Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels

UNIVERSITAT POLITÈCNICA DE CATALUNYA

MASTER THESIS

TITLE: STAMP project

MASTER DEGREE: Master's degree in Applications and Technologies for Unmanned Aircraft Systems

AUTHOR: Isaac Hoyas Ester

ADVISOR: Mario García Lozano

DIRECTOR: Xavier Banqué Casanovas

DATE: June 2018

Title: STAMP project

Author: Isaac Hoyas Ester

Advisor: Mario García Lozano

Director: Xavier Banqué Casanovas

Date: June 2018

Abstract

During the historical evolution of aerial photogrammetry all the production processes involved in its workflow have, in one way or another, been improved or optimized by the contemporaneous technological breakthroughs. There is however one area that, until today, continues unaltered since its inception, the Ground Control Point survey process which is still manually performed by a human.

The motivation of this master thesis is twofold, in one hand to study a method to automate the Ground Control Point collection process by using Remotely Piloted Air Systems as both, visual targets as well as Global Navigation Satellite System receivers and, on the other hand, study if the technological concept may become a viable business or not.

TABLE OF CONTENTS

INTRODUCTION

When a person or entity wants to create cartography of the surface of a given subject, like a portion of the planet Earth, there are two different approaches that can be followed.

The first approach would be to manually survey significant points of the surface to be mapped. This allows to create a dataset in the field that would only contain the data required to build the cartography. This method is human resource intensive because it is very time consuming on the field but, on the other hand, the processing of the data is relatively simple and fast.

The second approach would be to systematically scan the surface to be mapped by using Synthetic Aperture Radar (SAR), LIght Distance And Ranging (LIDAR) or orthorectified imagery also known as photogrammetry [1]. This second approach of collecting data is typically much quicker on the field than the first method but it also generates very large amounts of data that has to be processed in powerful workstations.

Among all the methods previously mentioned the most cost efficient when mapping large terrain areas is photogrammetry. This method is widely used in the booming Unmanned Air Vehicle (UAV) sector because digital cameras are becoming cheaper, smaller and lighter with ever increasing pixel counts.

In parallel to the cameras improvements there are also Global Navigation Satellite System (GNSS) receiver improvements. Those are becoming cheaper, smaller and lighter allowing for very low cost photogrammetric setups able to provide end results that rival in quality with what a few years back was only possible with a multimillion dollar aircraft.

However, there are areas that still need improvement, the most important of which is how to accurately relate the UAV photogrammetric end result with an absolute coordinate system tied to the planet Earth, process also known as georeferencing [2].

Georeferencing in photogrammetry can be tackled in two different ways, one is by providing accurate coordinates to each UAV camera shutter release typically achieved using very expensive dual frequency GNSS receivers and Inertial Measurement Unit (IMU), also known as direct georeferencing.

The second method is by providing coordinates to Ground Control Points (GCP) scattered throughout the aerial survey zone. This task is usually performed by sending a human surveyor equipped with either a total station ranging from 10 k€ to 30 k€ or using a high end dual frequency GNSS receiver (typically the preferred method) ranging from 10 k€ to 20 k€. This method is known as indirect georeferencing.

One example of human made GCP can be seen in Figure1 where a black and white high contrast pattern has been positioned against green grass providing good contrast and easy identification in the resulting aerial picture even when the UAV is flying at 120 metres Above Ground Level (AGL) and using wide lens (78.8° Field Of View).

Figure 1 50x50 cm GCP as seen in an aerial picture taken at 120m AGL

This GCP survey process, where a human operator has to visit each GCP location one by one, usually takes between half and a full working day. Although time may vary depending on area size, the number of GCPs, the desired accuracy of the survey and the orography of the terrain.

In very rough terrain, it may be impossible to deploy GCPs or it may imply severe risks to the surveyor and to the expensive and fragile equipment.

In cartographic flights intended to provide a final metric document usually both, direct and indirect georeferencing are used simultaneously providing the highest accuracy but also the most robust / reliable result.

In addition to establish the relationship between the photogrammetric end product and a known coordinate system, the GCPs are also used to assess how closely the photogrammetric final model fits the real world which is crucial to certify that the end result meets certain quality criteria.

In April 2016 PhD. Miquel Garcia Fernandez and MSc. Xavier Banqué Casanovas, the two founders of Rokubun, started to work in the basic outline of a system that could replace the human surveyors that collect the Ground Control Points (GCPs).

That system was also meant to replace the man made targets by a set of drones. Xavier and Miquel made a general sketch of the idea and named the concept STAMP but not long after the project was set in standby.

A schematic overview of the STAMP system operation can be seen in Figure 2

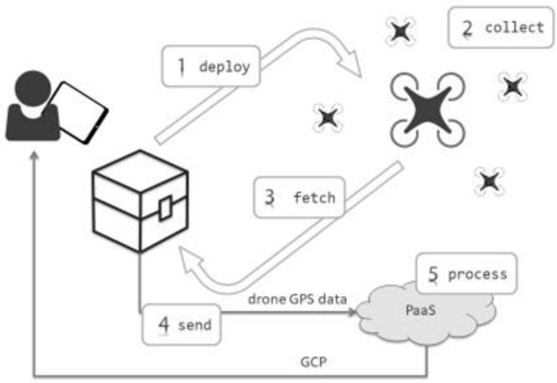

Figure 2 STAMP overview.

In January 2018 the project was recovered and reassigned to me with the errand to further develop the idea and study its technical and economic feasibility.

The idea behind STAMP is that it should be possible to reduce the GCP field survey time to just a few minutes by substituting the human land surveyor by a set of six to eleven small drones all controlled by a single operator through an easy to use app running on a tablet.

The STAMP drones tasked as GCPs would be equipped with Rokubun's Self-Powered Argonaut (SPA) single-frequency affordable GNSS receiver. The drone role would be to land on the location designated by the operator and remain landed throughout the photogrammetric flight; these drones acting as GCPs are known as "slave" drones.

The remaining drone, also known as master drone, would be tasked to perform the photogrammetric flight after all the slave drones have landed meaning that the master drone would capture every slave drone landed on the ground in the aerial pictures.

At the end of the flight of the master drone the slave drones would sequentially take off and return to the coordinates designated as "home point" always under the supervision of the operator.

After all the drones are back to the home coordinates the GNSS data collected by each drone would be downloaded to a PC (or tablet) and then be uploaded to Rokubun's Positioning as a Service (PaaS) through Internet to obtain a few minutes later an accurate positioning solution for each STAMP slave drone.

The post processing of the GNSS raw data collected on the field using the classic methods would likely take a few hours in the office however instead of using a multi-thousand euro package running locally on a computer the GNSS post processing software as conceived by Rokubun would be a cloud based, easy to use, pay per use Positioning-as-a-Service (PaaS).

In addition to the cost savings in workflow optimization, it is also expected that STAMP will reduce the costs in hardware and rationalize the expenses in software. Beyond enhancing today's photogrammetric workflows, STAMP will also allow to map areas were, previously, it was not possible to access, like plains over cliffs or lands beyond a river without bridge to cross to the other side.

The expectative is that STAMP, in addition to the increased GCP collection speed, should provide external accuracies (positioning in an absolute reference frame like ETRS89) orders of magnitude better than uncorrected GNSS Single Point Positioning.

Depending on the accuracy obtained in the stamp extensive field test STAMP would be suitable for different applications. For instance, STAMP may be able to match GIS expected accuracies (better than 30 centimetres) but not land surveying accuracies (centimetre level).

This document has been divided in three main chapters: chapter number one is a theoretical study of the technical feasibility of STAMP, chapter number two will present the results of the empirical testing's and the third chapter presents a study of the economic feasibility of the STAMP project.

.

TECHNICAL ANALYSIS

The next chapters will discuss different formal aspects of the STAMP system aiming to develop the following areas:

- To evaluate the technological readiness.
- Present the drone selection key factors
- The product development areas, where Rokubun should concentrate its efforts.
- The interactions with the current law.

All the areas mentioned earlier are fundamental not only in shaping STAMP towards a technically viable product, but also in ensuring that STAMP does not become a legal liability to Rokubun.

The drone selection process for this suitability analysis is based on seven technical characteristics that define the candidate drones. Among those characteristics, two, are especially important for the slave drone, weight and size. In addition to those factors the master drone selection is also driven by the available flight time.

By the end of this chapter it should be clear what hardware has been selected, what are the minimum requirements that the software should meet and also what are the interactions between STAMP and the Spanish legal frame.

1.1. Drone technological state of the art

The very first consideration that comes to mind when designing a drone based system is what drone platform is more adequate to the constraints of the project.

In the case of STAMP weight and size are primary considerations when selecting what drone platform to use, this is because, in a worst case scenario, the operator must carry eleven drones in a backpack plus batteries, a radio control and a tablet.

Another primary consideration is that the master drone camera must be able to register the slave drones in the aerial pictures in the worst case scenario when landed on the ground at 120 m AGL.

In summary the drone should be small enough to fit in the backpack but at the same time must be large enough to be seen on the aerial pictures.

It may be tempting to propose a very small slave drone with the objective to reduce weight and size and at the same time adopt a master drone with higher resolution camera able to resolve smaller details of the objects on the ground, such approach based on pixel count increase has a severe downside which is the exponential increase in the photogrammetric processing time.

Rokubun must have the capability to adapt the drone to such new application, meaning that at the very minimum an API available to the company must be available so that a tablet app to control the whole system could be designed.

Such strong primary considerations quickly narrowed down the potential drone platform candidates:

1. There are no ready to build drone kits that are foldable (provably due to structural concerns).
2. In the Commercial Of The Shelf (COTS) end user drone market there are a few options:
    a. DJI products: DJI first introduced the foldable drone concept The 27th of September of 2016, as of today there are three foldable variants, those are:
        i. DJI Mavic Pro (DMP)
        ii. DJI Mavic Pro Platinum (DMPP)
        iii. DJI Mavic Air (DMA).
    b. Other manufacturers: so far the alternatives to DJI are either lower cost copies of existing products which can't be customized like the Walkera Vitus or they are far more expensive Research and Development (R&D) projects that are larger in size and not affordable like the Skydio R1

1.2. Drone selection

All DJI drones are potential STAMP candidates as they are all supported in the DJI's Application Programming Interface (API) making them flexible in terms of future implementation in a unified Graphical User Interface (GUI) based on a tablet, they are also foldable, their weight is moderate and their cameras are of enough resolution being also gyrostabilized.

The following table summarises the differences between the DMP, the DMPP and the DMA. Those specifications that are not listed here is because either were all equal in all drones or they were irrelevant to the STAMP project:

	 MAVIC AIR	 MAVIC PRO	 MAVIC PRO PLATINUM
Price difference	65%	77%	100%
Body size	85%	100%	100%
Weight	59%	100%	100%
Flight time	70%	90%	100%
RF range	50%	100%	100%
Lens FOV	85°	79°	79°
Lens aperture	f/2.8	f/2.2	f/2.2

Table 1 Foldable DJI product line relative comparison.

The table fields shaded in green are those that have been deemed to fit better the requirements of the STAMP project. Note that a bigger number may not be a warranty of best fit.

1.2.1 Price

It must be taken in to account that the prices used to build this table are DJI's Manufacturer's Suggested Retail Price (MSRP) which are not fully representative of the prices that Rokubun would pay mainly for two reasons:

1. Rokubun can obtain manufacturer prices that are variable depending on the lump sums enquired to DJI but in any case always lower to the MSRP.
2. The prices on the table include a "full kit", that is, drone plus remote controller plus batteries when, for some of the drones it is possible to just

purchase the drone without a remote which make sense for all the STAMP slave drones.

The price of the drones finally selected to be part of STAMP will be discussed latter on during the analysis of the economic feasibility however it can be said that the lower the better.

1.2.2 Body Size

From portability point of view it is obvious that the smaller the better however it is necessary to consider that the size of the STAMP slave drones directly affects the visibility of those in the master drone aerial pictures so an equilibrium must be found between portability and visibility.

In order to determine if the size of the slave drone is sufficiently large to be properly captured by the camera of the master drone it will be necessary to evaluate the worst possible scenario case.

The higher the master drone flies the larger the size of the projection of each camera pixel becomes on the ground meaning that the spatial resolution will be worse and therefore it will be more difficult to resolve the slave drones in the aerial pictures.

The maximum legal height at which a drone can legally fly without the need to request special permissions it may be different on different countries.

A summary table listing a few representative countries follows:

Country	Max. height AGL.
Argentina	122 m
Australia	122 m
Brazil	122 m
Canada	90 m
Colombia	152 m
Finland	150 m
France	150 m
Germany	100 m
Ireland	122 m
Mexico	122 m
Spain	120 m
Turkey	100 m
UK	122 m
USA	122 m

Table 2 max. legal heights.

Taking into consideration that the focal length of the DMP and the DMPP is 4.8 mm, the picture dimensions are 4000x3000 pixels and the sensor size is 6.3x4.7 mm we can apply the following formulas to compute the Ground Sampling Distance (GSD):

$$GSD_{height} = \frac{Flight\ Altitude \times Sensor\ Height}{Focal\ Length \times Image\ Height} = \frac{120 \times 0.0047}{0.0048 \times 3000} = 0.039m$$

Equation 1

$$GSD_{width} = \frac{Flight\ Altitude \times Sensor\ Width}{Focal\ Length \times Image\ Width} = \frac{120 \times 0.0063}{0.0048 \times 4000} = 0.039m$$

Equation 2

A GSD of 39 mm means that the projection of the camera pixels located at the centre of the camera sensor would become a regular grid of square cells with a side size of 39 mm on the ground if the surface being photographed would be parallel to the sensor. This is equivalent to say that the ground would be sampled every 39 mm.

Under ideal conditions as per Nyquist sampling theorem a GSD of 4 cm would enable the observer looking at a DMPP picture to detect, well contrasted objects, sitting on the ground as small as 8 x 8 cm.

The size of the body of the DMA, which is the smallest DJI Mavic airframe available, is approximately 17x8 cm.

In a real world application a larger size slave drone would be advisable to be able to easily differentiate between the similarly sized objects surrounding the drone like stones or other elements.

The DMP and DMPP are slightly longer at 20x8 centimetres which means that, along the longitudinal axis, there will be an additional pixel occupied by the drone.

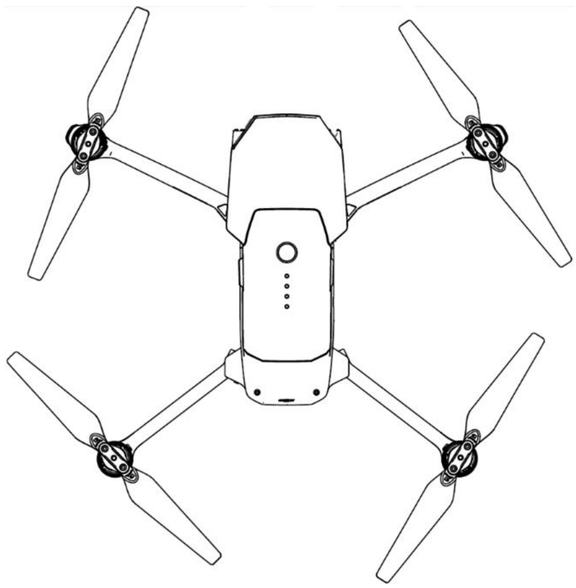

Figure 3 DMP CAD drawing as seen from above.

Let's review what would be the theoretical end result based on an artificially down-sampled a rasterized Compute Aided Drawing (CAD) design of the DMP/DMPP where the body and the propellers of the drone have been filled in with black colour.

Figure 4 DJI Mavic Pro visibility simulation at 90, 100, 120 and 150 meters AGL

Those qualitative results presented in Figure 4 can be summarised in a quantitate table as follows:

AGL height	Image Vertical Scale	GSD (mm/pixel)	Image footprint width over a flat surface	Image footprint height over a flat surface	Slave STAMP UAVs body pixel size
90 meters	1/19000	29	118 m	88 m	7 x 3
100 metres	1/21150	33	131 m	98 m	6 x 2
120 metres	1/25350	39	157 m	118 m	5 x 2
150 metres	1/31700	49	196 m	147 metres	3 x 2

Table 3 DMP/DMPP ground footprint vs GSD performance.

At a later stage the theoretical results being presented here will have to be reviewed with an empirical test to take in to account non-simulated factors like non optimal contrast, Complementary Metal–Oxide–Semiconductor (CMOS) Bayer pattern caused artefacts due to irregular quantic efficiency, optical induced deformations, etc.

In any case the 150 meters simulation of the DMP/DMPP is at the limit of visual perception therefore the smaller DMA has been discarded as a STAMP slave.

1.2.3 Drone weight

At 430 grams the DMA is, by far, the best contender, unfortunately, its small size and its battery life outweigh the benefits brought by the smaller weight.

1.2.4 Flight time

When evaluating the flight time we have to separate the two different roles that play the STAMP Master and Slave drones.

For the STAMP Master it is mandatory to use the best combination of weight to flight longevity ratio as this factor limits the extension of the terrain that can be covered by the STAMP master which in turn limits the size of the terrain that can be surveyed with STAMP.

A reduction in the number of transported extra batteries is important because each extra battery has a protective enclosure and electronics that add to the final weight of the system but don't add anything to the final solution.

So the drone selected for the STAMP master is the DMPP because every DMPP battery provides 3 additional minutes which is an improvement of 10% over the closest competitor, the DMP.

From STAMP slave point of view a cheaper drone with a shorter flight time but equal size as the DMPP is acceptable

It must be noted that some countries like Spain legally limit the maximum distance a drone can reach from its operator to 500 metres, this rule sets a limitation on how far the slave drones may have to fly back and forth. This means that a single battery per slave drone is enough in most flights

1.2.5 RF Range

The radio efficiency summarised as the maximum free space distance at which the drone would be able to downlink vide imagery / telemetry and the radio controller would be able to upload control commands to the drone, is a relevant aspect of the STAMP operation.

However not because the operator is ever going to reach such long ranges but rather because the higher the sensitivity of the radios, the better the antennas and the higher the robustness of the modulation the more reliable the radio link will be when the radio operation conditions are sub optimal.

This is significant to STAMP, because STAMP slaves are expected to regularly operate near the ground where obstructions are common. Considering that the legal frame of most countries requires the pilot to be in control of the drone at all times, even when it is operating autonomously, a highly attenuated radio link may mean the inability to operate.

Because of this DMP and DMPP have been selected.

1.2.6 Lens Field Of View (FOV)

Lens FOV or lens focal length is an intricate parameter that cannot and should not be gauged based on it's numerical magnitude.

Generally speaking photogrammetry is able to efficiently reconstruct a three-dimensional object out of a pair of bi-dimensional images as long as there is sufficient overlap (common ground) between the two images.

In short focal length optics (wide FOV) there are two main inconvenients:

1. The GSD of a camera equipped with a wide FOV lens is going to be worse (larger GSD) when compared to the same camera fitted with narrower FOV lens (tighter GSD), this means that that the final model will have less resolution when using wider lens all the other parameters of the flight being equal.
2. The outer parts of an image captured with a wide angle lens may be distorted in such a way that may not be recoverable using the standard Brown frame camera model meaning that usually are discarded.

The DMP and the DMPP both use the same camera equipped with an optic focal length of 28 mm in a 35 mm equivalent format, the lens can be considered wide enough for aerial photogrammetry, there is no need to use the wider 24 mm of the DMA.

1.2.7 Lens aperture

The “f number” parameter or aperture is a quantification how much light is able to pass a given optic in a pre-set time interval, the smaller the “f number” the more light that lens let go through.

The lens aperture has a direct effect on how much time a camera will have to leave the shutter open to gather enough photons to excite each CMOS sensor photocell to complete the picture.

For photogrammetric applications it is important to use lenses with a small “f number” because the camera is moving with the drone at a considerable forward speed and if the shutter is open for too long the pixels will suffer motion blur also known as ground smear.

Good photogrammetric practices dictate that ground smear must be kept below the GSD so that it does not negatively affect the final quality and accuracy of the orthomosaic typically this is achieved by reducing the forward speed of the drone.

This is especially important in rolling shutter cameras, like the ones in DJI drones, where each pixel line is sequentially scanned by the imaging sensor as opposed to higher end cameras using global shutter where all the pixels of the sensor are measured at once.

The combination of sensor/drone forward movement and sequential scan of the pixels can severely affect the image integrity causing relevant geometric deformations that must be dealt with in the processing software increasing the computational time.

Because the battery life of a drone is typically a limiting factor of the terrain extension that can be covered by a drone, reducing the speed is not a desirable solution because it means that the same battery will cover less terrain so every effort should be made to use the largest lens aperture possible.

To further complicate the problem in photogrammetry it may be desirable to fly in an overcast day to eliminate the hard shadows casted by the objects directly illuminated by the Sun because this may improve the quality of the model derived from the pictures as shadowy areas are typically noisier than well-lit areas of the image.

1.2.8 Drone selection conclusions

The DMPP has been selected as STAMP master mainly because it provides the best flight times of the three candidates being the only downside the slightly higher cost.

The DMP has been selected as STAMP slave mainly because of the lower cost compared to the DMPP additionally the shorter flight time should not hinder the ability of those drones to reach its designated positions within the photogrammetric survey area while still keeping a minimum size.

1.3. Rokubun STAMP

Rokubun will have to modify different parts of the currently existing drone systems, those are.

1.3.1 Drone enhancement

The DJI DMP and DMPP are equipped with a GNSS receiver able to track GPS and GLONASS constellations in single point positioning. This means that the GNSS receiver within the drone is able to track the satellites in view but there is no way to provide corrections to compensate for ionospheric delays, tropospheric wet and dry delays, inaccurate ephemeris or inaccurate satellite clocks.

The position provided by the GNSS receiver is expected to be within a bi-dimensional circle with a radius of ±2.5 m 50% of the time assuming that the receiver is stationary[1]. This kind of accuracy is good enough for drone

[1] Assumes no correction source at all, if Satellite Based Augmentation System is enabled, which currently is unclear, then that figure would decrease to ±2 metres 50% of the time assuming a stationary receiver but it would still be insuficient to meet most photogrammetric constraints.

navigation but it is not good enough to determine the position of the drone for photogrammetric uses where accuracies better than ±10 centimetres may be expected depending on the application.

Because of this, Rokubun will equip each STAMP drone with a derivative of the compact and light Argonaut GNSS receiver based on the u-blox NEO-M8T GNSS chipset.

The M8T chipset is actually very similar to the receiver on board of the DMP/DMPP drones but with a slight difference, instead of just provide the precomputed position based on the signals observed from the different satellites it also provides the raw data in which the position calculation is based on.

The Argonaut was designed to store the GNSS raw data in a microSD card with the objective to transfer that raw data in to a post-processing software to further enhance the positional accuracy and eventually meet the photogrammetric stringent requirements assuming that the raw GNSS data was captured under benign conditions.

The way that Rokubun proposes to post-process the raw GNSS observables is by using the web frontend “Positioning-as-a-Service” or PaaS for short. Behind the PaaS web frontend there is a server running a GNSS post-processing engine that tries to provide an as accurate position as possible with very little user intervention and returning results within minutes.

1.3.2 GNSS software enhancement

In the past, it used to be necessary to acquire a post processing software that typically costed around 6000 €. The software required the end user to be trained to properly configure the parameters and then it forced the end user to manually select, find and download the raw data files from a GNSS reference station that had to exactly match (or exceed) the time range of the GNSS rover.

Rokubun proposes a “pay per use” approach where the PaaS users would only pay for each post processing performed avoiding to pay large quantities upfront without knowing if there would be a return of investment that justifies the expense which is a critical consideration for small companies.

The PaaS has been built to automate all the tedious work related to finding the GNSS base stations saving precious operator time and avoiding possible mistakes.

The PaaS is able to perform its task automatically so there is no need to train the operator because all what is required is to upload the GNSS rover raw data files to Rokubun’s server.

1.3.3 Tablet software

One of the pillars of the STAMP system would be a tablet app based on the flexible DJI API that would:

1. Provide a point and click interface similar to Goggle Earth that would allow to plan the photogrammetric flight in an easy and intuitive way but providing enough technical details for advanced users and with the ability to cache maps to be used at a later moment in the field without internet.
2. Enable the user to select the lateral and the longitudinal overlap as well as the mission altitude so that the parallel flight lines typical of photogrammetric flights are automatically created.
3. Provide the possibility to use NASA's Shuttle Radar Topography Mission (SRTM) Digital Surface Model (DSM) [3] to allow terrain flight following for the DMPP.
4. Display a step by step check list for every step involved in the deployment of STAMP.
5. Control the status of the drone battery health parameters to ensure that there is enough battery to fulfil the mission and return to the landing point.
6. Send each DMP slave towards its targeted objective in a sequential fashion (one after the other, never simultaneously) with a preprogramed return flight profile so that if the slaves lose connection they could automatically return to the launch point autonomously.
7. Upload and execute the photogrammetric flight to the DMPP master.
8. Continuously display telemetry information for the drone in the air.
9. Provide the ability to the operator to immediately stop the procedures at any point, freezing the drone in the air and allowing the operator to provide manual controller inputs.
10. Record every command, input, log or event generated by the drone for legal purposes as well as for further analysis.

The design of this application has not been yet outlined and is outside the scope of this thesis.

1.4. Legal framework implications

There are very few legal limitations regarding drone sales, therefore STAMP itself would not be legally bound by any other regulations other than the ones that regulate the sale of commercial products. The lack of laws affecting the sale of drones does not mean that there are no rules to fly them, quite the opposite.

The regulation affecting STAMP operation, being a drone system exclusively targeted at the professional sector, is actually quite complex because there is no homogenized legal framework regarding drones, each country has its own variation.

Within the European countries the general trend is to conform each national regulation to the European Aviation Safety Agency (EASA) recommendations, but in the end every state member has its own law.

In the Spanish case, the Spanish Aviation Safety Agency (AESA) is the state agency defining the drone regulation framework within the country. The latest regulation iteration is written in the Royal Decree of the 29th December 2017. The law requires each commercial pilot to:

1. Be over 18 years old
2. Have a pilot license (may be specific for RPAS or a Private Pilot License).
3. Have a medical certificate of suitability.
4. Be insured by a government authorized insurer.

Each drone dedicated to commercial operations must have:

1. A license plate.
2. A certificate of characteristics.
3. A maintenance log.
4. An approved operation manual.

Each commercial operation must have an individually approved security study.

The basic legal limitation factors for drone operation are:

1. Day light operation only.
2. Maximum altitude 120 metres Above Ground Level (AGL).
3. Maximum distance from the pilot is 500 metres.
4. It is mandatory to operate within line of sight.
5. It is forbidden to fly over inhabited areas (villages, towns, cities…).
6. It is forbidden to fly over people with the exception of those related to the drone operation.
7. The UAV pilot must be in control of the drone at all times.
8. The drone must fly farther than 8 km from airports.
9. Sensitive facilities like military bases, nuclear power plants, jails, stadiums … should not be overflown

Most of these limitations can be softened or completely lifted if specific permissions are obtained from the competent authorities.

The legal procedure to obtain exemptions is slow and cumbersome that most companies do not even consider such possibility, this implies that the vast majority of today's commercial drone operations are executed under the previously mentioned legal constraints.

The only legal limitation that affects STAMP from technical perspective is the height limitation. The practical effect of that limitation has already been discussed in the drone selection title.

Most countries legally require the drone pilot to be in control of the UAV at all times. The objective of such rule is to ensure that an autonomous preprogramed flight using waypoints is not an excuse for the pilot to not to be able to immediately recover the drone control in case of an abnormal behaviour or if there is an air space intrusion by another aircraft.

Because one pilot should only control a single drone at any given time this means that swarms of drones are illegal because there is no way for a single pilot to effectively control all the flying drones simultaneously.

This implies that STAMP users will have to send slave drones one by one and wait until each drone lands before sending the next one so the master drone would only be able to take off after all slave drones have ben landed and vice versa.

The "one drone in the air at any given time" is not really a setback for STAMP because the inaccuracies inherent to the GNSS systems when operating without corrections make impossible to launch drones simultaneously without separating them 12 metres or more.

$$M8T_{accuracy} = \pm 2.5m\ CEP(50\%) \rightarrow 2DRMS(95\%) = CEP \times 2.4 = \pm 6m$$ [2]

Equation 3 GNSS Single Point Positioning (uncorrected) expected accuracy figures.

In addition to the separation between drones at the moment of take off the mobile application controlling the drone trajectories would have to intelligently adapt the path of each drone so that there are no crossings between slave drones routes.

An alternative solution to avoid mid-air collisions between drones would be to force each slave to fly at a different flight level separated 10 meters from each other to avoid mid-air collisions.

This last approach however is inconvenient because assuming that all the slave drones take off at the same moment the drone flying the highest would have to fly 120m AGL but the bottom drone would have to fly at 20 m AGL which is dangerously close to the trees or buildings.

[2] CEP stands for Circular Error Probability. 2DRMS stands for Horizontal Root Mean Square 2σ

1.5. Technical analysis conclusions

As previously discussed, we can conclude that, from drone technology standpoint the hardware available on the market today fulfils the STAMP needs, since DMP and DMPP are suitable candidates for STAMP from specification sheet point of view.

However, in the process of reviewing the market hardware platform availability a few DMP / DMPP weaknesses were unveiled, most of them linked to the DJI API and DJI firmware flexibility. Those limiting factors are discussed in greater detail along the COMMERCIAL STUDY chapter.

On the other hand, the modifications that Rokubun is expected to perform to the DMP / DMPP are limited to the addition of a COTS GNSS receiver manufactured by Rokubun, which is easy to implement.

The PaaS is already functional, however, the engine will gradually evolve towards a more refined post processing engine able to combine data from a GNSS receiver and from an IMU.

The tablet app project has not yet been started and its development targets listed in the present document are just a preliminary draft. The app concept will be further developed in a likely future document.

The legal framework does impose limitations to the drone operators but those limits do not hinder the usability of STAMP drones except for operation in urban areas, as you know, where special permissions would be required to overfly inhabited buildings.

2. FIELD TESTING

To ensure the practical viability of STAMP the following two chapters will verse about the preparation and end results of the two field tests that were carried out to determine if STAMP, as conceived in the technical analysis section, performs as expected:

- Field testing 1 - Master drone camera resolution study
- Field testing 2 - STAMP extensive field test

This field tests were necessary to reduce as much as possible the risk that arises from the untested hypothesis presented in the technical analysis section.

If the two field tests are successful it would mean that the DMP/DMPP camera is suitable for the project and also that the STAMP general concept can be deployed in the field with a reasonable success chance.

Even if the two tests presented in this section are successful, further analysis and field work would be required by Rokubun to ensure that the tablet software fulfils the customer expectations. The main reason is because the tablet app coding process has not yet been started, so obviously there is no way to perform testing on that part of the system.

2.1 Master drone camera resolution study

To ensure that the STAMP field test (see chapter 2.2) is successful a preliminary test must be performed to ensure that at least the DMP slaves are visible in the master imagery.

2.1.1 Problem presentation

The requirements to perform a STAMP field test are:

1. A test field far from buildings, urban areas, and inhabited areas in general that provides easy vehicle access and with no other drones flying around.
2. A network of highly visible and accurately measured Ground Control Points scattered through the survey zone to provide a trusted geometric network to compare the STAMP photogrammetric result against.
3. Ten DMP slave drones or if it is not possible to acquire such large amount of equipment ten silhouettes that simulate the presence of such drones on the ground.
4. Ten Rokubun SPA or Argonaut + battery GNSS receivers to accurately record the GNSS raw data as seen by each drone.
5. DMP or DMPP drone to perform the photogrammetric flight (unlike the slaves this drone must be real and it must also be of the category selected to obtain relevant results).
6. Flight planning app with photogrammetric planning capabilities on a tablet to control the flight of the DMP/DMPP as well as control the camera shutter releases and monitor telemetry.
7. A suitable GNSS fixed base station positioned over a point of well-known coordinates. It can either be provided by Rokubun or use one of the stations part of Institut Cartogràfic i Geològic de Catalunya (ICGC) CatNet network.
8. Software used by Rokubun to post process GNSS raw data.
9. Properly licensed photogrammetric software, preferably Agisoft PhotoScan.
10. Workstation running Windows to perform the GNSS calculations as well as the very CPU / GPU / memory intensive photogrammetric calculations.
11. A person who can help to spread GCPs and slave test subjects (assuming they are not real drones).
12. A full working day (around 8 hours) to perform all the field operations.
13. A full working day (about 8 hours) to perform the GNSS post-processing. Note that due to the special field conditions not currently contemplated in

Rokubun PaaS the web UI will not be used, instead a local running GUI will be used to tweak parameters.

14. About 24 to 48 hours to perform the photogrammetric processing of the many hundreds of images captured on the field.

As can be seen the logistics of a STAMP field test are considerable because of this it must be ensured that such an endeavour does have a reasonable chance of success.

The only factor that may cause a complete failure of the STAMP field test is the inability of the master camera to resolve the slave drones landed on the ground.

If the slave drones are not identifiable on the master imagery then there is no way to use the slave drones in the photogrammetric processing which in turn means that they would not be serving the purpose they were designed for, work as a GCP.

2.1.2 Preliminary Field Tests

The following field test was performed deserted fields eastwards of Barcelona's Velodrome, this test area provided a secure inhabited testing without having to worry about pedestrians or vehicles and at the same time it was easy to reach.

The drone used to take the aerial pictures was a DMP and the test subjects on the ground were paper silhouettes of a DMP painted in three different colours, white, black and pink.

The DMP was flown in a strictly vertical path just over the three paper silhouettes. Every 5 metres a DNG (raw) picture was taken until the master DMP reached 120 m AGL (maximum legal altitude).

The objective of this test was to determine at what height the slave drones where no longer perceptible in the master pictures.

The resulting Figures 5 and 6 will follow showing the two most extreme pictures taken during the test flight:

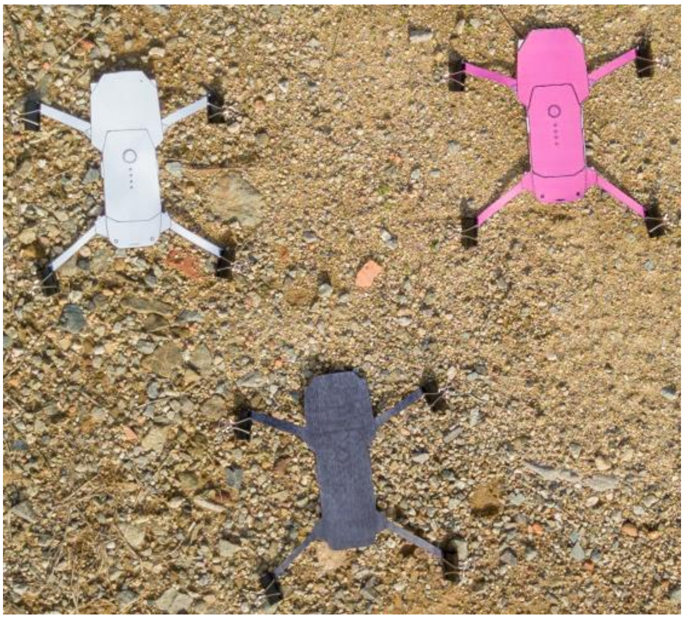

Figure 5 Crop of the control picture taken at 1.6 metres AGL

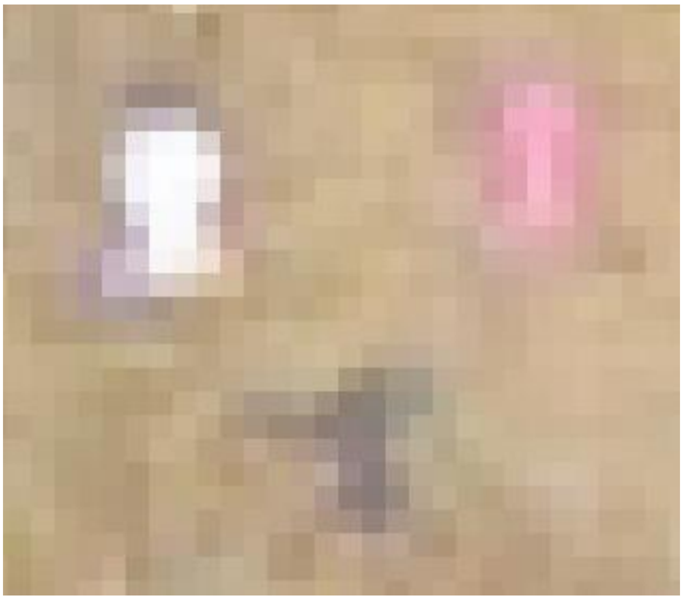

Figure 6 Crop of the picture taken at 120 metres AGL

As desired and expected the master DMP provided enough resolution to detect the slaves all along the vertical path until reaching 120m AGL.

The result of this test also suggests that it would not be feasible to fly much higher than 120 m AGL so for STAMP the current legal limitations are not a burden

The registration of the pink and black silhouettes is not as clear as it would be desirable but the white silhouette seems to achieve a good contrast with the sand in the background.

As white colour is the most reflective colour in the three basic image bands, red, green and blue it has been selected to perform the next STAMP test which is expected to take place against a green (grass) background.

2.2 STAMP extensive field test

This test objective is to simulate a STAMP system field deployment in a real scenario but unlike in a real world scenario it is also necessary to have means to truth test against an independent network of GCPs.

2.2.1 Location

The location chosen to field test STAMP had to have an area within a 500 meters radius, which is the legal limit, densely populated with pre-surveyed GCPs.

To the best of Rokubun's personnel knowledge there is only one facility that meets that requirement and that is Barcelona Drone Center (CATUAV) at Collsuspina, Moianes. Access to the facility was requested to CATUAV owners and they provided clearance to perform the test at the best of our convenience.

2.2.2 Status of CATUAV GCP network

The network of 44 GCPs available at CATUAV was surveyed by Setat Serveis Topogràfics in June 2016. Setat GCPs were distributed to provide support to a very specific project that was meant to operate along the main access path to the facility hence their distribution is mostly unbalanced.

Only the area near CATUAV underground facility has GCPs more evenly distributed. This quickly narrowed down the STAMP test area to the surrounding fields around CATUAV facilities as can be seen in Figure 7.

Figure 7 Aerial overview of CATUAV GCPs surveyed by Setat and selected flight zone.

So in summary Setat GCPs D01 to D20 and D43 to D44 were selected but their distribution was not fully satisfactory so further conversations with CATUAV were initiated with the objective to reinforce Setat GCP network.

Not long after it was discovered that CATUAV deployed long time ago another network of GCPs based on 50x50 cm square metallic plates over a bed of mortar.

Those GCPs were abandoned because their structural integrity was unclear and the lack of adhesion of the black paint used so only the markings on the ground were done but no survey was ever performed.

CATUAV old GCP network was mostly located in the empty space between Setat GCPs D06, D11, D43 and D44 which was very convenient because the terrain there is more abrupt.

2.2.3 Survey of CATUAV old GCP network

On May 3rd 2018 a GPS and GLONASS dual frequency Septentrio AsteRX-U GNSS receiver paired with a PolaNt-x MF antenna was used to survey CATUAV's old network of GCP.

Eleven GCPs were found, the vast majority in good structural condition but with the black paint gone so all of them were repainted and surveyed by observing each point with the GNSS antenna on a 2 m carbon fibre pole for approximately three minutes each at a sampling rate of 1 Hz (once a second)

The observation time and method is not compliant with best land surveying practices that recommend 15 minute observation periods or more with a sampling rate of one observation every 15 seconds with the antenna on a levelling base with optical plumb mounted on a stable tripod.

Best practices were not used because the available time was a limiting factor that was worsened by a difficult mountainous terrain that made difficult to move heavy equipment through the survey area.

Besides the terrain difficulty the GCPs were repainted without using a template to achieve well defined black and white line boundaries. The lack of accurately pre-cut template made the location of the centre of the GCP a bit uncertain.

Furthermore with best surveying practices accuracies of ±1cm 1σ (68% of the time) would be achievable in post processing but the expected average GCP of the DMP camera was 4 cm so an horizontal error below the expected GCP was acceptable.

The survey process of the 11 GCPs approximately took 5 hours of field time.

The Receiver Independent Exchange (RINEX) version 2.11containing GPS and GLONASS dual frequency raw observables files of the GNSS reference station Sant Bartomeu del Grau (SBAR) from the ICGC CatNet network were downloaded.

The settings used to post-process the 11 GCPs were exactly the same for all of them and were as follows:

- Constellations: GPS and GLONASS
- Frequencies: L1+L2
- Epoch sampling: 1Hz
- Positioning mode: kinematic
- Solution: forward + reverse (combined)
- Elevation mask: 15 degrees
- SNR mask: 38 dB-Hz
- Dynamics estimation: on
- Tide corrections: disabled
- Ionospheric model: as broadcasted
- Troposphere model: Saastamoinen
- Ephemeris: as broadcasted
- GPS ambiguity resolution: fix and hold
- GLONASS ambiguity resolution: disabled
- Ambiguity resolution threshold value: 3
- SBAR reference position: 41º58’48.38852’’ 2º10’27.45507’’ 938.003 m
- Datum transformation: none
- Geoid: none
- Antenna phase centre variation files: none

The standard deviations (variances) provided by the post processing software were in all cases optimistic for a GNSS observation, well below the centimetre in each axis.

Even if those variances are mathematically correct the observation periods are very short meaning that there is very little GNSS satellite geometry change. This means that because the GNSS errors are temporally correlated it is advisable to discard the variances and use a more pessimistic estimation based on ICGC standards.

ICGC uses a standardized fixed standard deviation in all their datashets based on statistical experience not on the mathematical calculus of the coordinates of each marking, this is applied in all their geodesic markings datasheets. An example can be seen in Figure 8.

ICGC Institut Cartogràfic i Geològic de Catalunya

FITXA DE SENYAL GEODÈSIC

Informació general

Codi ICC:	289105015
Província:	Barcelona
Comarca:	Moianès
Municipi:	Collsuspina
Full MTN50 (SQ/CCFF):	0364 / 37-14
Full MTN5 (CCFF):	289-105
Data de construcció:	18/02/2016
Data d'última revisió:	29/09/2016
Xarxa:	XU

Descripció:

Clau d'acer inoxidable amb la cabota formada per un tronc de piràmide de 4 centímetres de diàmetre superior i 3 centímetres de diàmetre inferior, situat sobre la vorera.

Coordenades

Sistema de referència:	ETRS89/00	
Projecció:	UTM Fus 31	Hemisferi N
X Projectada (X):	431591.763 m	σ: 0.030 m
Y Projectada (Y):	4630881.699 m	σ: 0.030 m
Factor d'escala (K):	0.99965758	
Convergència quadrícula (ω):	0º -32' 57.78270"	
Longitud (λ):	2º 10' 34.39845" E	σ: 0.00130 "
Latitud (φ):	41º 49' 36.72036" N	σ: 0.00097 "
Cota ortomètrica (H):	898.199 m	σ: 0.070 m
Model de geoide:	EGM08D595	N: 50.337 m
Cota el·lipsoïdal (h):	948.536 m	σ: 0.050 m
Referència de les cotes:	CSG	
Altura del pilar geodèsic:	N/A	
Té coordenades en ED50 (icc20060):	No	

Fotografia

Versió de la fitxa: 20170.171122

Figure 8 ICGC datasheet for the closest geodesic mark to CATUAV facilities.

To follow the IGCG example a 3D standard deviation 1σ of 5 cm was assumed for all the geodesic coordinates (latitude [λ], longitude [Φ] and height [h]) of the GCPs that were to be used in the STAMP trial.

The conjunction of Setat's GCPs with the old CATUAV GCP's does create a well-balanced dense network of 33 GCPs more or less evenly distributed on the terrain that can be used to test the STAMP accuracy against.

A summary of the coordinates of the centre of each GCP used for the STAMP test is shown in Table 4.

- In grey colour the coordinates of SBAR ICGC base station and the forced centring pillar right over CATUAV underground building roof.
- In blue colour the coordinates of the 11 GCPs surveyed with the Septentrio AsteRX receiver.
- In green colour the coordinates of the 22 GCPs surveyed by Setat for CATUAV.

Greyed fields correspond to information that is not typically used in photogrammetric work.

Point ID	ECEF Marker			Latitude				Longitude				UTM		Meridian Convergence				scale	Elipsoidal Height	Geoid	EGM08D595
	X (m)	Y (m)	Z (m)	Degrees	Minutes	Seconds	Degrees	Degrees	Minutes	Seconds	Degrees	X (m)	Y (m)	Degrees	Minutes	Seconds	Degrees	factor (k)	Marker	Undulation	Marker
SBAR	4745755.10	180181.14	4244588.95	41	58	48.3885	41.9801079	2	10	27.4551	2.1742931	431595.37	4647897.33	0	33	8.33	-0.55231	0.99965758	937.89	50.485	887.41
CATUAV	4758451.99	179719.46	4230446.95	41	48	33.0558	41.8091822	2	9	46.6057	2.1629460	430470.18	4628928.89	0	33	28.97	-0.55805	0.99965949	925.85	50.317	875.53
astrx_026	4758509.66	179630.48	4230350.85	41	48	29.5619	41.8082116	2	9	42.6599	2.1618500	430378.09	4628822.03	0	33	31.56	-0.55877	0.99965965	902.23	50.316	851.92
astrx_027	4758389.34	179653.59	4230483.90	41	48	35.3543	41.8098206	2	9	43.8567	2.1621824	430407.44	4629000.40	0	33	30.82	-0.55856	0.99965960	901.96	50.318	851.65
astrx_028	4758431.23	179529.01	4230403.26	41	48	32.6037	41.8090566	2	9	38.3955	2.1606654	430280.60	4628916.80	0	33	34.43	-0.55957	0.99965981	875.90	50.316	825.58
astrx_029	4758366.64	179531.23	4230461.93	41	48	35.4136	41.8098371	2	9	38.5972	2.1607214	430286.10	4629003.41	0	33	34.33	-0.55954	0.99965980	866.97	50.318	816.65
astrx_030	4758509.85	179684.03	4230370.89	41	48	29.9983	41.8083329	2	9	44.9775	2.1624938	430431.69	4628834.96	0	33	30.02	-0.55834	0.99965955	917.24	50.316	866.93
astrx_031	4758310.98	179752.40	4230568.84	41	48	39.0175	41.8108382	2	9	48.2621	2.1634061	430510.19	4629112.38	0	33	27.93	-0.55776	0.99965942	903.00	50.320	852.68
astrx_032	4758283.18	179868.99	4230624.09	41	48	40.8570	41.8113492	2	9	53.3542	2.1648206	430628.23	4629167.97	0	33	24.55	-0.55682	0.99965922	922.42	50.321	872.10
astrx_033	4758239.21	179851.09	4230648.83	41	48	42.4186	41.8117829	2	9	52.6513	2.1646254	430612.48	4629216.29	0	33	25.04	-0.55695	0.99965924	905.66	50.322	855.33
astrx_034	4758199.24	179749.74	4230656.22	41	48	43.5429	41.8120953	2	9	48.3296	2.1634249	430513.11	4629251.94	0	33	27.93	-0.55776	0.99965941	877.96	50.321	827.64
astrx_035	4758242.72	179692.01	4230603.33	41	48	41.3736	41.8114927	2	9	45.7595	2.1627110	430453.15	4629185.61	0	33	29.62	-0.55823	0.99965952	873.46	50.321	823.14
astrx_037	4758298.34	179663.04	4230539.94	41	48	38.6651	41.8107403	2	9	44.4144	2.1623373	430421.31	4629102.38	0	33	30.49	-0.55847	0.99965957	871.81	50.320	821.49
D01	4758417.54	179728.85	4230477.31	41	48	34.5250	41.8095903	2	9	47.0682	2.1630745	430481.29	4628974.10	0	33	28.67	-0.55796	0.99965947	920.70	50.318	870.38
D02	4758450.10	179714.47	4230447.62	41	48	33.1169	41.8091991	2	9	46.3927	2.1628869	430465.28	4628930.83	0	33	29.11	-0.55809	0.99965950	924.75	50.317	874.43
D03	4758462.47	179744.12	4230432.64	41	48	32.4635	41.8090176	2	9	47.6558	2.1632377	430494.23	4628910.39	0	33	28.26	-0.55785	0.99965945	924.81	50.317	874.49
D04	4758454.76	179730.51	4230442.82	41	48	32.8871	41.8091353	2	9	47.0793	2.1630776	430481.06	4628923.58	0	33	28.65	-0.55796	0.99965947	925.47	50.317	875.15
D05	4758459.04	179710.07	4230430.49	41	48	32.5136	41.8090316	2	9	46.1874	2.1628298	430460.37	4628912.27	0	33	29.24	-0.55812	0.99965951	919.87	50.317	869.55
D06	4758511.06	179689.23	4230370.91	41	48	29.9684	41.8083245	2	9	45.2005	2.1625557	430436.83	4628833.99	0	33	29.87	-0.55830	0.99965955	918.31	50.316	867.99
D07	4758518.42	179785.79	4230370.31	41	48	29.7162	41.8082545	2	9	49.3678	2.1637133	430532.91	4628825.28	0	33	27.09	-0.55752	0.99965938	926.10	50.316	875.79
D08	4758528.63	179828.99	4230357.60	41	48	29.1534	41.8080982	2	9	51.2213	2.1642281	430575.51	4628807.50	0	33	25.85	-0.55718	0.99965931	926.46	50.316	876.14
D09	4758507.37	179855.69	4230368.17	41	48	29.8458	41.8082905	2	9	52.4118	2.1645588	430603.19	4628828.59	0	33	25.06	-0.55696	0.99965926	918.42	50.316	868.10
D10	4758402.08	179869.70	4230498.52	41	48	35.2561	41.8097934	2	9	53.1903	2.1647751	430622.77	4628995.27	0	33	24.60	-0.55683	0.99965923	927.28	50.319	876.96
D11	4758318.65	179906.92	4230595.02	41	48	39.3581	41.8109328	2	9	54.9382	2.1652606	430664.33	4629121.39	0	33	23.48	-0.55652	0.99965916	930.53	50.320	880.21
D12	4758329.37	179919.62	4230579.15	41	48	38.7329	41.8107591	2	9	55.4702	2.1654084	430676.42	4629101.99	0	33	23.12	-0.55642	0.99965914	928.29	50.320	877.97
D13	4758294.48	180024.09	4230626.74	41	48	40.5504	41.8112640	2	10	0.0495	2.1666804	430782.62	4629157.02	0	33	20.08	-0.55558	0.99965895	936.97	50.321	886.65
D14	4758326.85	180016.74	4230583.88	41	48	38.8224	41.8107840	2	9	59.6780	2.1665772	430773.53	4629103.81	0	33	20.31	-0.55564	0.99965897	932.30	50.321	881.98
D15	4758267.10	180073.96	4230654.54	41	48	41.7722	41.8116034	2	10	2.2528	2.1672924	430833.82	4629194.21	0	33	18.63	-0.55517	0.99965887	936.51	50.322	886.19
D16	4758268.24	180087.91	4230648.57	41	48	41.5922	41.8115534	2	10	2.8551	2.1674598	430847.67	4629188.52	0	33	18.22	-0.55506	0.99965884	933.78	50.322	883.46
D17	4758140.07	180106.86	4230780.91	41	48	47.5406	41.8132057	2	10	3.8855	2.1677460	430873.22	4629371.74	0	33	17.60	-0.55489	0.99965880	927.08	50.324	876.76
D18	4758143.15	180157.24	4230782.33	41	48	47.4669	41.8131852	2	10	6.0608	2.1683502	430923.38	4629368.98	0	33	16.15	-0.55449	0.99965872	931.74	50.324	881.42
D19	4758144.60	180174.08	4230780.98	41	48	47.3893	41.8131637	2	10	6.7877	2.1685521	430940.13	4629366.43	0	33	15.66	-0.55435	0.99965869	932.40	50.324	882.07
D20	4758158.90	180200.57	4230760.62	41	48	46.5671	41.8129353	2	10	7.9110	2.1688642	430965.80	4629340.82	0	33	14.91	-0.55414	0.99965864	930.22	50.323	879.90
D43	4758433.57	179505.04	4230388.51	41	48	32.2164	41.8089490	2	9	37.3544	2.1603762	430256.47	4628905.09	0	33	35.12	-0.55976	0.99965985	867.15	50.316	816.83
D44	4758252.53	179692.08	4230591.99	41	48	40.8877	41.8113577	2	9	45.7465	2.1627074	430452.71	4629170.63	0	33	29.62	-0.55823	0.99965952	873.21	50.320	822.89

Table 4 summary of GCP coordinates.

2.2.4 Final survey area bounds

The area to be covered with STAMP was readjusted to fit the GCP network as depicted in Figure 9.

Figure 9 GCPs and aerial survey area

The 500 metres radius is depicted in red colour, within the circle you can see the area to be covered by the aerial pictures which is bounded by the green line so finally the planed flight looked as shown in Figure 10.

Figure 10 DMP flight path in white colour. Note that not all GCPs are visible in the image.

2.2.5 STAMP slave deployment rationale

The very minimum of slave DMPs that can be used to georeference an orthophoto is 5, assuming a good / even distribution over the working area, and the maximum number is typically considered as 10. More than 10 GCPs is considered an overkill.

To ensure that the metric results obtained with the DMPs were not affected by the errors inherent to the photogrammetric processes it was decided that all the DMPs must be positioned near existing GCPs.

To avoid extrapolation errors the DMPs silhouettes located in the exterior ring of the GCP network were always positioned towards the internal side of the ring.

2.2.6 STAMP slave availability

Due to budgetary constraints it was decided that it was not possible to purchase 10 DMP to operate as STAMP slaves so an alternative was to be found.

In the visibility tests paper silhouettes were used but there was always a person to watch the test subjects so wind or humidity was not a real problem but in the field test at CATUAV elements could have been less forgiving.

The best solution was to draw the DMP silhouette in a 2D CAD (as seen in Figure 11) and then order to a third party company to cut a 2 mm thick stainless steel plate using laser to create the 10 DMP test subjects.

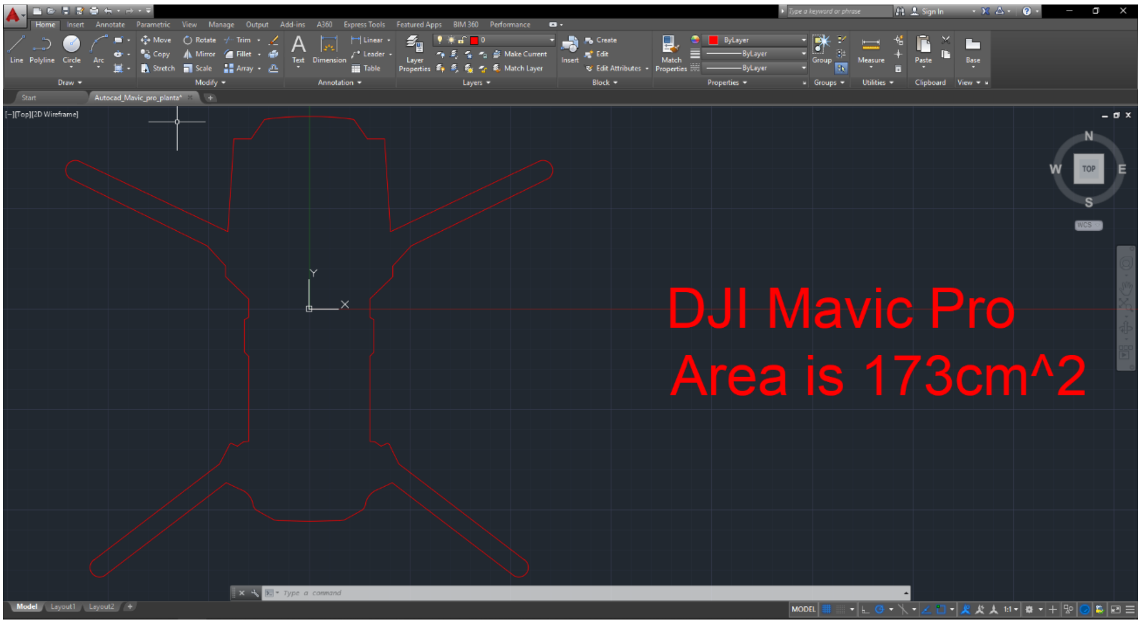

Figure 11 2D CAD drawing of the DMP.

The end result was 10 consistent and solid metallic plates that were not susceptible to wind, humidity or other external factors.

2.2.7 STAMP field survey

After a failed attempt on May 10th 2018 due to rainy weather conditions a successful attempt was performed on May 17th 2018.

The first step was to deploy the 33 pre-existing GCPs in addition to the 10 metallic silhouettes simulating the DMP accompanied by the 10 Rokubun Argonaut GNSS receivers plus the corresponding batteries.

The DMPs were distributed as follows:

GCP ID	Serial Number	Power on	Power Off
Astrx30	261017-1-0006	8:45:35	12:11:35
Astrx32	261017-1-0056	9:01:05	12:17:10
Astrx34	261017-1-0021	7:36:35	14:23:00
D01	261017-1-0208	7:55:40	23:59:59
D09	261017-1-0201	8:53:05	12:13:05
D14	261017-1-0121	9:13:10	17:13:00
D15	261017-1-0055	9:23:05	12:19:40
D17	261017-1-0051	9:48:30	13:44:55
D20	261017-1-0048	9:40:10	13:40:30
D43	261017-1-0013	7:21:05	14:31:25

Table 5 GCP and Argonaut serial number, power on and power off UTC times.

In the example picture below can be seen the relative size of a 50x50 cm GCP set on the ground and centred over the D15 surveyed point besides a DMP silhouette equipped with an Argonaut receiver on top of the metallic plate. The Mazda 2 car (small) may serve as a reference to gauge the proportions of the elements in the image.

Figure 12 D15 GCP, DMP stainless steel silhouette and car.

After all the GCPs and DMPs were deployed the DMP that was going to be used to perform the photogrammetric flight was prepared at CATUV facilities and was launched from the roof of the building.

In 23 minutes and 26 seconds the drone captured 518 aerial pictures in Adobe digital negative format also known as DNG based on tiff version 6 open standard. On average the image size was 23.2 Megabytes for a total of 11.7 Gigabytes.

2.2.8 Argonauts GNSS post processing

The settings used to post-process the 10 Argonauts over the DMP silhouettes were:

- Constellations: GPS and GLONASS
- Frequencies: L1
- Epoch sampling: 1Hz
- Positioning mode: static
- Solution: forward + reverse (combined)
- Elevation mask: 10 degrees
- SNR mask: 35 dB-Hz
- Dynamics estimation: disabled
- Tide corrections: disabled
- Ionospheric model: as broadcasted
- Troposphere model: Saastamoinen
- Ephemeris: as broadcasted
- GPS ambiguity resolution: fix and hold
- GLONASS ambiguity resolution: disabled
- Ambiguity resolution threshold value: 3
- SBAR reference position: 41º58'48.38852'' 2º10'27.45507'' 938.003 m
- Datum transformation: none
- Geoid: none
- Antenna phase centre variation files: none

The resulting ETRS89 geodesic coordinates (latitude, longitude and ellipsoidal height) are:

GCP ID	Serial Number	Latitude	Longitude	Height
Astrx30	261017-1-0006	41.808317973	2.162578191	918.33
Astrx32	261017-1-0056	41.811337521	2.164821013	922.72
Astrx34	261017-1-0021	41.812091129	2.163437401	878.13
D01	261017-1-0208	41.809616481	2.163097989	920.72
D09	261017-1-0201	41.808290308	2.164522570	919.40
D14	261017-1-0121	41.810795306	2.166601352	932.69
D15	261017-1-0055	41.811607963	2.167262006	936.42
D17	261017-1-0051	41.813209189	2.167793222	927.24
D20	261017-1-0048	41.812929946	2.168843918	930.31
D43	261017-1-0013	41.808950181	2.160389115	867.31

Table 6 DMP coordinates to be used in the photogrammetric coordinates.

2.2.9 Photogrammetric processing

The software used to process the aerial pictures and merge the result with the coordinates of the GCPs is Agisoft PhotoScan Professional version 1.4.2. (APS)

This software package is known to be computer efficient because it uses multi core CPUs as well as Nvidia GPU CUDA acceleration. This kind of optimization is very relevant when facing the processing of 518 raw images in a single work station.

The software also provides a good combination of flexibility and automation which is very convenient to perform the different comparisons that are required to assess STAMP suitability.

It is worth noting that typically in a photogrammetric work the two desired final deliverables are the Orthomosaic and the Digital Surface Model (DSM) but in this thesis we will focus on the resulting accuracy of the nonlinear least-squares algorithm used in the bundle adjustment of the aerial triangulation which is the first step required in the photogrammetric workflow.

APS can perform calculations and provide products like textured 3D models or Digital Terrain Models (DTM) among others that will not be represented in this thesis.

Figure 13 workflow chart depicts the steps within APS used to compute the GCP coordinates and errors as well as to export the typical outputs expected from a photogrammetric project even though those are not essential to fulfil the objectives of this thesis.

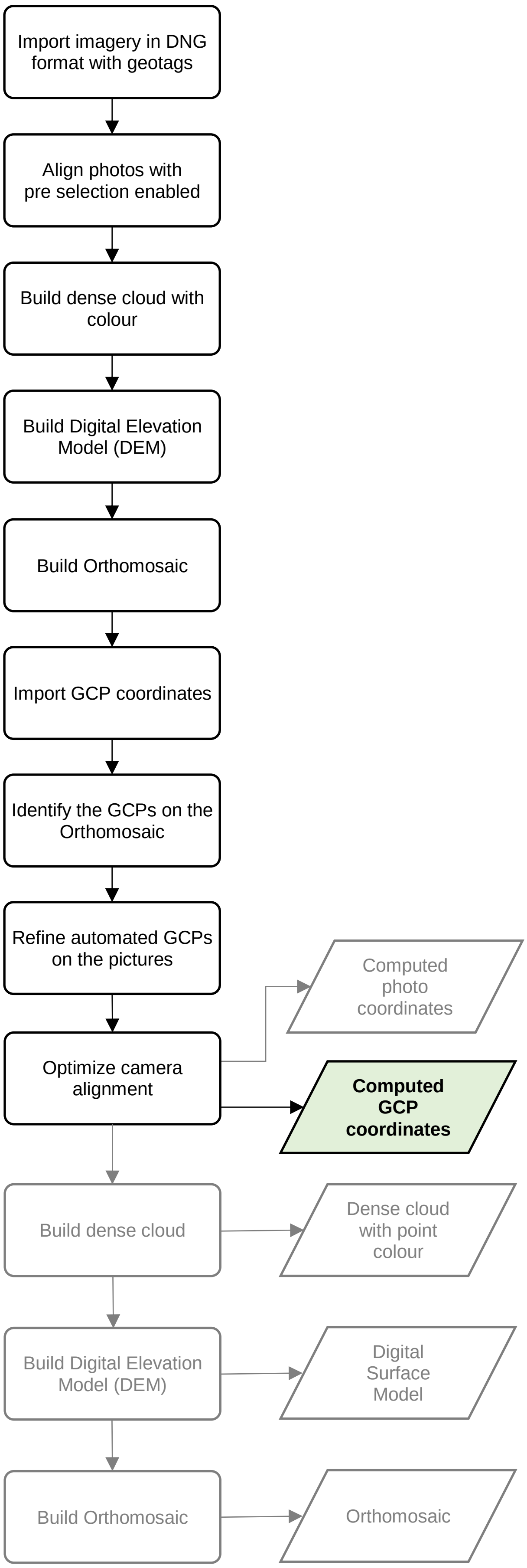

Figure 13 APS flowchart

Two different processings were performed within APS:

1. The aerial triangulation bundle adjustment is based on the GCPs from Setat survey and the Septentrio survey together to compute an optimized camera alignment. STAMP GCPs are adjusted as “check points” as an output of the aerial triangulation and only serve the purpose of evaluating the errors.
2. The aerial triangulation bundle adjustment is based on the 10 STAMP GCPs. Setat GCPs and the Septentrio GCPs are adjusted as “check points” as an output of the aerial triangulation and only serve the purpose of evaluating the errors.

2.2.9.1 Setat and Septentrio GCPs camera optimization

The outcome of this calculation allows us to see how diverges the different post-processed L1 only GNSS solutions from the photogrammetric solution based only on a heavily redundant network of GCPs measured with high end equipment.

The expectation is to easily identify any wrong GNSS carrier phase integer cycle fixings in the low cost L1 only solutions of the DMPs because the other GCPs will act as a truth.

	Initial coordinates					Computed coordinates					Errors (Initial-Computed)				
Point name	Enabled	Longitude	Latitude	Altitude	Accuracy	Longitude	Latitude	Altitude	Error	Images	Longitude	Latitude	Altitude	2D	3D
D01	1	2.1630745	41.8095903	920.70 m	0.05 m	2.1630747	41.8095907	920.71 m	0.5 pix	28	0.02 m	0.04 m	0.01 m	0.05 m	0.05 m
D02	1	2.1628869	41.8091991	924.75 m	0.05 m	2.1628872	41.8091998	924.83 m	0.5 pix	24	0.02 m	0.08 m	0.08 m	0.09 m	0.11 m
D03	1	2.1632377	41.8090176	924.81 m	0.05 m	2.1632381	41.8090180	924.85 m	0.7 pix	25	0.03 m	0.04 m	0.04 m	0.05 m	0.07 m
D04	1	2.1630776	41.8091353	925.47 m	0.05 m	2.1630777	41.8091358	925.43 m	0.6 pix	26	0.01 m	0.06 m	-0.04 m	0.06 m	0.07 m
D05	1	2.1628298	41.8090316	919.87 m	0.05 m	2.1628299	41.8090323	919.91 m	0.5 pix	26	0.01 m	0.07 m	0.04 m	0.07 m	0.08 m
D06	1	2.1625557	41.8083245	918.31 m	0.05 m	2.1625555	41.8083253	918.24 m	0.4 pix	24	-0.02 m	0.09 m	-0.07 m	0.09 m	0.11 m
D07	1	2.1637133	41.8082545	926.10 m	0.05 m	2.1637145	41.8082540	926.11 m	0.6 pix	30	0.10 m	-0.06 m	0.01 m	0.11 m	0.12 m
D08	1	2.1642281	41.8080982	926.46 m	0.05 m	2.1642294	41.8080972	926.46 m	0.5 pix	24	0.11 m	-0.11 m	0.00 m	0.16 m	0.16 m
D09	1	2.1645588	41.8082905	918.42 m	0.05 m	2.1645597	41.8082893	918.28 m	0.6 pix	23	0.07 m	-0.13 m	-0.14 m	0.15 m	0.21 m
D10	1	2.1647751	41.8097934	927.28 m	0.05 m	2.1647754	41.8097924	927.27 m	0.5 pix	30	0.02 m	-0.11 m	-0.01 m	0.11 m	0.11 m
D11	1	2.1652606	41.8109328	930.53 m	0.05 m	2.1652604	41.8109327	930.50 m	0.6 pix	20	-0.02 m	-0.01 m	-0.03 m	0.02 m	0.03 m
D13	1	2.1666804	41.8112640	936.97 m	0.05 m	2.1666813	41.8112636	936.95 m	0.6 pix	29	0.08 m	-0.04 m	-0.02 m	0.09 m	0.09 m
D14	1	2.1665772	41.8107840	932.30 m	0.05 m	2.1665787	41.8107832	932.27 m	0.4 pix	26	0.13 m	-0.09 m	-0.03 m	0.16 m	0.16 m
D15	1	2.1672924	41.8116034	936.51 m	0.05 m	2.1672931	41.8116027	936.48 m	0.4 pix	22	0.06 m	-0.07 m	-0.03 m	0.10 m	0.10 m
D16	1	2.1674598	41.8115534	933.78 m	0.05 m	2.1674607	41.8115526	933.78 m	0.8 pix	23	0.07 m	-0.09 m	0.00 m	0.11 m	0.11 m
D17	1	2.1677460	41.8132057	927.08 m	0.05 m	2.1677447	41.8132064	927.00 m	0.4 pix	27	-0.11 m	0.07 m	-0.08 m	0.13 m	0.15 m
D18	1	2.1683502	41.8131852	931.74 m	0.05 m	2.1683495	41.8131852	931.75 m	0.6 pix	21	-0.05 m	-0.01 m	0.01 m	0.06 m	0.06 m
D19	1	2.1685521	41.8131637	932.40 m	0.05 m	2.1685519	41.8131635	932.45 m	0.6 pix	25	-0.02 m	-0.02 m	0.05 m	0.02 m	0.05 m
D20	1	2.1688642	41.8129353	930.22 m	0.05 m	2.1688644	41.8129346	930.29 m	0.6 pix	21	0.01 m	-0.07 m	0.07 m	0.08 m	0.11 m
D43	1	2.1603762	41.8089490	867.15 m	0.05 m	2.1603760	41.8089493	867.04 m	0.4 pix	27	-0.01 m	0.03 m	-0.11 m	0.03 m	0.11 m
D44	1	2.1627074	41.8113577	873.21 m	0.05 m	2.1627067	41.8113574	873.02 m	0.6 pix	30	-0.06 m	-0.03 m	-0.19 m	0.06 m	0.20 m
Astrx26	1	2.1618500	41.8082116	902.23 m	0.05 m	2.1618492	41.8082124	902.34 m	0.4 pix	26	-0.07 m	0.08 m	0.11 m	0.11 m	0.16 m
Astrx27	1	2.1621824	41.8098206	901.96 m	0.05 m	2.1621820	41.8098210	901.98 m	0.3 pix	22	-0.03 m	0.05 m	0.02 m	0.06 m	0.06 m
Astrx28	1	2.1606654	41.8090566	875.90 m	0.05 m	2.1606657	41.8090568	875.95 m	0.5 pix	33	0.02 m	0.02 m	0.05 m	0.03 m	0.06 m
Astrx29	1	2.1607214	41.8098371	866.97 m	0.05 m	2.1607220	41.8098366	866.94 m	0.4 pix	24	0.05 m	-0.05 m	-0.03 m	0.07 m	0.08 m
Astrx30	1	2.1624938	41.8083329	917.24 m	0.05 m	2.1624940	41.8083337	917.32 m	0.4 pix	27	0.02 m	0.09 m	0.08 m	0.09 m	0.12 m
Astrx31	1	2.1634061	41.8108382	903.00 m	0.05 m	2.1634056	41.8108387	903.12 m	0.5 pix	28	-0.04 m	0.06 m	0.12 m	0.07 m	0.14 m
Astrx32	1	2.1648206	41.8113492	922.42 m	0.05 m	2.1648195	41.8113497	922.52 m	0.5 pix	29	-0.09 m	0.06 m	0.10 m	0.11 m	0.15 m
Astrx33	1	2.1646254	41.8117829	905.66 m	0.05 m	2.1646234	41.8117837	905.71 m	0.3 pix	31	-0.17 m	0.09 m	0.05 m	0.19 m	0.20 m
Astrx34	1	2.1634249	41.8120953	877.96 m	0.05 m	2.1634237	41.8120956	877.93 m	0.4 pix	28	-0.10 m	0.04 m	-0.03 m	0.11 m	0.11 m
Astrx35	1	2.1627110	41.8114927	873.46 m	0.05 m	2.1627108	41.8114922	873.45 m	0.5 pix	25	-0.02 m	-0.05 m	-0.01 m	0.06 m	0.06 m
Astrx37	1	2.1623373	41.8107403	871.81 m	0.05 m	2.1623368	41.8107401	871.76 m	0.5 pix	25	-0.04 m	-0.02 m	-0.05 m	0.04 m	0.06 m
D17_261017-1-0051	0	2.1677932	41.8132092	927.24 m	0.05 m	2.1677914	41.8132092	927.36 m	0.5 pix	26	-0.15 m	0.00 m	0.12 m	0.15 m	0.19 m
D20_261017-1-0048	0	2.1688440	41.8129299	930.31 m	0.05 m	2.1688441	41.8129289	930.51 m	0.7 pix	23	0.01 m	-0.11 m	0.20 m	0.11 m	0.23 m
D15_261017-1-0055	0	2.1672620	41.8116080	936.42 m	0.05 m	2.1672628	41.8116072	936.53 m	0.6 pix	24	0.07 m	-0.09 m	0.11 m	0.11 m	0.16 m
D14_261017-1-0121	0	2.1666014	41.8107953	932.69 m	0.05 m	2.1666027	41.8107944	932.77 m	0.4 pix	24	0.11 m	-0.10 m	0.08 m	0.15 m	0.17 m
Astrx32_261017-1-0056	0	2.1648210	41.8113375	922.72 m	0.05 m	2.1648199	41.8113381	922.83 m	0.5 pix	29	-0.10 m	0.07 m	0.11 m	0.12 m	0.16 m
Astrx34_261017-1-0021	0	2.1634374	41.8120911	878.13 m	0.05 m	2.1634361	41.8120913	878.06 m	0.4 pix	30	-0.11 m	0.02 m	-0.07 m	0.11 m	0.13 m
D01_261017-1-0208	0	2.1630980	41.8096165	920.72 m	0.05 m	2.1630981	41.8096168	920.76 m	0.5 pix	29	0.01 m	0.04 m	0.04 m	0.04 m	0.06 m
D09_261017-1-0201	0	2.1645226	41.8082903	919.40 m	0.05 m	2.1645234	41.8082889	919.43 m	0.6 pix	24	0.07 m	-0.15 m	0.03 m	0.17 m	0.17 m
D43_261017-1-0013	0	2.1603891	41.8089502	867.31 m	0.05 m	2.1603890	41.8089503	867.32 m	0.4 pix	20	-0.01 m	0.02 m	0.01 m	0.02 m	0.02 m
Astrx30_261017-1-0006	0	2.1625782	41.8083180	918.33 m	0.05 m	2.1625785	41.8083186	918.39 m	0.4 pix	24	0.02 m	0.07 m	0.06 m	0.07 m	0.09 m
Root Mean Square Error											**0.07 m**	**0.07 m**	**0.08 m**	**0.10 m**	**0.13 m**

Table 7 Setat and Septentrio GCPs used to compute the aerial triangulation.

The results of the first test depicted in Table 7 confirms that there are no outliers in the positioning results of the slave DMPs.

The largest slave DMP 3D positional error is 23 centimetres which is acceptable considering the antennas used and the dense vegetation nearby.

This test can be considered successful because the horizontal errors on each axis, latitude, longitude stay under two pixels (8 cm) which matches the expectation derived from Nyquist Shannon sampling theorem.

2.2.9.2 STAMP GCPs camera optimization

The expectation is that the RMSE will increase when compared to the result of the first test. This is so because there are less GCPs (10 vs 33) and the methods and the accuracy obtained out of the Rokubun Argonaut receivers provide less accurate positioning results .

	Initial coordinates					Computed coordinates					Errors (Initial-Computed)				
Point name	Enabled	Longitude	Latitude	Altitude	Accuracy	Longitude	Latitude	Altitude	Error	Images	Longitude	Latitude	Altitude	2D	3D
D01	0	2.1630745	41.8095903	920.70 m	0.05 m	2.1630751	41.8095910	920.70 m	0.5 pix	28	0.05 m	0.08 m	0.00 m	0.09 m	0.09 m
D02	0	2.1628869	41.8091991	924.75 m	0.05 m	2.1628879	41.8092004	924.87 m	0.5 pix	24	0.08 m	0.14 m	0.12 m	0.16 m	0.20 m
D03	0	2.1632377	41.8090176	924.81 m	0.05 m	2.1632388	41.8090184	924.86 m	0.7 pix	25	0.09 m	0.09 m	0.05 m	0.13 m	0.14 m
D04	0	2.1630776	41.8091353	925.47 m	0.05 m	2.1630784	41.8091363	925.46 m	0.6 pix	26	0.07 m	0.11 m	-0.01 m	0.13 m	0.13 m
D05	0	2.1628298	41.8090316	919.87 m	0.05 m	2.1628306	41.8090328	919.93 m	0.5 pix	26	0.06 m	0.14 m	0.06 m	0.15 m	0.16 m
D06	0	2.1625557	41.8083245	918.31 m	0.05 m	2.1625563	41.8083261	918.35 m	0.4 pix	24	0.05 m	0.18 m	0.04 m	0.18 m	0.19 m
D07	0	2.1637133	41.8082545	926.10 m	0.05 m	2.1637156	41.8082542	926.13 m	0.6 pix	30	0.19 m	-0.03 m	0.03 m	0.19 m	0.19 m
D08	0	2.1642281	41.8080982	926.46 m	0.05 m	2.1642307	41.8080971	926.42 m	0.5 pix	24	0.22 m	-0.12 m	-0.04 m	0.25 m	0.25 m
D09	0	2.1645588	41.8082905	918.42 m	0.05 m	2.1645608	41.8082891	918.11 m	0.6 pix	23	0.17 m	-0.16 m	-0.31 m	0.23 m	0.39 m
D10	0	2.1647751	41.8097934	927.28 m	0.05 m	2.1647758	41.8097922	927.17 m	0.5 pix	30	0.06 m	-0.14 m	-0.11 m	0.15 m	0.19 m
D11	0	2.1652606	41.8109328	930.53 m	0.05 m	2.1652602	41.8109325	930.50 m	0.6 pix	20	-0.03 m	-0.04 m	-0.03 m	0.05 m	0.06 m
D13	0	2.1666804	41.8112640	936.97 m	0.05 m	2.1666818	41.8112633	936.88 m	0.6 pix	29	0.12 m	-0.08 m	-0.09 m	0.14 m	0.16 m
D14	0	2.1665772	41.8107840	932.30 m	0.05 m	2.1665794	41.8107827	932.13 m	0.4 pix	26	0.18 m	-0.14 m	-0.17 m	0.23 m	0.29 m
D15	0	2.1672924	41.8116034	936.51 m	0.05 m	2.1672938	41.8116025	936.36 m	0.4 pix	22	0.12 m	-0.10 m	-0.15 m	0.15 m	0.21 m
D16	0	2.1674598	41.8115534	933.78 m	0.05 m	2.1674614	41.8115524	933.61 m	0.8 pix	23	0.14 m	-0.12 m	-0.17 m	0.18 m	0.25 m
D17	0	2.1677460	41.8132057	927.08 m	0.05 m	2.1677442	41.8132068	926.91 m	0.4 pix	27	-0.15 m	0.12 m	-0.17 m	0.19 m	0.25 m
D18	0	2.1683502	41.8131852	931.74 m	0.05 m	2.1683494	41.8131855	931.66 m	0.6 pix	21	-0.07 m	0.03 m	-0.08 m	0.07 m	0.11 m
D19	0	2.1685521	41.8131637	932.40 m	0.05 m	2.1685519	41.8131638	932.35 m	0.6 pix	25	-0.02 m	0.01 m	-0.05 m	0.02 m	0.06 m
D20	0	2.1688642	41.8129353	930.22 m	0.05 m	2.1688646	41.8129349	930.13 m	0.6 pix	21	0.04 m	-0.05 m	-0.09 m	0.06 m	0.11 m
D43	0	2.1603762	41.8089490	867.15 m	0.05 m	2.1603760	41.8089503	866.99 m	0.4 pix	27	-0.01 m	0.14 m	-0.16 m	0.14 m	0.21 m
D44	0	2.1627074	41.8113577	873.21 m	0.05 m	2.1627053	41.8113577	872.78 m	0.6 pix	30	-0.17 m	0.00 m	-0.43 m	0.17 m	0.46 m
Astrx26	0	2.1618500	41.8082116	902.23 m	0.05 m	2.1618495	41.8082134	902.46 m	0.4 pix	26	-0.04 m	0.20 m	0.23 m	0.20 m	0.31 m
Astrx27	0	2.1621824	41.8098206	901.96 m	0.05 m	2.1621820	41.8098215	901.89 m	0.3 pix	22	-0.03 m	0.10 m	-0.07 m	0.10 m	0.12 m
Astrx28	0	2.1606654	41.8090566	875.90 m	0.05 m	2.1606657	41.8090578	875.91 m	0.5 pix	33	0.03 m	0.13 m	0.01 m	0.13 m	0.13 m
Astrx29	0	2.1607214	41.8098371	866.97 m	0.05 m	2.1607220	41.8098372	866.72 m	0.4 pix	24	0.05 m	0.01 m	-0.25 m	0.05 m	0.25 m
Astrx30	0	2.1624938	41.8083329	917.24 m	0.05 m	2.1624947	41.8083345	917.44 m	0.4 pix	27	0.08 m	0.18 m	0.20 m	0.20 m	0.28 m
Astrx31	0	2.1634061	41.8108382	903.00 m	0.05 m	2.1634049	41.8108388	903.03 m	0.5 pix	28	-0.10 m	0.07 m	0.03 m	0.13 m	0.13 m
Astrx32	0	2.1648206	41.8113492	922.42 m	0.05 m	2.1648188	41.8113497	922.54 m	0.5 pix	29	-0.15 m	0.05 m	0.12 m	0.16 m	0.20 m
Astrx33	0	2.1646254	41.8117829	905.66 m	0.05 m	2.1646221	41.8117839	905.68 m	0.3 pix	31	-0.28 m	0.11 m	0.02 m	0.30 m	0.30 m
Astrx34	0	2.1634249	41.8120953	877.96 m	0.05 m	2.1634218	41.8120960	877.81 m	0.4 pix	28	-0.25 m	0.08 m	-0.15 m	0.27 m	0.31 m
Astrx35	0	2.1627110	41.8114927	873.46 m	0.05 m	2.1627093	41.8114925	873.23 m	0.5 pix	25	-0.14 m	-0.02 m	-0.23 m	0.14 m	0.27 m
Astrx37	0	2.1623373	41.8107403	871.81 m	0.05 m	2.1623359	41.8107404	871.47 m	0.5 pix	35	-0.12 m	0.01 m	-0.34 m	0.12 m	0.36 m
D17_261017-1-0051	1	2.1677932	41.8132092	927.24 m	0.05 m	2.1677910	41.8132096	927.27 m	0.5 pix	26	-0.19 m	0.05 m	0.03 m	0.19 m	0.20 m
D20_261017-1-0048	1	2.1688440	41.8129299	930.31 m	0.05 m	2.1688444	41.8129292	930.34 m	0.7 pix	23	0.03 m	-0.08 m	0.03 m	0.09 m	0.10 m
D15_261017-1-0055	1	2.1672620	41.8116080	936.42 m	0.05 m	2.1672635	41.8116069	936.42 m	0.6 pix	24	0.12 m	-0.12 m	0.00 m	0.17 m	0.17 m
D14_261017-1-0121	1	2.1666014	41.8107953	932.69 m	0.05 m	2.1666034	41.8107940	932.64 m	0.4 pix	24	0.17 m	-0.15 m	-0.05 m	0.23 m	0.23 m
Astrx32_261017-1-0056	1	2.1648210	41.8113375	922.72 m	0.05 m	2.1648191	41.8113381	922.86 m	0.5 pix	29	-0.16 m	0.06 m	0.14 m	0.17 m	0.22 m
Astrx34_261017-1-0021	1	2.1634374	41.8120911	878.13 m	0.05 m	2.1634342	41.8120917	877.94 m	0.4 pix	30	-0.26 m	0.06 m	-0.19 m	0.27 m	0.33 m
D01_261017-1-0208	1	2.1630980	41.8096165	920.72 m	0.05 m	2.1630984	41.8096171	920.75 m	0.5 pix	29	0.03 m	0.07 m	0.03 m	0.08 m	0.08 m
D09_261017-1-0201	1	2.1645226	41.8082903	919.40 m	0.05 m	2.1645246	41.8082887	919.28 m	0.6 pix	24	0.17 m	-0.18 m	-0.12 m	0.25 m	0.27 m
D43_261017-1-0013	1	2.1603891	41.8089502	867.31 m	0.05 m	2.1603890	41.8089513	867.27 m	0.4 pix	20	-0.01 m	0.13 m	-0.04 m	0.13 m	0.13 m
Astrx30_261017-1-0006	1	2.1625782	41.8083180	918.33 m	0.05 m	2.1625792	41.8083194	918.50 m	0.4 pix	24	0.08 m	0.16 m	0.17 m	0.18 m	0.25 m
Root Mean Square Error											**0.13 m**	**0.11 m**	**0.15 m**	**0.17 m**	**0.23 m**

Table 8 STAMP GCPs used to compute the aerial triangulation.

The STAMP result in Table 8 confirm the expectations of increased errors, from 10 cm in the horizontal plane in the first experiment to 17 cm of RMSE in the second.

The horizontal RMSE error obtained with STAMP is below the expected error for the aerial triangulation GCPs used for best orthomosaic available for CATUAV zone which is the ICGC 1:2500 Ortophoto.

2.3 Field testing conclusions

The field testing conclusions are as follows:

a) In relationship to the first test: *Master drone camera resolution study*.

The resolution testing has verified the hypothesis that the DMP / DMPP camera when flying at 120 m AGL is able to correctly register the DMP silhouette landed on the ground, provided that there is enough contrast between the target and the background.

Because 120 m AGL is the worst case scenario that can be legally tested in Spain without requesting a special authorization and it was successful, we can conclude that as a consequence it has been demonstrated that any camera capturing pictures below 120 m AGL would also provide enough image resolution to accurately identify the DMPs landed on the ground.

b) In relationship to the second test: *STAMP extensive field test.*

After the confirmation that the DMP / DMPP camera was able to resolve the targets on the ground, it was also confirmed that the second test that simulated a STAMP field deploy was good to go.

The second test involved a photogrammetric survey that had two different sets of GCPs, 10 were white DMP silhouettes and 33 were 50x50 cm black / white pre-surveyed GCPs targets.

This last test was flown at 120 metres AGL and the flight covered 27 hectares.

The STAMP photogrammetric positional error result is twice the error obtained when processing with the GCPs surveyed with the high end receiver as can be seen in Table 9. Those results fall within the GIS accuracy standards (under 30 cm) which is acceptable for stamp intended use.

	RMSE Lat.	RMSE Lon.	RMSE Hgt.
High end	0.07 m	0.07 m	0.08 m
STAMP	0.13 m	0.11 m	0.15 m

Table 9 GCPs Root Mean Square Errors

This means that from photogrammetric point of view STAMP is expected to be a viable product whenever the altitude of the aerial camera stays below the 120 mark.

3 COMMERCIAL STUDY

This commercial study chapter wants to present the key commercial factors involved in the STAMP market release and upcoming years so that it can be used to gauge how fast would be the return of investment.

However it should not be understood as an exhaustive document like a business plan in which it would be discussed the team background, company setup, value proposition, the added value, product readiness, market context, R&D strategy, intellectual property, competitive advantages, the business model, channels, customer relationship, SWOT analysis, etc.

To evaluate if there is a market opportunity for STAMP it is necessary to understand what is the direction the market is moving to. In this first section we will review if the DMP / DMPP market is large enough to support a new comer offering a new product that has never been marketed before.

3.1 Potential figures and trends[3]

In year 2015 3.1 million drones were sold all around the world, in 2016 were 8.1 and in 2017 have been 12.5 million. A 2^{nd} degree polynomial regression projection predicts that 16.5 million drones will be sold along year 2018.

Assuming DJI market share is kept constant from 2017 to 2018 at 72%, which is a very conservative estimation considering that in 2016 was 50%, this would mean that DJI is expected to sell 11.9 million of drones.

From the 11.9 million of drones sold, 45% or 5.4 million, would either be Phantom 4 or Mavic Pro. From those 5.4 million, 5% or 268000 will be sold to companies that will use the drone for survey & mapping purposes. The end users of the 268000 drones can either be drone service providers, analytics / derived products value-added providers or end consumers.

As a summary 70% of all drone sales in the $1000 - $2000 range are used for professional purposes.

The numbers presented above suggest that the DMP and DMPP are well known in the professional pilot community, which is likely to imply a low market penetration resistance because it has the largest user base of all the drone user segment.

[3] The data presented in this section has been elaborated based on “Skylogic Research 2017 Drone Market Sector Report 4” Due to copyright restrictions this report will not be added into the appendix.

From company revenue perspective, as depicted in Figure 14, the vast majority of the companies, 46%, generate under $50000 of revenue per year, those are unlikely to be suitable candidates for the STAMP system as it is doubtful that they are able to invest on a non-essential system.

The companies generating $50000 or more, 16%, are considered potential candidates for STAMP.

The companies that report no revenue at all from drone operations may also be interesting as it means that the drone systems are used as means to generate revenues in other sectors. Unfortunately with the information available it is not possible to have an insight how attractive that market niche may be as typically operations within that segment are not publicized.

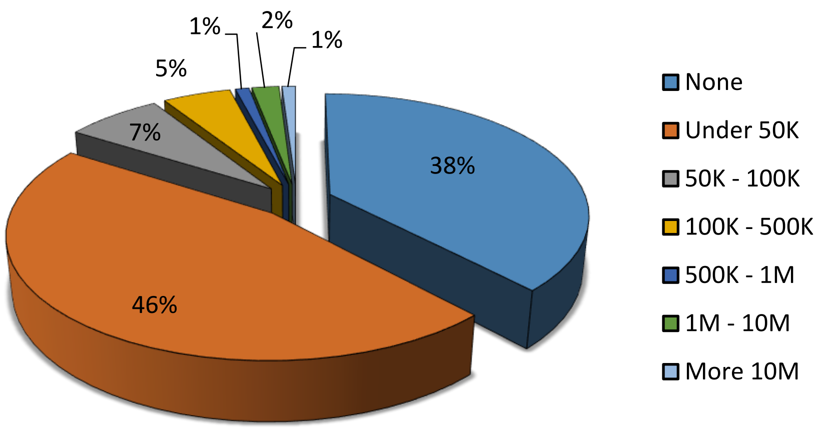

Figure 14 Company revenue from commercial drone operations

In Figure 15, it can be seen that on average the vast majority of drone operators, 79%, only fly less than 5 projects per month so it can be assumed that those companies would not be able to afford the STAMP costs.

The remainder of the companies, 21%, would likely benefit from STAMP so it is assumed that for every 5 photogrammetric projects per month one STAMP system would be justified

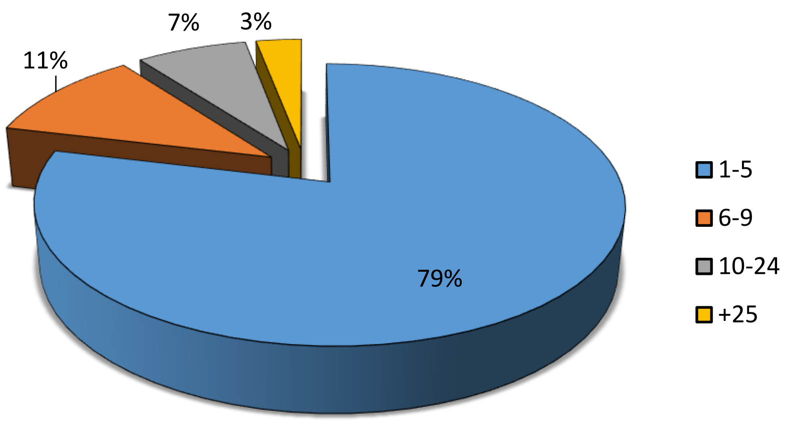

Figure 15 Average number of drone projects per month

In summary, taking into account all the figures previously presented and the competence from PropellerAero GCPs, which will be explained further down, for year 2018 the expected candidate market size for the STAMP project roughly is 259000 systems. Projecting those market estimation numbers into the future we get the forecast depicted in Figure 16

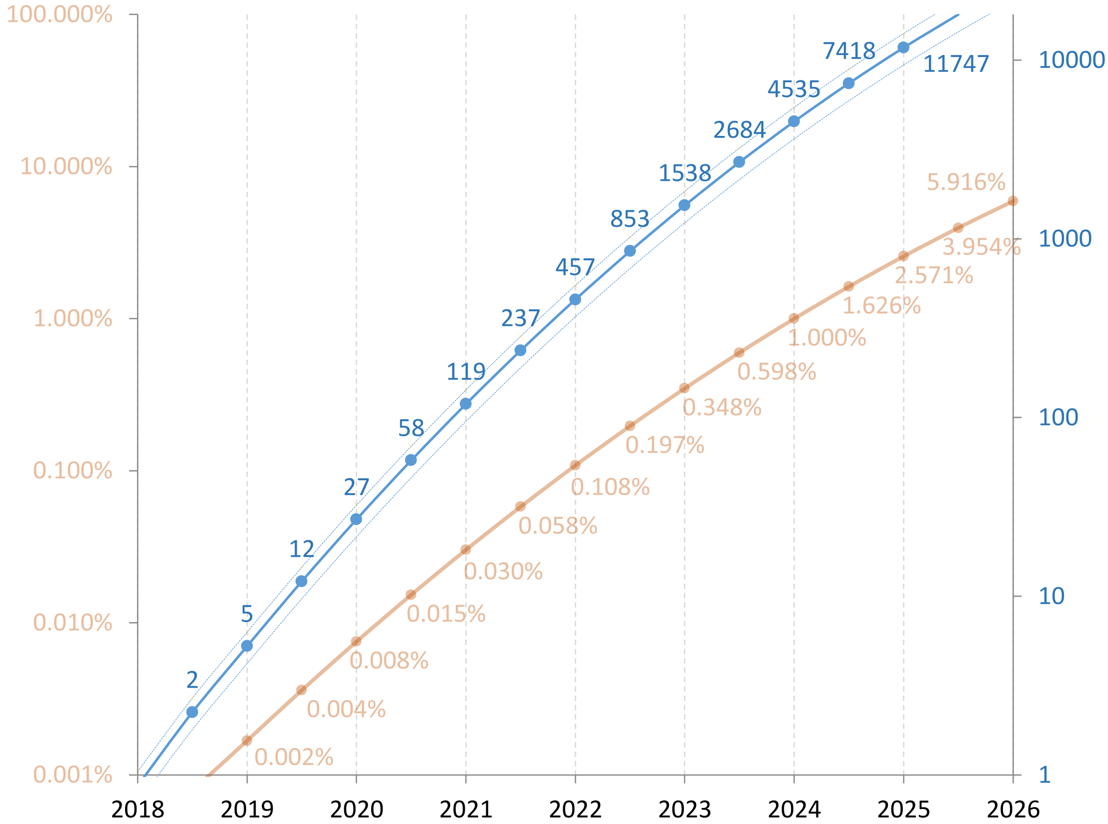

Figure 16 Expected technology adoption rate vs. expected number of STAMP units sold.

3.2 Analysis and segmentation

The professional drone market is typically segmented in the verticals listed in Figure 17

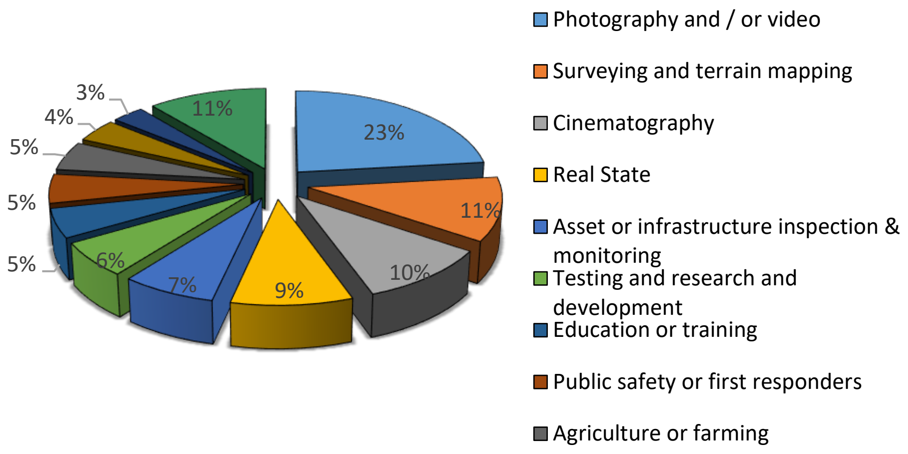

Figure 17 UAV market verticals

STAMP is mainly oriented at the “survey and terrain mapping” vertical but it may also have use in cinematography to create 3D models to be used in movies, infrastructure monitoring, public safety to reconstruct car accidents, precision agriculture to level the terrain to avoid pond formation, and construction stock pile volume management.

3.3 The Competition

There seems to be an increase in the number of professional drone systems that come equipped with survey grade dual frequency RTK GNSS receivers to provide high accuracy positioning to the drone capturing aerial pictures with the objective to perform direct georeferencing of the images captured by the drone.

Those high end systems come at a very high premium cost and require the end user to setup a local base station with a radio link continuously operating that must be kept alive for the whole duration of the flight as otherwise the pictures may not be georeferenced correctly.

The high end receiver approach also has the inconvenience of draining the drone battery and adding weight / complexity to the system.

RTK receivers do not represent a real competence to STAMP because there is no real need to obtain the pictures with a precise positional stamp right in the field and the complexity of the RTK setup unnecessarily increases the system setup time

The consequences of a possible drone crash may cause catastrophic failures in very expensive equipment making a repair a prohibitive endeavour.

The pricing for two relevant competitors is:

- The Trimble UX5-HP UAS (RTK capable) costs around $40000 not including GNSS post processing software nor the GNSS base station nor the photogrammetric software
- The Sensefly eBee costs between $25000 and $27000 depending on the options but it does includes the Pix4D photogrammetric software license which is valued in 6500€ but it does not include the GNSS post processing software nor it includes GNSS base station.

During the development of the STAMP system we have not identified any direct competitor using drones as GCPs however we have located a single indirect competitor (see Table 10)

Company Name:	Propeller Aerobotics Pty. Ltd. (or PropellerAero for short)
Registration date:	08-May-2014
Employees:	24 based in Australia, 5 in the US and 3 in Canada
Twitter followers:	932
Linked in followers:	987

Table 10 Competitor basic company details.

The competing product is a battery powered GCP (see Figure 18 AeroPoint GCP) with an L1 only GNSS receiver integrated in the centre of the target with logging capability (see Table 11)

Product Name:	AeroPoints
Release date:	August 2016
Patents:	Australian patent number AU2015903258
Patent file date:	13-August-2015
Price:	6000 US dollars per a group of ten AeroPoints

Table 11 Competitor product basic information.

Figure 18 AeroPoint GCP

The bundle includes one year of post processing in PropellerAero own cloud based SaaS platform and every additional year costs $600.

We believe that their product does have some drawbacks that are worth mentioning:

1. AeroPoints must be manually spread over the survey area.
2. Each AeroPoint weight is 1.55 kg and measures 54.4x54.4x3.2 cm so the weight of 10 would be around 15.5 kg and the size 54.4x54.4x32 cm that suggests that a single operator is unlikely to carry them all in his backpack in addition to the drone, the batteries, the remote control and tablet. It looks like AeroPoint GCPs have been designed to be carried in a vehicle, in fact the corporative web page only lists applications where the Aeropoints are being spread by a wheeled vehicle.
3. The raw data from the AeroPoints is not exportable in open standard formats like RINEX, in fact the end users are forced to use a mobile app to directly upload the files from AeroPoint to PropellerAero servers. This means that the end users will never be able to handle the files exported by the AeroPoints. This implies that end users are forced to pay the $600 a year if they want to obtain the coordinates with the embedded GNSS receiver.
4. There is no official representation outside Australia and US, it may be difficult / expensive to repair.
5. Spain is being served from the Netherlands, so PropellerAero presence in southern Europe is scarce at best.

3.4 Comparative product analysis

In the end of degree project [4] there is a profitability comparison between a Trimble UX5 UAV and a land surveying of the same area performed by high end GNSS receiver located. The area in which the test was performed is mostly open fields therefore it is the ideal location to execute a photogrammetric survey:

	Trimble UX5 UAV	Trimble R10 GNSS receiver
3120 hectares per year	21213 €	10923 €
4320 hectares per year	49247 €	12581 €

Table 12 Industrial benefit over the course of a year

As per Table 12 from company revenue perspective the UAV survey provides almost a 200% improvement over a GNSS survey in the small test field and almost a 400% improvement in a test field that is just 140% larger.

The conclusion is that in any job where the features to survey are visible from the sky the survey work should be tackled with UAV instead of classic techniques, at least from profitability point of view.

3.5 Revenue Streams

STAMP chosen drone Manufacturer's Suggested Retail Price (MSRP) would be set as per the following estimative tables.

The minimum hardware required to supply a fully working STAMP system would be:

Providers		30/1/2018	Entry Configuration				
Brand	**Item description**	**MSRP Unit Price**	**Number**	**MSRP Total**	**Margin**	**Rokubun's cost**	**Margin**
DJI	Mavic Pro Platinum + battery + remote controller	1 300.00 €	1	1 300.00 €	5.00%	1 235.00 €	65.00 €
DJI	Mavic Pro Platinum extra battery	100.00 €	3	300.00 €	5.00%	285.00 €	15.00 €
DJI	Mavic Pro Platinum 2 propellers	10.00 €	1	10.00 €	5.00%	9.50 €	0.50 €
DJI	Standalone Mavic Pro + battery (no remote no charger)	900.00 €	5	4 500.00 €	5.00%	4 275.00 €	225.00 €
DJI	Mavic Pro extra battery	100.00 €	1	100.00 €	5.00%	95.00 €	5.00 €
DJI	Mavic Pro 2 propellers	10.00 €	1	10.00 €	5.00%	9.50 €	0.50 €
DJI	Mavic Pro 4 way battery bays	45.00 €	2	90.00 €	5.00%	85.50 €	4.50 €
DJI	Mavic Pro 50w battery charger	22.00 €	2	44.00 €	5.00%	41.80 €	2.20 €
DJI	AC battery charger cable	5.00 €	2	10.00 €	5.00%	9.50 €	0.50 €
DJI	Propeller protectors	180.00 €	6	1 080.00 €	5.00%	1 026.00 €	54.00 €
DJI	High brightnes CrystalSky 5.50 inch tablet	469.00 €	1	469.00 €	5.00%	445.55 €	23.45 €
DJI	High brightnes CrystalSky 7.85 inch tablet	699.00 €	0	- €	5.00%	- €	- €
DJI	Ultrabright CrystalSky 7.85 inch tablet	1 149.00 €	0	- €	5.00%	- €	- €
DJI	CrystalSky remote holder	90.00 €	1	90.00 €	5.00%	85.50 €	4.50 €
DJI	SanDisk Extreme microSD 64GB	34.00 €	1	34.00 €	5.00%	32.30 €	1.70 €
PGYTECH	Landing gear extension for Mavic Pro	25.00 €	6	150.00 €	0.00%	150.00 €	- €
MicroRaptor	Pro Large Duffel Bag / Backpack - With Paded Divider	225.00 €	1	225.00 €	0.00%	225.00 €	- €
MightySkins	DJI Mavic Pro Quadcopter Drone Skin	30.00 €	5	46.00 €	0.00%	46.00 €	- €
Rokubun	SPA	450.00 €	6	2 700.00 €	66.67%	900.00 €	1 800.00 €
				11 158.00 €	**19.73%**	**8 956.15 €**	**2 201.85 €**

Table 13 Entry level STAMP system hardware list

The hardware required to provide a top end STAMP system would be:

Providers		30/1/2018	Highest specification system				
Brand	**Item description**	**MSRP Unit Price**	**Number**	**MSRP Total**	**Margin**	**Rokubun's cost**	**Margin**
DJI	Mavic Pro Platinum + battery + remote controller	1 300.00 €	1	1 300.00 €	5.00%	1 235.00 €	65.00 €
DJI	Mavic Pro Platinum extra battery	100.00 €	4	400.00 €	5.00%	380.00 €	20.00 €
DJI	Mavic Pro Platinum 2 propellers	10.00 €	1	10.00 €	5.00%	9.50 €	0.50 €
DJI	Standalone Mavic Pro + battery (no remote no charger)	900.00 €	10	9 000.00 €	5.00%	8 550.00 €	450.00 €
DJI	Mavic Pro extra battery	100.00 €	1	100.00 €	5.00%	95.00 €	5.00 €
DJI	Mavic Pro 2 propellers	10.00 €	1	10.00 €	5.00%	9.50 €	0.50 €
DJI	Mavic Pro 4 way battery bays	45.00 €	4	180.00 €	5.00%	171.00 €	9.00 €
DJI	Mavic Pro 50w battery charger	22.00 €	4	88.00 €	5.00%	83.60 €	4.40 €
DJI	AC battery charger cable	5.00 €	4	20.00 €	5.00%	19.00 €	1.00 €
DJI	Propeller protectors	180.00 €	11	1 980.00 €	5.00%	1 881.00 €	99.00 €
DJI	High brightnes CrystalSky 5.50 inch tablet	469.00 €	0	- €	5.00%	- €	- €
DJI	High brightnes CrystalSky 7.85 inch tablet	699.00 €	0	- €	5.00%	- €	- €
DJI	Ultrabright CrystalSky 7.85 inch tablet	1 149.00 €	1	1 149.00 €	5.00%	1 091.55 €	57.45 €
DJI	CrystalSky remote holder	90.00 €	1	90.00 €	5.00%	85.50 €	4.50 €
DJI	SanDisk Extreme microSD 64GB	34.00 €	1	34.00 €	5.00%	32.30 €	1.70 €
PGYTECH	Landing gear extension for Mavic Pro	25.00 €	11	275.00 €	0.00%	275.00 €	- €
MicroRaptor	Pro Large Duffel Bag / Backpack - With Paded Divider	225.00 €	1	225.00 €	0.00%	225.00 €	- €
MightySkins	DJI Mavic Pro Quadcopter Drone Skin	30.00 €	10	311.00 €	0.00%	311.00 €	- €
Rokubun	SPA	450.00 €	11	4 950.00 €	66.67%	1 650.00 €	3 300.00 €
				20 122.00 €	**19.97%**	**16 103.95 €**	**4 018.05 €**

Table 14 Complete STAMP system hardware list.

In between the two extreme configurations presented the end user can decide the options to include in his system based on the needs regarding accuracy, extension of the areas to be mapped and funds availability.

STAMP is designed to be upgradeable so if the end user decides at a later date that he needs a 7 drone system instead of the basic 5 drone system he just needs to purchase the two missing drones.

Because Rokubun is a company born to develop GNSS navigation algorithms, the intent of STAMP is to open another access point for customers to use the Rokubun's post processing engine.

STAMP was conceived as a sustainable business that should provide a moderate commercial benefit because the main revenues are expected to come from the PaaS post-processing engine.

Rokubun's PaaS post processing engine still is in test phase so the final pricing has not yet been decided but most likely Rokubun will charge customers by the processing mode selected, which determines the result final accuracy.

The more accurate the result obtained from PaaS is, the more expensive the processing should be and the other way around.

This pricing strategy ensures:

1. Power users of the PaaS do not pay more than 100€ per processing without having to worry about monthly fees.
2. The payment is small enough so that it does not become an entry barrier, especially when compared to $3000~$6000 software packages.
3. It would take 120 days to reach 3000 € mark making Rokubun's PaaS much more budget friendly than commercial software packages.

4. Sporadic users like small land surveying companies pay a predictable, easy to compute figure helping them to forecast their operational costs.
5. As per our market survey the proposed price for Rokubun's target market, the L1 fixed integer ambiguity resolution (45€) is the highest that we believe the market is ready to accept.
6. The PaaS positioning solutions that can be obtained from other sources at a low cost is also provided at low cost from the PaaS even though long observations may lead to a reasonably accurate result (like PPP).

The PaaS payment would be completely automated. All what the customer would be required to do is to select one of the price points listed in Figure 19.

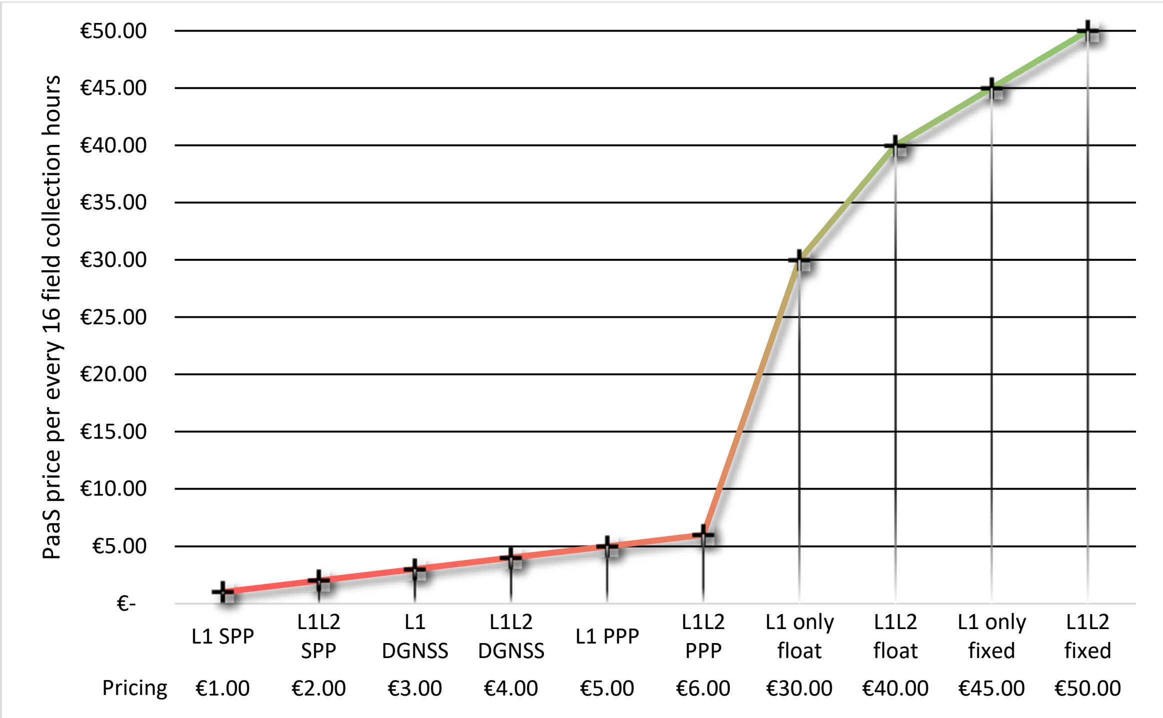

Figure 19 PaaS pricing price evolution.

After selecting the desired accuracy the uploaded raw data file it would be parsed to determine the first and last observation times. Three different situations may arise as per

Raw data falls within payed period?	**Higher accuracy requested ?**	**User pays:**
Yes	No	Nothing because he already paid for higher accuracy.
	Yes	Difference between what has been paid and the new accuracy
No	Irrelevant	Pays full price as per previous graph.

Table 15 Raw data file temporal range fitness.

Because customer accounts at Rokubun's PaaS would contain the encrypted banking details all the usage charges would be instantaneously executed through a secure e-banking platform

While it is in Rokubun's best interest to ease as much as possible the transactions it is also important to ensure that there are no mistakes from the end user side so the end user would have to confirm each processing to ensure that is aware of the costs involved.

3.6 Supply chain

The supply chain of STAMP is relatively simple because it only involves products manufactured in house and products manufactured or stoked by DJI.

The Argonaut / SPA receivers are manufactured by Rokubun and Rokubun can adapt the production rate as well as stoking at will.

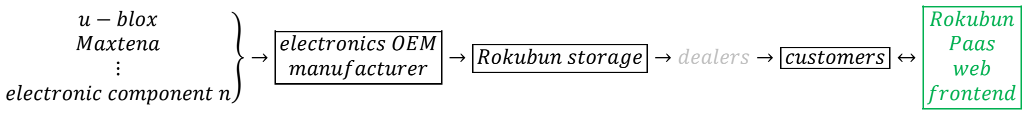

Figure 20 Argonaut and SPA supply chain

PaaS is mostly software (except the servers) and does not really require of a supply chain understanding the term in the classical sense.

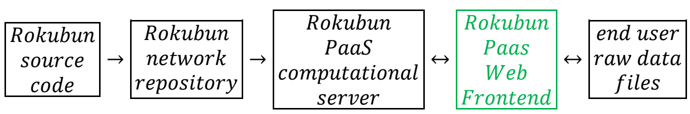

Figure 21 PaaS supply chain

STAMP supply chain, while not controlled by Rokubun, it is mainly driven by a very large manufacturer that has a strong presence in the market, the risk of shortages is very mild, the only exception being when a new product is released but this is not the case of the DMP/DMPP.

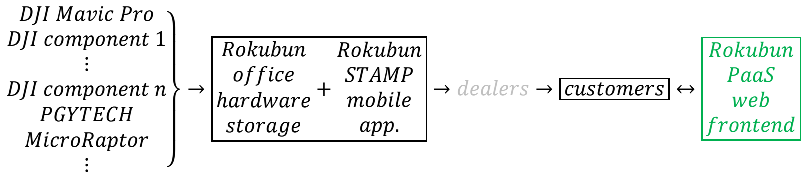

Figure 22 STAMP supply chain

3.7 Key Partners

The main partnership that Rokubun needs to successfully initialize the STAMP project is with Dà-Jiāng Innovations Science and Technology Co., Ltd (Chinese: 大疆创新科技有限公司; doing business as DJI) headquartered in Shenzhen, Guangdong.

This partnership is central to Rokubun's STAMP system because the factory default firmware loaded in DJI COTS drones and more specifically on the Mavics does not allow certain operations that are required to successfully deploy slave drones.

As of today, there is only a pending "show stopper" regarding the STAMP project and that is DJI drone firmware and API capabilities:

1. As per DJI manuals and API documentation on their web pages it clear that the firmware and API do not support more than one single drone paired with the radio control at the same time. This means that it would not be possible to fly multiple drones at the same time. At the light of the current legal texts this is a desirable limitation.
2. Only one single drone can be paired with the remote control at any given time this means that a pilot would be unable to retrieve the slave drones manually denying the benefits of the STAMP system.
3. The current DJI Mavic firmware does not include a SubSecTime field in the JPEG EXIF tag. As a consequence the time stamp of the pictures taken by the STAMP master drone temporal resolution is only at second level, it does not reach millisecond. This would deny the possibility to install a Rokubun GNSS receiver in the master drone because it would not be possible to accurately correlate the aerial pictures with the GNSS data.
4. DJI drones, to the best of our knowledge, are not capable to perform flight plans that include landing at supplied coordinates, powering off the motors (to save battery while on the ground) and automatically take off after a pre-set time. This missing feature is important when sending STAMP slave drones to areas where there is no possibility to have a viable radio-link due to obstructions caused by terrain, vegetation and similar obstructions.

Rokubun only requires from DJI a the few adaptations on their COTS Mavic drone firmware and API listed above,

Some of those software adaptations have deep implications on the behaviour of the drones allowing them to perform manoeuvres that may cross the line of legality.

Up until today DJI has been selling generic drones into the consumer and prosumer market that due to the quality, availability, robustness, size, weight and low cost have been adapted to professional applications like videography and photogrammetry.

DJI started their drone company by segmenting their market horizontally however in the recent years there has been a change of strategy and DJI is starting to target solutions to specific market verticals like agriculture.

This specialization in DJI products can be perceived as a company that is providing hardware to the Original Equipment Manufacturer (OEM) market but at the same time may also be interested in releasing products to the same end users that Rokubun would.

As of today DJI is not a STAMP competitor because it has never released any product specifically tailored to photogrammetry however the after mentioned precedent makes difficult for us to evaluate DJI's future intentions.

DJI has already warranted Rokubun an industrial discount over 5% on all the products we need for the STAMP but those discounts oscillate on the total lump sum of the material requested.

3.8 Risk Mitigation

The following risk analysis table summarises several key risks related to STAMP project which are identified, classified and a mitigation strategy is presented.

Risk	Impact (e.g. Cost, Schedule, Technical)	Likelihood of occurrence	Severity of consequences	Risk Magnitude	Precaution Measures	Mitigation plan	Cost of risk mitigation
Multiple Mavic controller pairing firmware modification	Technical	5	Show stoper	Very high	None can be taken	A different, more customizable drone	low
Absence of milliseconds in the JPEG EXIF	Technical	5	Show stoper	Low	Preliminary study on using second resolution time stamp	We suspect that the impact can be severly mitigated by using the API	low
Flight plan aplicability after landing	Technical	4	Limited	Moderate	Pending on DJI response.	None, the targeted market size impact is likely to be small	low
Currency fluctuations may impact the cost of the STAMP	Cost	2	Low	Low	None, stocking is not an option for Rokubun	Item price will be updated on every customer enquiry	low
Some components may become unavailable	Schedule	2	Low	Low	None, stocking is not an option for Rokubun	Issue long lead times and use other vendors (at a higher cost)	moderate

Table 16 Risk mitigation table

Table 16 demonstrates that there are show stopper issues that do require addressing before attempting to build a STAMP prototype.

Because DJI is the STAMP key supplier of drones and those are limited by what can be done with their firmware, before any further attempt to continue with the project it should be clarified what is DJI willingness to help Rokubun by introducing the required changes.

3.9 Cost Structure & Financial Projection

In this section, a review of what are the most important costs to operate the business, what are the most expensive key activities and resources, what are the fixed costs, what are your variable costs and what are the sources of income projected for the following three years is presented.

	Year -1	Year 1	Year 2	Year 3
	€	€	€	€
Sales Revenue				
STAMP hardware		€ 105 681	€ 541 471	€ 2 393 180
Positioning as a Service		€ 22 140	€ 116 279	€ 595 774
Total Sales Revenue [J]	€ -	€ 127 821	€ 657 750	€ 2 988 954
Direct cost of Sales				
STAMP hardware		€ 84 578	€ 433 348	€ 1 915 299
Positioning as a Service		€ 1 000	€ 1 300	€ 1 000
Total Cost of Sales [K]	€ -	€ 85 578	€ 434 648	€ 1 916 299
Gross Profit [L=J-K]	€ -	€ 42 243	€ 223 103	€ 1 072 655
Operating Expenses				
Sales and Marketing				
Advertising		€ 10 000	€ 13 000	€ 26 000
Direct marketing		€ -	€ -	€ -
Missions		€ 15 000	€ 19 500	€ 39 000
Total Sales and Marketing Expenses [M]	€ -	€ 25 000	€ 32 500	€ 65 000
Research and Development				
Technology licenses		€ -	€ -	€ -
Patents		€ -	€ -	€ -
Other expenses (specify)		€ -	€ -	€ -
Total Research and Development Expens	€ -	€ -	€ -	€ -
General and Adminstrative				
Wages and salaries		€ 258 500	€ 336 050	€ 672 100
Outside services		€ 3 600	€ 4 680	€ 9 360
Meals and entertainment		€ 1 000	€ 1 300	€ 2 600
Rent		€ 8 400	€ 10 920	€ 21 840
Telephone		€ 840	€ 1 092	€ 2 184
Utilities		€ 500	€ 650	€ 1 300
Depreciation		€ 2 000	€ 2 600	€ 5 200
Insurance		€ 200	€ 260	€ 520
Repairs and maintenance		€ -	€ -	€ -
Other expenses (specify)		€ -	€ -	€ -
Total General and Adminstrative Expense	€ -	€ 275 040	€ 357 552	€ 715 104
Total Operating Expenses [P=M+N+O]	€ -	€ 300 040	€ 390 052	€ 780 104
Income from Operations [Q=L-P]	€ -	-€ 257 797	-€ 166 949	€ 292 551
Other Income [R]		€ -	€ -	€ -
Taxes				
Taxes		€ -	€ -	€ 73 138
Total Taxes [S]	€ -	€ -	€ -	€ 73 138
Net Profit [T=Q+R-S]	€ -	-€ 257 797	-€ 166 949	€ 219 413

Table 17 Profit & Loss Projection

Taking into consideration the income projections presented in Figure 16, the costs in Table 13 and Table 14 as well as the company costs of operation that

Rokubun is already familiar with we obtain Table 17 which as can be seen in “Net Profit” row the venture would break even between years two and three.

3.10 Commercial Study conclusions

After researching the data required to compose the commercial study of this master thesis, the conclusions are as follows:

The reviewed documentation shows that the potential user base for STAMP is around 268000 users.

On the one hand there is no direct competition, the closest being the AeroPoints sold by PropellerAero. This augurs a smooth market penetration without having to manage a price race against other competitors.

On the other hand, the expected number of STAMP units sold plus the industrial DMP/DMPP price provided to Rokubun by DJI allow Rokubun to keep the MSRP in line with what a user would expect to pay when purchasing the equipment directly from DJI while still keeping a good benefit margin.

Moreover, it must be noted that the commercial analysis is based on some untested hypothesis and assumptions. For instance: the technological adoption rate, assumed identical from other technologies and the document in which the market study is based on a partial picture of the global market, mainly the US.

From supply chain point of view there are show stoppers that must be resolved before continuing any further in to the project as those may render DJI products as not suitable for STAMP.

Finally, STAMP is expected to become a viable business with the possibility to provide positive net profits by the third year after the product release date.

4 CONCLUSION

After reviewing each chapter specific conclusions and the research performed the following global conclusions have been reached:

As the writing of the present master thesis progressed it became gradually clearer that the STAMP project, as devised by Xavier Banqué and Miquel Garcia, it has been found that is a viable product, both, from technical as well as from commercial point of view.

However, this thesis leaves some aspects to be further evaluated in future studies. Two of the main STAMP aspects that will need further attention are: the software to be run in a tablet that must be devised by Rokubun and the partnership to be stablished with DJI

In summary, every single STAMP aspect reviewed in this document passes the evaluation criteria with a good final result.

5 REFERENCES

5.1 Acronyms

2DRMS Horizontal Root Mean Square 2σ

AESA Spanish Aviation Safety Agency

AGL Above Ground Level

API Application Programming Interface

APS Agisoft PhotoScan Professional

CAD Compute Aided Drawing

CEP Circular Error Probability

CMOS Complementary Metal–Oxide–Semiconductor

COTS Commercial Of The Shelf

CPU Central Processing Unit

CUDA Compute Unified Device Architecture

DEM Digital Elevation Model

DJI Dà-Jiāng Innovations

DMA DJI Mavic Air

DMP DJI Mavic Pro

DMPP DJI Mavic Pro Platinum

DNG Digital Negative

DSM Digital Surface Model

DTM Digital Terrain Models

EASA European Aviation Safety Agency

ED50 European Datum 1950

EETAC Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels

EGM08 Earth Gravitational Model 2008

ESA European Space Agency

ETRS89 European Terrestrial Reference System 1989

EXIF Exchangeable Image File

FOV Field Of View

GCP Ground Control Points

GLONASS Global'naya Navigatsionnaya Sputnikovaya Sistema

GNSS Global Navigation Satellite System

GPS Global Positioning System

GPU Graphic Processing Unit

GSD Ground Sampling Distance

GUI Graphical User Interface

GUI Graphical User Interface

ICGC Institut Cartogràfic i Geològic de Catalunya

IMU Inertial Measurement Unit

JPEG Joint Photographic Experts Group

LIDAR LIght Distance And Ranging

microSD micro Secure Digital

MSRP Manufacturer's Suggested Retail Price

MSc Master in Science

MTN Mapa Topogràfic Nacional

NASA National Aeronautics and Space Administration

OEM Original Equipment Manufacturer

PC Personal Computer

PPP Precise Point Positioning

PaaS Positioning as a Service

PhD Philosophy Doctor

R&D Research and Development

RINEX Receiver Independent Exchange

RMSE Root Mean Square Error

RPAS Remotely Piloted Aircraft Systems

RTK Real Time Kinematic

SAR Synthetic Aperture Radar

SBAR Sant Bartomeu del Grau

SNR Signal to Noise Ratio

SPA Self-Powered Argonaut

SRTM Shuttle Radar Topography Mission

UAS Unmanned aerial system

UAV Unmanned Air Vehicle

UI User Interface

UTM Universal Transverse Mercator

XU Xarxa Utilitaria

5.2 Bibliography

[1] "Photogrammetry," 15 05 2018. [Online]. Available: https://en.wikipedia.org/wiki/Photogrammetry. [Accessed 21 05 2018].

[2] "Georeferencing," 22 04 2018. [Online]. Available: https://en.wikipedia.org/wiki/Georeferencing. [Accessed 21 05 2018].

[3] E. Ramirez, “Shuttle Radar Topography Mission,” Jet Propulsion Laboratory, NASA, 14 6 2018. [Online]. Available: https://www2.jpl.nasa.gov/srtm/. [Accessed 14 6 2018].

[4] A. C. R. &. G. B. Abellán, “Fotogrametría de UAV de ala fija y comparación con topografia clásica,” Madrid, 2015.