Deployment of unmanned aircraft systems as part of precision agriculture in Finland

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Foreword

This thesis is the final objective for us to earn our bachelors' degree in aeronautical engineering. It is a representation of the knowledge we acquired through the past three years. It takes a lot of time and patience to wright and this couldn't be done without the help of others. That's why we want to thank some persons in particular.

First of all, we want to thank Antti Perttula. He was our promotor at TAMK and helped us a lot with finding a topic for the thesis between all the projects they had running. He also helped us to contact other people concerning our thesis and he gave us advice about what subjects we should implement. Above that there was his support troughout the whole process.

Secondly we want to thank Aleksi and Veli, two finnish students who helped us a lot with the practical tests in our thesis. Their knowledge of UAS was indispensable to bring this project to a good end.

We also want to thank Miss Verhaegen, to correct our thesis on English grammar and to give us some advice for the lay-out.

Additionally we want to thank our school in Belgium, VIVES for giving us the chance to participate in this amazing Erasmus experience.

Last, but not least we want to thank our parents for supporting us through all this years of study. Without them this whole journey wouldn't be possible.

ABSTRACT

Tampereenammattikorkeakoulu
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Carlier Niels & Desloovere Matthias:
Deployment of UAS as part of precision agriculture in Finland

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This thesis is written as part of a project to modify an unmanned aerial vehicle (UAV) for agricultural purposes in Finland. On demand of a farmer with a big plot of land, we're searching for a solution to make pest control effective and environmental friendly at the same time. This will be done by using a UAV to check yellow measurement papers for the amount of insects sticking on them. If the amount exceeds a certain number, the farmer is supposed to start using pest control on that specific plot of land. This is part of a concept called precision agriculture and it is estimated to save up to 75% on fertilizer and pesticides. So the use of this method means a cost saving for the farmer and at the same time it has a positive influence on the environment.

Furthermore it will be determined what type of UAV is most suitable for this task. Therefore some requirements have to be taken into account. Such as the possibility of the device to fly autonomously to the different measurement papers while using a pre-set flight plan. Also the different requirements for camera performance, sensors and flight time will be investigated, as well as the potential to transport and install the measurement papers with this device.

This project shows in general that for the agricultural sector, UAV's can be a big advancement. The monitoring of the crops, the irrigating as well as the combination of these and other functions can be done very efficiently. To get familiar with this subject, the first part of this thesis wil consist of a theoretical approach of UAV's and all related terminology.

Key words: UAV, insects, measuring paper, precision agriculture

ABSTRACT

Tampereenammattikorkeakoulu
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Carlier Niels & Desloovere Matthias:
Gebruik van UAS als onderdeel van precision agriculture in Finland

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Deze thesis is geschreven in het kader van een project met als doel het implementeren van een unmanned aerial vehicle (UAV) voor gebruik in de landbouw. Op vraag van een lokale boer met een groot stuk land, wordt er gezocht naar mogelijkheden om pest control effectiever en milieuvriendelijker te maken. Hiervoor wordt vertrokken vanuit het idee om een UAV te gebruiken om de gele meetpapieren voor insecten te controleren. Wanneer de hoeveelheid insecten op het papier een bepaalde waarde overschrijdt, weet de boer namelijk dat het is aangeraden om het betreffende veld te besproeien. Deze manier van werken maakt deel uit van het concept "precision agriculture" en er wordt geschat dat dit concept tot 75% kan besparen op meststof en pesticiden. Voor de boer betekent dit zowel een kostenbesparing als een positievere invloed op het milieu.

Er wordt verder ook onderzocht welk type UAV het meest geschikt is voor deze opdracht. Hierbij wordt rekening gehouden met bepaalde eisen zoals het feit dat het toestel autonoom moet vliegen naar de verschillende meetpapieren door gebruik te maken van een vooraf ingesteld vluchtplan. Ook wordt er gekeken naar de mogelijkheden op vlak van camera prestaties, sensoren en vliegtijd en wordt de optie onderzocht voor het vervoer en bevestigen van de meetbladen met het toestel.

Dit project toont algemeen aan dat de mogelijkheden voor het gebruik van UAV's in de agrarische sector zeer uitgebreid zijn. Het observeren van de gewassen, het besproeien evenals de combinatie van deze en andere functies kan hierbij zeer efficient uitgevoerd worden. Om vertrouwd te geraken met het onderwerp, worden UAV's en alle verwante begrippen hier eerst theoretsich behandeld.

Sleutelwoorden: UAV, landbouw, meetpapieren, insecten, precision agriculture

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Introduction

The farming season in Finland usually starts in the end of april. Due to the many lakes, not only the crops, but also many insects come to life at once in this period. This can become a problem for the farmers because a lot of these insects feed on the crops.

The goal of this thesis is to design or modify a UAV that can be used in the agricultural sector to monitor the presence of these insects. One of the local farmers came up with the idea of making his pest control program more efficient by using the advantages of unmanned aircraft systems. The technology is already widely used in the agricultural sector as part of precision agriculture. This is an ecological and economical friendly method of farming that uses new technologies to make farming more efficient, but therefore the crops need to be monitored very precisely.

At the moment the farmer makes use of measuring papers on which flies and other insects are caught. Based on the number of insects sticking to the paper, it is determined whether spraying is required or not. This means that the farmer has to collect all the measurement papers by himself on different locations on the field. This is a very time consuming job for him.

That’s where the (unmanned aerial system) UAS comes in. The idea is that the camera takes pictures of the insect measuring papers on all the locations of the field, so that the farmer receives the pictures of the measuring paper in real time or after the UAV flew its route. In addition it could be possible to add some extra mechanisms which would make it possible to remove the old measuring paper and add a new one. This would help the farmer to be even more efficient.

The main problem that has to be overcome here is the fact that the camera needs to be very precisely in front of the paper and take a picture from the right angle. If we want all of this to be done automatically, we have to come up with a solution for the UAV to firstly target the paper when in autopilot and then bring itself in the right position to take the picture.
Another interesting feature to keep in mind for this mission is the flight time of the UAV. The battery capacity should be determined, depending on the size of the farmers’ fields and the amount of stops the UAV has to take to shoot al the pictures of the papers.

List of abbreviations

BVLOS	Beyond Visual Line Of Sight
CW	Clockwise
CCW	Counter Clockwise
CE	Conformité Européenne
DOF	Degrees of Freedom
ESC	Electronic Speed Controller
FAA	Federal Aviation Administration
FC	Flight Controller
FCC	Federal Communications Commission
FPV	First Person View
GCS	Ground Control Station
GPS	Global Positioning System
IMU	Inertial Measurement Unit
LED	Light-Emitting Diode
LIPO	Lithium Polymer
MTOW	Maximum Takeoff Weight
RC	Radio Controlled
RF	Radio Frequency
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
RX	Radio Receiver
SAR	Search and Rescue
SDK	Software Development Kit
TAMK	Tampere university of applied sciences
TRAFI	Finnish transport safety agency
TX	Radio Transmitter
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
VLOS	Visual Line Of Sight
VTOL	Vertical take-off and landing

Definitions

UAS must always be considered as a number of sub-systems. There is the unmanned aerial vehicle (UAV) itself, often referred to as “drones” although this is a term which was first used by the military to define unmanned flying objects to destroy during tests. On the other hand there is the control system, its payloads and other subsystems such as: launch and recovery, support, communication, transport, etc.

Another commonly used term is remotely piloted aircraft system (RPAS). This type of UAS has a ‘pilot’ which operates the remotely piloted aircraft (RPA) mostly from a ground control station (GCS). (Demonstrating RPAS integration in the European aviation system, 2016)

This term exists because there also are UAS without a remote pilot, these are autonomous air vehicles. In general we will use the term UAV or UAS in our thesis from now on, because it includes all the types and exceptions.

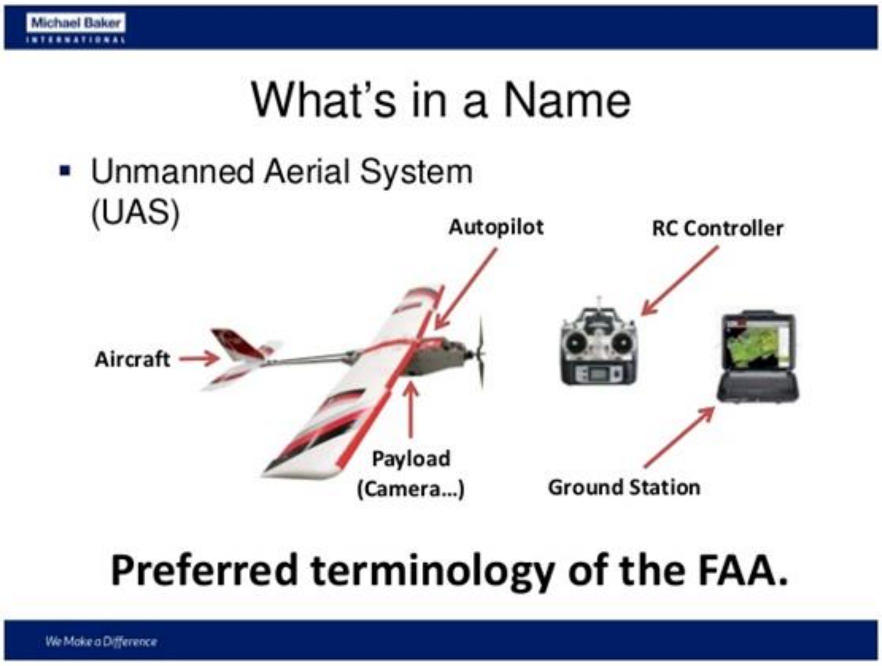


Figure 1: Overview unmanned aerial system (Tuschhoff, 2016)

1 What are UAS?

UAS's are an upcoming technology with a wide range of opportunities in many different fields e.g. agriculture, construction, photography, movie making, pipeline control, SAR,…

It is of course essential to integrate these UAV's into manned aircraft environment. To do this in an efficient way, some simple principles can be followed:

clarify to UAV pilots that it is impossible to fly near other aircrafts without adding a big amount of risk in getting an incident or accident, better identify the UAV so that avoidance actions can be executed more easily and eventualy which steps that can be taken to limit the chances that an UAV starts flying into active airspace. These principles will make sure that the UAS won't influence manned aircraft space in a bad way.

To implement these principles in a clear and easy to understand regulation is a difficult objective, but necessary for transparant functionality.

Depending of the field of use, other types of UAV's are desired. The big difference between UAV's and manned aircraft is the absence of an onboard crew. Unmanned aircraft have some advantages over manned aircraft. In many industrial and military purposes the possibility of a smaller sized aircraft is very desirable as they can fly closer to obstacles with less risk of safety e.g. flying near high voltage cables. Sometimes they can be used for operations which are otherwise impossible e.g. detailed inspections of cooling towers and chimneys. There are already many European states where this kind of inspections are taking place. (Aircraft systems, sd)

They are quickly deployable for emergency situations and with the upcoming issue of global warming, the least environmental pollution is also becoming a big advantage. Last, but not least, the overall cost to operate an UAS is generally much lower using a manned aircraft, for example a helicopter, for the same task. This includes: labor costs, fuel costs and maintenance costs. Some disadvantages are: privacy perspective, it's a new technology and people aren't totally comfortable with the idea of unmanned aircraft flying above their heads and taking pictures. There's also the possibility that people start hacking the software of the UAS and take over control or use the collected data for other purposes. (Austin, 2010)

2 Different kind of UAV's

2.1 Airships

2.1.1 What?

The different types of airships can be divided into two subgroups: blimps and zeppelins. These two are totally different from the fixed wing and multirotor designs. Instead of using a propeller or rotor to gain lift, the airship makes use of a kind of gas under pressure that's lighter than the surrounding air to stay in the air. The gases that are most often used to keep the airship in the air are helium and hydrogen. (Glossary of Airship Terms)

The difference between a blimp and a zeppelin is that a blimp has no supporting structure on the inside except for the envelope to keep the gas inside and withstand its pressure, which also gives the aircraft its form. A zeppelin consists of an inside structure made out of composite materials or plastic. The zeppelin or blimp is mostly covered with a foil of nylon or polyurethane.

The airships use one or more propellers with their accompanying engines and flight controls to steer the airship in the right direction. The blimp has two kinds of flight controls: a rudder to control the yaw movement and an elevator to control pitch movement.

The engines attached to the airship will provide the thrust that is needed for its forward movement. (Freudenrich, 2018)

Blimps and zeppelins are mainly used to make publicity at festivals and concerts thanks to their long flight time and economical use of energy. A blimp can also serve as an observation platform or act as an communication platform. Another advantages is that this UAV is very maneuverable and capable to change the direction of the airship very quickly without changing speed, or even flying stationary.

Figure 2: A 17M blimp from TCOM, this aircraft can be used as surveillance platform for military and civilian purposes. (17M Aerostat)

Figure 2: TCOM 17M (17M Aerostat)

2.2 Fixed wing

2.2.1 What?

The design of this UAV type differs a lot from the normal multi rotors that you often see in the streetscape. A fixed wing UAV is a configuration that closely resembles a manned airplane. The UAV makes use of a wing profile and a propulsive engine to generate lift to keep itself in the air. The control surfaces in the wings control the aircraft around his lateral, vertical, and horizontal axis. It gives the UAV the capability to pitch, roll and yaw. (Ben, 2015)

2.2.2 Advantages and disadvantages

One of the advantages of a fixed wing UAV over a multirotor is that it consists of a more basic design structure. The simpler structure ensures more operational time in the air because the maintenance and repair process is less complex than the multirotor UAV's. It is also more efficient because of the good aerodynamic design.

The biggest advantage of a fixed wing UAV is that it has more efficient aerodynamics that results in longer flight times and the possibility to reach a higher speed. This also gives the opportunity for a fixed wing type to stay in the air for a long time with a fairly small battery compared to a multirotor. This property gives the UAV the opportunity to scan large survey areas and do long air measurements in a certain area.

These fixed wing UAV's do not have the ability to hover like a multirotor or a normal civil helicopter. The aircraft must fly in a forward motion otherwise it can't generate lift if there is no moving air over the wings. This means that these configurations are not suitable for al kind of operations. One exception is the vertical take-off and landing (VTOL) configuration. This modification makes it possible for the UAV to change the direction of the generated thrust during take-off/landing and cruise flight and in addition it can land on areas that are otherwise difficult to reach. (De Roo, 2017)

2.2.3 The fixed wing UAV division group

The fixed wing UAV's are divided once again into conventional, flying wing and canard. Every type of fixed wing UAV has his own characteristics.

Conventional

Conventional fixed wing UAV's look like gliders. They can soare in the air for a long time and make use of a push or a pull propeller. They find their applicability in measuring the air quality and observation purposes e.g. environmental issues.

The DT18 from Delair (Figure 3)Figure 3: DT18 is an example of such a conventional UAV and this model is configurated with a V-tail. It is used to survey, monitor and inspect a certain area.

Figure 3: DT18 (DT18 HD, 2017)

Flying wing

A flying wing (Figure 4) is an aircraft with a complex design, it has the shape of a forward pointing arrow and has no fuselage neither a vertical tail at the back. The wings of this kind of aircraft are delta wings, due to its difficult design, it can't be controlled very easily. Also the stability of a flying wing is very bad, to control one of these, a good autopilot is really a must.

These type of UAV's are often used to do area scans of big plots of land during which they are able to count the plants, and measure the growth of the plants. Measuring the quantity of sand on a construction site is also one of the possibilities where this kind of UAV can be a huge advantage, because it can be done more accurate and faster than a land surveyor can do. (Types of Drones, 2018)

Figure 4: UX5 Delair (http://delair.aero/ux5-2-3/, 2017)

Canard configuration

A canard configuration has his horizontal stabilizer mounted before the main wings instead of on the tail. The canard on a plane is used in two ways: to generate lift and reduce the main wing loading or to create a better pitch control and to make the plane better manoeuvrable. (Alek Udris, 2014)

The aircrafts design gets more efficient with the use of a control/lifting canard. It is therefore also used for long duration flights. The applications of this aircraft are diverse, from search and rescue operations to delivering cargo.

On (Figure 5) is an example of an unmanned vehicle from Piaggio Aerospace. The P.1HH HammerHead is powered by 2 turboprops and used for Intelligence, Surveillance and Reconnaissance (ISR) missions. (http://www.p1hh.piaggioaerospace.it/)

Figure 5: Piaggo P.1 Hammerhead (http://www.p1hh.piaggioaerospace.it/)

2.2.4 Usability for this project

For this project a fixed wing UAV is not suitable because it must be able to inspect the agriculture paper and therefore it must hover in one place to take a picture of the paper.

2.3 Rotary wing

2.3.1 What?

The rotary type is the UAV that will be recognized by most people as a “drone”, it consists of a few motors with the assigned propellers that are pointed upwards. Underneath the motor and propellers you have the body of the UAV and the landing gear is mounted on the bottom, the cargo and payload are usually attached to the airframe or landing gear structure.

Most of the rotary UAV’s are multirotor types but there are some that only use one motor to fly through the air. These are based on the design of a helicopter.

2.3.2 Advantages and disadvantages

One of the most important features of a multirotor is that the UAV has the ability to hover at the same place.

The fact that a multirotor makes use of rotating propellers to keep its vertical position in the air ensures that it takes a lot of energy to keep enough amount of lift to fly as compared to a fixed wing UAV. This leads to the conclusion that this type has a much shorter flight time for the same battery size and is less efficient than a fixed wing UAV.

2.3.3 The rotary RPAS division group

One of the most popular multirotor UAV’s in the rotary category is a phantom from DJI (Figure 6). It is a quadcopter, this means that it uses four propellers and motors to gain its lift and thrust. This UAV is easy to fly because a compass and a global positioning system (GPS) are implemented in the control mechanism. This product is mostly used by photographers and creators to capture aerial pictures and movies.

But a multirotor UAV offers more opportunities than only capturing pictures and videos for fun. Because of its four rotors, it is possible to perform fast and versatile movements in all directions without the need to substitute in stability.

In combination with its small size, it is perfectly designed to perform difficult monitoring tasks that are otherwise impossible to manage. (Brown, 2017)

Figure 6: DJI Phantom 4 (Phantom 4 series)

The black hornet (Figure 7) is a military micro UAV developed in Norway, and it is used by the Norwegian, United states, Australian and British Army to perform spying missions and collect important data without being noticed. It is a drone that makes use of one motor and two propellers, it has the same configuration of a helicopter. This is an example to make clear that there are also UAV's with one engine that can be a multirotor. (Proxy Dynamics FLIR)

Figure 7: Black hornet (Black Hornet Nano, 2017)

With this UAV it is also possible to make sure that an area is free from danger without taking the risk of losing a scouting soldier. The drone has three camera's: one looking forward, one looking straight down, and one pointing downward at 45 degrees. With its GCS it is possible to control the UAV based on the images of the cameras, the GCS receives the images live. The UAV can be a great help for soldiers on a mission. It‘s easy to carry because of the low weight and its small size, it is small enough to fit in one hand. (Black Hornet Nano, 2017)

2.3.4 Aerodynamics of a multirotor UAV

In contrast to fixed wing aircrafts, rotary wings get their lift force by horizontally positioned rotating airfoils. These airfoils use the same principal as conventional propellers and wings to generate lift. Because of the shape of the airfoil, air molecules will move faster at one side compared to the other. This higher velocity creates a lower pressure and additionally this difference in pressure between the two sides generates lift. The direction of this lifting force is from the higher to the lower pressure. (Figure 8)

Helicopters and multirotors are both rotary wings, but multirotors differ by using three or more rotors to create their lift. The speed of rotation (ω), which is measured in rounds per minute (RPM), gives the rotor its thrust (T) to create lift. The higher the speed, the more lift this rotor will create. (Figure 9, Left)

When a rotor spins, the created torque force (Q) will try to spin the body of the aircraft the other way. A helicopter solves this problem by using a tail rotor to create thrust in the opposite direction. For the multirotors, each rotor turns in the opposite direction than the rotor next to it. This way the torque forces will neutralize each other and the UAV can stay in the same position. (Figure 9, Right)

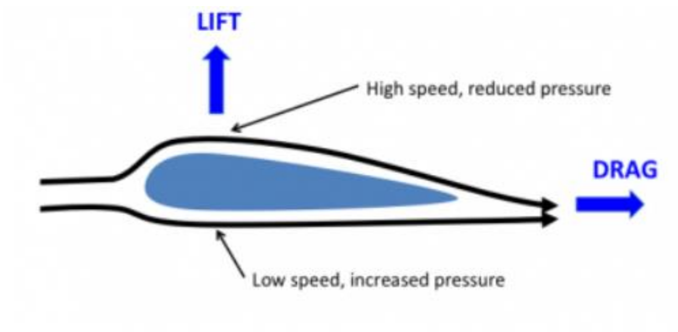


Figure 8: Lift generating airfoil (aviation stackexchange, 2017)

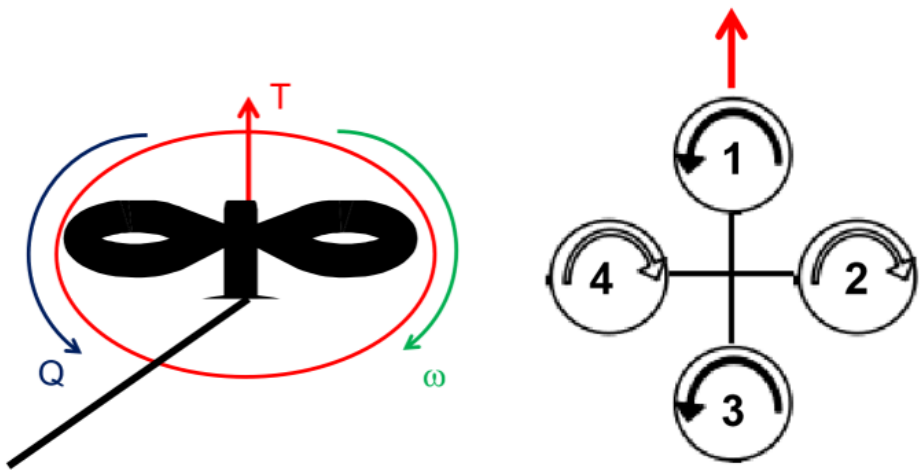


Figure 9: Multirotor aerodynamics (De Roo, 2017)

2.3.5 Multirotor operation

To go straight up and down in a vertical line, it is sufficient to higher or lower the speed of all the motors at the same time and at the same amount. When you want the multirotor to do roll, pitch or yaw movements, the motors have to adapt their speed in relation to each other. The roll and pitch movements are caused by increasing the speed of the motor on that side of the multirotor you want to roll. The speed of the opposite motor will decrease. This action helps the roll movement and at the same time it makes sure that the aircraft won't make a yaw movement.

A yaw movement is created by increasing the speed of the motors that are rotating in the opposite direction of the movement you want to cause. That way the torque force will get stronger in the opposite direction, which causes a rotation of the whole multirotor's body. This means that a yaw movement in the counter clockwise (CCW) direction, needs an increase in speed of the clockwise rotating motors/rotors. (Figure 10)

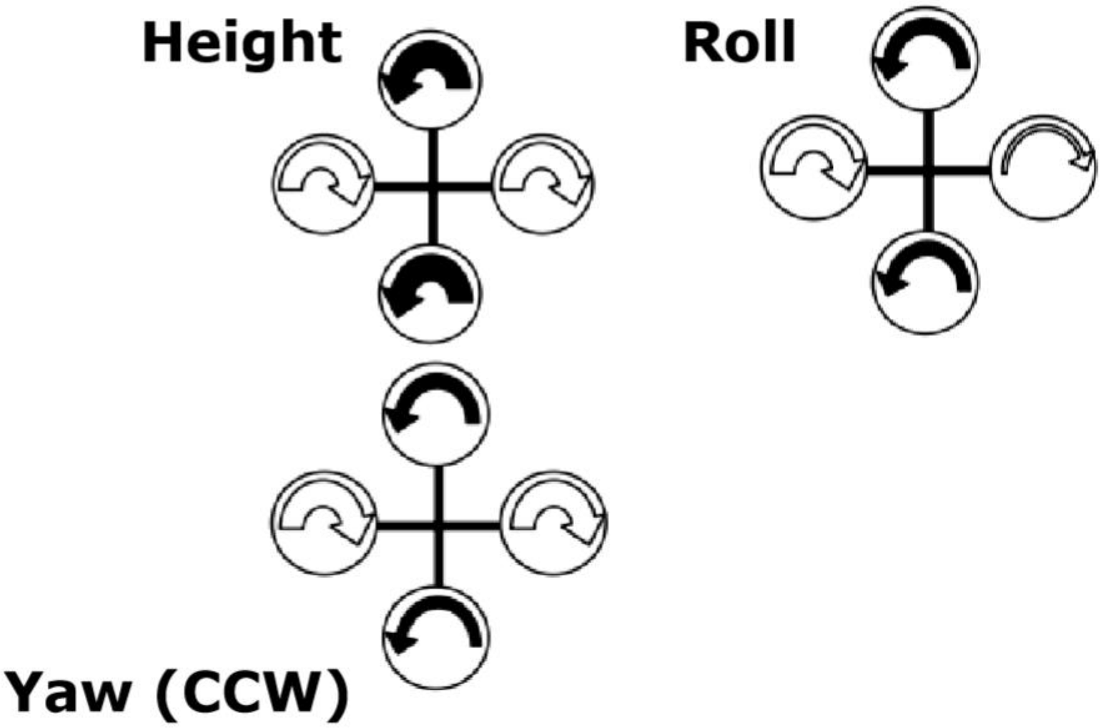


Figure 10: Multirotor movements (De Roo, 2017)

2.3.6 Usability for this project

For this project a multirotor UAV is most suitable because it has the ability to hover on the same place and that is important to take a good and sharp picture from the measurement paper. (Roo, 2017)

3 Electrical propulsion system

3.1 Single motor propulsion system (without flight controller)

The main components of a single-motor electrical propulsion system are: a lithium polymer battery, electronic speed controller (ESC), receiver (RX), transmitter (TX) and a brushless motor. The battery supplies the UAV with power and is connected to the ESC, which is connected to the motor and receiver. The receiver receives the signals from the linked transmitter on the ground and controls the ESC with this signals. With the transmitter it is possible to control the speed of the motor from the ground. The speed of the motor is additionally determined by the signal of the electronic speed controller. This system is mostly used for manual radio controlled aircrafts, for example the RC hobbyplanes in the recreational clubs. This single motor propulsion system is made for conventional RC fixed wing planes. (Propulsion system, UAV Guide)

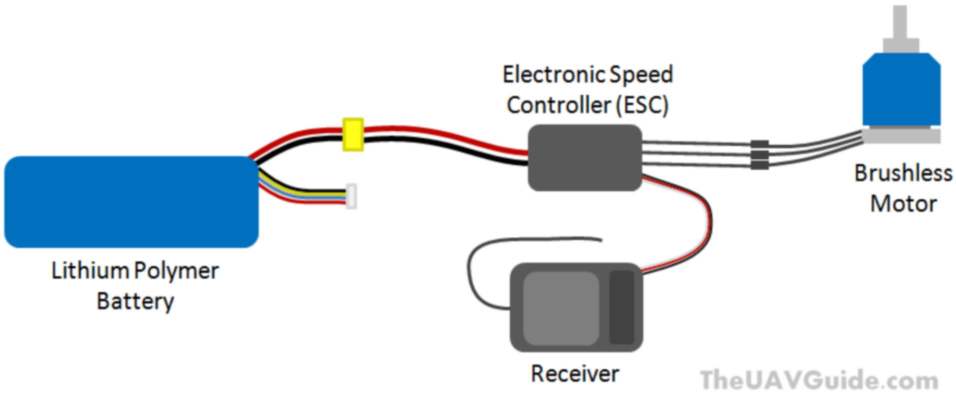


Figure 11: Single motor propulsion system (Propulsion system, UAV Guide)

3.2 Multirotor motor propulsion system

In contrast to single motor propulsion systems, multirotor systems mostly require more than one motor. Another necessity that can't be forgotten is the flight controller and the power distribution board. As with the previous propulsion system the RX is receiving the transmitting signal from the TX and gives it to the input of the flight controller. The flight controller (FC) is a small electronic board with the function to adjust the right speed of each motor in respons of the input. The FC gives that resulting signal to each ESC of the corresponding motor (Clym, 2014). The power distribution is needed to provide power for al the flight controllers and the motors (Propulsion system, UAV Guide). This motor propulsion system is especially made for multirotors, the flight controller is defintely needed because man isn't capable to control the speed of three or more motors at the same time.

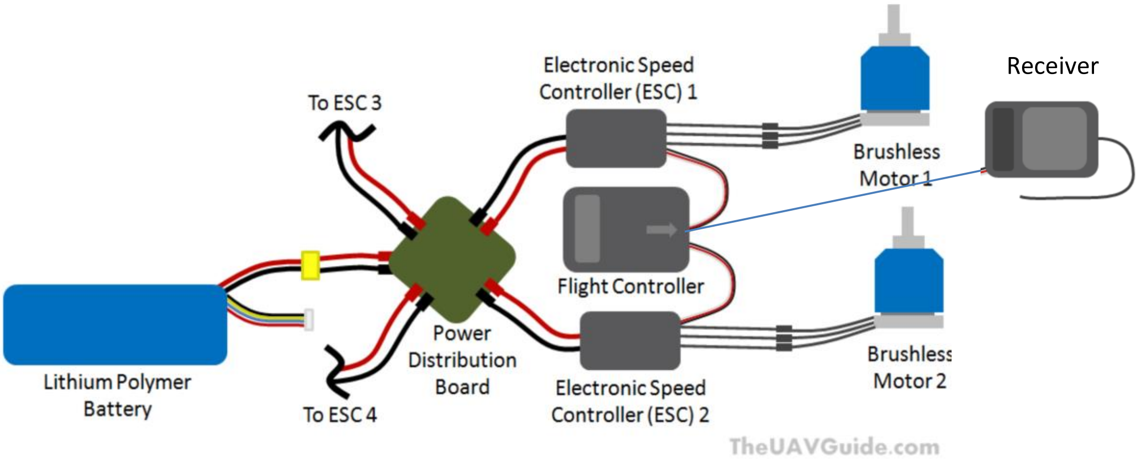


Figure 12: Multirotor motor propulsion system (Propulsion system, UAV Guide)

3.3 Electrical motors

To lift of a multirotor UAV, DC brushless motors are often used because of the absence of brushes that can wear out. Without brushes, the maximum speed of the engine is also higher than normal DC motors. The brushless motors also have the advantage of being more efficient than the motors with brushes.

Every motor is characterized by its specifications, one of the most important features is the KV value of the engine. The KV value stands for the number of revolutions per minute per volt that the engine runs without load. The KV value determines whether an engine runs slowly or quickly and if it has a high or low torque. A high KV value means the RPM is high and the torque is low. A low value on the other hand means that the RPM is low and the torque is high.

For this project the official motors of DJI Matrice are used and the KV value for this type of motors has an amount of 350 KV. The used battery is 22,2 V, if we make a quick calculation the speed of the motors will be 7770 rpm (350 x 22,2 = 7770).

3.3.1 Principle of brushless DC motor

There are two kinds of brushless motors: inrunners and outrunners. Both engines operate according to the same principle. They have both a stator and a rotor.
The only difference is that for the outrunner there is a permanent magnet which is placed on the moving axis and for the inrunner the coil is placed on the axis and the housing is the moving part.

3.4 Li-Po Batteries

Lithium polymer (Li-Po) batteries are used in UAV's because these batteries have a very high power to weight ratio and can fit in almost any shape. They can contain very high capacities and high discharge rates. The charging time of these batteries is also fairly limited. In one to two hours these batteries are charged. (global battery market industry report review, upsbatterycenter)

These are the batteries that are best suited for long duration flights because they are the most efficient. This can be concluded from the graph (Figure 13), but nevertheless these batteries are dangerous if not used properly. Li-Po batteries can catch fire and explode if they are over charged or discharged to a very low value. When mistreating the batteries e.g. the appearance of punctures or dents after a hard landing or when accidently dropping the battery while carrying it around, can lead to the battery catching fire.
A Li-Po safety bag can be a good precaution to use when loading the batteries. This bag made primarily out of glass fibre is fireproof and designed to stop or slow down a fire. (James, 2016)

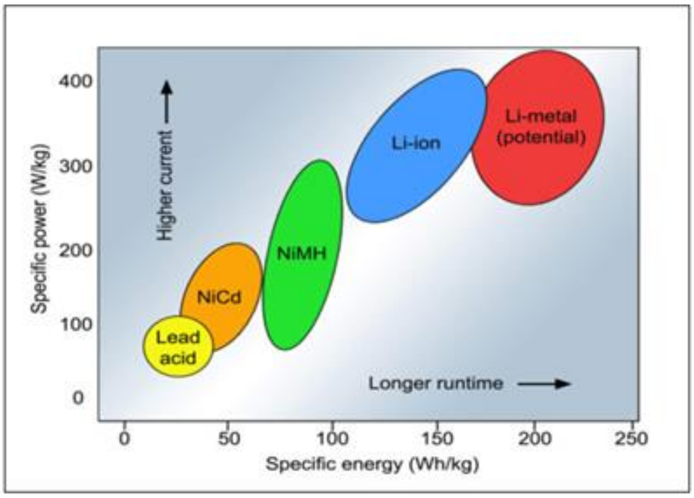


Figure 13: Comparison of energy density for different batteries

(global battery market industry report review, upsbatterycenter)

Another small disadvantage for Li-Po batteries is their shorter lifespan, an average Li-Po battery lasts about 200 to 250 charge cycles.

3.4.1 The right battery for our project ?

There are three important characteristics that need some extra attention before buying a Li-Po battery: the capacity of the battery, the cell count/voltage and the discharge (C) rating. Figure 14 is a detailed picture of a Li-Po battery with all the characteristics.

Figure 14: Specifications of the LI-PO battery (Lipo Guide, Roger's Hobby Center)

The capacity of the battery is a measurement of how much power the battery can hold. The unit of measure is in milliamp hours (mAh). The higher the number of capacity, the longer the runtime will be. It shows how much drain that can be put on the battery to discharge it in one hour. In our case the conversion would be:

5000 mAh = 5 Amp hour (5Ah)

The cell count/voltage: A Li-Po battery has a nominal voltage of 3.7 V for each cell, it is also possible that two or more cells are placed in series to get a higher voltage. In Figure 14, there are two cells in series that gives a nominal voltage of 7,4 V. This can be concluded by the 2S (two cells in series) or the 7,4V at the battery package.

The voltage of the battery pack has an influence on the speed of the aircraft, it determines the RPM of the brushless motors. The higher the voltage, the higher the RPM of the motor. (Lipo Guide, Roger's Hobby Center)

The discharge rating or C rating of a battery is a value that is used to explain how fast a battery can be discharged safely without damaging the battery.
To find out what the maximum continuous amperage is, you have to multiply the number before the C with the capacity of the battery. In this case the discharge rating is 50 C.

50 C = 50 x Capacity in Ampere C discharge rating of the battery = 50 x 5 = 250 A

The resulting amperage of 250 A that we become, is the maximum amount of load that the battery can handle without damage.

Besides this there is sometimes a second C rating for charging, this rating gives the maximum amperage on which you can safely charge the battery. In our case the C rating is 3C, if there is no charging C rating on the casing, then it is safe to simply recharge with 1C. (Lipo Guide, Roger's Hobby Center)

3 C = 3 x Capacity in Ampere C charge rating of the battery = 3 x 5 = 15 A

4 The flight controller and its associated equipment responsible for flying

The flight controller is the heart of the drone. If this mechanism fails, the drone will crash. Aside of that, also the associated equipment must function perfectly so that the drone is able to fly accurately. In this chapter all the equipment and systems that are needed for this agricultural experiment will be explained shortly.

4.1 Flight controller

As mentioned before, the flight controller is very important for the drone. We can differentiate roughly three different ways of flying with each their respective type of flight controller. There are flight controllers for racing and freestyle, aerial photography and autonomous flights.

The flight controller is an onboard computer that combines control information from the pilot and adaptive information from the sensors to arrange the speed of the motors and fly the aircraft in the direction that the pilot desires. A command from the pilot with the sticks will be received by the flight controller through the receiver. The flight controller does the calculations, necessary for the speed of the motors, with the implementation of accelerometers, magnetometers and GPS. These signals generated by the flight controller are sent to the ESC's of the motors. The combination of the different speeds of each motor will ensure that the UAV makes the right movements according to the input of the pilot. (Clym, 2014)

Most of the flight controllers especially also have a second function, it provides the real-time status of the UAV. These Telemetry information[1] will be sent to the supporting ground station and includes:

- aircraft status, position, velocity and altitude,
- remaining battery capacity information,
- sensor information (Compass, IMU, Satellite positioning),
- return to home status.

  (DJI Developer, 2017) (Reid, 2017)

[1] Telemetry information: Real time information from the UAV to the groundstation about key components like battery level, position…

4.1.1 FPV Drone racing flight controller

For flying FPV (first person view) drone racing or flying acrobatic with the UAV, a fast responsive flight controller is necessary and it needs to be small and light to mount on the small racing quads. The flight controller must be able to recover very fast from high roll angles and any movement that you make with the sticks of the transmitter must provide a response from the UAV as soon as possible. (Smith, 2016)

Racing flight controllers aren't so expensive due their absence of GPS and altimeter, the majority of the FC's uses only an inertial measurement unit (IMU). Mostly there is a possibility to add a GPS or altimeter but most of the user don't care about it and like to fly it manually. The IMU gives the UAV a six degrees of freedom[2] (DOF) that is the bare minimum to fly the UAV. The flight controller controls the situation of the UAV based on a three axis accelerometer and a three axis gyroscope from the IMU. The FC's of racing UAV's are mostly opensource so it's possible to put on other software and adjust settings to your own flying style. An example of a racing flight controller is the CC3D, this is one of the cheapest and most common used racing flight controllers. (Fpv racing flight controller buying guide , 2017)

Figure 15: Racing quadcopter (Storm racing drone , sd)

Figure 16: Typical racing flight controller CC3D (Flight controllers, sd)

[2] Six degrees of freedom: is the freedom of movement of a rigid body (UAV) in the three-dimensional space.

4.1.2 Aerial photography flight controller

While you are flying to make movies and photos, the drone need to fly as stable as possible to have a smooth image footage. That means that the flight controller has to have very quiet flight characteristics and a slow maneuverability.

Aerial photography flight controllers are more advanced than the FC’s for racing quads, besides the IMU there is a GPS, magnetometer, altimeter and sometimes sense and avoid sensors implemented. Even these flightcontrollers have fail safe capacities like automatic coming home when the battery is low or give a warning that the drone is flying to far and will lose his signal. In stead of having a 6 DOF flight controller with the racing quads, the flight controllers for aerial photograpy has a 10 or more DOF board with the implementations of GPS, altimeter, magnetometer… But the most important thing is that there is a good gimbal and camera is connected to the flight controller and that the flight controller is able to sent the video to the groundstation. (Smith, 2016)

The FC’s for these UAV’s are mostly integrated in the UAV itself for instance with the DJI Inspire or DJI Spark. There exists also separately flightcontrollers like Ardupilot APM and DJI Nava M – V2 to build your own photographical UAV. With these systems it is possible to attach GPS, Light-emitting diodes (LED’s), gimbal and camera and other compatible systems.

Figure 18: DJI Inspire with integrated flight controller (Brown J. , sd)

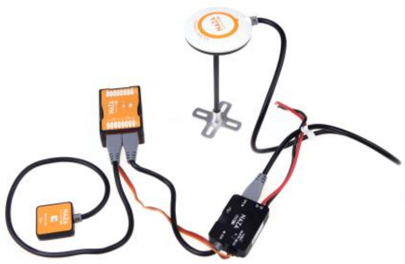


Figure 17: DJI NAZA V2 (Flight controller and GPS, sd)

4.1.3 Flight controllers for autonomous flights

The flight controllers for autonomous flights are quite similar as the Flightcontrollers used for aerial photography. The FC’s for autonomous flights have also many sensors that can be implemented, the only difference between these FC’s is that for autonomous flights there is a possibility to program the drone more. This FC allows you to do more than just an automatic flight, It is possible to develop an application for a certain goal. For instance the 3DR pixhawk is such a FC that is fully programmable, the FC has an opensource layout so it is possible to make your own program. (Drone Flight controller: 3 type of flying style, 2017)

For the DJI matrice 100 there is a supporting DJI SDK kit, it is possible to program on the existing software from the UAV. This ensures that there are fewer bugs in your program and you are sure that you are not changing important software from the DJI matrice 100.

Which is also important characteristic of this FC is that this FC is equipped with a backup system where different sensors are redundant. When one of the sensors is stuck, the other one takes over the function. For example the 3DR pixhawk has an redundant power supply, automatic failover and a microSD card for high-rate logging over extended periods of time. (Top 5 Best Advanced Flight Controllers For Aerial Photography and Plane FPV, 2016)

Figure 19: Seperate flightcontroller 3DR Pixhawk (Drone parts , sd)

4.2 IMU

The IMU is a measurement device that measures the acceleration and the angular rate from a body in our case it is measured from the UAV. It has the function to keep the UAV stable and balanced as it flies, it provides flight stabilization that makes it easier to control the drone. The IMU contains 3 accelerometers and 3 gyroscopes.

4.2.1 Accelerometer

The accelerometer measures the rate of acceleration along the X,Y,Z (pitch, roll and yaw) of the UAV. The accelerometers sense the static and dynamic acceleration, the acceleration is measured in m/s^2 or in G-force and 1G equals 9,81 m/s^2.

4.2.2 Gyroscope

The gyroscopes measure the angular speed along the X,Y,Z axes (pitch, roll and yaw) of the UAV. The angular speed is represented in units of rotations per minute (RPM), or degrees per second (°/s). The problem of monitoring a body or a UAV only with a accelerometer is that isn’t possible to know the exact orientation. Accelerometers are not influenced by gravity unlike gyro’s are affected.

To know the precise orientation of the UAV, the flight controller needs both information from the accelerometers and gyro’s. The FC will calculate with the statistics from the accelerometers and gyro’s the orientation, position and velocity. First the acceleration is integrated with the time, together with an estimation of the gravity, to calculate the current velocity. Then the velocity is integrated, to calculate the current position of the UAV. (ACCELEROMETER, GYRO AND IMU BUYING GUIDE, sd)

4.3 Magnetometer or compass

The magnetometer is a sensor that measures the magnetic direction of the UAV that is influenced by the earth’s magnetic field. This sensor has the function to know in which direction the drone is faced. Compass sensors are very sensitive for magnetic interference, that’s the reason why this sensor must often be calibrated. These magnetic interference can be caused by magnetic influence from wires, motors, ESC. Even by transporting the UAV in the car can the compass be confused from the magnetic interference from the speakers. (Beginners guide to drone autopilots (flight controllers) and how they work, 2015)

4.4 Altimeter

It is always important for the UAV to keep a safe distance above the ground. That’s why it is necessary to have some kind of sensing device to give this position as accurate as possible, especially when flying missions are close to the ground like in our case.
This can be measured either by radio waves (RADAR), optical sensors (LIDAR), GPS or barometric.

4.5 Camera/payload

It is very important for the farmer to get a clear image of the paper because it determines whether or not to spray his fields, which has a direct effect on the cost status. TAMK university has two UAV’s from which can be chosen, the DJI Matrice with the DJI zenmuse X5R camera and the DJI Phantom 4. These are both quadcopters, but differ in size and performance. (Zenmuse X5R)

4.6 GPS

The GPS can be a huge help to fly certain routes on big open fields with the place of the measurement papers set as waypoints. It is on the other hand not precise enough to stay stable and hover on one place in front of the paper with only the GPS signals. The precision of the GPS is only 2,5 meter, that’s why obstacle sensors are required when flying close to the ground and other obstacles such as trees, plants, farming machinery,…

4.7 Autopilot

Together with the flight controller this system controls the UAV through the air when no one is controlling it from a ground station. When adding an autopilot to the control system, the farmer saves even more time for doing other tasks while the UAV flies autonomously to all the pre-set places, takes pictures and send them to an extern computer or stores them on a storage device in the UAV all by itself. This can be done easily with the DJI Ground Station app. More advanced programming can be done with the software development kit DJI SDK.

4.8 Ground equipment

When the flight path of the UAV is fully planned beforehand, the flight can be flown totally autonomously in theory. However a radio controlled (RC) controller will always be recommended because of the possibility to take over control in hazardous situations or when the pilot wants the flight to be cancelled for some reason. Together with this it can also be handy to have a real-time connection with the camera of the UAV to follow the route whenever you want. This is also a psychological support to get the feeling in keeping some kind of control and observation over the UAV and its mission.

4.9 Sense and avoid system

A sense and avoid system gives the UAV the possibility to sense objects and automatically adapts its flight path to avoid it. The sense part and the avoid part are two different systems that can be seen apart from each other. The technology has many different implementations. Some UAV's can only sense objects from about 1 meter in front of them and then just start hovering in the same place in front of the object, while other more advanced systems have the ability to sense obstacles and airborne objects from several hundred meters away in every directions and also have the ability to automatically avoid this objects.

The aviation authorities are mostly concerned with the airborne collision avoidance while UAV manufacturers are more focused on obstacle detect and avoidance systems to meet the demands of the customers. (Snow, 2017)

The sensing part can be accomplished by ultrasonic sensors, optical flow sensors, camera's or a combination of these technologies. (Current development of UAV sense and avoid system, 2016)

Despite the rapid evolution in technology, these systems aren't perfect and fail-safe of course. So no matter how advanced this technology gets, a certain amount of responsibility and good common sense will always be needed.

For the practical implementation of this project in the agricultural sector, it is highly recommended to make use of such an avoidance system to firmly move from one field to another without the risk of crashing into a tree, fence, crops or other objects.

5 Precision agriculture

Precision agriculture is a farming method based on the idea of giving the right crops the exact amount of resources they need to grow big enough and to keep them in good condition. This resources can be water, pesticides, fertilizers and other nutrients. It also involves the use of information technology and many others such as sensors and robotics to optimize every aspect of farming as good as possible (Schmaltz, 2017). When this method is carried out efficiently, it results in a large saving of time and pesticides which directly influences the economical and ecological aspect in a positive way.
This results in an ongoing research to constantly find new and better ideas to implement in this farming method. The introduction of the global positioning system (GPS) was the first big step forward for precision agriculture. With this technology, farmers were able to drive and navigate their agricultural vehicles automatically by using an automatic steering system which is controlled by a connection to the sattelites that gives it the right coordinates to maintain its position on the field. Human errors can be strongly reduced with this technology.

5.1 The role of UAV’s

To know what resources the farmer has to use and when and where to deploy them, a precise observation of the different parameters of the crops is necessary to know the condition of the plants. There parameters include the growth, colour and the amount of water and nutrients in the crops.
The growing technology of UAV’s has given some new opportunities in this case. One of the biggest is the usage of multispectral cameras to observe the condition of the plants from above. Especially a fixed wing UAV can do the scanning of a large area in a short amount of time and without using a lot of energy. The same applies to the spraying of the fields, this is mostly done with specially equipped multirotor drones. Besides these two commonly used methods, there are many more possibilities in this matter. The project, where this thesis is about, is one of them. Monitoring the insect measurement papers on your own is a time consuming and monotonous job, which makes it easy to make mistakes due to a lack of attention. A self controllable UAV makes this task a lot easier and the job can be planned precisely beforehand. Although, no matter what the benefits are, this technology isn’t flawless and therefore it is still important to keep an eye on the UAV while it is doing its tasks. The electrical equipment can always fail and also the external factors in the environment can change faster than you think.

6 The choice of UAV

At Tampere university of applied sciences (TAMK), there are several UAV's available to use for this thesis. As previously indicated a rotary UAV is best suited for this project because of the hover capability that these types have. TAMK has a DJI Phantom 4 and a DJI Matrice with DJI zenmuse X5R in his possession in the category rotary wing.

To determine which UAV is best suitable for the project, some research has to be done about the following parameters: camera quality (payload), battery (flight time) and range. Also the possibility to program the UAV for automatic flight is a deal breaker.

6.1 Camera

It is very important for the farmer to get a clear image of the paper because it determines whether or not to spray his fields, which has a direct effect on the cost status.
That is why a camera test was done to determine which of the two quadcopters is best suitable for the farmer's needs. In advance it would be obvious that the camera of the DJI Matrice would be the better option because it has a smaller FOV (field of view) in contrast to the DJI Phantom 4, but the Phantom has more Megapixels than the Matrice so a test can give a clear answer to this question.

The camera tests consisted of taking multiple pictures of a test paper on a certain distance. The photos were taken at a distance of 0.75 m to a distance of 1.5 m with the DJI Phantom 4 and DJI Matrice. The distance of 0.75 to 1.5 m is the average distance that the UAV will hover in front of the measurement paper. The test was done with exact the same camera settings (same ISO and aperture value) for the Phantom and Matrice.

If we compare the pictures from the Zenmuse X5R and Phantom 4, it becomes clear that the pictures from the DJI Matrice with the Zenmuse X5R camera are sharper and closer.
Figure 20: The sharpness test in detail, the picture of the Zenmuse camera on the leftside is sharper and clearer than the right one of the Phantom 4.
Considering the zoom of the camera the photos of the Matrice (left side) and Phantom (right side) can be compared. These two pictures are taken from a distance of 0,5m. It can be concluded that the test paper is closer in the frame on the picture from the DJI Matrice, taken with the DJI Zenmuse Camera.

The closer the subject comes in the frame, the more distance the quadcopter can keep between lens and paper. In photography terms this means that the left picture is taken with a greater focal length than the right picture.

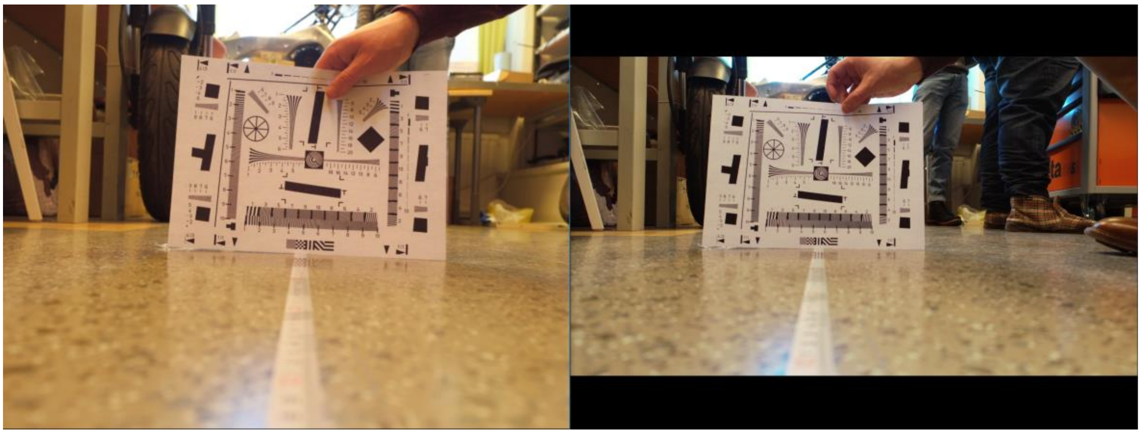


Figure 20: Test paper distance measuring

6.1.1 Conclusion

Concerning sharpness and zoom area, the DJI Matrice with the Zenmuse camera has the best results. The Zenmuse camera has also the advantage that the objective is interchangeable. At this point the best option is to put a zoom lens on the camera for the first test flight, this will be recommended because the UAV needs to keep a safe distance of more than half a meter between itself and the measuring paper considering the accuracy of the GPS position which is about 2,5 meter and in the assumption that the obstacle sensors won't be available in time.

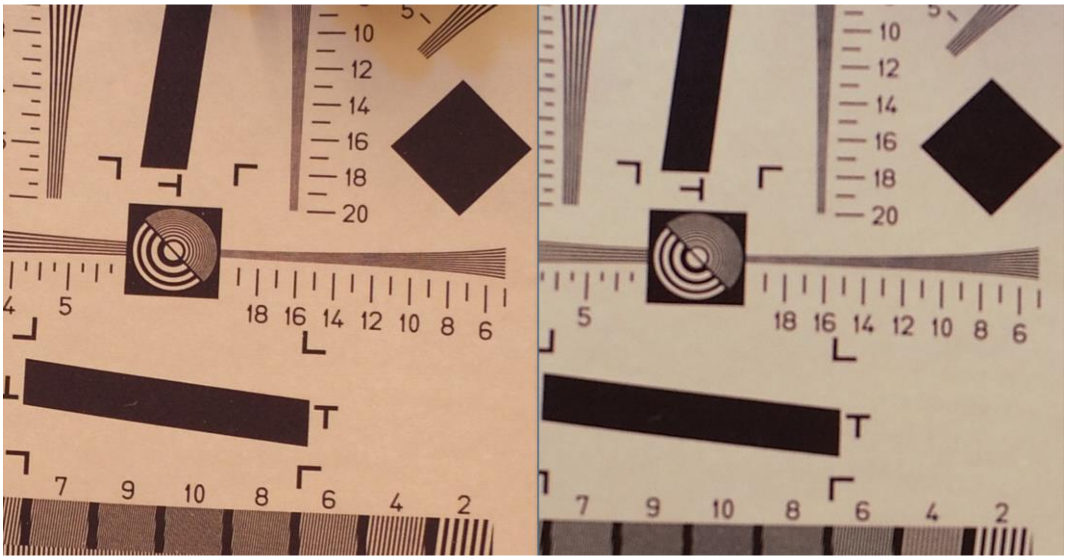


Figure 21: Test picture result (Left DJI Matrice 100 ; Right DJI Phantom 4)

6.2 Battery/ flight time

The flight time of the phantom 4 is 28 minutes when using the TB48D batteries, which is the case for this project, and when flying in optimal flight conditions. This means in calm weather conditions and when the speed of the UAV is constant. For the Matrice 100 the flight time can be extended up to 40 minutes with an extra battery slot. The actual flight time however is strongly influenced by the payload which can vary a lot for the customizable Matrice 100. For example when flying with one battery with a payload of 500g (which is approximately the weight of the Zenmuse X5R camera and gimbal combined), the flight time goes down from 28 minutes to 20 minutes. If the payload goes up to a maximum of 1kg, the flight time will be approximately 16 minutes. (Matrice 100 Specs)

6.3 Range of the UAV

This depends whether the device is in federal communication commission (FCC) mode or in Conformité Européenne (CE) mode. In the USA they use FCC mode. In Finland, which is part of the European Union, CE mode is used and this has an influence on the range that you can reach with your UAV. They are both certification standards which add limits to the use of electromagnetic radiation. These limits are necessary to protect the electromagnetic spectrum so interferences between different devices are avoided.

The electromagnetic power limit of the frequency band is more limited in CE mode so this explains why the range of the same device is more limited in Europe. (Selecting the Right FCC/CE Compliant Wireless Module, 2017)

For our UAV, the DJI Matrice 100 and flying in Finland, the range when flying in unobstructed area without any interferences is limited to 3,5 km. To compare, the range would go to 5 km when using FCC mode. What kind of mode your device will use is determined by the location of your GPS. (Matrice 100 Specs)

7 Insect monitoring

As previously stated the measuring papers are used to get an idea of the amount of insects that are present in the vicinity of the field. There are different ways to place these papers in the field. They can be either flat and placed on a stand between the crops or wrapped around a cylindrical structure and mounted on a pole. Either way the function is the same and it is important that this function won't be influenced by any external factors. For this project the UAV will be the new external factor so we have to make sure that its presence will be without any disturbance.

7.1 Removing the measuring paper and attaching a new one

This issue was handled in collaboration with some Finnish students who are working on a project for the same topic. They already did some research about what the best design would be for attaching the measuring paper in the field. Their design of a mounting structure for this paper is based on a cone structure that fits in its corresponding hollow cone shaped place on the ground. The massive conus contains a structure to attach the paper and an eye closure to pick up the whole structure. The structure with the eye closure and the measuring paper is removable and can be picked up by the UAV. The idea is that the Matrice collects the used measuring paper and places a new one with his hook structure attached to it. Their designed prototypes will be implemented in this thesis and a supporting component will be made to attach the hook on the UAV.

7.2 The maximum payload of the drone

Before the developing of this structure can be started, it is important to know how much payload the UAV need to handle. This determines not only the weight of the new attachment, but also the maximum operation time of the Matrice. This parameter runs parallel with 6.2 Battery/ flight time. A short calculation needs to be made here.

DJI Matrice (with TB48D battery)	2431g
Zenmuse X5R with gimbal	583g
Guidance sensors front and back	173,2g
Total	3187,2g
Maximum Takeoff Weight (MTOW)	3600g
Maximum extra payload	412g

(Matrice 100 Specs)

7.3 Attaching the hook to the drone

The idea of this structure followed out of the design of the Finnish students, they already made a CAD design of the hook in Solidworks that could be adjusted to make it fit on the drone. The biggest concern about the Finnish design is that the hook would be too long to be attached underneath the drone. This can lead to some dangerous situations when flying close to the ground or the crops, or when the drone needs to do an emergency landing.

On the other hand, the hook must be long enough so that the camera will be able to keep the hook in its field of view. When the camera is tilted down, it won't be able to manage this when the hook is about the same length as the lens. The total height from the ground to the bottom of the drone frame is only 149 mm. (Figure 22)

Therefore a compromise between these both problems had to be found.

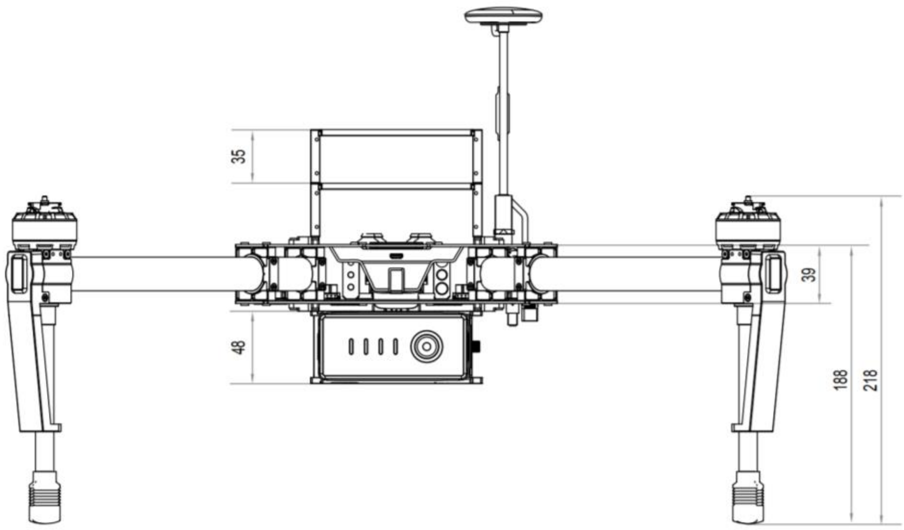


Figure 22: Dimensions DJI Matrice 100 (DJI, 2016)

Three possible solutions were found to optimize the position of the hook:

1. make the connection to the hook of a flexible material;
2. use a retractable hook so that the hook can fold in if the drone lands;
3. make an extension to the landing gear so that the frame is slightly higher than before.

The extension of the landinggear seems to be the better solution because then it's possible to use a fixed hook that won't move when you try to pick op the supporting structure of the measurement paper.

There is already an extension structure for the landing gear of the DJI Matrice. That structure is designed in that way that the extension structure screws on the existing landing gear. A German company designed these extensions with the screw thread, it is even possible to connect more than one extension part on the landing gear. The extensions have a length of 55 mm that results in a lengthiness of 50 mm of the landing gear because of the screw thread that in fits in the main landing gear. The price of the landing gear extension is 69 euro for four extensions. (DJI Matrice 100 - Landing Gear Extension, sd)

Figure 23: Extension landing parts DJI Matrice 100

Figure 24: Extension landing gear parts that fit in eachother for DJI Matrice 100

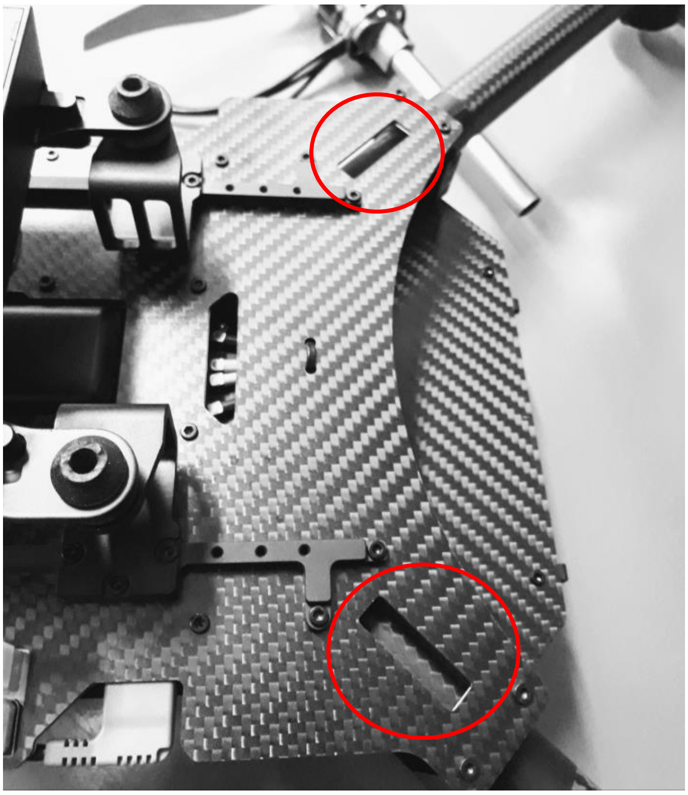


Figure 25: Rectangle cutouts to attach the hook

7.3.1 3D drawing in Inventor

The hook can be attached to the Matrice on two points. The two rectangular cutouts have a dimension of 28 mm to 8 mm. (Figure 25)

Two parts were designed that are connected with a dovetail join. One part is made to fit in the the frame of the RPA and the other part to the hook in order to take the measuring paper.

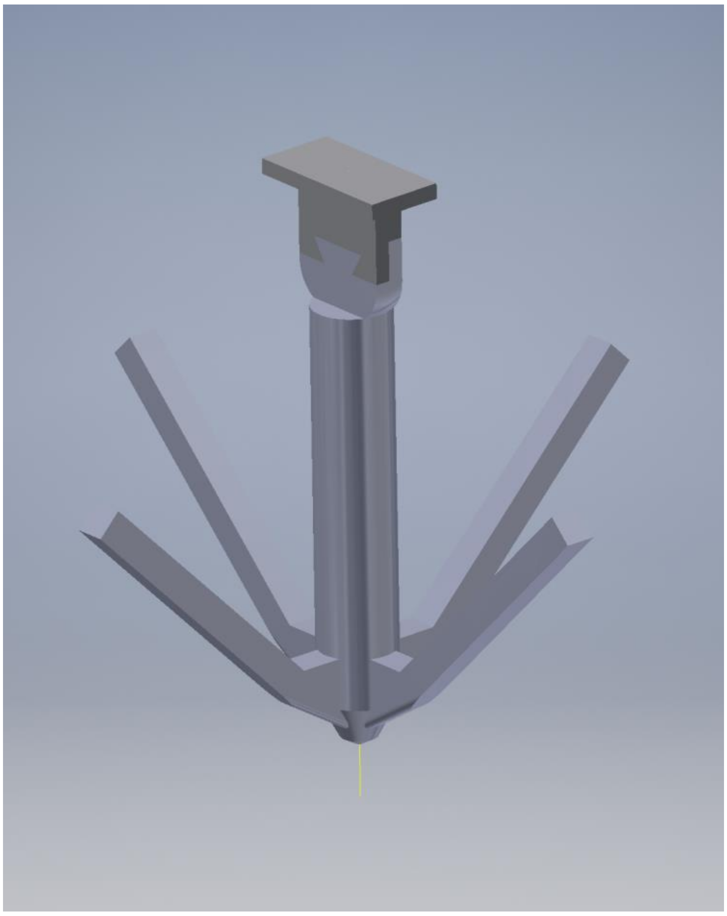


Figure 26: 3D example of the hook structure and dovetail joint

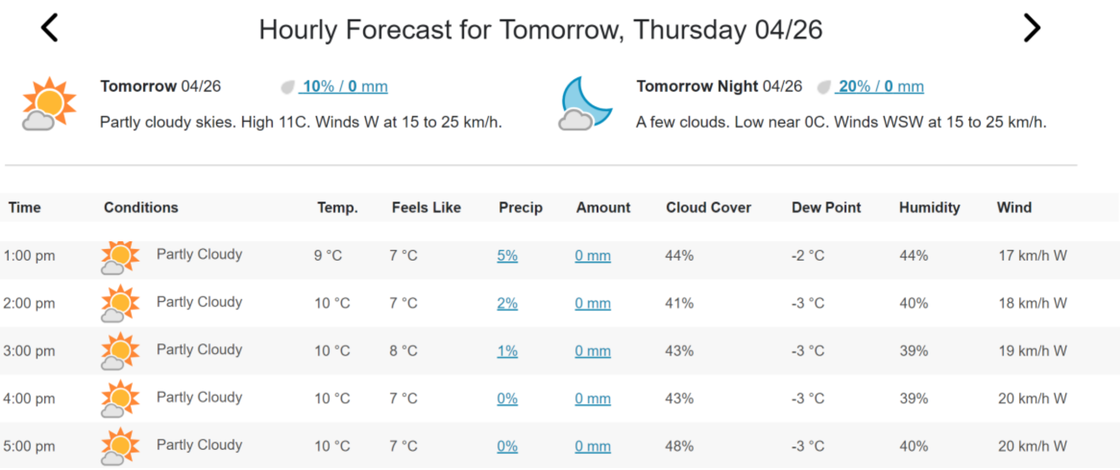
8 Practical test 1

8.1 Flight preparation

Since the weather was finally getting better, a first test flight with the DJI Matrice 100 was made at the beginning of April. For this first flight in Tampere region a short flight preparation was made to be sure that the flight conditions are perfect to do the test flight. Also the location had to be suitable for the automatic flight with the UAV.

8.1.1 Weather and KP index

First the local weather was checked on a weather forecast website the day before the actual flight. The website that was used for this preparation is Weather underground (Figure 27), on that website you can see the predictions of the weather every hour. Keeping this information in mind, the flight was planned between 03.00 PM and 05.00 PM.



Hourly Forecast for Tomorrow, Thursday 04/26

Tomorrow 04/26 10% / 0 mm
Partly cloudy skies. High 11C. Winds W at 15 to 25 km/h.

Tomorrow Night 04/26 20% / 0 mm
A few clouds. Low near 0C. Winds WSW at 15 to 25 km/h.

Time	Conditions	Temp.	Feels Like	Precip	Amount	Cloud Cover	Dew Point	Humidity	Wind
1:00 pm	Partly Cloudy	9 °C	7 °C	5%	0 mm	44%	-2 °C	44%	17 km/h W
2:00 pm	Partly Cloudy	10 °C	7 °C	2%	0 mm	41%	-3 °C	40%	18 km/h W
3:00 pm	Partly Cloudy	10 °C	8 °C	1%	0 mm	43%	-3 °C	39%	19 km/h W
4:00 pm	Partly Cloudy	10 °C	7 °C	0%	0 mm	43%	-3 °C	39%	20 km/h W
5:00 pm	Partly Cloudy	10 °C	7 °C	0%	0 mm	48%	-3 °C	40%	20 km/h W

Figure 27: Weather forecast 26/04/2018 (Steremberg, 2018)

Another application called UAV forecast was used during this flight preparation. It is an app to check out if the weather conditions, GPS signals and KP index are optimal to launch the RPAS in the air. At that moment the circumstances were perfect to fly.

Besides the weather forecast to keep an eye on, there is another phenomenum that you need to keep in mind if you launch a UAV: the sun’s activity. The sun creates geomagnetic activity and this can affect the GPS signals. The KP index is a term to express the amount of geomagnetic disruption caused by the solar activity, on a scale from 0 (calm) to 9 (major storm).

A disturbed GPS reception can lead to a wrong orientation of the UAV, that makes the position determination inaccurately. Worst case, the device can completely lose its GPS point of location and can have a fly-away.

To prevent this problems it's necessary to check the KP index before you fly. (Figure 28) With a KP index from 0-3 you don't need to worry, with a KP index from 3-5 there might be a chance of GPS signal interruption. If you notice a KP index five or higher it's better to cancel or postpone the flight. (De Jager, 2016)

Donderdag 2018-04-26: zonsopkomst 05:29, zonsondergang 21:17									
Tijd	Windstoten	Temp	Neerslag	Bewolking	Zichtbaarheid	Zichtbare Sat	Kp	Gesch. GPS-sat Verg.	Goed Om Te Vliegen?
00:00	21 km/h →	5°C	0%	2%	n/a	15	2	12,8	ja
01:00	19 km/h →	5°C	0%	-	n/a	17	2	15,2	ja
02:00	18 km/h →	4°C	0%	-	n/a	16	2	13,7	ja
03:00	16 km/h →	4°C	0%	1%	n/a	17	2	14,3	ja
04:00	16 km/h ↓	4°C	0%	1%	n/a	19	2	15,3	ja
05:00	16 km/h ↖	3°C	0%	-	n/a	15	2	12,1	ja
06:00	17 km/h →	3°C	0%	-	n/a	15	1	12,9	ja
07:00	18 km/h →	3°C	0%	-	n/a	16	1	14,8	ja
08:00	18 km/h →	4°C	0%	-	n/a	13	1	12,6	ja
09:00	19 km/h →	5°C	0%	-	n/a	15	1	14,3	ja
10:00	20 km/h ↗	7°C	0%	-	n/a	17	1	16,1	ja
11:00	20 km/h ↘	8°C	4%	1%	n/a	13	1	12,6	ja
12:00	20 km/h →	9°C	5%	2%	n/a	17	1	15,7	ja

Figure 28: UAV Forecast 26/04/2018 (Lloyd, 2018)

8.1.2 Location

For the location a training field from the local soccer club was chosen. On that day there was no activity so the whole soccer field was free of obstacles to exercise with the Matrice. Nevertheless it was important to keep in mind that the local hospitals heli spot was nearby (Figure 29), the restrictions in that area say that you are limited to fly at a height of maximum 50 meter with the UAV.

For this operation there was no need to fly above 50 meters, because the Matrice just had to fly from point to point without any obstacles on its way.

Figure 29: Restriction map Tampere

Figure 30: Detail flight location

8.1.3 Drone calibration

Calibration of the aircraft is also an important thing to notice before you take off. Flying an UAV with an incorrectly adjusted compass can cause drifting, varying unresponsive control(s), exaggerated pitching during take-off and even a fly-away. Also the inertial measurement unit (IMU) needs to be calibrated, it is responsible for determining the current location.

There are two components that are important to calibrate before you fly: the magnetometer and the IMU with his accelerometers. The magnetometer determines the magnetic direction of the UAV that is influenced by the earth's magnetic field. The accelerometer is responsible for keeping the device stable and balanced as it flies. (De Leon, 2015)

The magnetometer can be disrupted by any radio frequent (RF) source for instance the magnets in an audio speaker, RF powered mobile radios and mobile stations. One of the most common causes of magnetic interference with the magnetic compass is that the UAV is too close to the speakers in the car when it gets transported.

The IMU contains six accelerometers, these accelerometers can be disturbed by different factors like changes in temperature or any sudden shocks and vibrations during transportation.

It's important to calibrate those two sensors frequently, also the way in which the device is calibrated is very important:

1. Calibrate the UAV outdoors.
2. Make sure there are no magnetic sources in the vicinity during calibration.
    - Watch out for rebar in concrete.
    - Watch out for underground and overhead powerlines.
3. Follow the manufacturer's manual specific for you UAV.
   (Joel, 2015)

Calibration procedure of the DJI Matrice 100

A very important step when you set up your flight, is that you first turn on your controller and then the UAV itself. If you turn on the UAV first, there's a possibility that it picks up another signal and the aircraft can become uncontrollable and can fly away without connection to the controller.

To make connection with the UAV, search in the app for advanced settings and chose sensors and next for IMU calibration. (Figure 31) Make sure that the UAV is standing on a flat surface, in the next five minutes the IMU will be calibrated. (Corrigan, 2017)

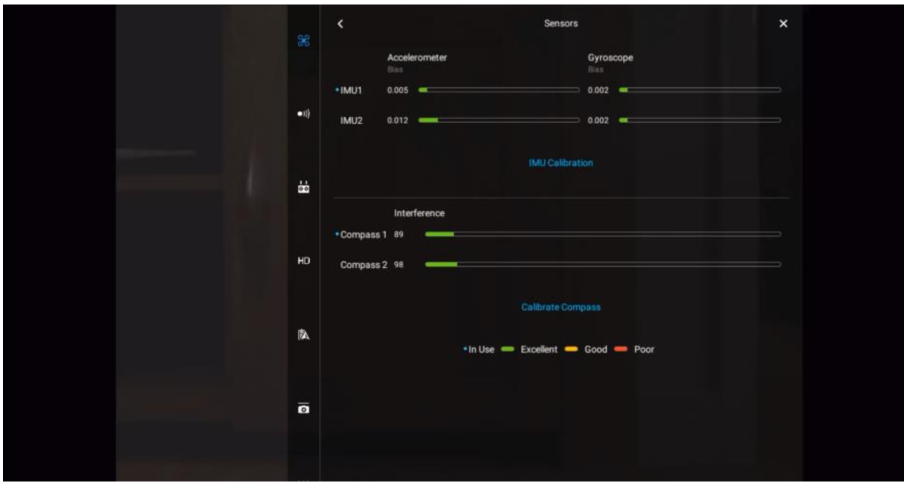


Figure 31: IMU calibration

To calibrate the compass, go to the advanced settings and chose for calibrate compass, next you have to follow the steps on the screen:

1. Hold the aircraft horizontally, and rotate it 360 degrees along the central axis. The aircraft’s status indicator will emit a solid green light.
2. Hold the aircraft vertically with its nose pointing downwards, and rotate it 360 degrees around its central axis.
3. After this procedure the UAV will be calibrated.

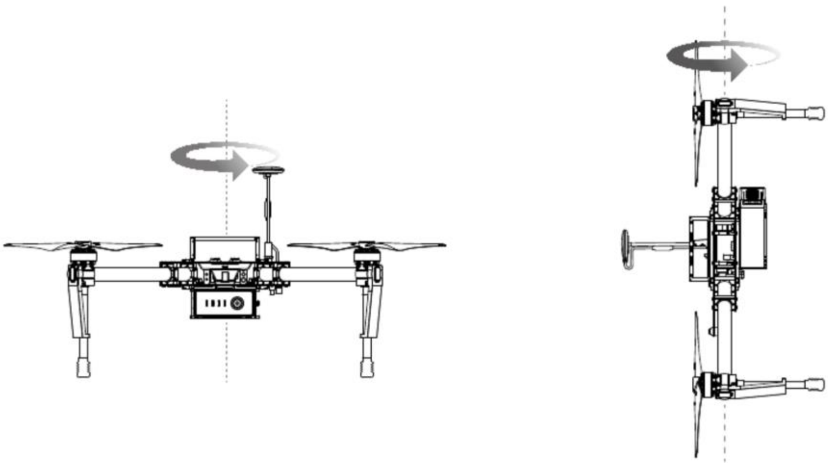


Figure 32: Compass calibration (DJI, 2016)

8.2 The flight

The actual flight was performed by Aleksi, a Finnish student with a lot of experience with flying the DJI Matrice 100. With his help a flight plan was created on the DJI GS PRO app. This is an app created by DJI that gives you a stable ground station to use on your tablet or mobile phone. Because this app only supports Apple products at the moment, an Apple iPad from TAMK had to be used. In the picture you can see that there are actually more than three waypoints. The waypoints with the blue circles around them are the actual spots where the test stands are located (Figure 33). The blue point in the picture is the one that is selected in the app and with this function the pilot is able to add certain parameters and actions to a specific waypoint of the flight. One action is selected in the print screen of this flight plan, which is the picture of the paper that will be taken automatically. Another item to notice is the altitude, when the UAV reaches the waypoints with the test papers, it will descend vertically to an altitude of 1.5 meter. This is necessary to have a clear view on the paper before taking the picture. Figure 34 shows us the other waypoints. These are chosen in between the test stands to get the Matrice up to a higher altitude which is a safer way to fly over the fields and trees from one measuring paper to another. In this test an altitude of 21.1 meter was chosen which gave the UAV enough tolerance to perform a safe flight. Of course this altitude can be adapted to the height of the surrounding trees or other obstacles near the fields such as buildings or high voltage cables. Aside of this change in altitude and a change in flight direction depending on the safest route, no further actions were taken during the flight between the test stands. After the pre-flight checks, it was time to start a first flight to see where the UAV would effectively hover when reaching the defined spots on the app. This test was performed three times to make sure that the Matrice's hover places won't diverge too much. After doing this, the different stands with the test papers were placed on the three corresponding locations on the field on a distance of approximately 2,5 meter of the drones hovering spots.

This way the Matrice flew to the different spots on its own and when the stopovers were reached, a picture of the test paper was automatically taken by the DJI's Zenmuse camera.

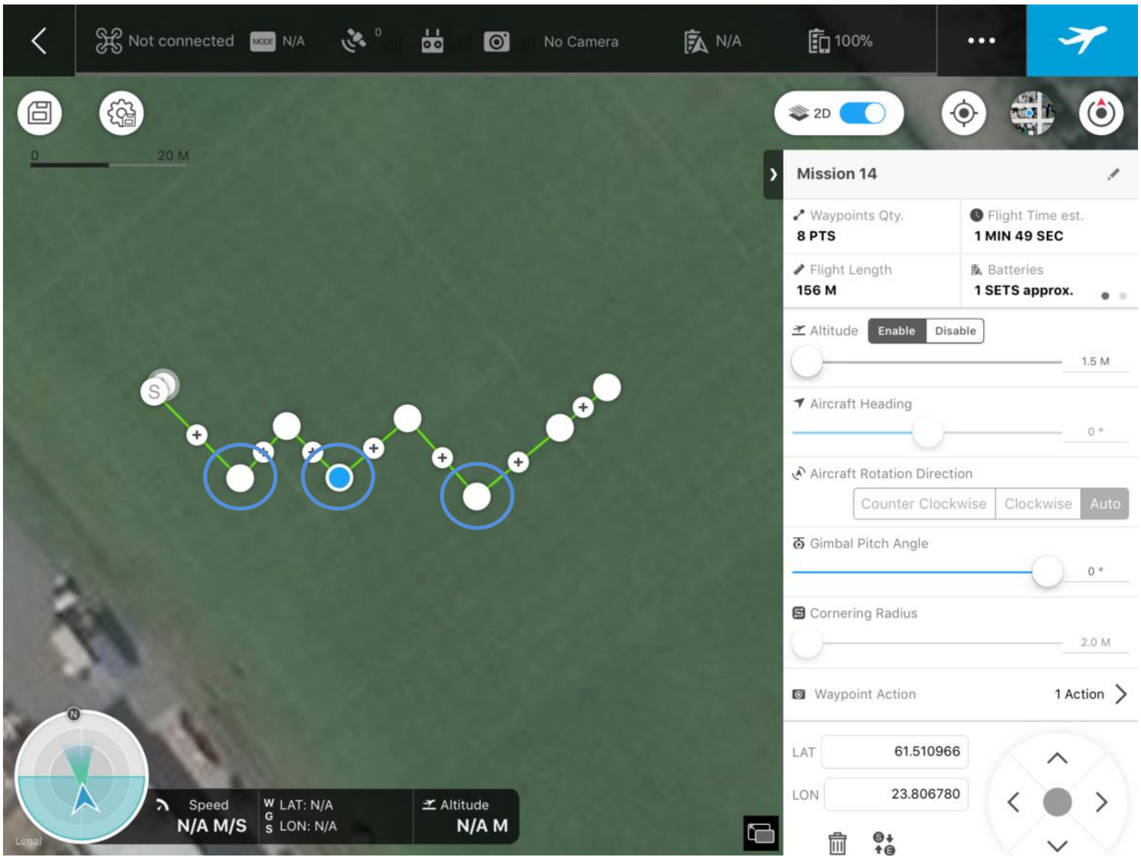


Figure 33: DJI GS pro (waypoints with test papers)

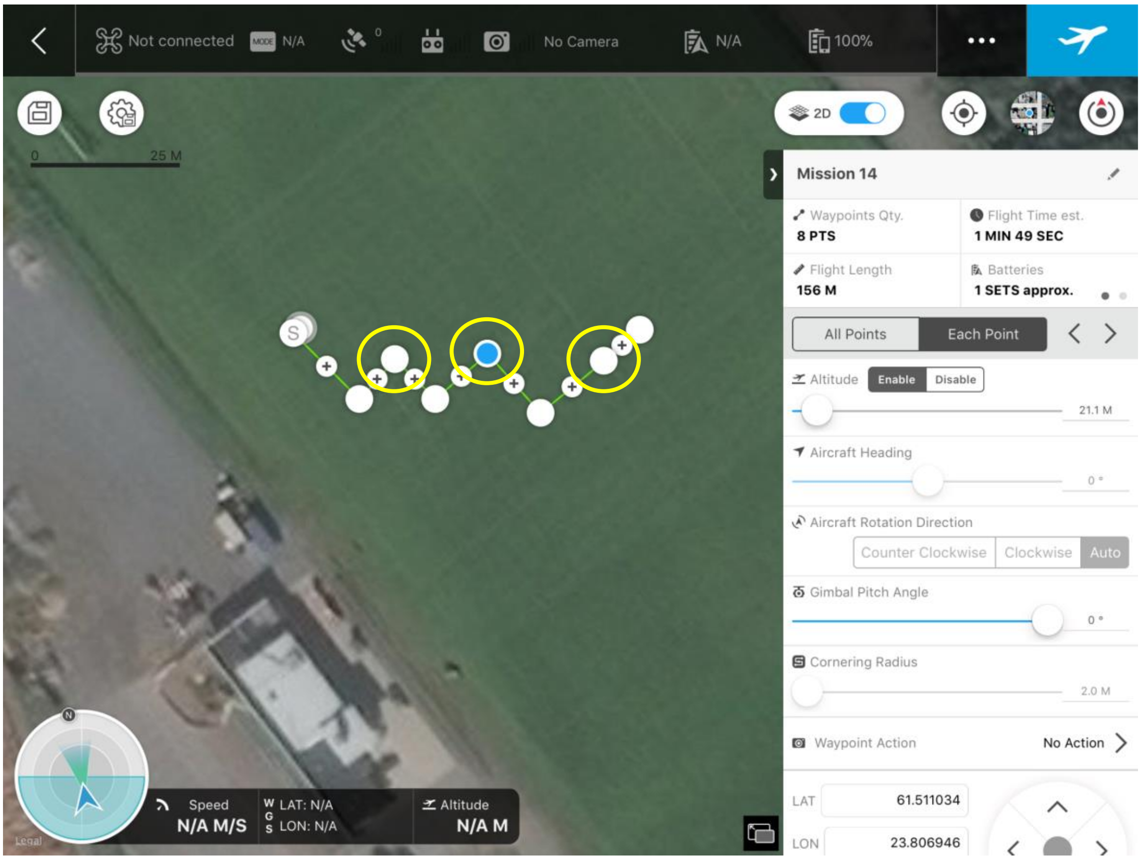


Figure 34: DJI GS pro (waypoints in between test papers)

The results are shown in Figure 35.

Due to the open field, the trained pilot and the good weather conditions, there weren't many great risks during this operation. But the DJI Matrice that was used, wasn't equipped with obstacle sensors neither in the horizontal plane nor to the ground. This made it important to keep extra caution when flying close to the ground or close to obstacles, in this case the stands with test papers. When the test was finished, there was still some time for all the participants to test and improve their own flight skills with the DJI Matrice.

Figure 35: Test papers

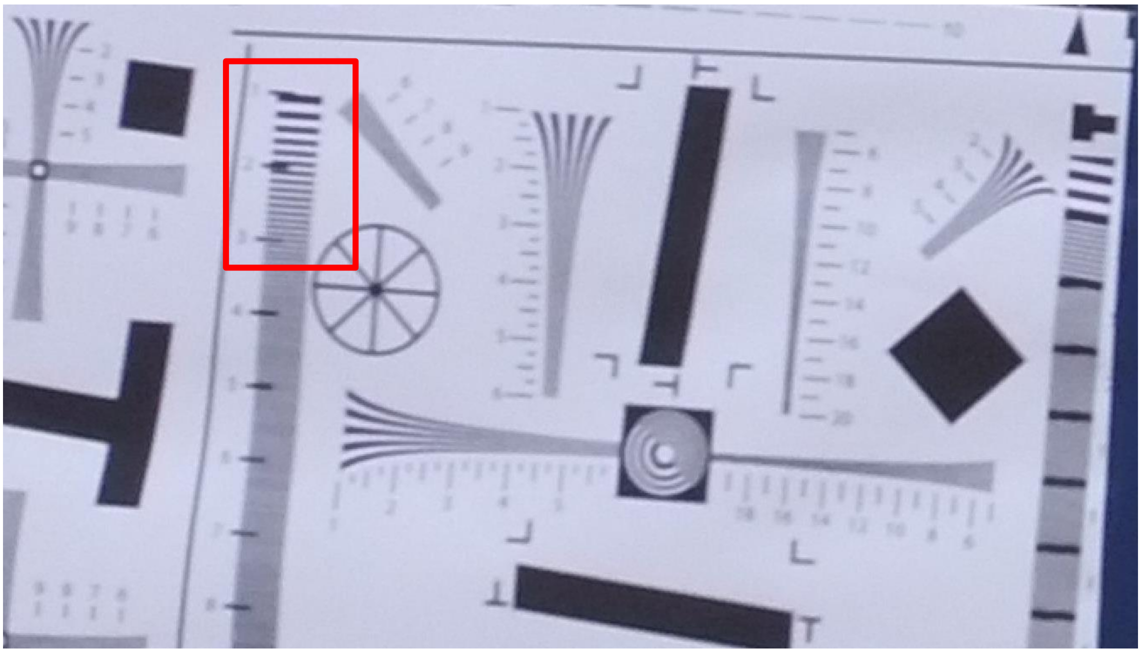


Figure 36: Test paper 2x zoomed

8.3 Post flight report

These pictures give a first impression of how the Matrice will shoot the pictures of the test papers and how clear it will be to estimate the amount of insects on the paper. Of course there are several parameters which can and will be different on the actual location of the field. Thinking of weather conditions (sun, shadow, rain, wind), height of the paper (different for every crop) and other obstacles such as trees, fences and buildings. All these factors make it important to do another test on the actual location in admission of the farmer.

Figure 36 shows a picture of one of the test papers zoomed in 200%. The numbers that are written next to the lines in the red box, display the amount of different lines in one millimeter. In this picture the lines can be differentiated untill three lines per millimeter.

This means that, with this camera and the drone hovering on a distance of approxiamtely 2,5 meter in front of the measuring paper, it is possible to differentiate up to three insects per millimeter.

9 Regulations

9.1 Comparison of UAS regulations in Finland and Belgium

Because of the fact that we are flying with UAV’s in Finland, it seems correct to learn and understand the differences between the regulations in Belgium and Finland. The Finnish government more specifically the Finnish transport safety agency (TRAFI) publishes the legislation on aviation including the subject of unmanned aviation. In Belgium we have the same principle. The government, specifically the Federal Public Service Mobility and Transport, publishes the legislation about aviation.

If we start with the size of the country and the population, then it is already very clear that there is much more open space in Finland compared to Belgium. The total area of Finland is more than ten times as big as Belgium while the population is only half.
This fact alone explains why you can find more space to fly in Finland.

In Finland there is also a distinction between recreational flights and flights for professional use. Everything that does not belong to hobby or sport flights, belongs to aerial work. Even when no costs are involved, for example a teacher who flies the RPA in the context of his lesson.

Recreational UAV pilots in Finland are allowed to fly without permission to a height of 150 meters. Except for no-fly zones[3] and close to airports. Flying a UAV near an airport is permitted as long as the horizontal distance between the airport and the UAV is at least 5 km and the altitude of the drone is beneath 50 meters within the controlled area. The maximum take-off weight (MTOW) is set to 25 kg. Except above densely populated areas, then the maximum take-off weight is limited to 7 kg . For this type of flight no license is required.

Aerial work pilots who fly for commercial purposes don’t need to do an exam or have a special license to fly their drone, the rules for recreational pilots are mostly the same as for aerial work pilots. (TRAFI Finnish Transport Safety Agency , 2015)

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[3] No-fly zone : a no fly-zone is a designated area that is determined by the governement where you are not allowed to fly your drone.

In both cases, recreation flights and flights for aerial work, the responsible person must have a minimum age of 18 years. The pilot can be younger, as long as the responsible person is over 18 years old an nearby. If you want to fly a drone on you own before your 18th birthday it is possible as a model aircraft operation or flying indoors is also a possiblity.

In Belgium the maximum height to fly a UAV without the need of a license is 10 meter and this is allowed only on your private property. The maximum take-off weight is 1kg in this case. Besides this there are also Class 2, 1b and 1a licenses. In this case a certain registration and qualification is needed, but you can fly drones up to 5 kg and 45 meter for class 2 and 150 kg up to 90 meter with a class 1 certification. With a class 1a the pilot is allowed to fly over persons. It is very clear that the rules in Belgium are very strict when compared to these in Finland. In both countries the UAV has to remain in Visual line of sight (VLOS) of the pilot unless for areas that are specifically preserved for that purpose. But while it is in Belgium only possible to fly during daylight, it is in Finland also possible to fly during night time as long as your aircraft is equipped with visual navigation lights and the pilot is aware of the possible approach of any other manned or unmanned aircraft. (Craeyvelt, 2017)

9.2 Different procedures and certifications in Finland

As mentioned above the RPA-pilot doesn’t need a special license to fly the drone but there are some administrative requirements to comply with the legislation.

Both categories of dronepilots need these administrative requirements:

1. take an insurance against third party damages;
2. mark your drone with a sticker that has the name of the responsible person and their contact information.

For flight operations with the aim of aerial work there are extra formalities that have to be done:

1. Make a notification on the use of remotely piloted aircraft to the online system from TRAFI once a year and remember to update your information when you change your address or aircrafts;

2. Keep a log of all your flights.

   The log needs to contain specific information:
   - date;
   - location;
   - commander of the aircraft;
   - manufacturer and model of the aircraft;
   - the start and end time of the flight or series of flights;
   - whether the flight is
     - a visual line-of-sight (VLOS) operation or
     - a beyond visual line-of-sight (BVLOS) operation;
   - the nature of the flight operation and, where applicable, the presence of an RPA observer.

     (TRAFI Finnish Transport Agency , 2016)

10 Conclusion and discussion

After getting the idea to modify a UAV for agricultural purposes, we were very excited to begin with this project and to extend our knowledge about the UAV-world. We learned a lot about the different kinds UAV’s and about all the possibilities that this technology can bring for every industry. In many situations it isn’t the technology which limits the ideas for new concepts, but mostly the regulations. It isn’t an easy task to constantly adjust the rules for such a fast improving technology and this can lead to some obstructions in the research and development department. To compare the regulations between Finland and Belgium was therefore a very interesting task.

Ofcourse writing a thesis is a whole process that includes research, learning, writing, reading, adjusting and improving. It isn’t difficult to imagine that not everything went perfect from the first attempt in all these steps. It is in fact part of the learning process to find solutions for certain difficulties that come together with writing a thesis. This objective to efficiently search for solutions to problems may be one of the most important skills we improved while writing this thesis.

As previously stated there were some bigger and minor problems we came upon during the writing of this thesis.
At first we wanted to develop a full automatic system. So that there is no need of a person to control the sticks of the drone anymore. With the Dji SDK kit it was possible to program a full automatic system, but we missed the programming skills and we didn’t had the time to learn how to work with this software.

Another problem is that we never had the chance to meet the farmer. If we could have had a meeting with the farmer, we could use his recommendations together with the precise information about the fields and surroundings to set up a more efficient plan of using the UAV system to control the insect measuring papers. Additionally we could make a better estimation of whether or not the drone application we set up was suitable for the agricultural tasks the farmer had in mind.

During the whole process of writing this thesis, the co-operation between us went very well. We have had the same courses about UAV’s and aviation in general, so there wasn’t any big discussion about the theoretical facts in this matter. Although we sometimes had some different ideas about the practical realization of the project and about how and when to set the end goal of the thesis. In fact we didn’t saw this different opinions as a limitation to our ideas, but more as an enrichment. Writing the thesis together was a very educational experience for both of us and we are sure that this will help us a lot during future projects.

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