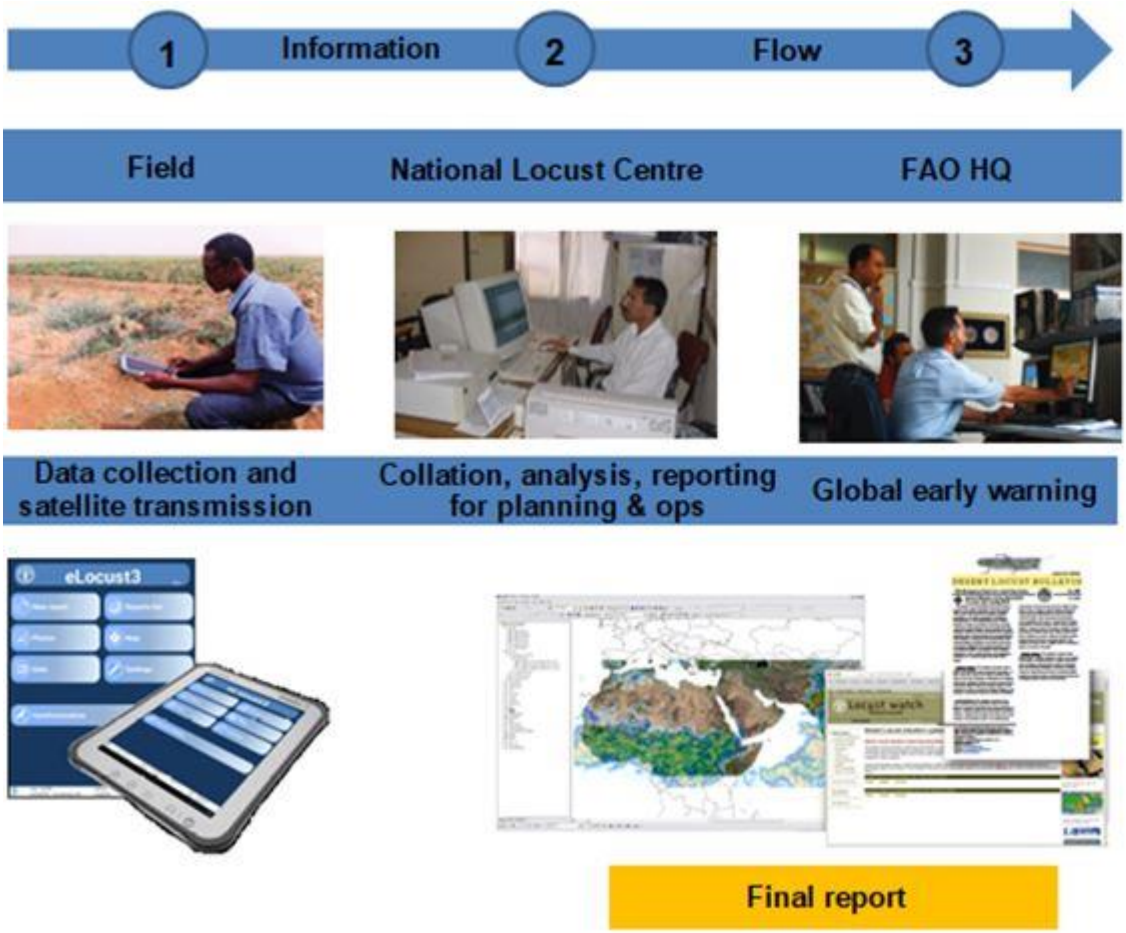


Fig. 1.7. Information flow diagram

Because this phase depends entirely on the data obtained in the previous two, if the data of the first ones have not the quality enough or are not sufficient, the result of this phase is absolutely irrelevant and the time invested is useless. As mentioned before, it is in the phase of obtaining data where it has to invest in tools that improve the quality and the reliability of the data. Data that, once processed, will define areas with more danger and where it should be acted.

1.2.1.4 Control operations

In order to finish the current process, the defined areas are taken from the processing of the previous data and it is carried out accordingly using the suitable chemical products for each zone. The current control operations are carried out in two different ways:

- Extensive spraying can be carried out, that is, the spraying is done with small airplanes or trucks. This option is not the most appropriate for precision spraying, as there is no adequate fumigation control, pesticides are wasted and fumble areas can be sprayed, which can seriously and unnecessarily affect the environment.
- The second method is do the control operation in an intensively way, with a survey team equipped with fumigator backpacks. The accuracy of the work in this case increases notably, and large quantities of pesticides are no longer wasted, but at the same time it is transformed into a very slow and difficult operation to carry out in extensive areas.

1.3 Main objectives of the project

After studying the current methodologies, it has been shown that all the techniques have to evolve even more in the application of control strategies.

The main objectives of this project can be defined as:

- Retake the project of the first phase to improve current methodologies, reactivate it, improve and create a solution architecture based on prevention as a fundamental priority.

- Base the prevention system on a more accurate and early high-level remote sensing. Find other indicators to reduce the areas susceptible to the proliferation of locusts.

- Increase the autonomy of the battery of the fixed-wing platform, perform the flight tests to check its behaviour in flight and prepare the assembly and configuration manuals.

- The last objective that has been set is to make a total update of the proposed methodology based on UAV technology to reactivate negotiations with FAO and companies participating in that environment. In this way an invitation would be agreed to take all the team to the Mauritanian Desert to do some tests in real conditions together with the Government of Mauritania and its air forces and thus demonstrate that an evolution has been made that makes the project feasible and that we have technology and knowledge. Only the financing is missing.

CHAPTER 2. INNOVATIONS OF THE PROPOSED SOLUTION

2.1 The importance of an updating

This chapter describes the structure of the solution in addition to the innovations that have been incorporated over these months.

It is worth noting that the fundamental objective of this project, apart from the technical and engineering know-how acquired during the development of the platforms, is to update and make a face-lift to the work and efforts carried out by Hemav employees over the last years.

With this update in platforms, operating procedures thanks to new technologies, it is expected to reactivate negotiations and commercial synergies with FAO and other entities that are potentially clients willing to invest in the total development of the project.

In addition, with the reactivation of possible contracts with the FAO it is foreseen its presentation in future editions of the acclaimed million dollar contest Drones For Good.

2.2 A new and powerful high level remote sensing system

2.2.1 Limitations of the current MODIS data system

In this first phase, the satellite images of the study areas are analysed to identify regions of a country where the weather and ecological conditions can be favourable for locusts, in particular, they are selected in areas where are recent rains have occurred and where vegetation may be present.

Currently, the data on rainfall and vegetation estimation provided by FAO are obtained through MODIS which is a scientific instrument launched on board the Earth Satellite, and on board the Satellite Aqua.

The following figures (Fig. 1.7 and Fig. 1.8) obtained from IRI[2] show the rainfall and vegetation predictions from June to September 2016.

[2] International Research Institute for Climate and Society

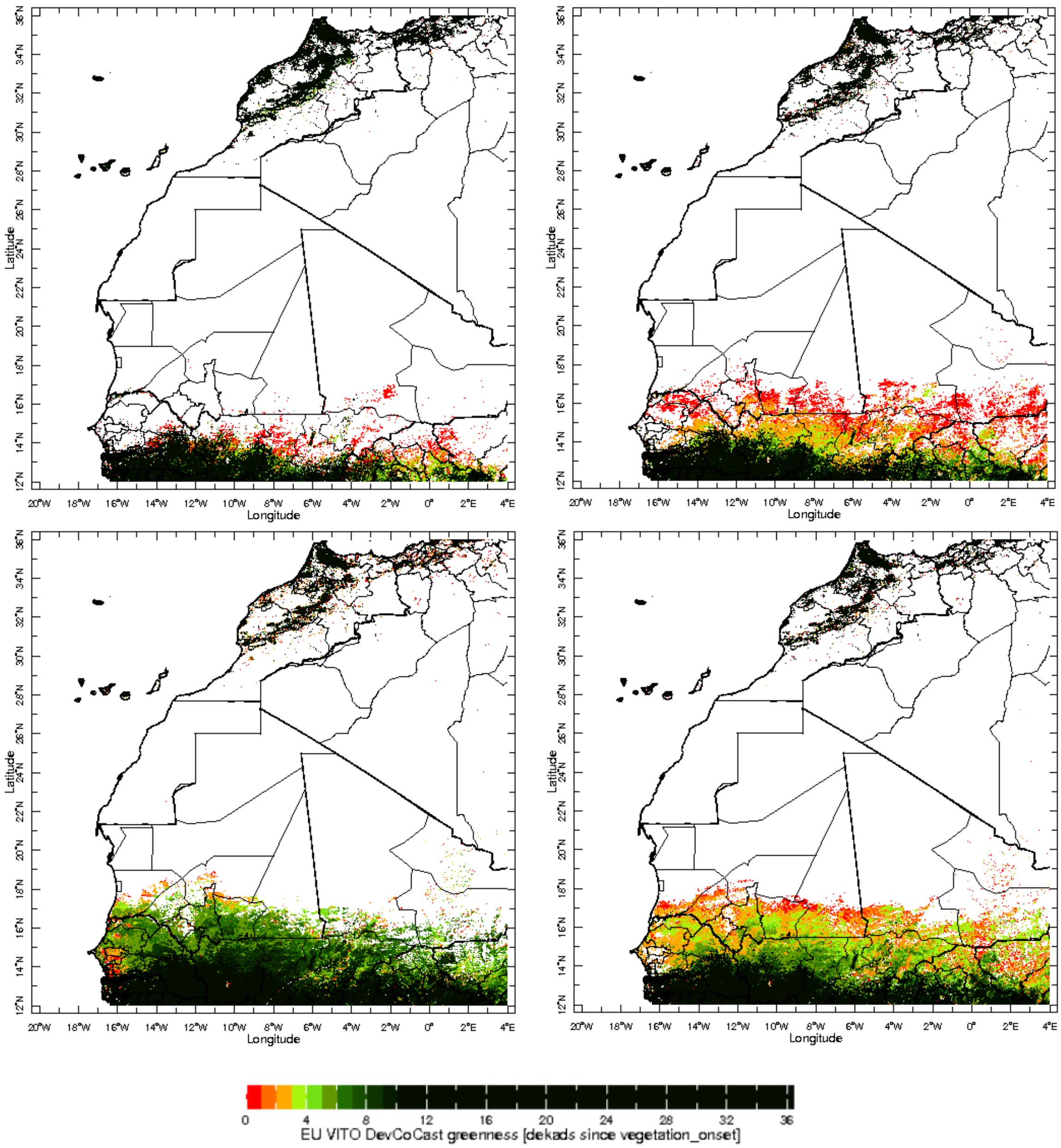


Fig. 2.1. Vegetation estimations. Upper left corner from left to right (June; July, August; September)

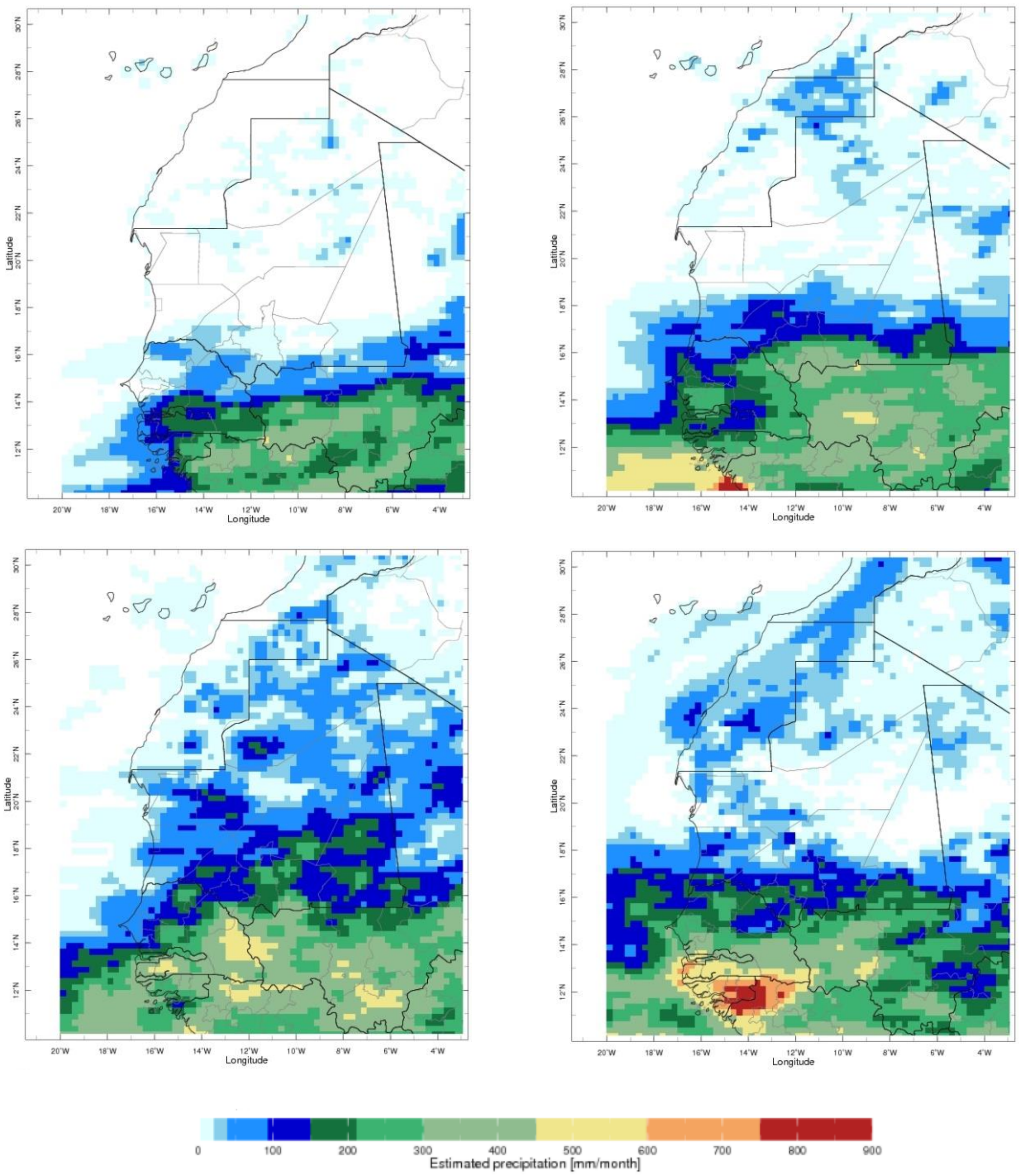


Fig. 2.2. Rainfall predictions. Upper left corner from left to right (June; July, August; September)

In spite of this, its resolution means that the data are transformed into areas of very long range, making it impossible to define precisely the most critical areas.

To remedy this problem of large areas that would make the use of drones impracticable due to surfaces of hundreds of square kilometres to fly over, several technologies from NASA and ESA have been combined as presented in the following section.

2.2.2 The solution is called SMELLS

2.2.2.1 Introduction to SMELLS

The **Soil Moisture for dEsert Locust earLy Survey (SMELLS)** innovator addresses research questions related to plagues of desert locust affecting severely the agricultural productivity and with that food security in Africa. The project focuses on synergy between observations of the SMOS and Sentinel-1 missions to derive soil moisture for detection of desert locust population outbreak or early upsurge stages before their population can expand into full-scale plagues.

2.2.2.2 Objectives of SMELLS

SMELLS will implement an innovative approach to combine Sentinel-1 SAR data with thermal disaggregated SMOS-derived soil moisture to derive a soil moisture product at both high-spatial and high-temporal resolution to provide a new tool for decision-makers in the Desert locust preventive control system.

Remote sensing tools developed so far for Desert locust preventive control focus on vegetation levels and particularly on Normalized Difference Vegetation Index (NDVI) and derived products. Recent works demonstrated the possibility to forecast locust presence based on these remote sensing data. However, using vegetation status can lead Desert locust managers to a problem of temporal scale of prediction to decide when to send survey teams. Indeed, NDVI or derived vegetation greenness maps might arrive to the managers in a temporal frame at the same time than locust populations actually develop.

To be able to take earlier the decision to send survey teams, one solution is to have timely information about soil moisture, which precedes vegetation. Additionally, soil moisture is a very good indicator of reproduction potential of an area, since Desert locust females choose and need moist areas to lay their eggs. SMELLS will be a first attempt to include soil moisture information in the tools of Desert locust managers.

In this context, the main objectives of the project are:

- The establishment of a dialogue between developers and desert locust monitoring users about their requirements related to soil moisture remote sensing.
- The development of an innovative approach to derive high resolution Soil Moisture products from Sentinel-1 in synergy with SMOS data,
- Assessing the capacity of Soil Moisture to predict locust presence to be used in the framework of Desert locust preventive management.

2.2.3 Results of implementing SMELLS

ESA's Soil Moisture and Ocean Salinity (SMOS) mission is dedicated to making global observations of soil moisture over land and salinity over oceans.
By consistently mapping these two important components in the water cycle, SMOS is advancing our understanding of the exchange processes between Earth's surface and atmosphere and is helping to improve weather and climate models. The SMOS satellite captures images of 'brightness temperature' that correspond to radiation emitted from Earth's surface, which can be used to gain information on soil moisture (SM) at a resolution of 50 km per pixel.

SM is a land state variable governing the interaction between the land surface and atmosphere through playing its role in various components of the water and energy cycle, such as evapotranspiration, groundwater recharge, and surface runoff.

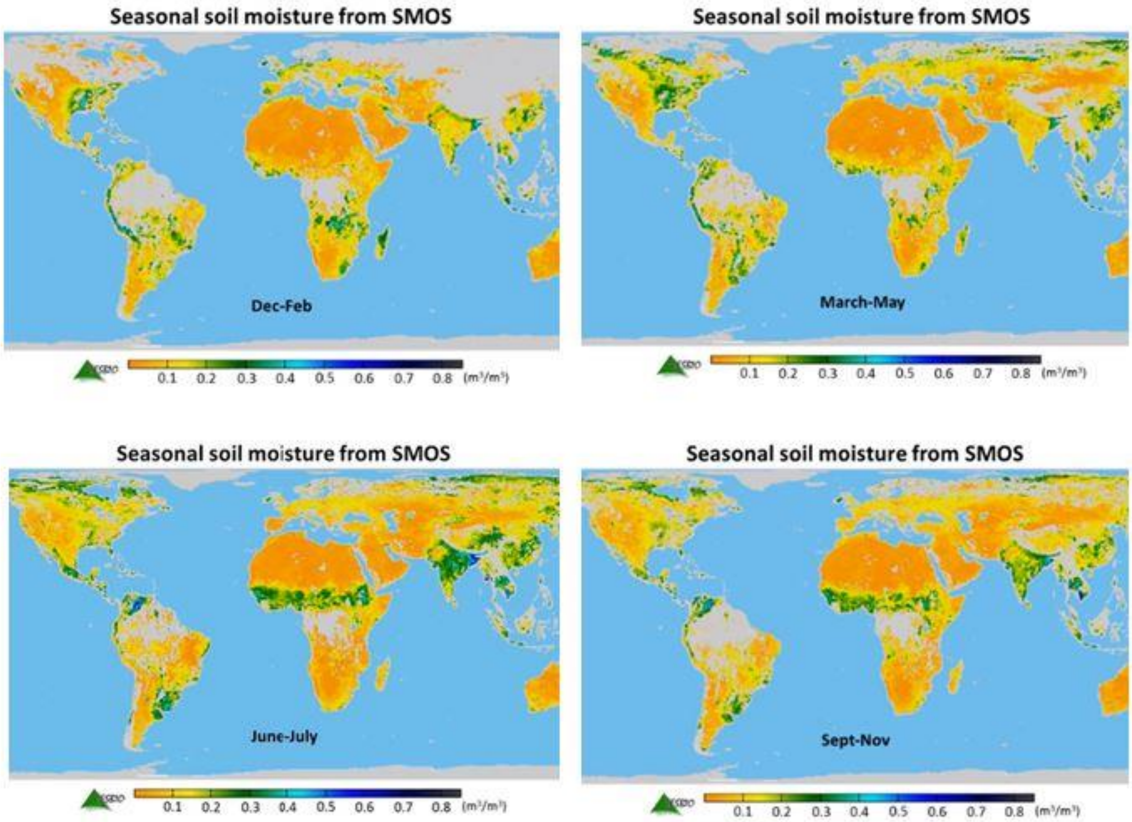


Fig. 2.3. Seasonal soil moisture from SMOS

Every month is divided in three decades, the first two decades have 10 days (i.e., 1-10, 11-20), and the third is comprised of the remaining days of the month. The typical value of surface soil moisture goes from 0-0.05 m^3/m^3 (completely dry soil) up to 0.5 m^3/m^3 (completely wet soil**). Relevant ranges for locust monitoring are between 0.10-0.20 m^3/m^3.**

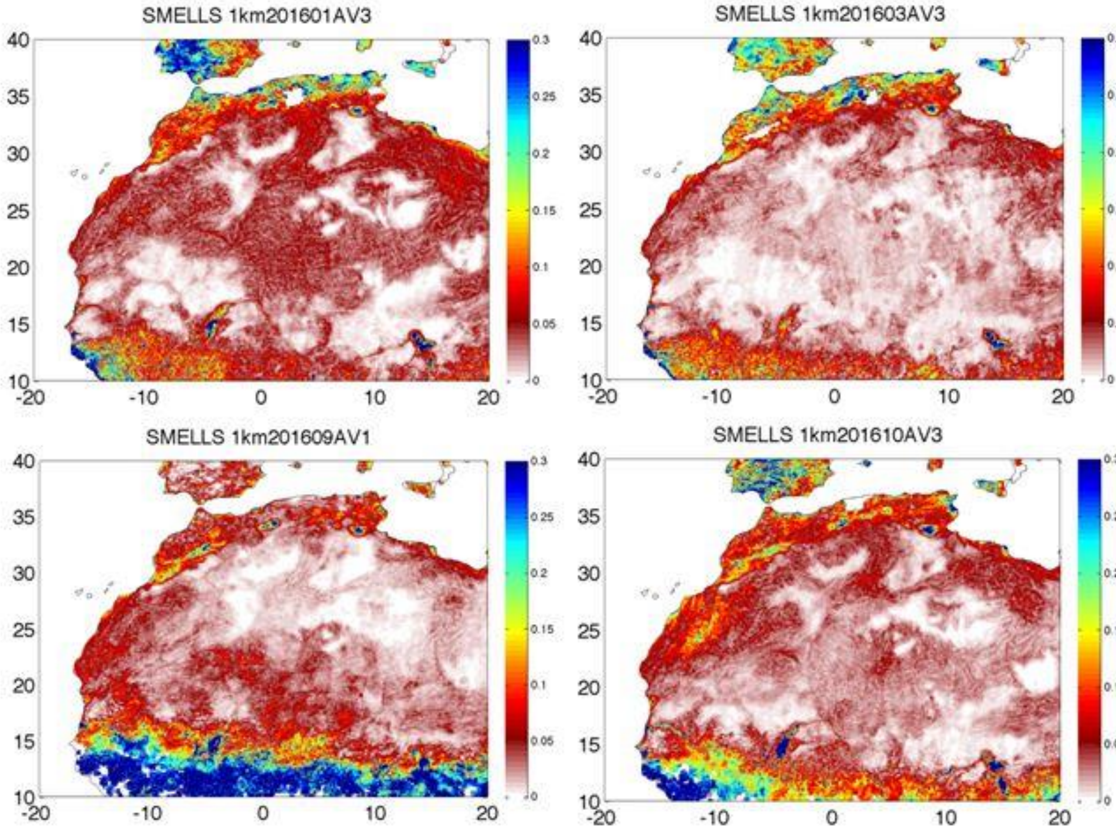


Fig. 2.4. SMELLS 1km Soil Moisture Estimates

The measurement unit of soil moisture is the “volumetric soil moisture content” which refers to the volume of water in a given volume of soil. This type of Soil moisture Content is measured in $m^3.m^{-3}$ (how much of a cubic metre is water out of the entire cubic metre of soil sample). Alternately, the Volumetric Soil Moisture content can be referred to as a % of volume (which is much easier).

By combining this information with medium-resolution coverage from the MODIS instrument on NASA’s Aqua and Terra satellites and Sentinel-1 SAR data the team downscaled SMOS soil moisture to a resolution of 1 km per pixel. The measurements were then used to **create maps showing areas with favourable locust swarming conditions about 2 to 3 months.**

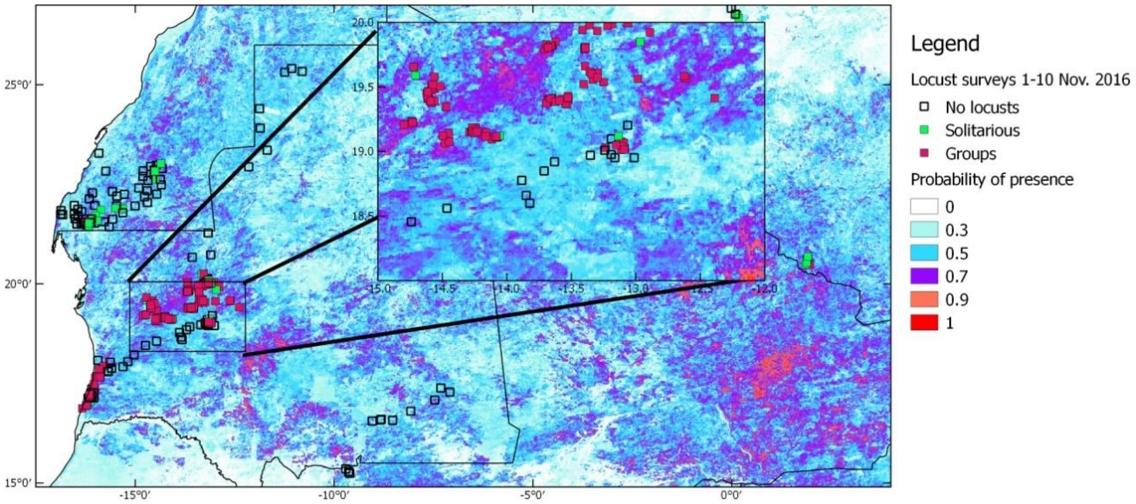


Fig. 2.5. Predicting locust plagues with Soil moisture data from the SMOS satellite and the MODIS instrument.

Finally, temporally-interpolated spatially-disaggregated SMOS data based on synergy between soil moisture and precipitation models can define an accurate prediction of locust presence about 2-3 months ahead compared with current methodologies based only on vegetation and rainfall indices that only allows to predict presence only 1 month ahead as have been discussed throughout this section. Putting all this together the results and advantages that entails are public and notorious as it demonstrates Fig. 2.5.

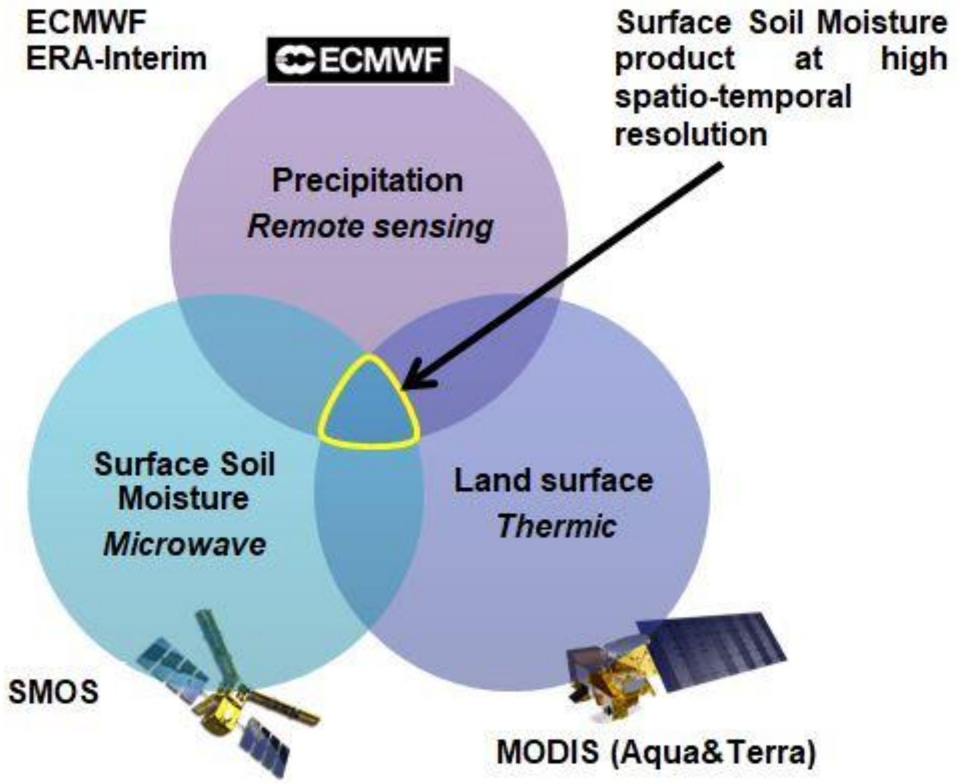


Fig. 2.6. Venn's Diagram of new high level sensing combined solution

2.2.4 Future expected advances on high level remote sensing

In the following subsection is introduced a substantial improvement in the image resolution for forecasting locust presence. As it have been said, this first phase of the global solution methodology proposed is extremely important for a good management of survey teams which is translated in social, time and economic savings. So far we have talked about 1 kilometre resolutions. However, NASA, ESA and multiple entities involved in the fight against desert locust are developing 100 meters resolutions. Even so it is worth mentioning that this process is under development. Below is shown the qualitative difference between 1 kilometre and 100 meters resolutions.

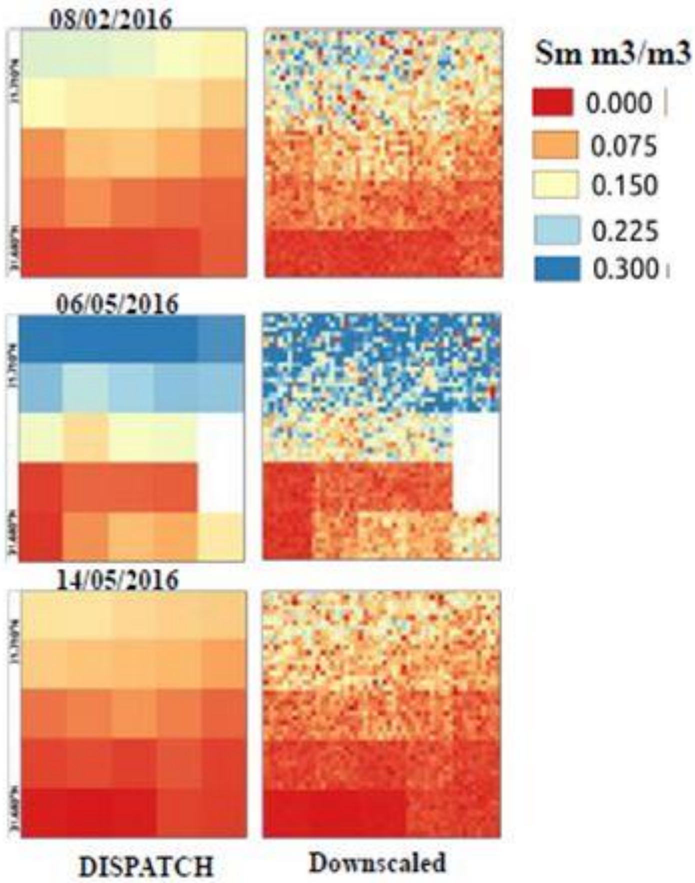


Fig. 2.7. Spatial distribution of the 1 km DISPATCH product and disaggregated soil moisture over 100 m resolution.

The 40 km resolution SMOS data is first disaggregated to 1 km resolution using C4DIS[3] processor, which employs the DISPATCH[4] algorithm and ancillary 1 km resolution MODIS data. Then, different methods are applied for disaggregating the 1 km DISPATCH product to 100 m resolution using Sentinel-1 data as an independent source of information.

[3] Details about C4DIS processor product can be found in [4]
[4] DISaggregation based on Physical And Theoretical scale CHange

Finally it is shown the results obtained during tests in the study area located at the east of Morocco.

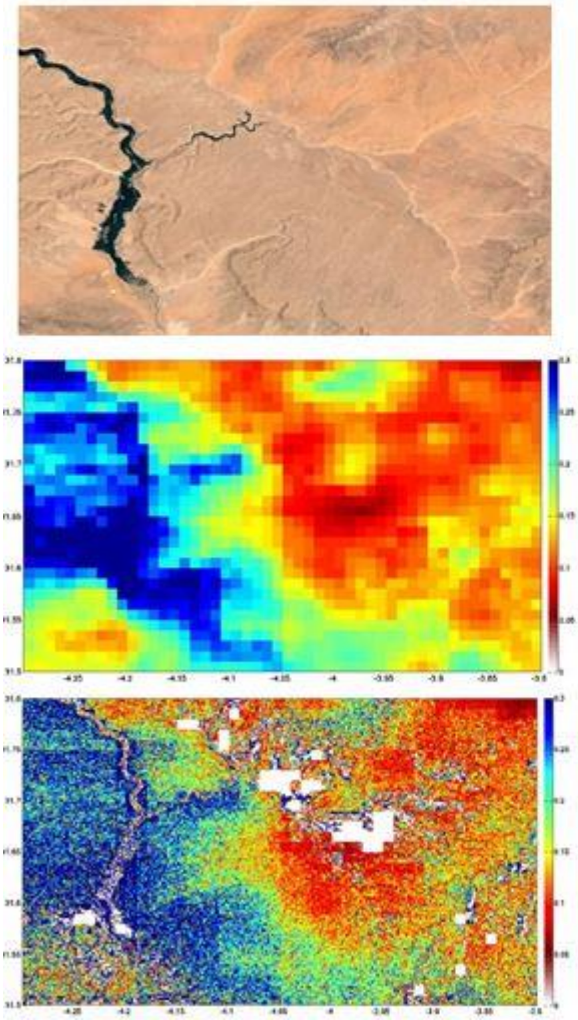


Fig. 2.8. From up to down. Area of study. 1km SMELLS. 100m SMELLS.

CHAPTER 3. HP2. THE NEW FIXED WING AIRFRAME

In the next chapter, the new fixed-wing platform that replaces its previous version is introduced. Its technical specifications are detailed in addition to the assembly and configuration operations that have been carried out in the *Hemav* engineering department.

3.1 Function to play

The new fixed-wing developed by *Hemav* is called HP2. This platform will be the responsible of performing the extensive study flights equipped with a multispectral camera, specifically a *MicaSense RedEdge-M.* This special camera is installed in the drone to perform an inspection of the zone and find the vegetation areas where is more probably that there are swarms of locusts and also to detect the juvenile nymphs locusts and do a more exhaustive prevention and control operations.

All technical details, scope and potential of the *MicaSense RedEdge-M* are introduced in later sections.

3.2 Its predecessor

To record the technical work done in the engineering workshop and the leap of improvement that it takes to replace a fixed-wing platform with another, a brief mention is made of what was its predecessor as well as the most notable differences between both drones.

The fixed-wing that was proposed in previous studies was the *X8 Skywalker* (Fig. 3.1)

Fig. 3.1. Fixed-wing platform X8 Skywalker

3.3 The HP2[5]

The fixed-wing platform HP2 (Fig. 3.2.) is *Hemav's* bet to turn it into the bulwark of the fixed-wing fleet to combat desert locust plagues.

Fig. 3.2. HP2 fixed-wing platform

As can be seen in the image, the *HP2* is composed by the fuselage, its two wings with a delta configuration, their respective winglets and finally the ailerons.

One of the most important characteristics for which it was chosen this model is due to its high airframe service life due to wing robustness and maintainability plus its powerful propulsion system for steep climbs and high altitude flights.

Its airframe is made of EPO foam reinforced with a carbon fiber structure. As it has been said its robustness in adverse operating conditions such as dust, sand, hard vegetation such as reeds or brambles makes it perfect to operate in the natural habitat of the desert locust before hard hits and landings in irregular areas.

[5] Due to content limitations, the work carried out in the engineering workshop that includes the assembly of the platform and configuration of the on-board control systems are attached in an annex dedicated exclusively to the *HP2*.

Ultimately, to strengthen the decision to replace the *X8 Skywalker* with the *HP2* is the robustness of the *HP2* thanks to its carbon fiber reinforcements Its takeoff is made from a catapult where the takeoff angle can be adjusted and the direction of face to the wind contrary to the manual release of the *X8 Skywalker*. Finally, another decisive point is that the *HP2* is equipped with the controller *Pixhawk2* unlike the *Pixhawk* installed in the *X8 Skywalker*.

Specifications:

Hardware

- Type Fixed wing
- Weight 2.35 kg
- Wingspan 1.5m
- Dimensions 150 cm x 72 cm x 19 cm
- Material EPP foam; carbon frame structure
- Propulsion Electric pusher propeller; brushless 700W motor
- Camera *MicaSense RedEdge-M*

Operation

- Endurance[6] 80 minutes
- Range 54km
- Cruise Speed 80kph
- Take off
  - Type Catapult launch
  - Angle 20 degrees
- Landing
  - Type Belly landing with parachute

[6] ISO standard atmosphere conditions.

3.3.1 Advantages of the Pixhawk2

The *Pixhawk2* is basically the autopilot. This has algorithms for altitude and position and provides guidance algorithms, navigation and control for different types of multirotor drones, fixed wing and even rovers. The hardware of *Pixhawk2* has its software called *Dronecode* that controls it and connects with different sensors, telemetry extensions and other peripheral accessories.

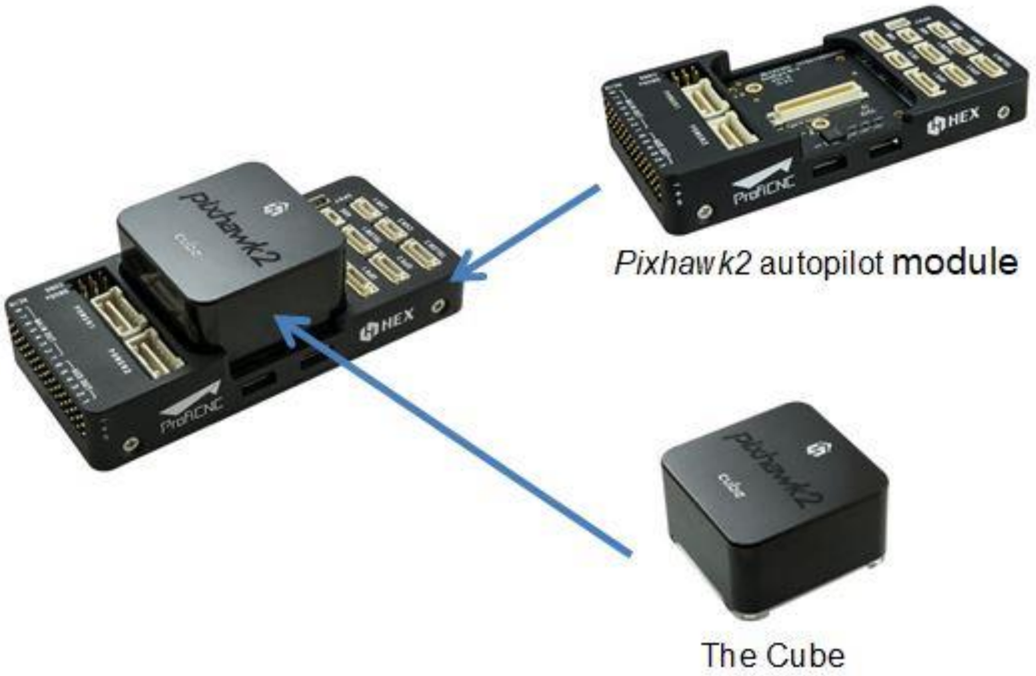


Fig. 3.3. Autopilot controller Kit

The following table summarizes the advantages of *Pixhawk2* versus its predecessor.

Table 3.1. Differences between Pixhawk2 and Pixhawk

	Pixhawk 2	*Pixhawk*
Modular Cube design	Yes	No
Damped IMU[7]	Yes	No
Triple redundant IMU	Yes	No
CM level GPS[8]	Yes	No
Multiple GPS system	Yes	No
Allow flights in extreme temperatures	Yes	No
Open development environment	Yes	Yes

Finally the fully description is exposed:

- Processor:
  - 32-bit ARM Cortex M4 core with FPU
  - 168 MHz / 256 Kb RAM / 2 Mb Flash
  - 32-bit failsafe co-processor
- Sensors:
  - 3x triple axis accelerometers
  - 3x triple axis gyroscopes
  - 3x triple axis magnetometers
  - 2x barometers
- Power:
  - Redundant power supply with automatic failover
  - Servo rail high-power (7 V) and high-current ready
  - All peripheral outputs over-current protected, all inputs ESD[9] protected
- Interfaces:
  - 14x PWM servo outputs (8 from IO, 6 from FMU[10])
  - 5x general purpose serial ports, 2 with full flow control
  - 2x I2C ports
  - 2x CAN Bus interference
  - 3x Analogue inputs (3.3V and 6.6V)

[7] Inertial measurement unit (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.
[8] Centimetre-Level Accuracy
[9] Electrostatic Discharge
[10] Flight Management Unit

The *Pixhawk2 Cube* has a total of 29 MEMS[11] sensors in it and it comes 100% RTK (Real Time Kinematic) GPS ready. The (RTK) satellite navigation is a technique used to enhance the precision of position data derived from satellite-based positioning systems (global navigation satellite systems, GNSS). It uses measurements of the phase of the signal's carrier wave, rather than the information content of the signal, and relies on a single reference station or interpolated virtual station to provide real-time corrections, providing up to centimetre-level accuracy. This the footnote 7 concept (CM level GPS)

A heater is also added to the IMU's to work in extreme cold temperatures and some LEDs were removed to improve gyroscopes noise. The FMU and IMU system are separated, reducing interference to sensors.

Another interesting feature is the EMI[12] filtering. EMI filtering is provided at key points in the system using high-insertion-loss pass-through filters. These filters are paired with TVS[13] diodes at the peripheral connectors to suppress power transients. Reverse polarity protection is provided at each of the power inputs. USB signals are filtered and terminated with a combined termination/TVS array. Most digital peripheral signals (all PWM outputs, serial ports, I2C port) are driven using ESD-enhanced buffers and feature series blocking resistors to reduce the risk of damage due to transients or accidental misconnections.

Finally to complete the controller, the Here GPS system is added.

Fig. 3.4. Here GPS

This GPS offers reception of up to 3 GNSS (GPS, Galileo, GLONASS, BeiDou) has 67 dBm navigation sensitivity. Supports all satellite augmentation systems and has advanced jamming and spoofing detection.

[11] Microelectromechanical Systems
[12] Electromagnetic Interference
[13] Transient Voltage Suppression

3.3.2 Communication Kit

In this section, all the systems responsible of the communications between the base station on ground and the platforms are detailed.

On one hand is necessary the radio link to control manually the platform if it the pilot's intervention was necessary. All flights performed with the fixed wing drone in desert locust prevention operations are designed to be autonomous. *Hemav* uses in all the other platforms the *FrSky 2.4GHz ACCST TARANIS X9D PLUS and X8R Combo Digital Radio System*[14].

Fig. 3.5. Emitter and receiver devices

[14] For additional specific technical details consult the manufacturer's datasheet:
Broadcasting Station Datasheet
Receiver Datasheet

In the other hand, another basic link of communications is the long range telemetry. This device is the responsible of flight data parameters such us speed, altitude…etc. The *jD-RF868Plus Longrange telemetry* is used in all our platforms.

Fig. 3.6. Long range telemetry kit

This set is specially made for European customers who cannot use 900 Mhz due to its illegal use. For this reason the 868 Mhz are employed in HP2 platform. The kit consists of:

- RFD868-X Radio Modems with enclosures
- Antennas, 868MHz Quarter wave monopole 2.1dBi
- 2 x Antennas, 868MHz Half wave dipole 3dBi
- 1 x USB cable
- 1 x DF13/GH cable

3.3.3 Visual equipment

This section includes the visual equipment installed in the HP2. As it has been previously introduced, it is the *MicaSense RedEdge-M* multispectral camera. This multispectral camera has been selected for several reasons: Is the used by *Hemav* in all the services offered to its customers engaged in agriculture. This is due to its rugged built-to-last and one of the most flexible solutions in the market nowadays. It is lightweight to work integrating seamlessly no matter the platform.

Fig. 3.7. MicaSense RedEdge-M

3.3.3.1 Technical details

The following table summarizes the most important specifications:

Table 3.2. MicaSense RedEdge-M Specifications

Weight	180 gr
Dimensions	9.4cm x 6.3cm x 4.6cm
Spectral Band	Blue (450-515..520 nm)
	Green (515..520-590..600 nm)
	Red (600..630-680..690 nm)
	Red Edge (680-730 nm)
	Near-IR (750-900 nm)
GSD[15]	8cm/pixel (per band) at 120m AGL
Capture Rate	1 capture per second (all bands)

[15] The Ground Sampling Distance (GSD) is the distance between two consecutive pixel centres measured on the ground. The bigger the value of the image GSD, the lower the spatial resolution of the image and the less visible details. The GSD is related to the flight height: the higher the altitude of the flight, the bigger the GSD value.

3.3.3.2 Analysing the spectral signature of desert locusts

The FAO requires a robust and easy to implement approach to integrate local environmental information in the desert locust early warning system. A study carried out by the Wageningen University and Research Centre in the Netherlands investigated the use of hyperspectral camera to measure the spectral signature of juvenile nymphs and adult Desert Locusts. Results from this study showed that it is feasible to use hyperspectral sensing to identify patches of locust habitat and detect the presence of locusts. Spectral signatures of the nymphs and adults were recorded using a hyperspectral camera. The results consistently showed that the juvenile nymphs reflect more than the adult locust. Two spectral regions, from 613nm to 700nm and from 744nm to 900nm, were identified as significant for differentiating locusts from vegetation.

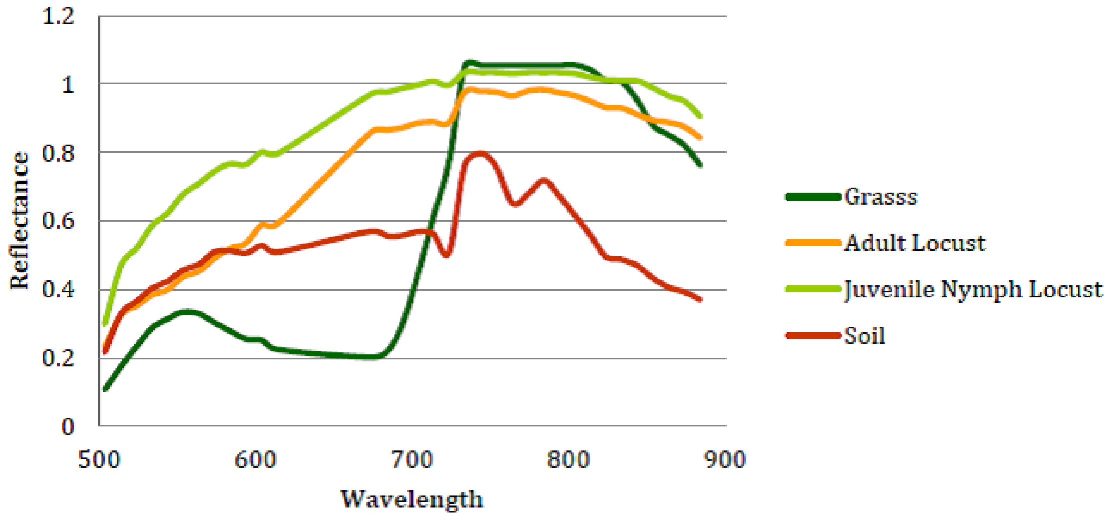


Fig. 3.8. Spectral signatures of grass and locust in simulated desert environment

Starting from these studies and under the premise of the different spectral signature between nymphs and adults, the following is proposed: The nymphs have a higher reflectance than adults and in their biological phase have not developed wings to move through the air but they already congregate in visible groups. Knowing that wavelength fringes that should be isolated from the rest, locust masses can be detected from the air using a multispectral camera such as MicaSense RedEdge-M.

This new approach gives way to increasing the level of prevention since locusts would be detected in a non-critical phase thanks to their reduced ability to travel by air. The survey teams would go to the points and eliminate the risk or plague before it occurs.

This hypothesis of solution using multispectral cameras thanks to the results obtained through hyperspectral cameras was corroborated to a certain extent with the department of data and image processing of Hemav.

In short, if the naked eye can see the locust masses from the air, a multispectral camera can also see them. With a multispectral camera critical points where there are presence of nymphs will be marked for subsequent control operations. Nevertheless, is recommended further investigations on the spectral signature because there is here is the potential to develop a locust detection index.

3.4 Flight tests

This section presents the flight tests carried out in the Hemav test field. It is divided into 3 phases. An initial block of tests and calibrations, a second block of improvements in the flight performances and finally the final tests to validate the correct operation in all flight phases and determine that the drone is ready for commercial exploitation.

3.4.1 Initial tests

Once the assembly of the platforms is finished (Annex A includes the steps carried out in the Hemav engineering workshop for the assembly of the platforms and the configuration) all the material and the pilots are taken to the test field to begin the first flight tests and see how it behaves and detect the deficiencies or possible errors committed in the assembly.

3.4.1.1 Base station installation

It is essential to recreate the working environment that the survey teams in the desert will encounter. Once the site is reached, the platforms are deployed, the launching catapults are mounted and the computer equipment is switched on. (Fig 3.9).

Fig. 3.9. Flying test base station deployment

3.4.1.2 Take off problems

During the first take off tests several fails occurred as is shown in the following figure.

Fig. 3.10. Fail take off

After analyzing the recordings in slow motion, it was detected that due start the engine with 100% of the power, the drone was displaced due to the moment caused by the instantaneous rotation of the motor and its propeller. Furthermore, when the engine is installed in the fuselage, it is not completely aligned parallel to the longitudinal axis of the fuselage.

3.4.2 Improvments in the airframe and starting setups

Due to the problems detected in the previous section, modifications were made in the engine installation and in the configuration for the engine start in the workshop.

These modifications consist of placing a flat washer between the non-slip pressure washer on the base of the motor to compensate for misalignment. The level of misalignment has not been calculated because it was small but just enough to give problems at take-off.

Finally, another of the corrections is to program the start of the engine progressively to avoid mis-positioning on top of the launch catapult that caused the instant start at maximum power.

3.4.5 Final tests

The last phase of tests served to validate that the assembly plans are correct, the configuration of the on-board control systems is easy, optimal and fast and that the modifications have been adequate. Below are the basic steps to complete a full flight. You can see all the details in the annex.

Fig. 3.11. Preparation of the HP2 airframe

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Once the HP2 is ready, still do the accelerometer, compass and level calibration.

Fig. 3.12. Accelerometer calibration

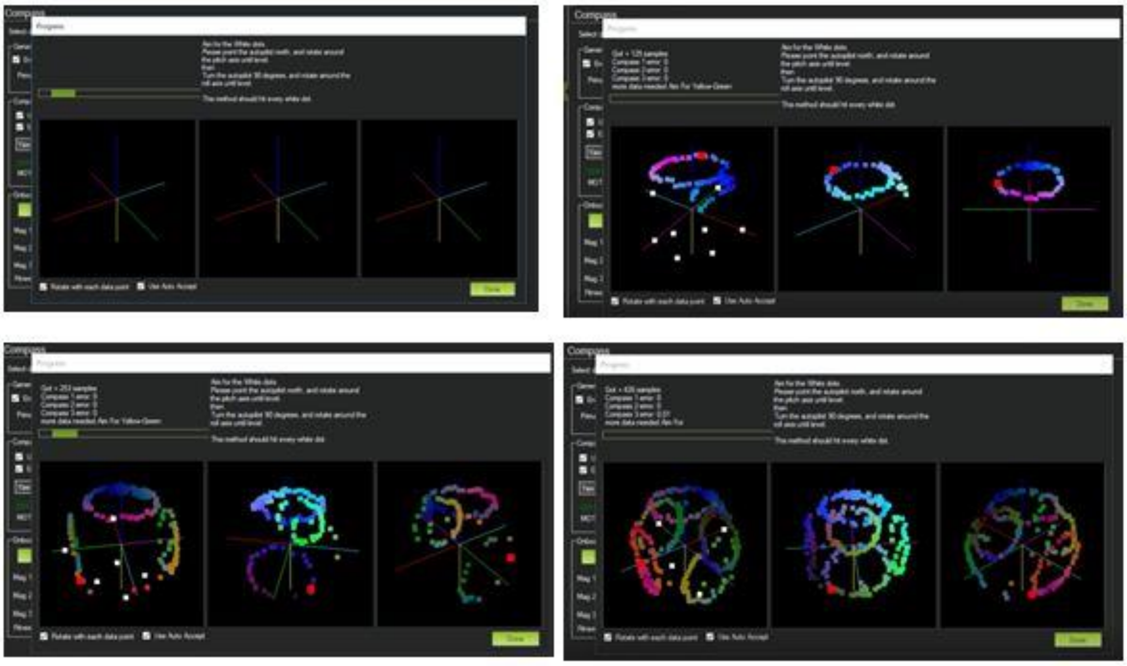


Fig. 3.13. Compass calibration

Finally, the flight plan is loaded, the pitot tube is calibrated and the take-off can be carried out.

Fig. 3.14. Flight plan loaded and pitot tube calibrated

3.4.5.1. Complete flight and some considerations

Finally a complete flight was performed successfully and currently it is a fully operational platform with a standardized operational process

Fig. 3.15. Complete flight

During the flight, the ground staff should do the basic checks of EKF[16] status and vibrations. Is normal that during rapid turns the compas EKF value make a peak but return to normal. If any parameter increases too much and stays fixed immediately the parachute is deployed and an emergency landing is made.

[16] Extended Kalman Filter (EKF) is an algorithm used to estimate vehicle position, velocity and angular orientation based on rate gyroscopes, accelerometer, compass (magnetometer), GPS, airspeed and barometric pressure measurements.

CHAPTER 4. FINAL OPERATION ARCHITECTURE

In this chapter is presented the new operating architecture that is proposed, the differences and improvements with respect to the previous solution architecture are discussed as well.

A section is also dedicated to collect another line of work that has been dedicated to this project and which is more focused on the management of relations and the reactivation of negotiations between international organizations such as the FAO, the Mauritanian government and its air forces and finally Ministry of Foreign Affairs and Cooperation of the Government of Spain.

4.1 Satellite data

Information from satellites will be used in a new way to predict favourable conditions for Desert Locust swarms. The new technology will help to increase the warning time for locust outbreaks by up to two months as has been said.

Using data from satellites as explained in chapter 2, a new tool has been developed to monitor the conditions that can lead to swarming locusts, such as soil moisture and green vegetation.

Soil moisture indicates how much water is available for vegetation growth and favourable locust breeding conditions, and can therefore predict the presence of locusts 2-3 months in advance.

The new tool was validated in Algeria, Mali, Mauritania and Morocco. Using the example of Mauritania's last outbreak in 2016, the team was able to identify a time lag of about 70 days from the initial signs of soil moisture to when the outbreak eventually occurred. The additional early warning will allow more time for national authorities to prepare for control measures when facing future outbreaks.

4.2 Extensive study

Once the first phase of high-level detection by satellite is constituted and carried out, the second phase of the project begins.

The data analysis of the satellites has been completed and the areas potentially susceptible to housing the adequate environmental conditions for the appearance of the desert locusts are marked on the map. The surveillance teams come to the area with fixed wing platforms equipped with multispectral cameras. With the multispectral mapping of the zones, the zones of vegetation are distinguished and, furthermore, by isolating the red spectral bands and near IR, swarms and masses of nymphs can be detected.

This point is the key because prevention is essential to avoid entering to control phases. This is thanks to the advancement of the transformation of locusts to winged insects and even if it is done with a sufficiently high forecast it will be possible to fumigate the areas to avoid totally the laying of eggs. This would be the ideal scenario.

4.3 Control operation

The last phase of the process is the fumigation of the areas that are the most critical after passing the filters of the first two phases. The fumigation can go by two lines of action.

- The first and most probable at the moment, is fumigation with purpose of extermination of the lobster with its own presence in the zone of application of the pesticide.

- The second possibility of application is an absolute prevention, that is to say fumigate the zones to avoid the laying of eggs and with it, the appearance of locusts. This will only be possible in the future, when the proposed methodology is sufficiently tested by all the governments of the territories most affected by the desert locust and there is good communication and coordination between FAO, survey teams, governments, companies…etc.

4.3.1 Rotatory platform

In this section it should be noted that one of the two rotary wing platforms is dispensed with. In the initial methodology, a platform equipped with high definition cameras was needed to fly over green areas and detect the presence of locusts. The second platform would be used for the subsequent fumigation.

Thanks to the advances presented throughout the document, only one rotating wing platform will be necessary since the presence of the locusts in the green areas will be integrated done with the HP2 platform. Then it will be passed to the fumigation through a single rotary wing platform.

This generates a great impact at the level of reduction of equipment, infrastructure, time and money. The fundamental pillars that a project can be declared possible or not.

The proposed platform is the DJI S1000 (Fig. 4.1.). This model has been chosen because it has the highest load capacity of the entire range of rotated wings of Hemav. Also because it has been tested for years in multiple agricultural operations with excellent results. See the specifications in the annex.

Fig. 4.1. Rotatory wing platform DJI S1000

4.3.2 The pesticide

Recent advances in research with biological pesticides, together with better surveillance and information, could make the war take a very different turn. These products can greatly reduce the use of chemical pesticides.

A promising factor is the research currently being carried out by the International Center for Insect Physiology and Ecology (ICIPE) in Nairobi. A team from this institution, led by an expert from Tanzania, Ahmed Hassanali, has identified and synthesized a pheromone - a chemical signal of sexual attraction - specific to locust that can be used against young insects with a devastating effect.

Phenylacetonitrile - or PAN for short - is a pheromone that normally controls the behaviour of adult males, who also use it to alert other males to leave them alone during mating. But as Hassanali discovered, it has very different effects among young locust specimens, which do not yet have wings.

While the adult locust gather in swarms, the young specimens, if given the right conditions, cease to behave individually and become flocks of about 5 kilometres in length. They are only somewhat less voracious than adults, who consume the equivalent of their own weight in food each day.

In three separate test fields - the last one in Sudan last year - Hassanali's team showed that even minimal doses of PAN were able to stop and disperse clouds of young locusts. The PAN causes insects to disintegrate and return to solitary behaviour. Disoriented, some of them lose their appetite, while others become cannibals and eat their companions. The survivors are easy prey for predators.

What makes PAN particularly attractive is that it takes only a fraction - usually less than 10ml/hectare - of the usual amounts of chemical or biological pesticides. This translates into a much more contained financial cost: 50 cents per hectare, compared to 12 dollars for chemical pesticides or 15-20 dollars for biopesticides. It is undoubtedly an element of great importance for the countries at the forefront of the war against locusts, many of which are among the poorest in the world.

4.4 Final and comparative summary

Below is a table summarizing the current system carried out by the FAO teams, the first improvement proposal and the current significant improvements.

Tabla 4.1. Comparative table between solutions

	Actual Method	**First advance**	**Current improved proposal**
High level remote sensing	Based on satellite data on rainfall, green areas and vegetation growth rates. Maximum anticipation: 3 weeks.	Based on satellite data on rainfall, green areas and vegetation growth rates. Maximum anticipation: 3 weeks.	SMELLS method. Based on satellite data on soil moisture, rainfall, green areas, and vegetation growth rates. Maximum anticipation: 2-3 months.
Desert locust swarms location	Survey ground teams crossing the desert with pickups and trucks.	A fixed-wing drone with a 45-minute autonomy and another rotary-wing drone with high-definition visual cameras.	A fixed-wing drone with a range of 80 minutes equipped with a multispectral camera.
Phase of control and extermination of pests and locusts	Survey ground teams equipped with backpacks full of pesticides and expensive spraying planes.	Drone rotary wing with precision fumigation system.	Drone rotary wing with precision fumigation system.

4.5 Project management and future relationships

Since the idea of studying the possible implementation of UAV technology in the fight against desert locust, relations and contacts have been maintained with important entities and companies involved in the same problem.

Hemav, has had the pleasure and the privilege of having confidence from the beginning with the Food and Agriculture Organization of the United Nations. As a contact and direct mentor we are talking about Keith Cressman, senior locust forecasting officer, responsible for operating FAO's Desert Locust information Service (DLIS) that provides early warning to affected countries and the international community.

The acquisition of a scholarship from the Spanish Agency for International Cooperation for Development (ACEID) has also been managed through the Ministry of Foreign Affairs and Cooperation of the Government of Spain.

Finally, the most recent, representative and relevant event is the negotiation of an invitation from the Government of Mauritania together with the supervision and assistance of the country's air forces which are providing companies an opportunity to exercise their UAVs (drones) under real conditions opening a temporary corridor for trials in Mauritania.

This field exercise will allow companies to test our drones under real conditions in the Desert Locust habitat to determine if we already meet the requirements for extensive assessment, intensive search and control operations or if we have the technology and possibilities to meet such requirements within 12 to 18 months.

CHAPTER 5. CONCLUSIONS

To conclude the project, we proceed to take stock of what has been achieved and improved, what remains to be done and the forecasts that we have on the evolution of the problem posed.

Finally, the conclusions that have been drawn throughout the work and research are broken down to leave a new solid base of work from which to start.

5.1 Technical improvements

From the technical and engineering point, a great step forward has been made in relation to satellite data collection and, above all, the work to improve the fixed wing drone. These improvements mean the following:

- Create a totally new, better and greater prevention framework.
- The flight autonomy has been increased by 43.75%.
- The new platform is more durable, resistant and adapted for flight in adverse geographical areas.
- The number of rotary wing platforms has been reduced. What makes the solution simpler, cheaper and smarter
- The amount of data to be processed is also considerably reduced thanks to the previous point.

Definitely, it is public and notorious that UAV technology is very present both in our daily life and in multiple technological and industrial sectors. The unmanned aircraft are a reality to which pay close attention, invest in them to explore and exploit all their possibilities.

5.2 Social progress

If we talk about how improve and influence our new methodology at the social level we have reached the following conclusions that reinforce the proposed changes:

- Levels of safety and security are increased.
- It is not necessary to expose the teams in inhospitable and dangerous territories due to weather conditions, areas in military conflict or animal attacks.
- The logistics in the transport is improved, the necessary equipment is reduced and the quality of the tasks to be performed by the survey ground teams is improved as well.

5.3 Full committed to CSR

Corporate Social Responsibility (CSR) is a way of direct the companies looking to the future, betting on the sustainability and responsibility. Based on the management of the impacts that its activity generates about its customers, employees, shareholders, local communities, environment and society in general.

The improvements and the own solution that has been raised throughout this work is completely committed to the three basic pillars (economy, environment, social) that every company and engineer must internalize and apply.

This solution is linked to the activity of the company and has a vocation for permanence. It is oriented to the improvement and protection of the environment as well as the sustained growth of the local communities such as the country or continent.

Definitely, this project has been based on a solid base aimed at creating a solution for the protection of the environment, improving the quality of work and reducing operating costs. All this through a responsible, sustainable and booming technology such as the UAV.

BIBLIOGRAPHY

[1] Symmons, P.M. and Cressman, K. “Desert Locust Guidelines, Biology and behaviour,” *Food and Agriculture Organization of the United Nations*., pp. 2-40, (2001).

[2] Bryner, J., “New Weapon Against Desert Locusts Plagues: Satellite images”, *Live Science* (2017).

[3] Ali Eweys, O.; Escorihuela, M. J.; Villar J.M.; Er-Raki, S.; Amazirh, A.; Olivera, L.; Jarlan, L.; Khabba, S.; Merli, O., “Disaggregation of SMOS Soil Moisture to 100 m Resolution Using MODIS Optical/Thermal and Sentinel-1 Radar Data: Evaluation over a Bare Soil Site in Morocco”, *Remote Sensing,* 9(11), 1-17, (2017).

[4] Molero, B.; Merlin, O.; Malbéteau, Y.; Al Bitar, A.; Cabot, F.; Stefan, V.; Kerr, Y.; Bacon, S.; Cosh, M.H.; Bindlish, R., “SMOS disaggregated soil moisture product at 1 km resolution: Processor overview and first validation results”, *Remote Sensing,* 180, 361–376, (2016).

[5] Bashir, M.O and Hassanali, A., “Novel cross-stage solitarising effect of gregarious-phase adult desert locust (*Schistocera gregaria (Forskal))* pheromone on hoppers”, *Journal of Insect Physiology,* 56(6), 640-645, (2010).

[6] Fischer, N.; De Koning, R.; Ngwenyama, B.; Slenders, L.; Wools, L., “The potential use of UAVs in a Desert Locust early warning system for preventive control”, *Wageningen University&Research,* (2015).

[7] Escorihuela, M. J.; Quintana, P., Olivier, M., “Comparison of remote sensing and simulated soil moisture datasets across a range of spatial resolution in Mediterranean landscapes” *Science,* 180, 99-114, (2016).

[8] “MODIS Analysis Tool.” [Online]. Available: http://iridl.ldeo.columbia.edu/maproom/Food_Security/Locusts/Regional/MODIS/index.html.

[0] “Greenness Estimates.” [Online]. Available: http://iridl.ldeo.columbia.edu/maproom/Food_Security/Locusts/Regional/greenness.html.

[10] “Monthly Rainfall Estimates.” [Online]. Available: http://iridl.ldeo.columbia.edu/maproom/Food_Security/Locusts/Regional/Monthly_Rainfall/index.html.

[11] “Soil moisture data” [Online], Availabe: http://smells.isardsat.com/data-portal/

Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels

UNIVERSITAT POLITÈCNICA DE CATALUNYA

ANNEXOS

TÍTOL DEL TFG: Development of a system for detection, control and prevention of locust pests using UAV platforms

TITULACIÓ: Grau en Enginyeria d'Aeroports

AUTOR: Daniel Bajiou Mroczkwoski

DIRECTOR: Oscar Casas Piedrafita

DATA: 8 de febrer del 2018

APENDIX 1. HP2 ASSEMBLY AND CONFIGURATION PLAN

Airframe assembly steps

1. Place propeller on the motor shaft with a non-slip washer.

2. With the help of a template mark on the top cover two holes at a distance of 3 cm from the sides and drill with a drill of 6 mm in diameter.



3. Cut 4 cm of the servo cable and re-crimp.



4. Place Velcro on the top and bottom side of the small top cap with Epoxy glue.


5. Also place Velcro with epoxy glue on the large top cover of the platform as shown in the image.

6. Cut about half a centimeter of porexpan to insert the Pixhawk. Then, place Velcro on the remaining ledge.

7. Remove small screws to remove the lower cover.

8. Put the antenna on the SMA adapter.

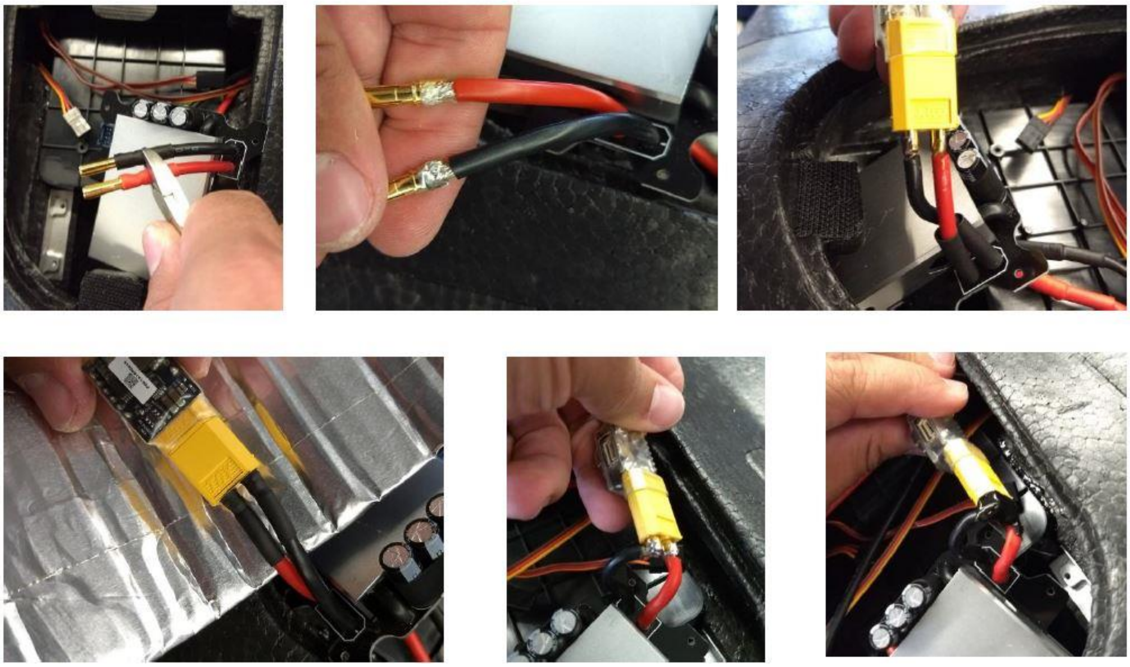
9. Drill a hole with a 7 mm diameter drill bit to insert the antenna.

10. Replace the cover and the screws. Check all the screws and tighten them more if necessary.

11. Make hole to put the thread on the bottom.

12. Remove the foam from the ESC part, mark the hole of the MicaSense and make the hole.

13. Unscrew the ESC and weld the XT60



14. Stick Buzzer on top of the ESC with thick double-sided tape.

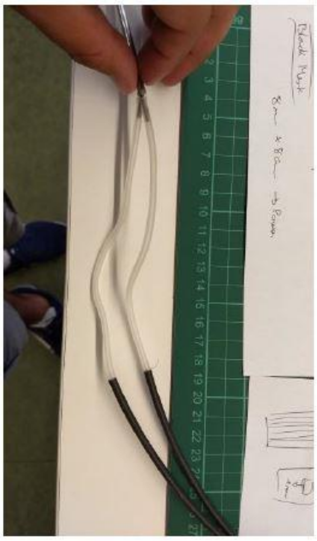
15. Screw Pixhawk to the 3D piece and secure with thin double-sided tape.

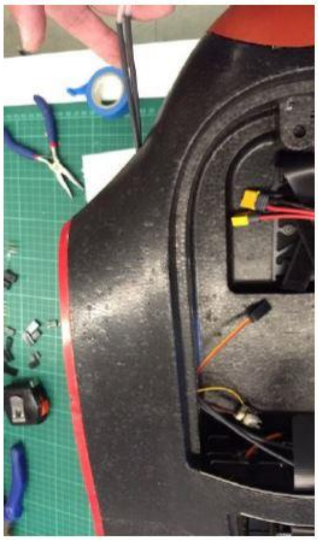
16. Place 3D piece on the fuselage and screw.

17. Pass the two cables of the MicaSense and the I2C with the help of a heat shrink.

18. Make the connections of these cables, except I2C (not yet, to have freedom with the pitot).

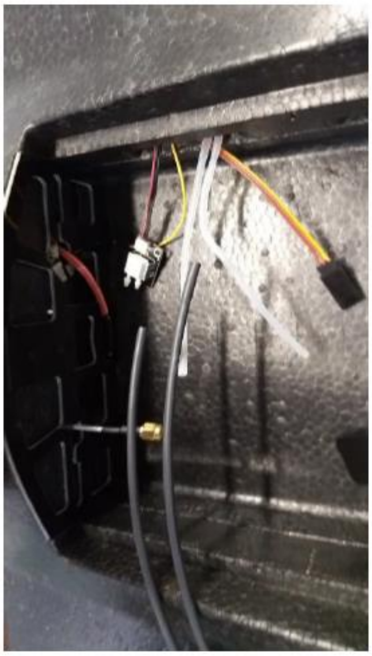
19. Pass pitot tube with the help of the thermo-retractable (check that the pitot tube is not pinched).





20. Pass tubes through the hole and insert 3D piece in the pitot. Stretch the tubes to the maximum and cut them to size.

21. Identify the tubes (the straight and the side) and connect them to the plate, the straight goes up and the other down.



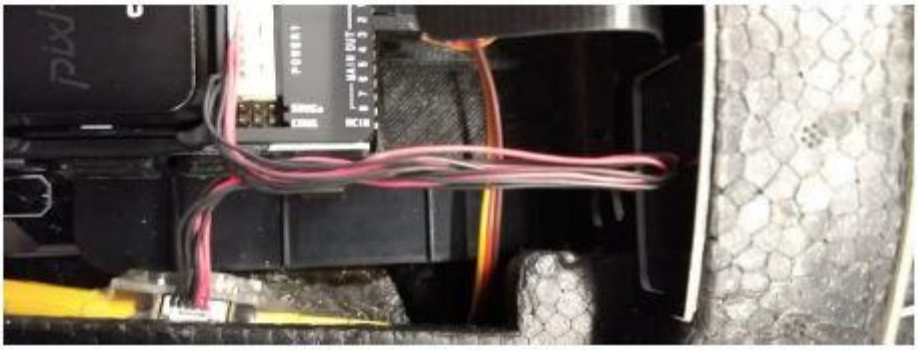
22. Hook the plate with double-sided tape. Ensure that the tubes are straight and the I2C cable is not pinched.

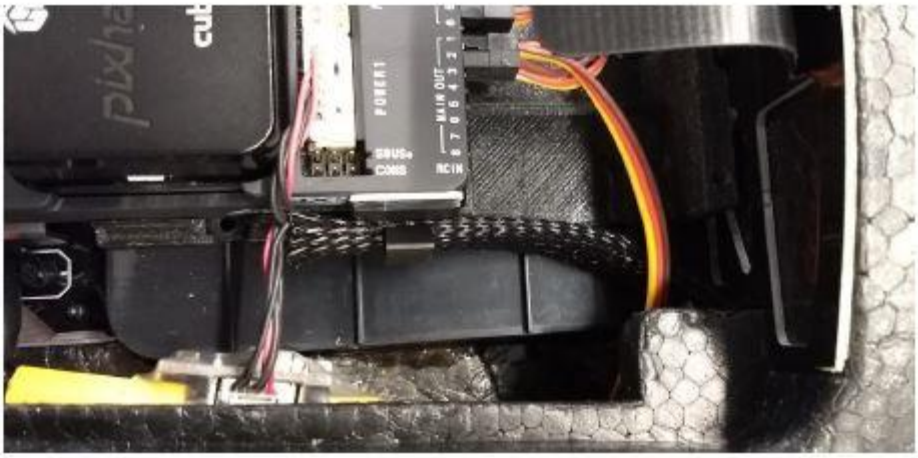
23. Connect I2C to Pixhawk.

24. Place a staple in Pixhawk.

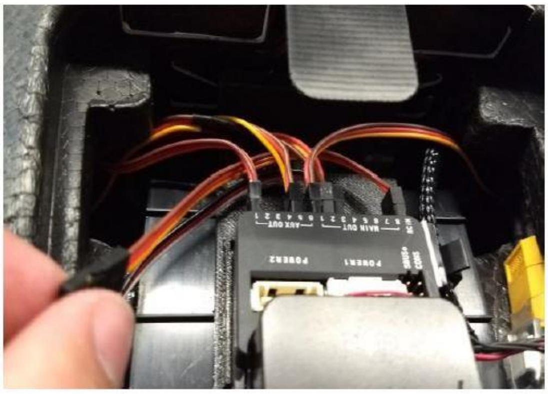
25. Connect the Power Module

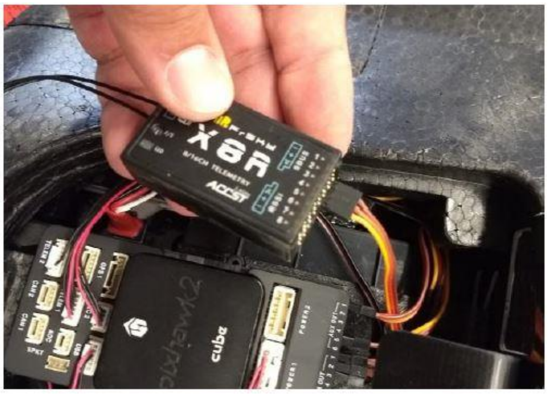
26. *Blackmesh* to join all the cables.





27. Connect the CH3 Pixhawk battery cable.
28. RC IN cable for the receiver.





29. Pick up cables

30. Remove telemetry module from its box and put heat shrink by cutting the side of the heatsink to facilitate cooling. Engage telemetry (with the thermo-retractable) with 3M.

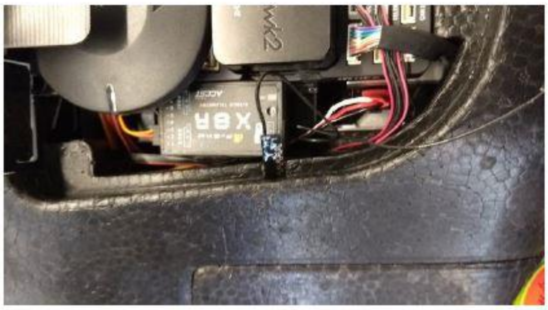

31. Connect signal cable and antenna.

32. Hook GPS and insert in 3D piece.



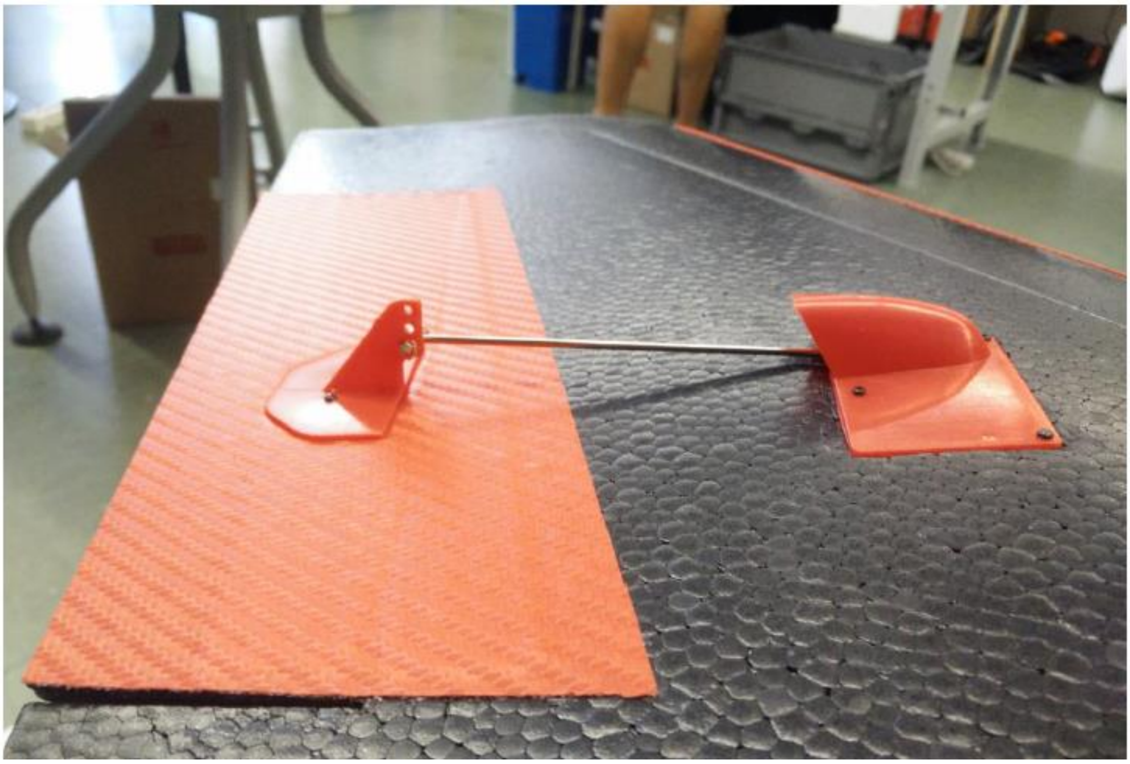

33. Make a cut in the fuselage to pass the cable and insert the antenna.






34. Make a longitudinal cut around the hole of the Micasense to hold the rope of the parachute.

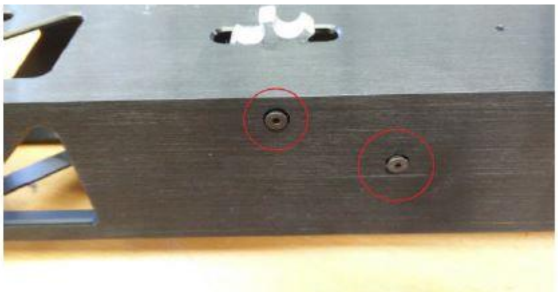
35. Change the rod that connects the servo with the aileron to the hole closest to the wing.



Catapult assembly steps

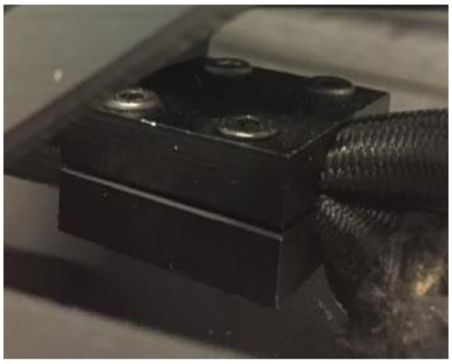
1. Make sure that the cleft at the end of the leg is perfectly centered. In case not, file until get it. (Repeat for the two units). This process can be done with the mill, reducing only one millimeter should be necessary.

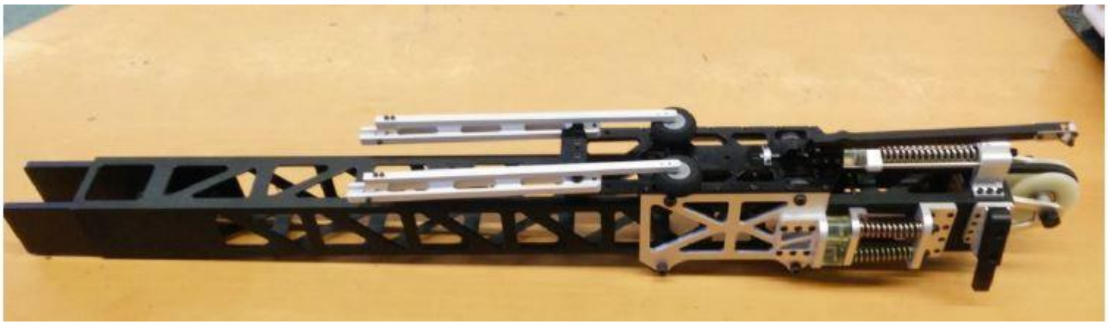
2. Center the shaft and tighten the screws of the pins with a 2 mm allen key until they are flush with the structure.



3. With the help of a shank make the thread along the entire length of the hole.

4. Make sure ALL fasteners are properly tightened and that the catapult remains functional. The screws that tighten the rope should be tightened until the separation between plates is homogeneous of 1 mm.

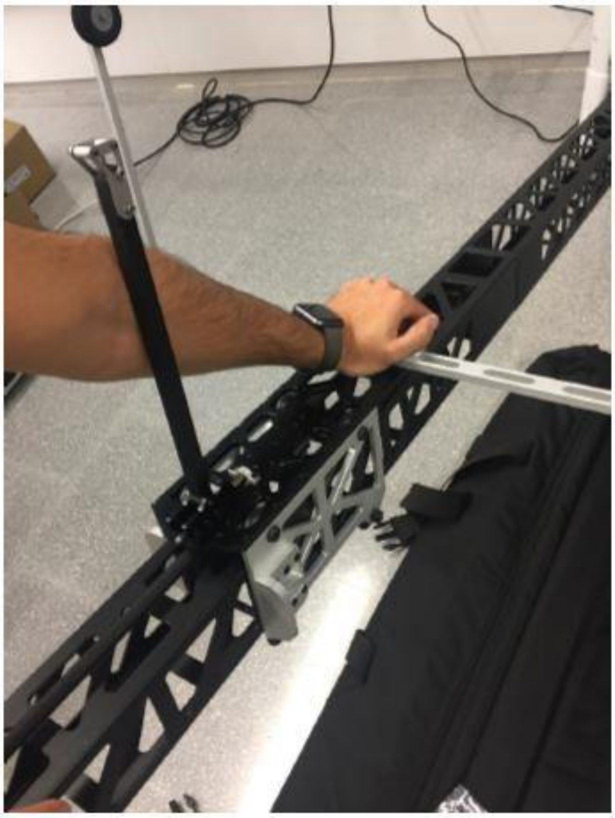




5. Lower the wheels to the last position. It must be checked that once it has been screwed again, the nut is tight but the wheel has clearance to be able to turn freely.

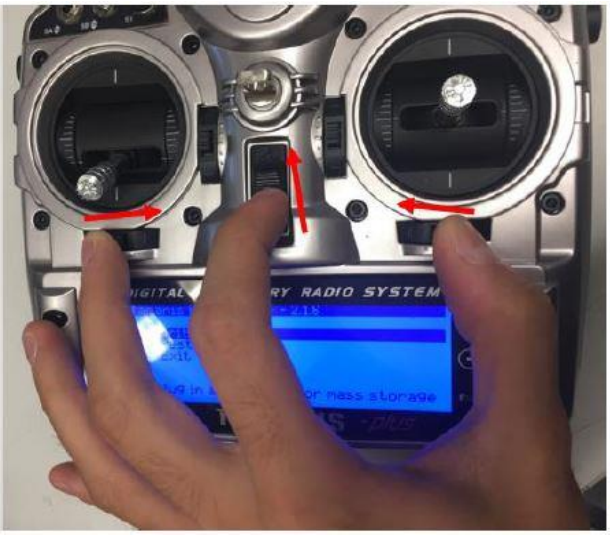
6. Hook foam where the trigger is supported so as not to abrade the surface.

7. Finally, mount the catapult and make the following checks:
    a. That all the mounting screws enter and tighten correctly.
    b. That the trigger, when you move the car down is firmly caught.
    c. Move the car down (without reaching the end) to check that it slides correctly between the two parts of the catapult (both up and down).

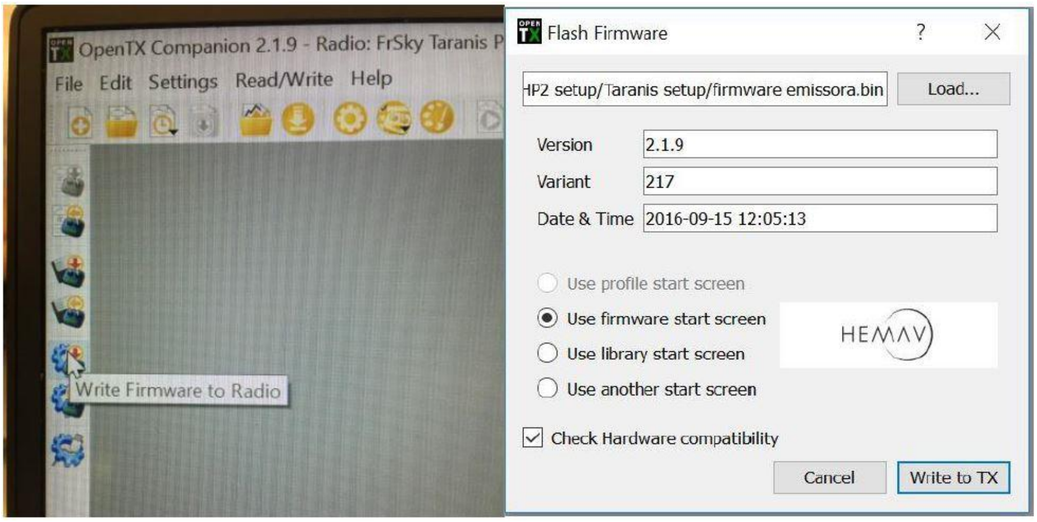


Configuration manual of the HP2 electronics

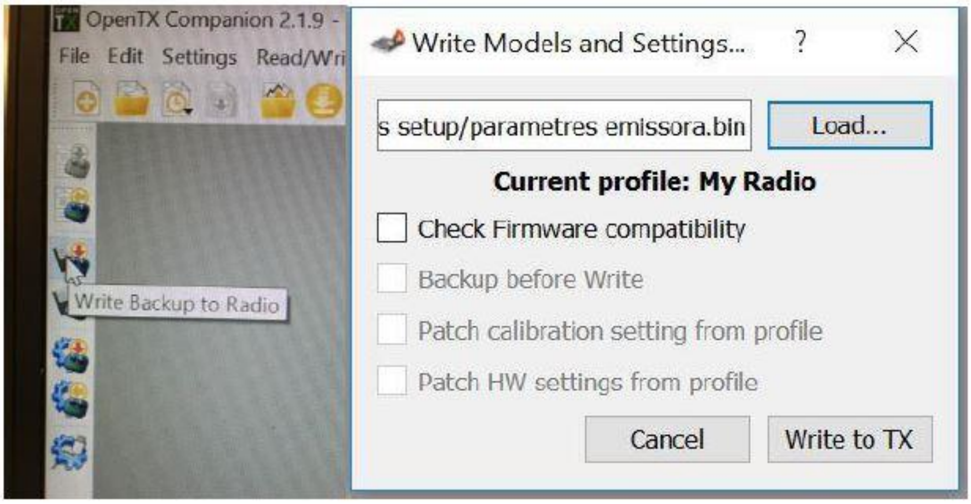
1. Program the Taranis station.
    a. First, you have to turn on the station to be able to program it. To do this, keep the Trims towards the center and turn on the station. Once switched on, we connect the MiniUSB to the station and the PC and open the Companion 2.1 program.



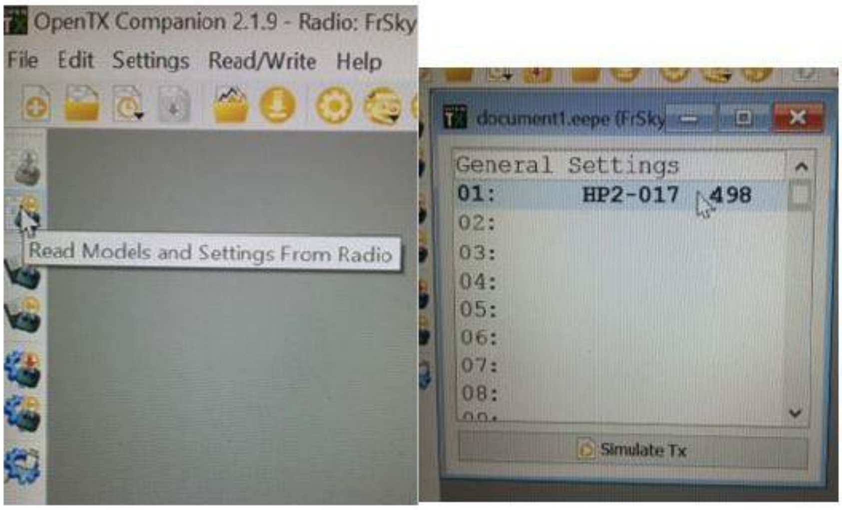
    b. First we load the corresponding firmware. To do this, click on Write FW to Radio, select the file Firmware emisora.bin and click on Write to TX.

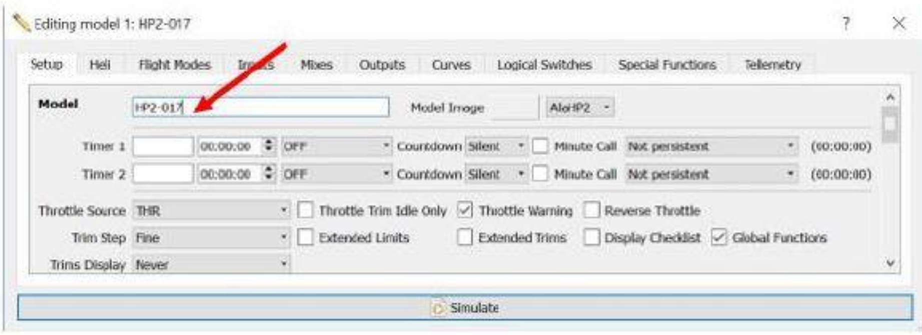


c. Next, we load the parameters and models. To do this, click on Write Backup to Radio, select the file Parametres emisora.bin and click on Write to TX.

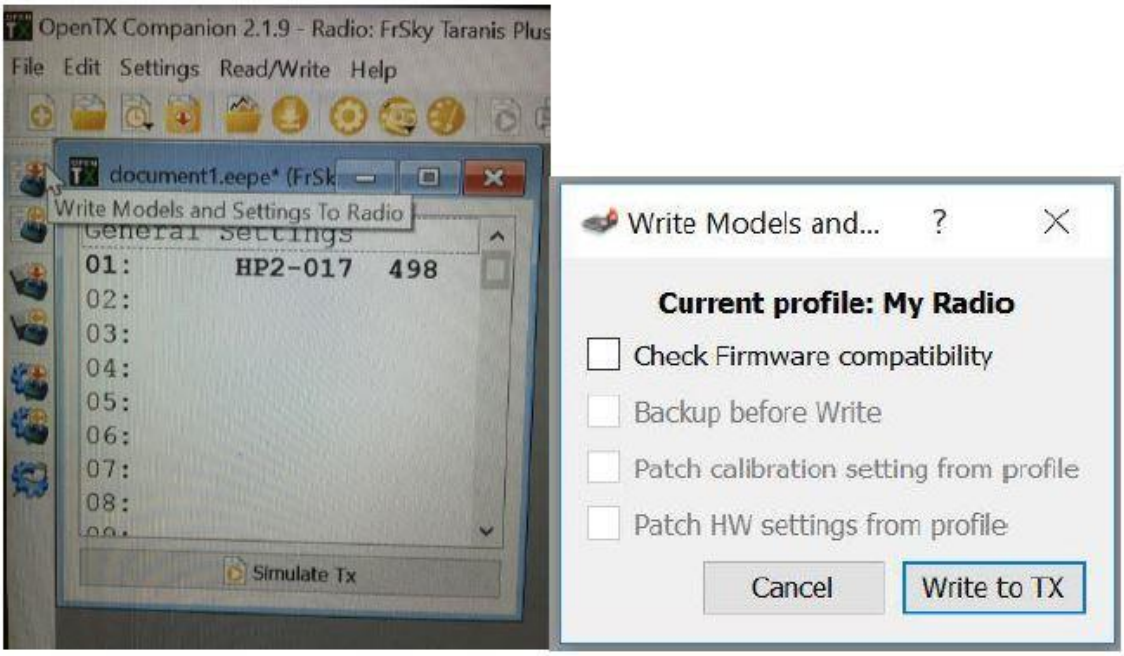


d. We read the parameters and models by clicking on Read Models and Settings From Radio. Next, we double click on the model that appears and change to the name that corresponds to it. Finally, we close the window.

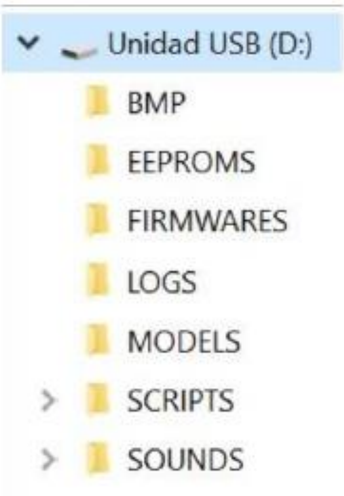




e. Now we click on Write Models and Settings to Radio and click on Write to TX.



f. Then we can close the Companion 2.1 program and transfer the files to the SD card. For this, it can be done either directly via USB (in the root USB drive) or by removing the SD card from the station (much faster transfer). Existing files must be replaced (drag all the contents with the folders and replace when the message comes out).

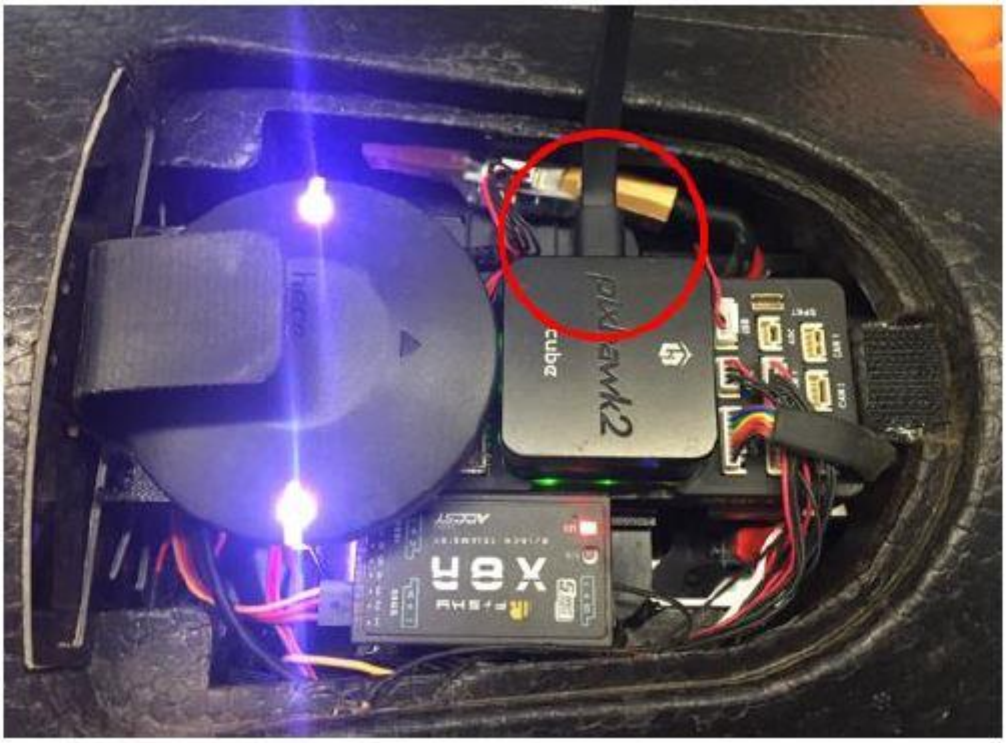


g. Finally, the station is calibrated. To do this, we reset the station (without the USB cable connected and with the SD card inserted if it had been removed) and on the main page, we keep pressing the Menu key until a menu appears.

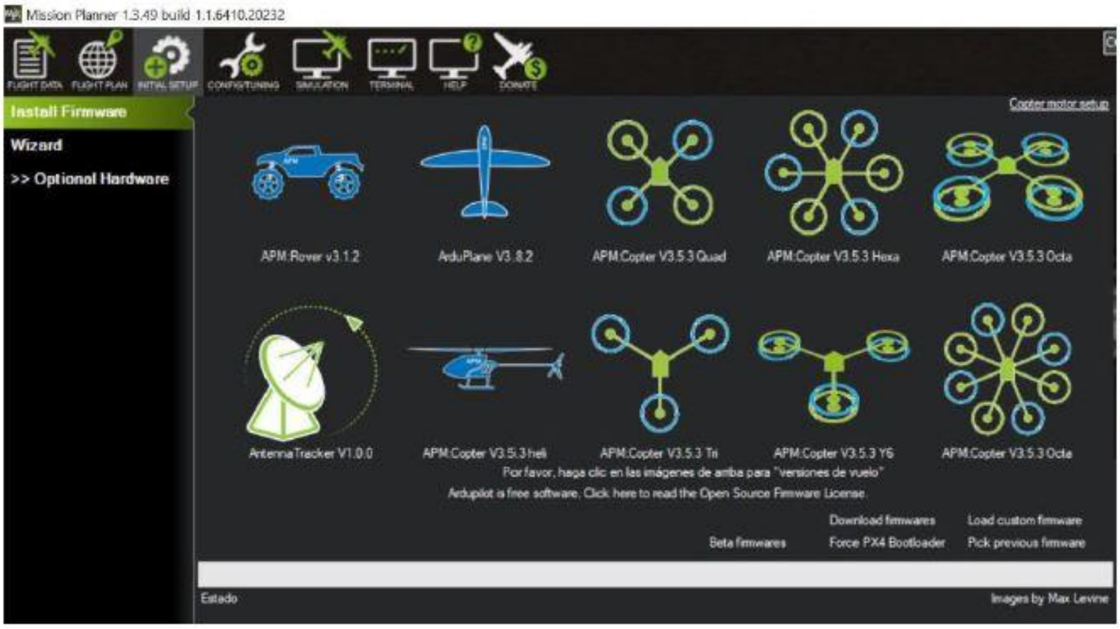
h. We move to the page and follow the instructions to calibrate the sticks and potentiometers of the station.

2. HP2 programming

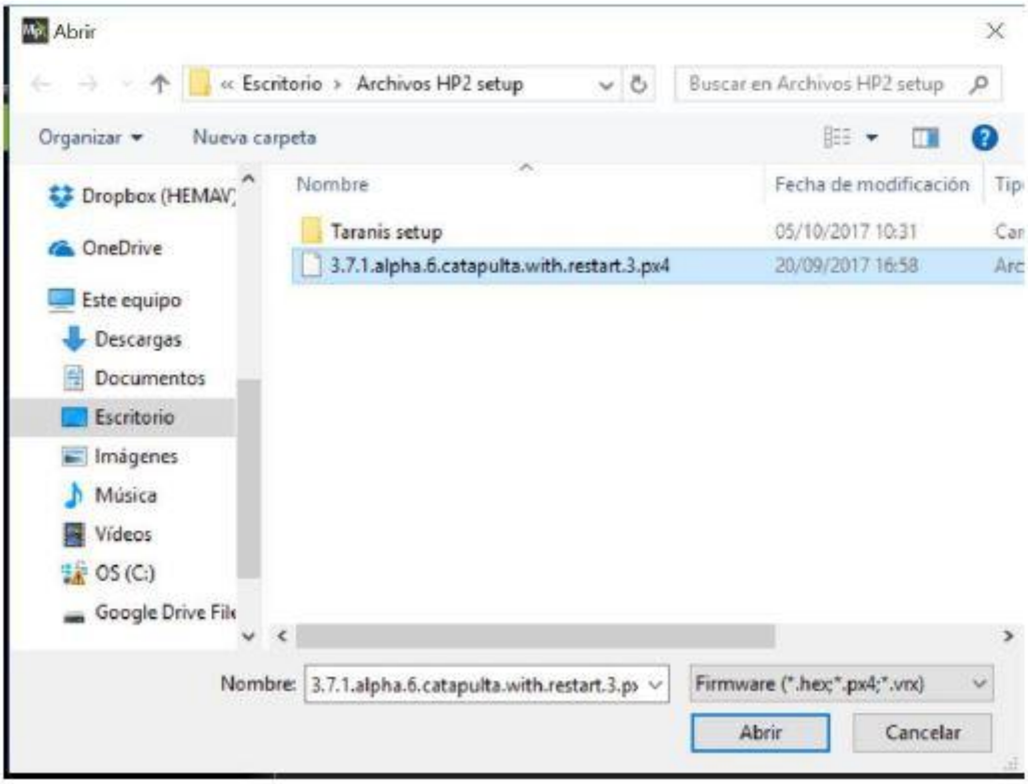
a. We connect the MicroUSB cable of the Pixhawk Cube and the PC and open Mission Planner.



b. Click on Initial Setup / Install Firmware and then Load Custom Firmware.



c. Load the corresponding Firmware (.px4). We wait for the FW to load and follow the instructions on the screen.



d. Next, we load the parameters. To do this, Configtunning / Full Parameter List and click on Compare Params. We load the corresponding parameters and click on continue when the parameters that will be written appear.

e. Then, restart the Pixhawk and reconnect and repeat step "d" to compare the parameters and write them again. This step is VERY IMPORTANT since with the first writing all parameters are not loaded, writing is necessary a second time.

f. We repeat step "e" again to ensure that all the parameters have been written correctly. When the window with the different parameters to be written appears, if only parameters of the accelerometers and gyroscope appear, it means that all have already been written correctly and it is not necessary to do it again.

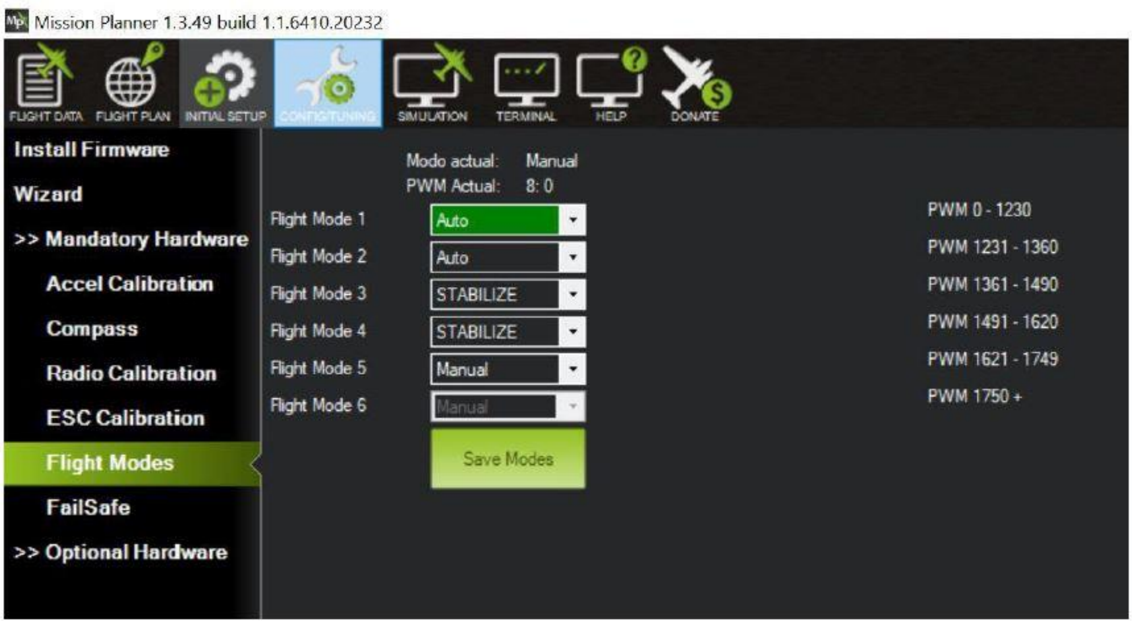
g. Next, we go to Configtunning / Full Parameter List and use the search engine in the right sidebar to find the parameters that are shown in the following list and verify that the values match, otherwise, modify the ones that do not match and re-write them.

AHRS_ORIENTATION	4
COMPASS_LEARN	1
ARSPD_SKIP_CAL	1
ARSPD_AUTOCAL	0
MIN_GNDSPD_CM	1000
LIM_ROLL_CD	4500
LIM_PITCH_MAX	2500
NAVL1_DAMPING	0.8
NAVL1_PERIOD	15
KFF_RDDRMIX	0
DSPOILR_RUD_RATE	0
THROTTLE_NUDGE	0
STICK_MIXING	0
ARSPD_FBW_MAX	50
ARSPD_FBW_MIN	17
SR2_ADSB	0
SR2_EXT_STAT	0
SR2_EXTRA1	10
SR2_EXTRA2	0
SR2_EXTRA3	10
SR2_PARAMS	0
SR2_POSITION	10
SR2_RAW_CTRL	0
SR2_RAW_SENS	0
SR2_RC_CHAN	0
SERIAL2_BAUD	57

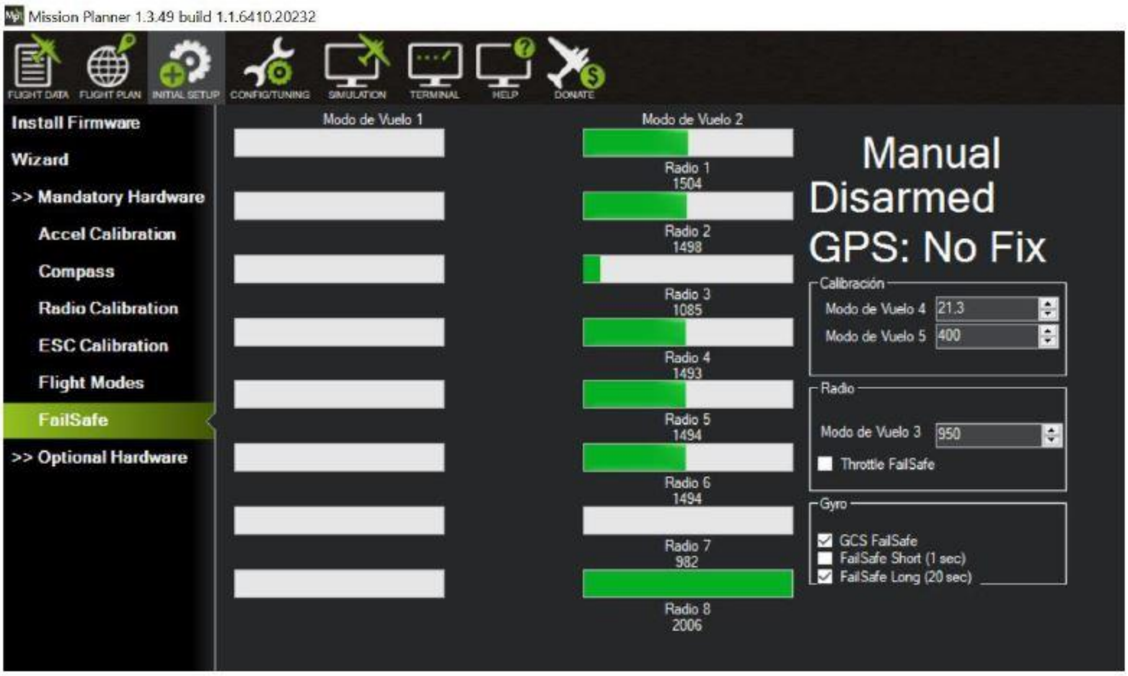
h. **Calibrate Airspeed.** We go to Flight Data / Actions and select PREFLIGHT_CALIBRATION and click on Take Action. This allows the Airspeed to be calibrated and its value (AS) should decrease to 1.5-3.

i. **Calibrate Radio**. To do this, go to Initial Setup / Radio Calibration and, with the station on, click on Calibrar Radio. Then the sticks must be moved with their maximum travels.

j. We check the Flight modes. We go to ConfigTunning / Flight Modes and check the 3 flight modes (Manual, Stabilize and Auto) and verify that these are activated with the stick of the station.



k. Check FailSafe GCS. Go to Initial Setup / FailSafe and verify that the GCS FailSafe and FailSafe Long (20 sec) is activated.



3. **Change the NetID of the air and ground telemetry.**

   a. First, we connect the battery to the platform, open Mission Planner and connect with MavLink**.**
   b. Once connected, we click to Disconnect and navigate to Initial Setup / Sik Radio.
   c. Act followed, we load the settings in Load Settings and adjust the value of NetID with the number that belongs to it. In the case of the HAR8 they go from 0 to 99, taking as value the registration number, for example if it is the HAR8-012, we will assign the NetID # 12.

   d. Once assigned the value of NetID, we give *Copy required to remote* and then, in *Save Settings*. Probably once the process is finished; it will give us an error, which is normal for it to be processed.

   e. It has been observed that, following this procedure, an extra step must be made, since ground telemetry does not save this NetID change the first time.

   f. Next, we disconnect the battery from the platform, disconnect the ground telemetry and close Mission Planner.

   g. We connect the ground telemetry to the PC, open Mission Planner and go back to Initial Setup / Sik Radio. Load the parameters (Load Settings) and check the value of NetID, if it has not been modified correctly (probably if it is the first time it has been modified), we re-enter the value that belongs to it and we give Save Settings.

h. When the process is finished (a *Done* will appear below) we close Mission Planner and disconnect the ground telemetry from the PC.

i. Finally, we perform the test of connecting both telemetries, if they connect correctly the process can be considered finished, otherwise, it will be necessary to check which of the two telemetries has not changed its value, remembering that the value of NetID = 25 is the one it is given by default.

APENDIX 2. DJI S1000 DATASHEET

Date :	February 24, 2014
S1000 User Manual Version :	1.00
S1000 ESC Firmware Version :	3.6

S1000 Overview

1. Safe and stable

(1) The S1000's V type mixer design provides large amounts of propulsion while improving power efficiency. Combined with a DJI flight controllers like the A2, it is guaranteed to remain stable even with the loss of a rotor.

(2) Integrated into the center frame is a power distribution system using our patented coaxial cable connector. It is more efficient, reliable and easy to install and eliminates the need for soldering. Its main power cord uses an AS150 sparkproof plug and an XT150 plug, preventing creators from mixing up polarity when plugging in the battery and preventing short circuits.

(3) All frame arms as well as the retractable landing gear are made from carbon fiber, ensuring light weight and high structural stability.

2. Professional octocopter

(1) Weighing approximately 4kg with a maximum takeoff weight of about 11kg, the S1000 can easily carry equipment as heavy as a 5D mark 3. Used with a 6S 15000mAh battery it can fly for up to 15 minutes.

(2) The gimbal is mounted low on the frame on a specially designed bracket. When combined with our retractable landing gear, it offers a clear and wide shooting angle.

(3) Gimbal and battery are mounted to the same bracket, with dampers placed between the bracket and the frame. This significantly reduces high-frequency vibrations and makes shots clearer and sharper. The battery tray's position also makes it more stable and convenient for mounting and dismounting.

(4) Supports all Zenmuse Z15 gimbal systems.

(5) Optimized for A2 wiring and installation, connecting an A2 flight controller and setting flight parameters is easy. The A2's antenna is kept away from any carbon fiber or metal, ensuring a better signal.

3. Portable and easy to use

(1) All eight arms can be completely folded down and the 1552 folding propeller can be tucked away, minimizing the S1000's size for transportation.

(2) To fly, simply lift the frame arms up, lock them in place with the red clips and power up the system. This greatly saves on pre-flight prep time.

(3) On the center frame there are 3 XT60 power sockets and 8 positions reserved for equipment installation, making installs easier and tidier.

4. Easy to control and fly

(1) Each frame arm is designed with an 8° introversive and a 3° inclination, making the aircraft more stable when rolling and pitching and more flexible when rotating.

(2) Each frame arm has a built-in 40A electronic speed controller (ESC). When combined with its 4114 pro motor and high performance 1552 folding propellers, it is capable of a maximum thrust of 2.5Kg.

Frame	
Diagonal Wheelbase	1045mm
Frame Arm Length	386mm
Frame Arm Weight (with Motor, ESC, Propeller)	325g
Center Frame Diameter	337.5mm
Center Frame Weight (with Landing Gear Mounting Base, Servos)	1330g
Landing Gear Size	460mm(Length)×511mm(Width)×305mm(Height) (Top width: 155 mm)
Motor	
Stator Size	41×14mm
kV	400rpm/V
Max Power	500W
Weight (with Cooling Fan)	158g
ESC	
Working Current	40A
Working Voltage	6S LiPo
Signal Frequency	30Hz ~ 450Hz
Drive PWM Frequency	8KHz
Weight (with Radiators)	35g
Foldable Propeller (1552/1552R)	
Material	High strength performance engineered plastics
Size	15×5.2inch
Weight	13g
Flight Parameters	
Takeoff Weight	6.0Kg ~ 11.0Kg
Total Weight	4.2Kg
Power Battery	LiPo (6S, 10000mAh~20000mAh, 15C(Min))
Max Power Consumption	4000W
Hovering Power Consumption	1500W (@9.5Kg Takeoff Weight)
Hovering Time	15min (@15000mAh& 9.5Kg Takeoff Weight)
Working Environment Temperature	-10 ^{o}C ~ +40 ^{o}C