Graduation Project

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1 Drones in Business

1.1 Introduction

Drones are taking off across all business sectors.according to pwc [1], it is estimated that the total addressable value of drone powered solutions in all applicable industries is estimated at over $127bn. The industry with the best prospects for drone applications is infrastructure, with total addressable value of just over $45bn.

	2015
Infrastructure	45.2
Transport	13.0
Insurance	6.8
Media & Ent.	8.8
Telecommunication	6.3
Agriculture	32.4
Security	10.5
Mining	4.3
Total	**127.3**

Table 1.1: pwc' Survey results[8]

[1]pwc is a multinational professional services network corporation,which focuses on audit and assurance, tax and consulting services. they help resolve complex issues and identify opportunities.

1.2 Applicable Applications in Egypt

1.2.1 Using drones in Percision Agriculture

1.2.1.1 Introduction

Agricultural drones have been changing the face of farming and cultivation heavily the past 3-5 years, and completely changing the way that many farmers and other entities go about their business. This drones have the ability to check storm damage, monitor crop progress, and make sure that both crops and herds are healthy.

Precision agriculture is a farming management concept that uses drones for agriculture to measure, observe, and respond to variability found in crops.

When you implement all of the new technology that is available out there including drones in agriculture, you can apply resources (even if limited), to make sure that the farm has a very maximum yield.

Figure 1.1: Fertilizers spreading drone

1.2.1.2 Applications

Crop Health It is no secret that there is a strong need for increased agricultural production given the increase expected in population around the globe. There are finite agriculture resources and growers are expected to produce more with less. The need for improved management practices is acute. In order to implement improved practices reliable, timely, and actionable data is required. Enter in-season on-demand aerial imagery.

Aerial imagery is used by consultants (CCAs, scouts, agronomists), cooperatives, and agriculture service providers to assist in calculating the economic differences between the "good" and "bad" crop condition zones enabling improved management decisions. Often times, determining crop health without the "bird's eye view" from aerial imagery is difficult.

One of the main image types to determine crop health is the Near Infrared (NIR) image. The NIR is most effective to determine the vegetative health of the crop as the other imagery bands (Red, Blue, Green) are "absorbed" by the plant to create food.

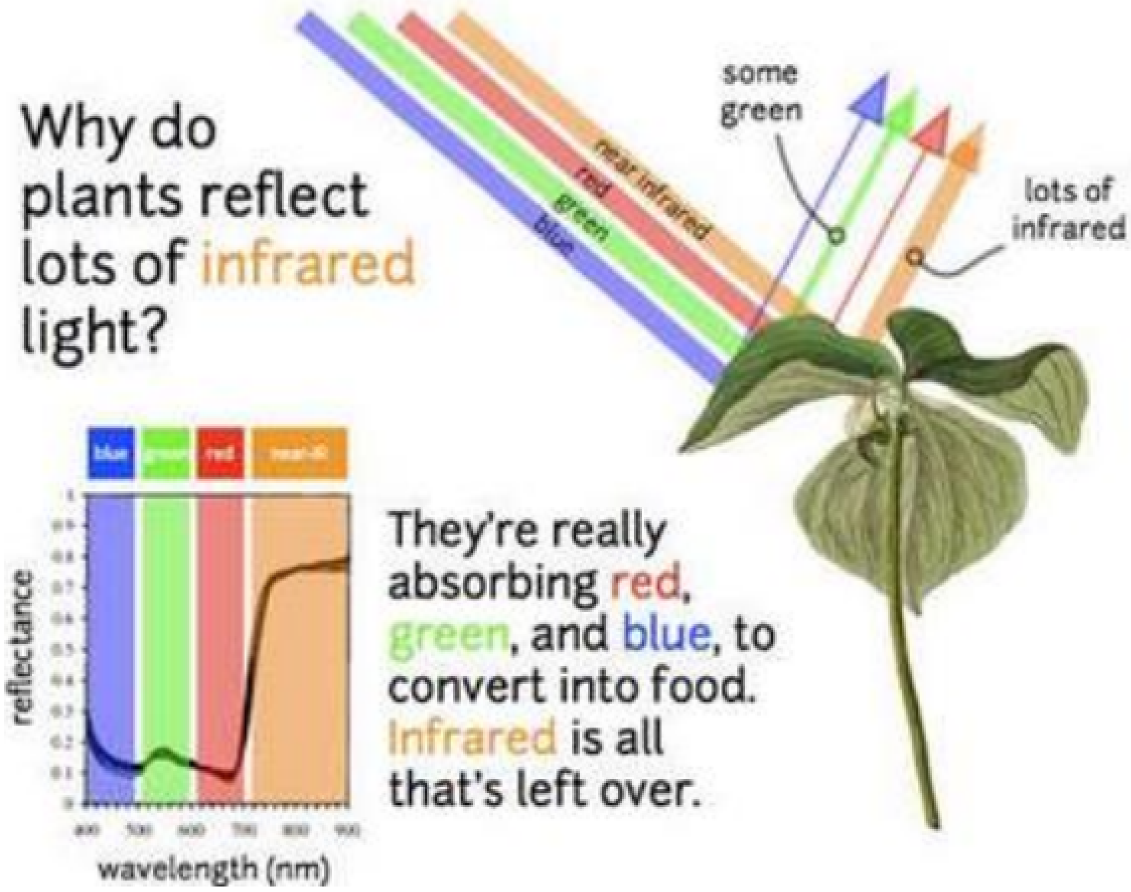


Figure 1.2: Reflection of light on plant

The NIR band used in conjunction with the red band is utilized to create a vegetation index commonly called a Normalized Difference Vegetation Index (NDVI).

The NDVI provides quantitative information on the health of the crop in the field. The green colored zones have the most robust and volume of vegetation while the yellow and red zones represent less vegetation. This information can be used to make management decisions on the application of inputs like fertilizer and fungicide.

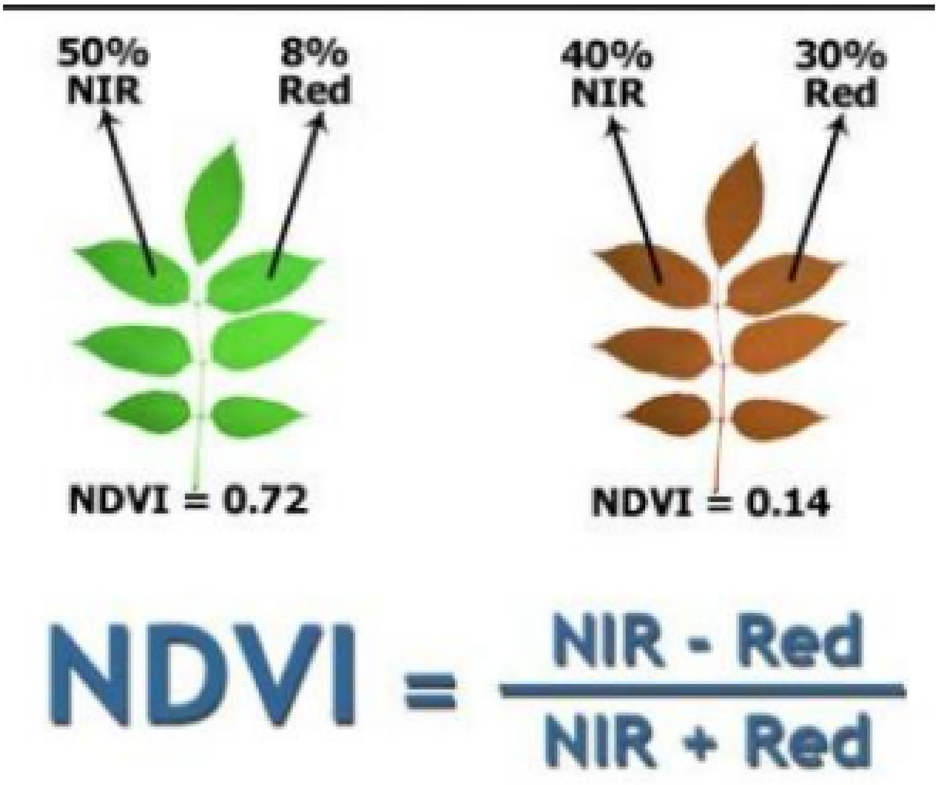


Figure 1.3: NDVI formula

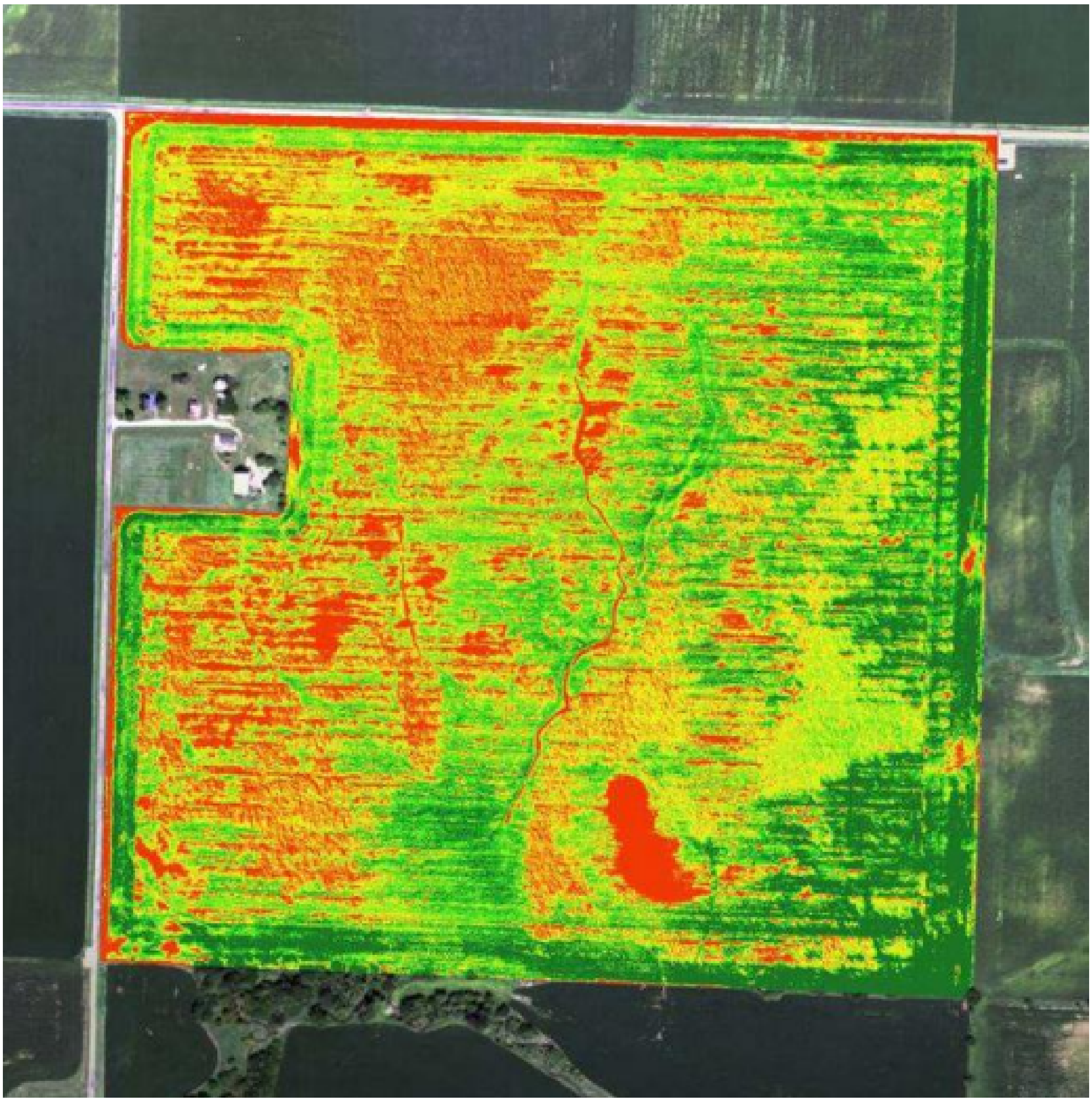


Figure 1.4: NDVI image example

Compaction The term "soil compaction" refers to a change in state of the soil that increases its bulk density. Soil compaction is becoming more and more important due to the fact that:

- Equipment is larger
- Uncontrolled traffic

- Earlier field operations
- Operating on wet soils

Identifying compacted areas within a field with the naked eye is difficult and compaction is a difficult variable to measure from the ground without equipment (eg soil penetrometer) and high labor costs.

If a soil is over-compacted there is significant risk of yield reductions as compacted soils affect both soil and plant growth alike:

Effects On Soil	Effects on Plant Growth
Porosity	Root growt
Aeration	Nutrient uptake
Structure	Water Infiltration/Utilization

Aerial imagery shows subtle patterns of soil compaction that are almost impossible to see from the ground. By comparing patterns of traffic and irregular crop growth, problem areas due to compaction are easily identifiable. In Figure 1 above, the red areas on the north side of the field showed yield losses of 45-65 bushels per acre while the red strip on the east side showed yield losses of 20-30 bushels per acre

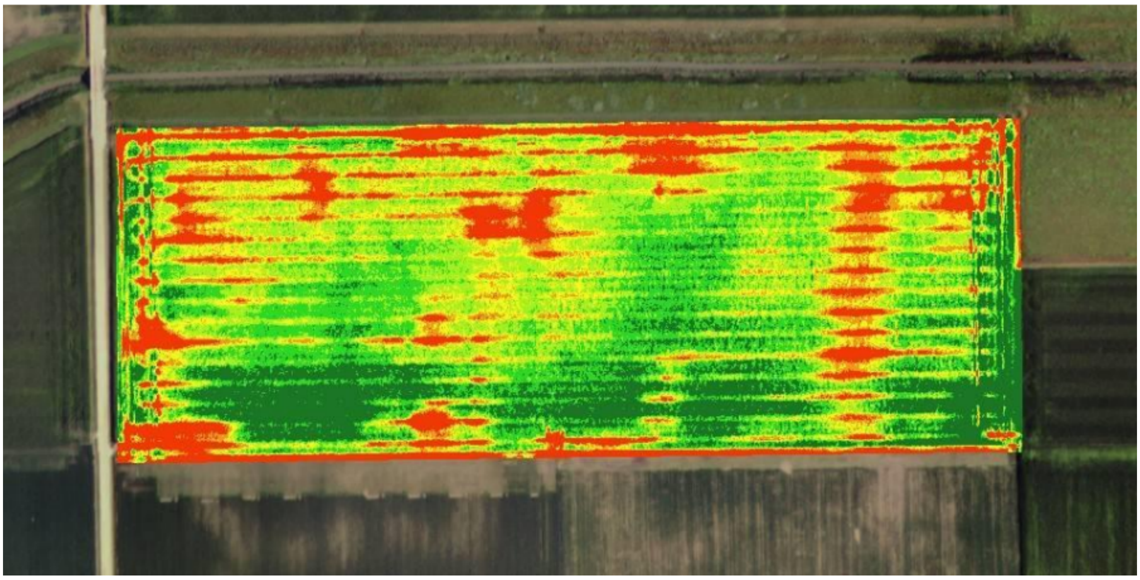


Figure 1.5: NDVI showing effects of compaction

Variable rate application Variable rate application (VRA) is the method of applying varying rates of inputs in the appropriate zones within an individual field. The ultimate goals of VRA are:

- Maximize farm profitability
- Increase efficiencies in the application of crop inputs
- Ensure environmental safety and sustainability

The management of in-season nitrogen application(s) is a critical component to land management. Mismanagement can result in yield loss and negative impacts to the environment. Given this importance, companies and individuals alike are turning toward aerial imagery as a means to develop nitrogen management zones and the corresponding VRA. The economical nitrogen rate can vary substantially within individual fields. It is difficult to assess these differences in a timely manner without the use of remote sensing. An aerial image, when analyzed appropriately, can provide the agronomist with key insights on the crop. For example, the near-infrared (NIR) light reflecting off a nitrogen stressed corn crop is quite less than a non-nitrogen stressed crop.

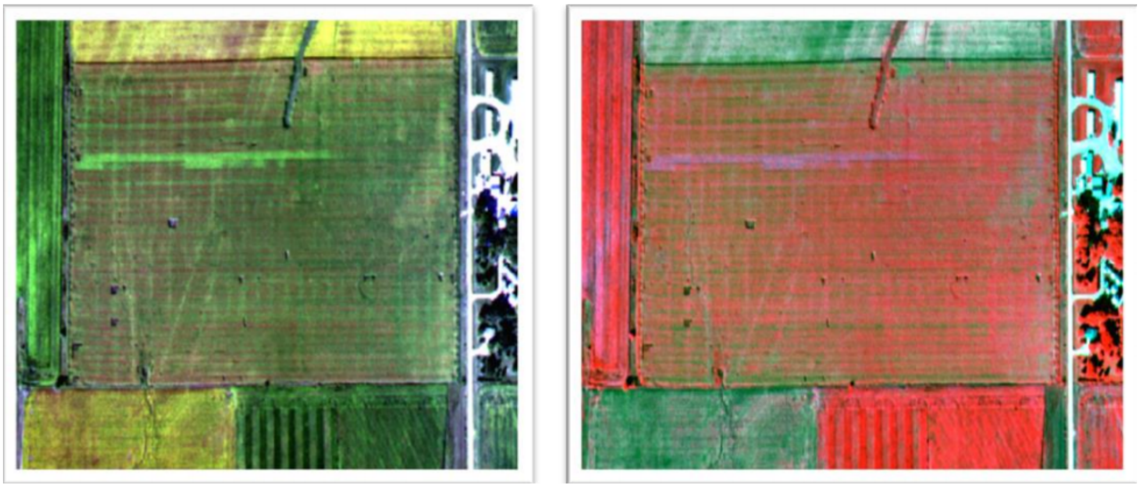


Figure 1.6: True color and NIR showing nitrogen stress

Once aerial images have been utilized to target scouting efforts, a VRA fertilization file can be created using precision agriculture software (ie Mapshots, SST, AgFleet, etc...) Another application of aerial imagery for VRA is using the bare soil image to create zones to apply soil nutrients and/or amendments. Whether you are looking at VR seeding, VRA for fertilization, or VRA for herbicide/fungicide and aerial image is the data layer to use to enable better management decisions and increase profitability.

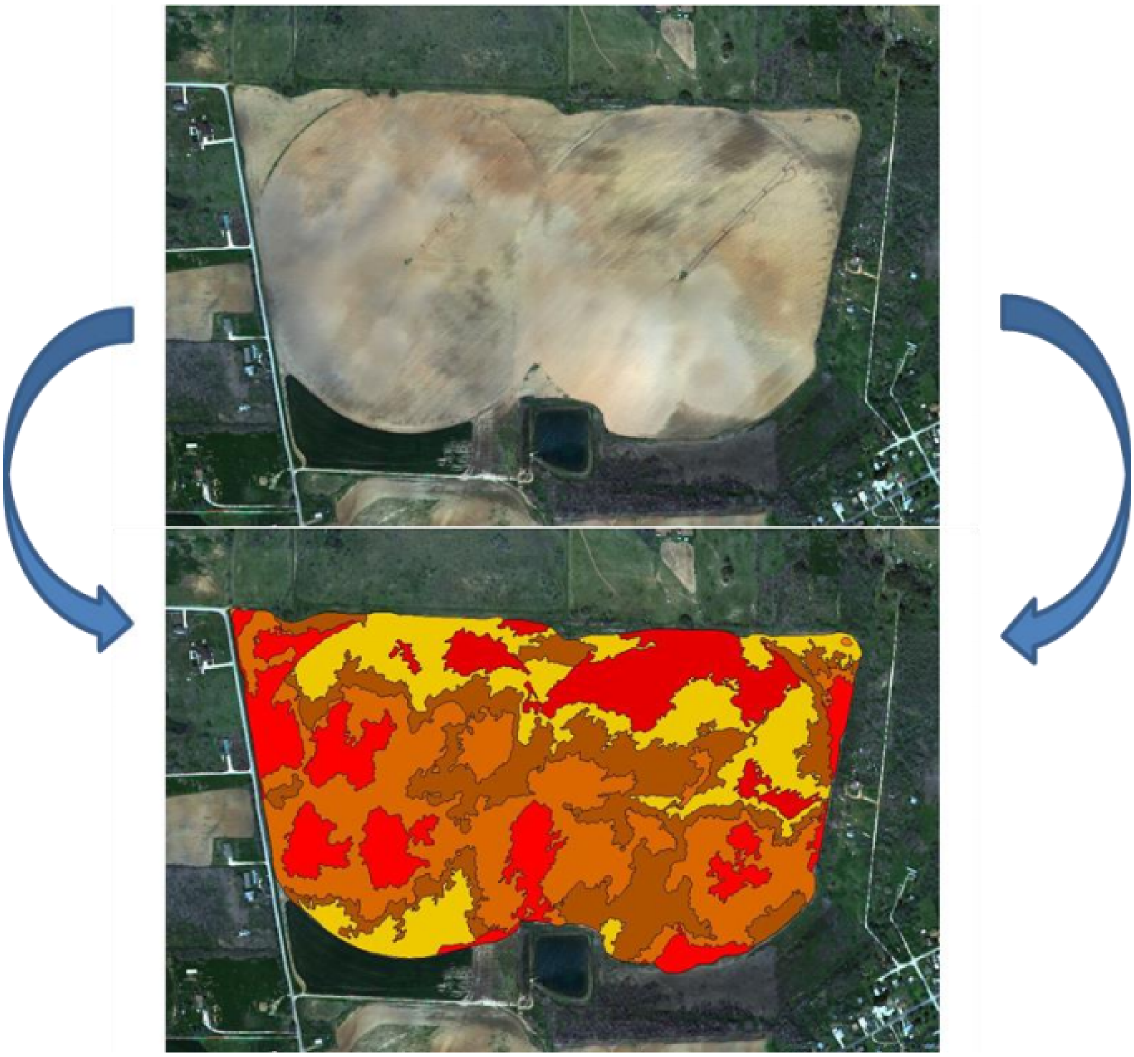


Figure 1.7: VRA image

1.2.1.3 Case Studies

Cotton

Situation Farmers apply herbicides uniformly across fields before planting to ensure good field conditions for planting

Action Use NDVI imagery to identify weeded areas, Apply herbicide only in weeded areas or intensify herbicide applications in heavily weeded areas.

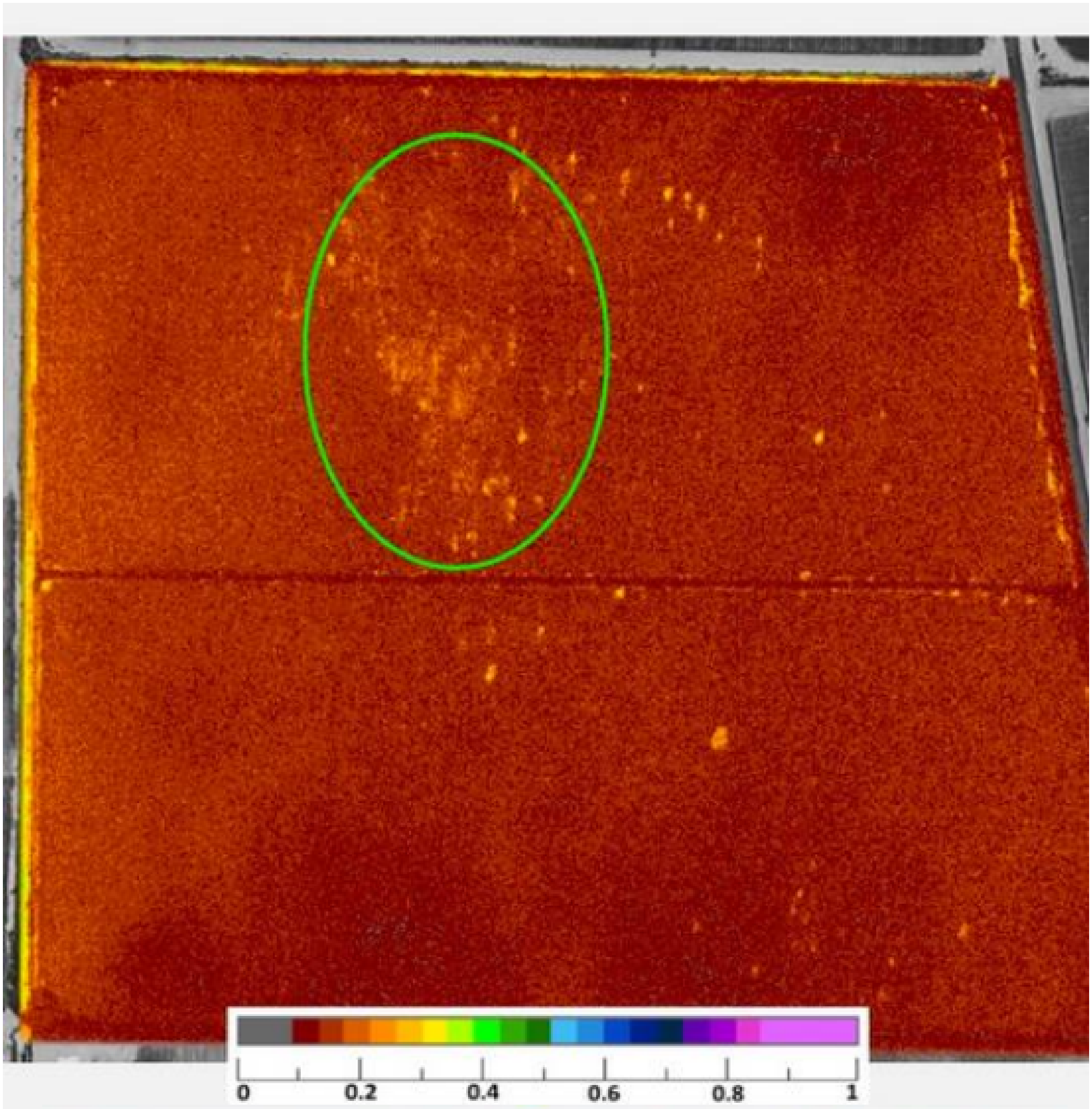


Figure 1.8: Weeded areas

Planter malfunction

Situation Malfunctioning planter can cause 100% loss in nonplanted areas, but such areas can be difficult to locate and quantify.

Action Use imagery to Identify areas to re-plant

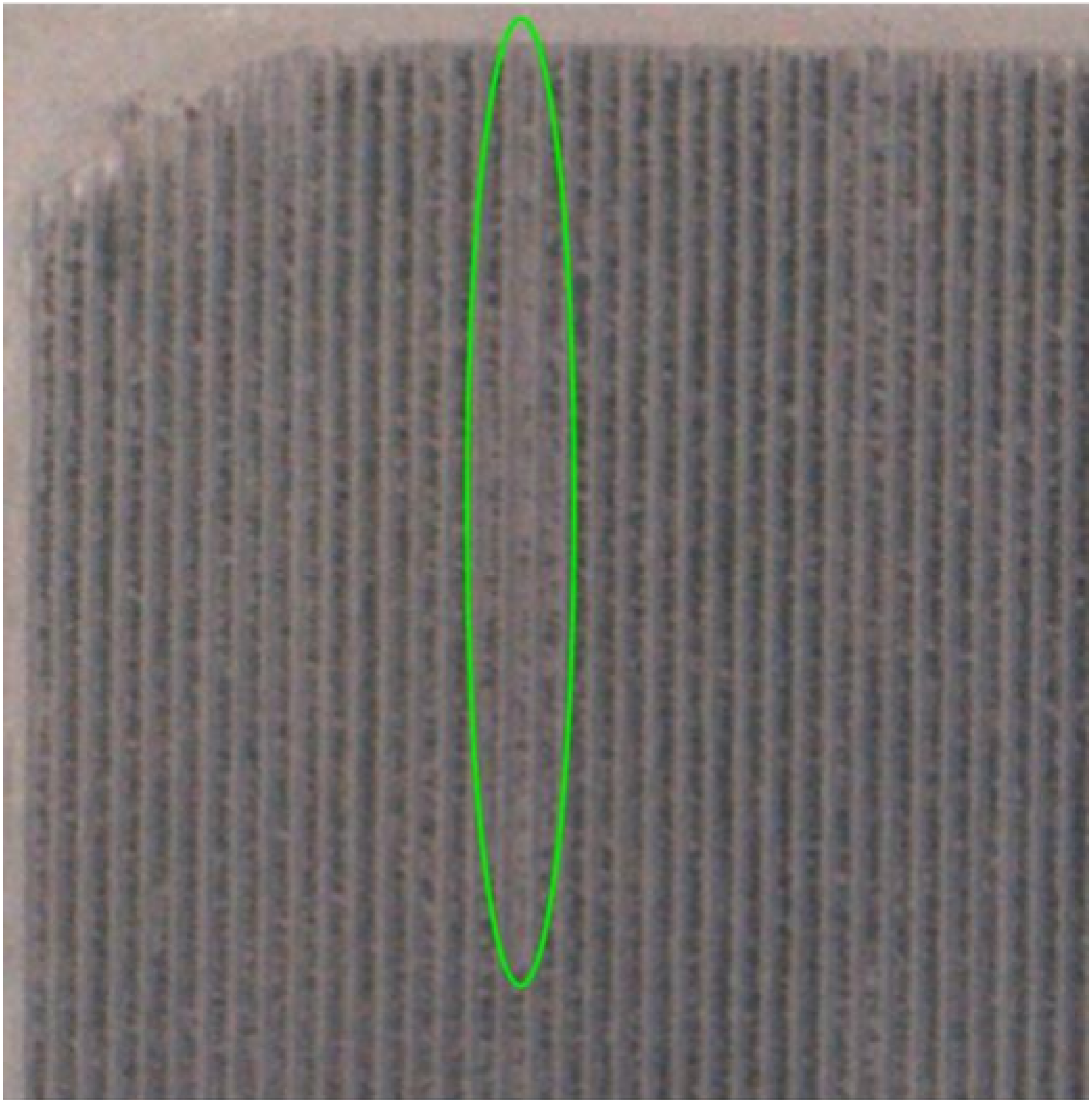


Figure 1.9: Nonplanted areas

Targeted insecticide applications(plant bugs)

Situation Farmers generally apply insecticides uniformly, although early stage plant bugs generally only attack high vigor areas

Action Use NDVI imagery to identify high vigor areas, thus applying insecticide where needed

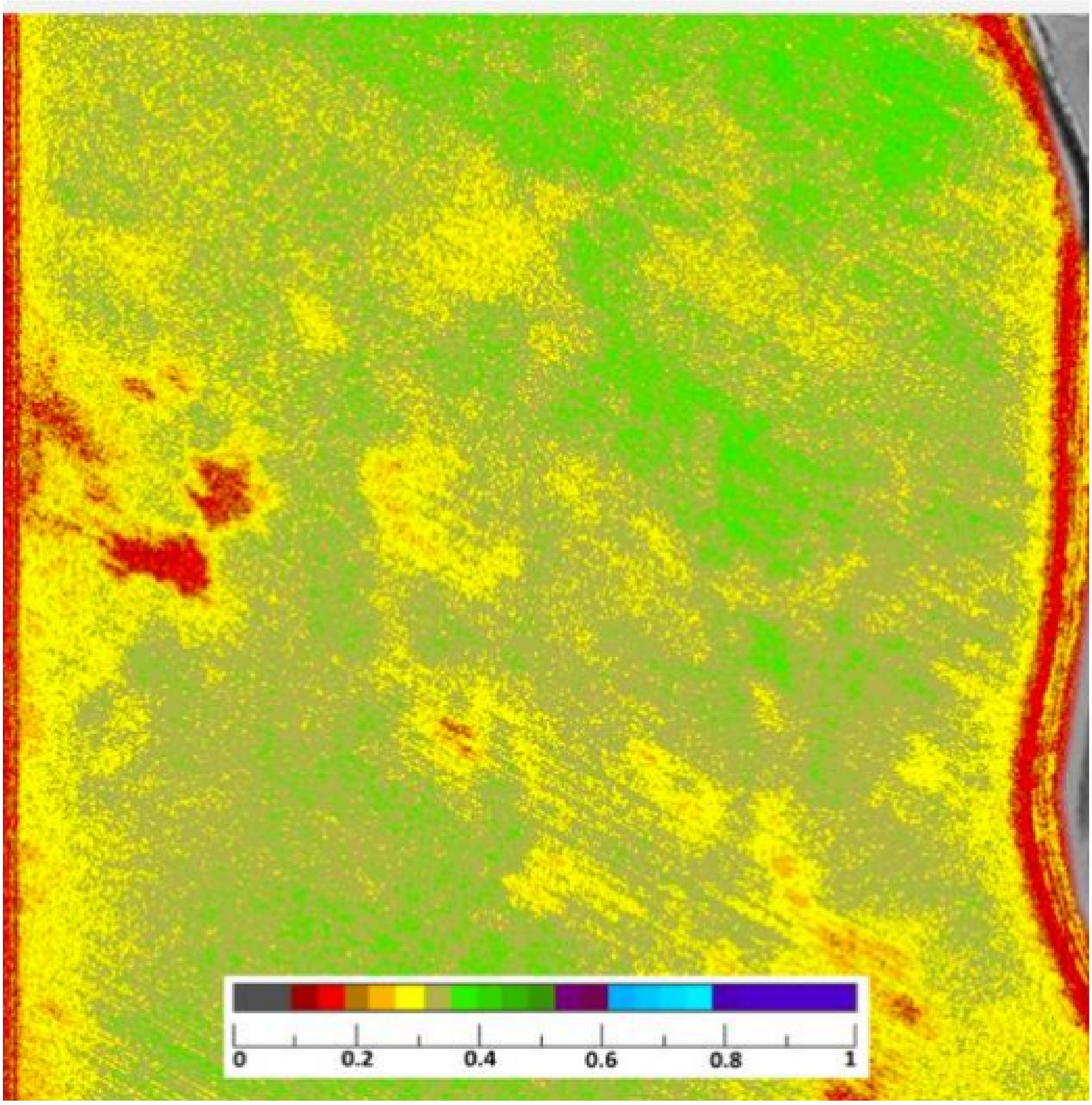
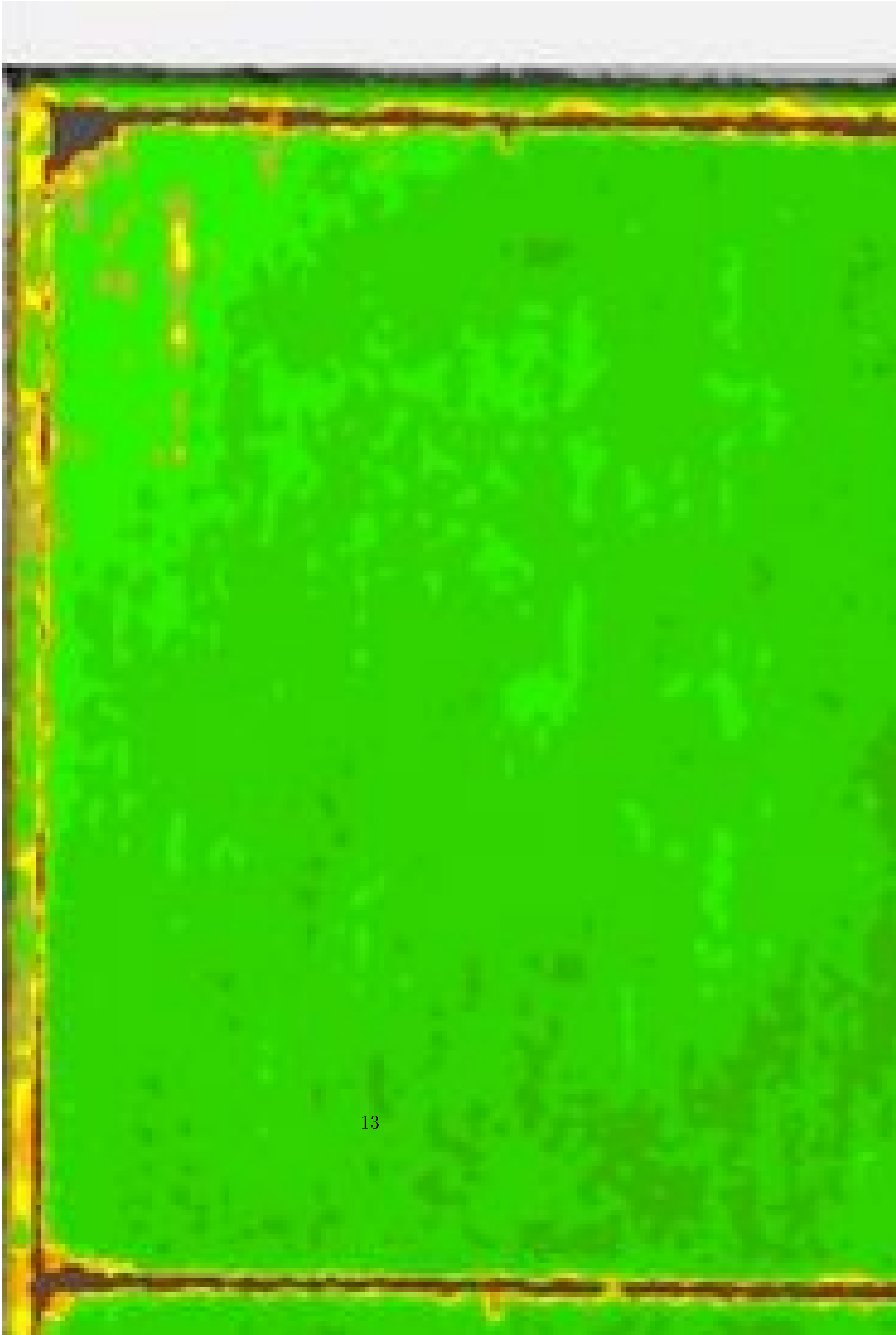


Figure 1.10: High vigor areas

Fertilizer second application

Situation Farmers generally make second nitrogen application uniformly or based on soil maps, where NDVI imagery may provide better representation of nitrogen needs

Action Use NDVI imagery to provide accurate assessment of relative vigor in field to develop fertilizer zones



Center pivot emitter failure

Situation Plugged center pivot emitters not visible by visual inspection, but revealed through NDVI and Thermal Imagery

Action Repair plugged sprinklers

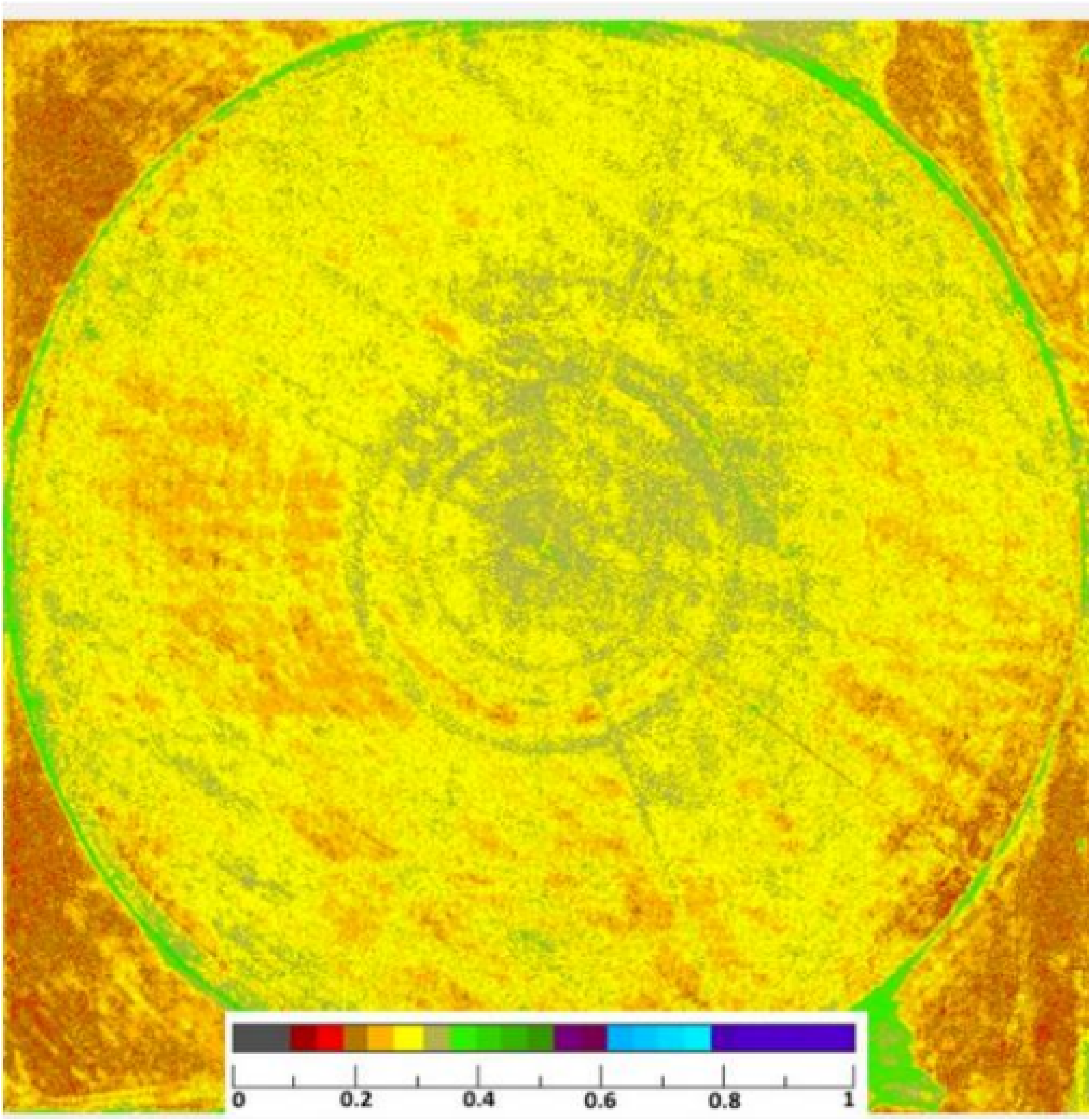


Figure 1.12: Plugged center pivot emitters zones

Inefficient furrow irrigation

Situation Furrows do not flow efficiently, resulting in uneven application of irrigation water. Difficult to assess from the ground with naked eye, but thermal and NDVI imagery enable problem areas to be identified and repaired

Action Repair furrow irrigation efficiencies

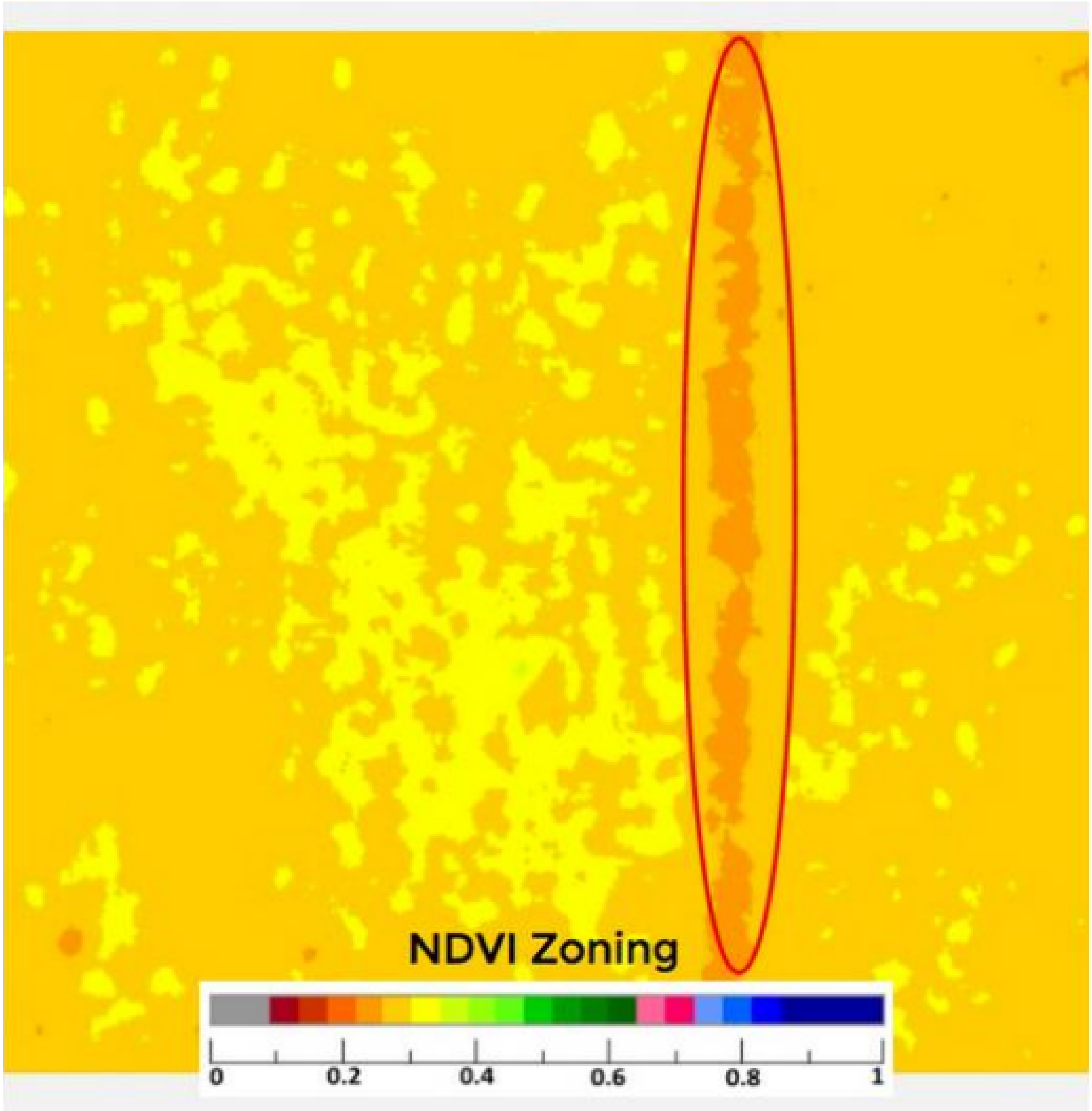


Figure 1.13: Inefficient furrow irrigation zones

Targeted insecticide application (spider mites)

Situation Farmers generally do not apply insecticides, unless scouting identifies a problem, NDVI imagery enable problem areas to be identified and sprayed

Action Use NDVI imagery to identify infested areas, thus applying insecticide when needed

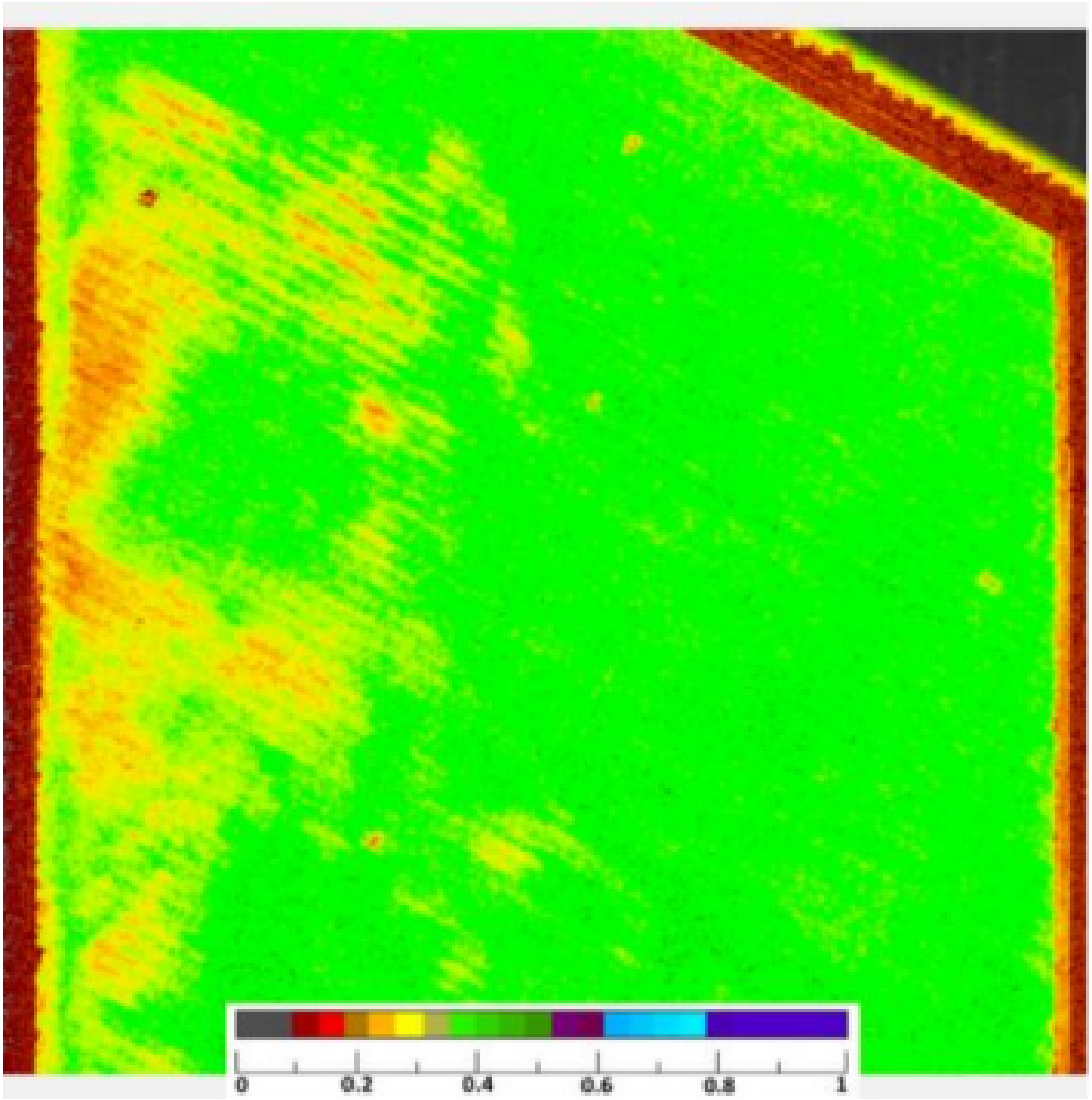


Figure 1.14: Spider mites zones

Targeted weed control

Situation Scouts currently sample the field randomly to discover potential issues or to assess crops. Aerial imagery allows for targeted scouting.

Action Identify areas for scout to visit to discover issues or accurately assess crop, allowing for targeted pest and weed applications

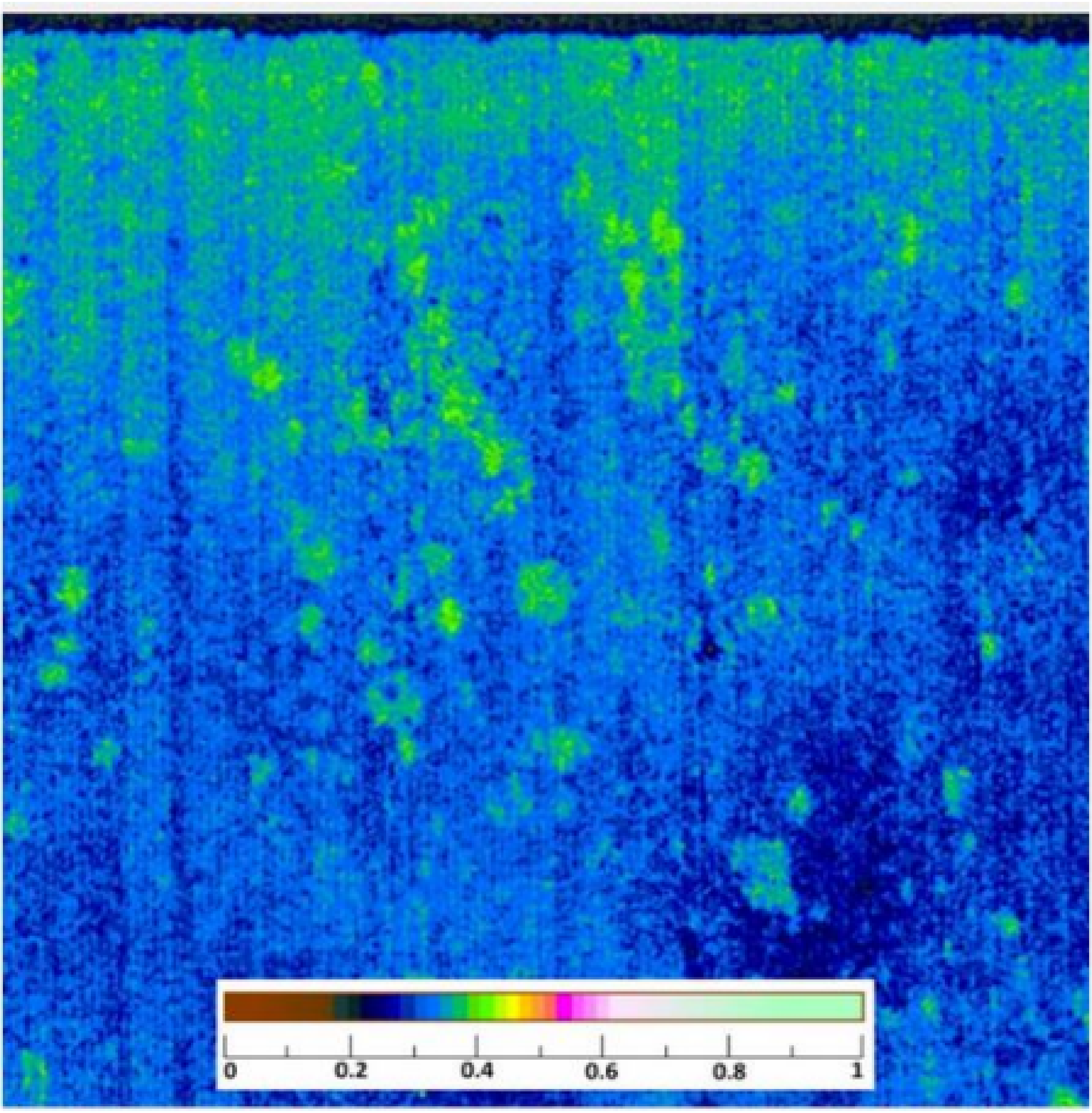


Figure 1.15: Targeted weed zone

Plant growth regulator

Situation Field grows unevenly, necessitating variable applications of PGRs in different areas of field

Action Identify PGR application zones, Apply different rates of PGR in different zonested pest and weed applications

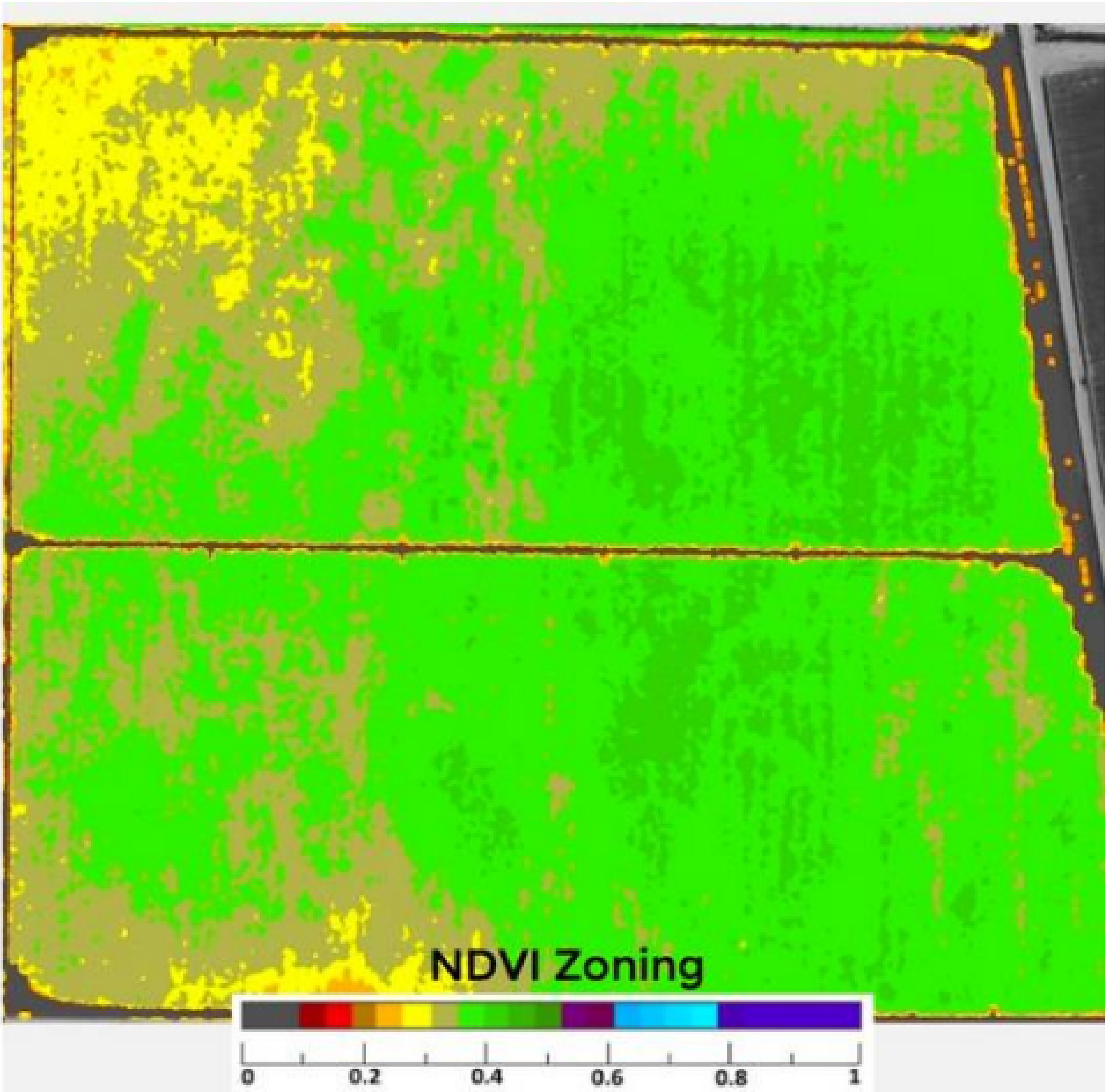


Figure 1.16: Unevenly planted zones

Defoliant application

Situation Field matures unevenly, resulting in difficult balance between defoliant efficacy, yield levels, and harvest requirements

Action Time defoliant application to achieve maximum efficacy to achieve optimal yields and lint quality

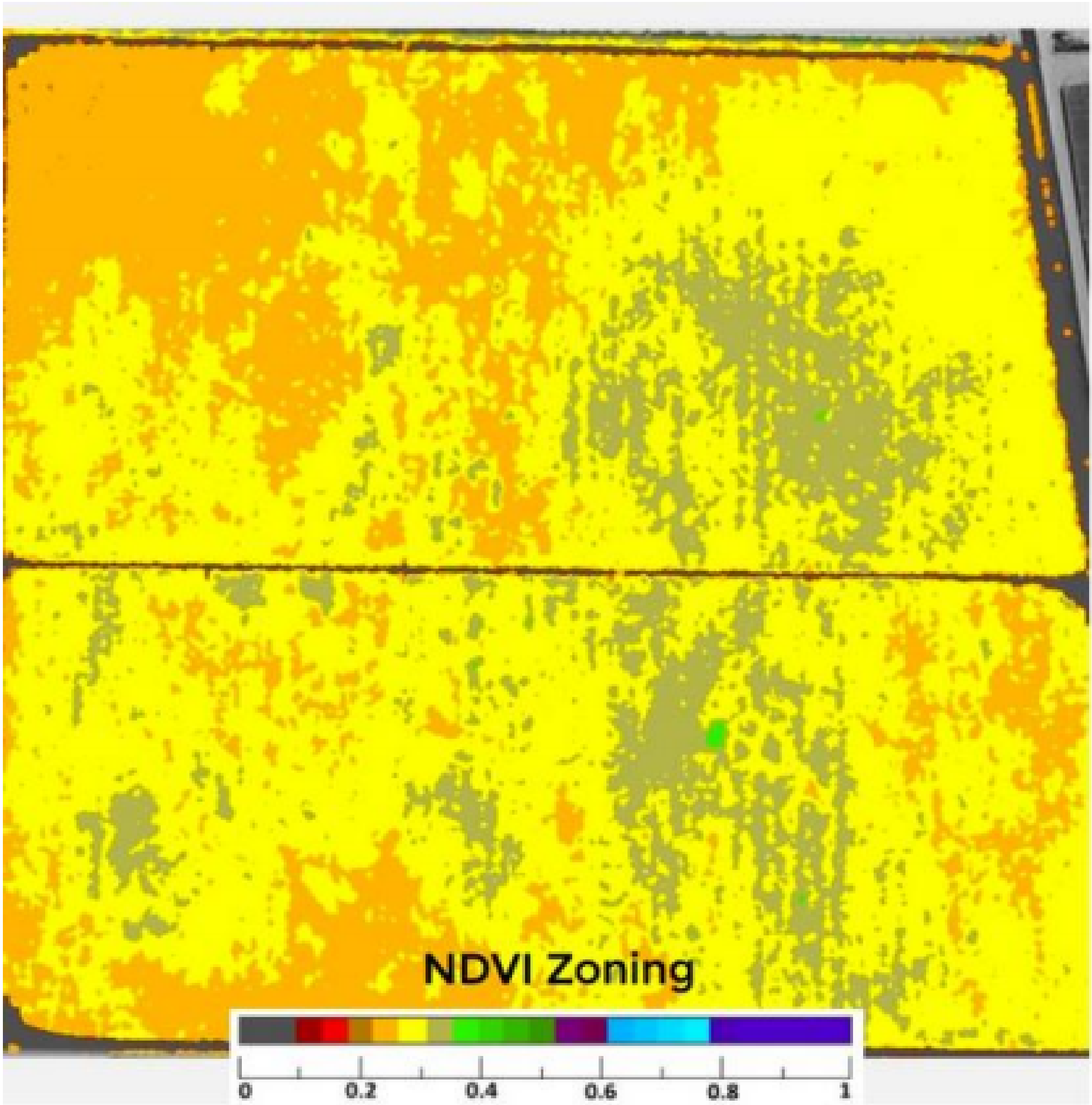


Figure 1.17: Unevenly matured zones

Soil amendments

Situation Soils greatly affect yield and value, but it is very difficult to discern geospatial distribution of soils without aerial imagery

Action Infrared and NDVI imagery highlights differing soil types, allowing for targeted soil amendments

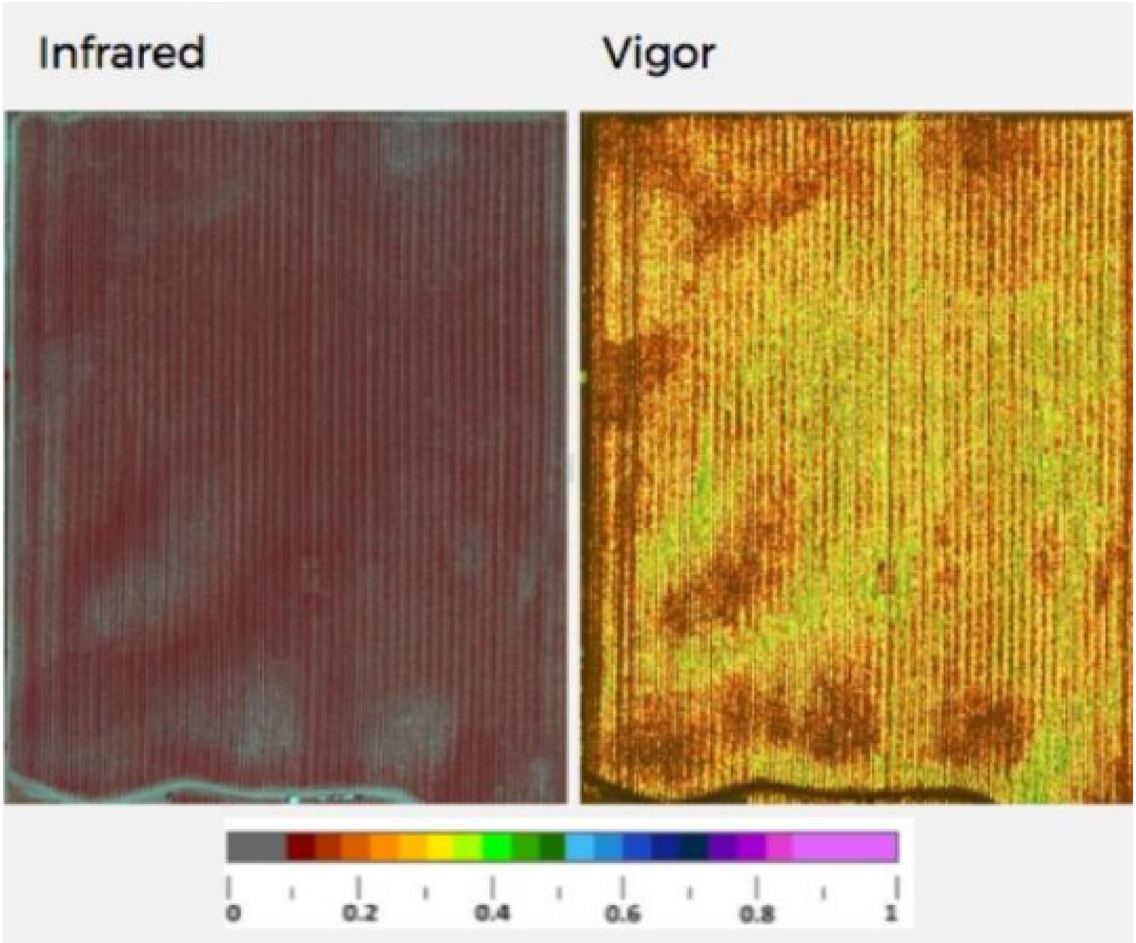


Figure 1.18: Differing soil types zones

powdery mildew

Situation Scouts randomly scout the vineyard for powdery mildew colonies throughout the season

Action NDVI imagery highlights high-vigor areas that are susceptible to powdery mildew, enabling targeted scouting, treatments or thinning.

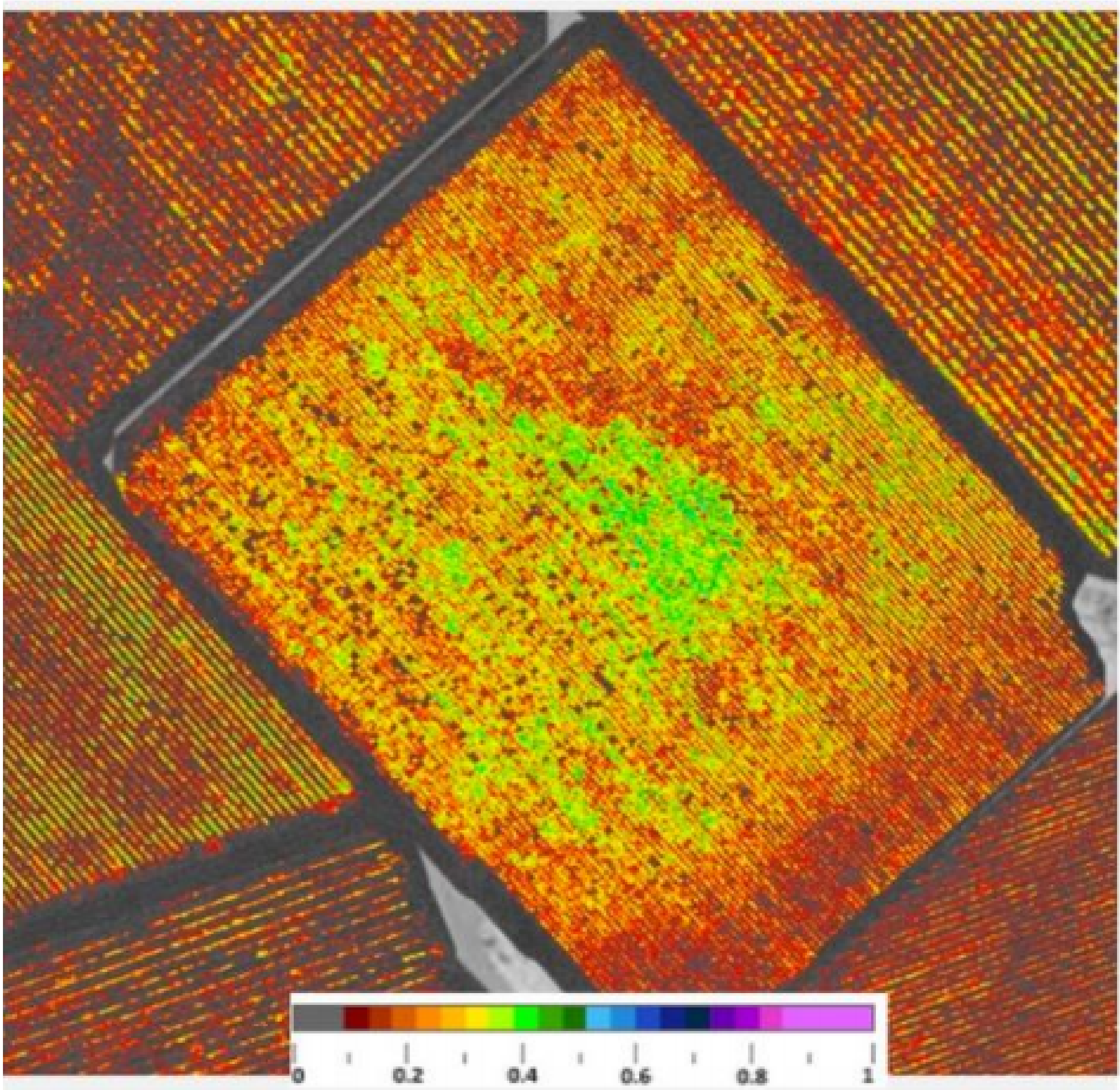


Figure 1.19: Infected powdery mildew zones

Diseases control

Situation Diseases can adversely affect yield, but diseased areas can be be difficult to identify

Action Use NDVI imagery to identify infected areas, thus applying fungicide when and where needed

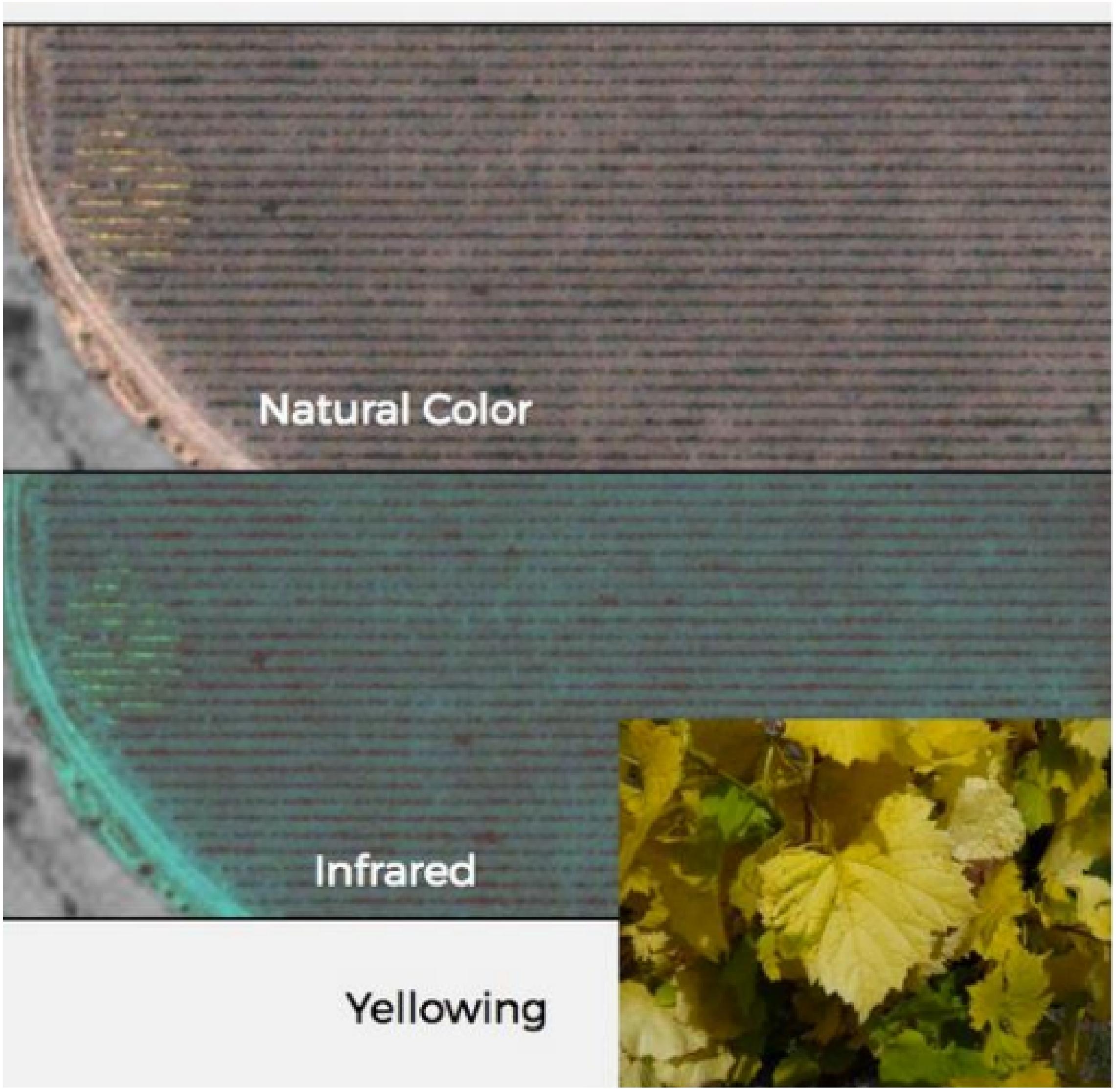


Figure 1.20: Infected zones

Weed control

Situation Weeds can adversely affect yield, but weedy areas can be be difficult to locate and target

Action Use NDVI imagery to identify weedy areas, thus applying herbicides when and where needed

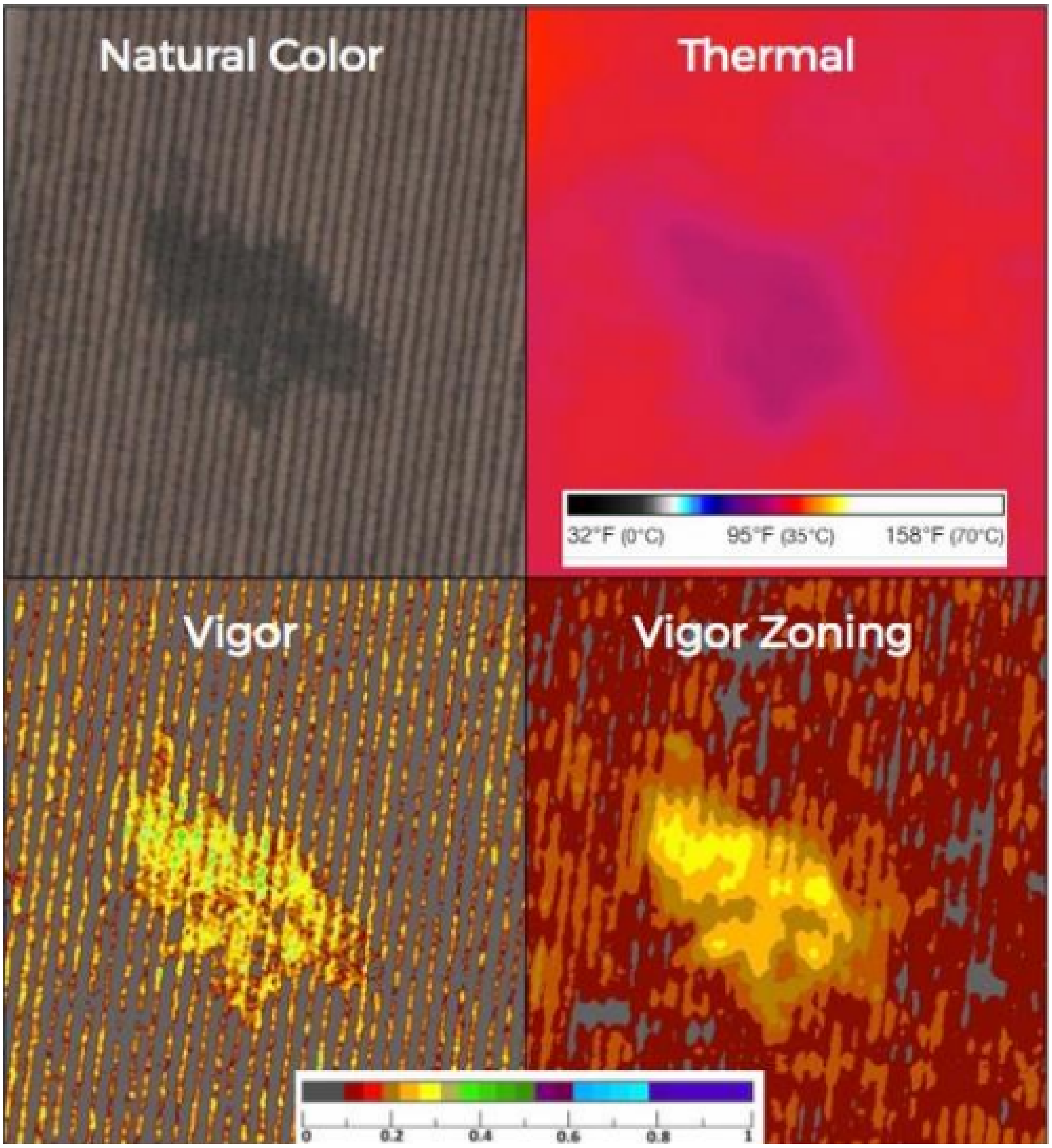


Figure 1.21: Weedy zones

Irrigation leaks

Situation Irrigation systems leak, causing excess vine vigor which diminishes grape quality and thus adversely affects price. Irrigation leaks are difficult to identify without aerial imagery.

Action Use thermal and NDVI imagery to identify irrigation leaks to be repaired, resulting in higher grape quality across vineyard

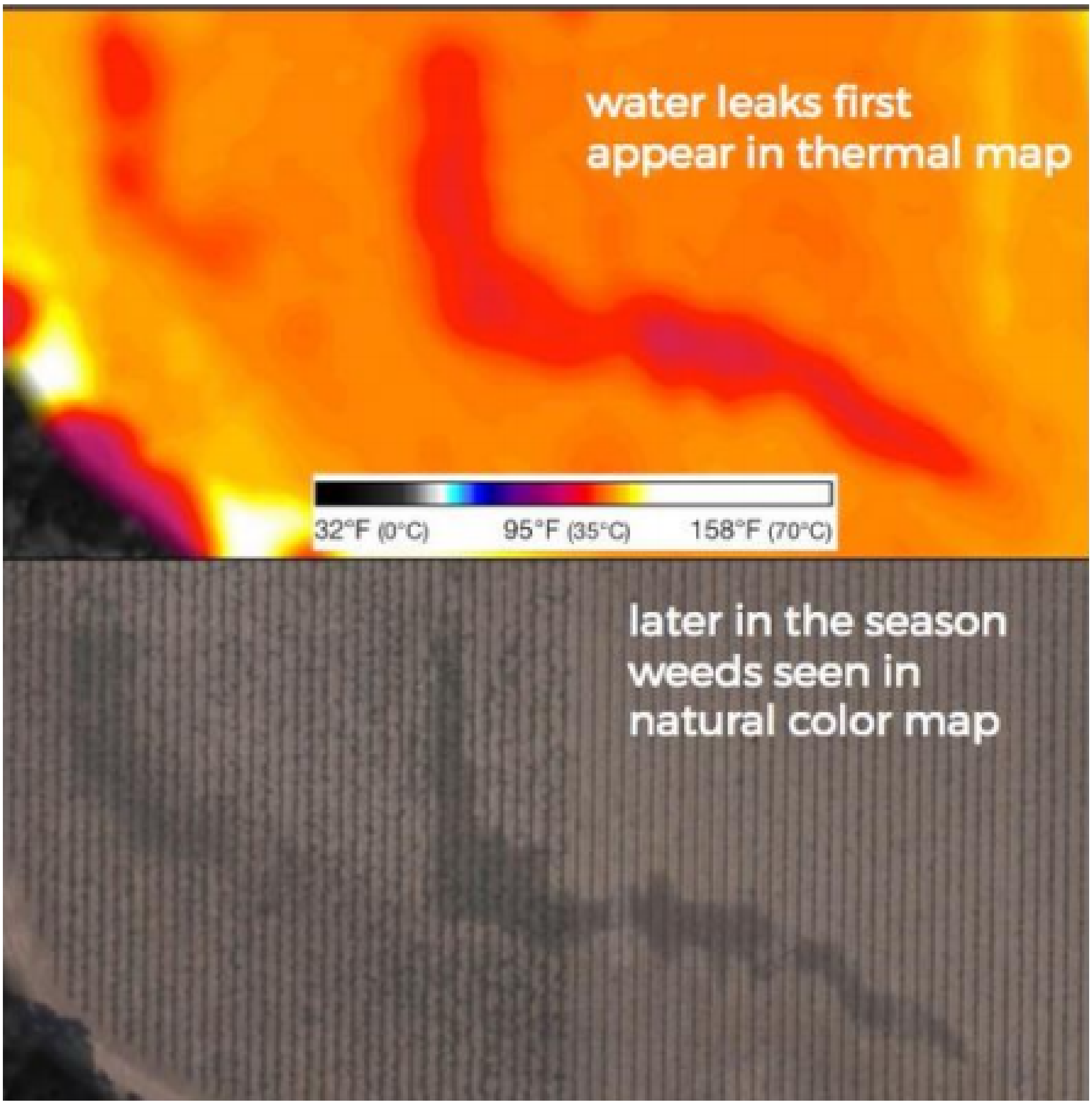


Figure 1.22: Irrigation systems leak zones

Irrigation optimization

Situation Uneven field vigor results in sub-optimal irrigation deliveries (i.e., some parts of vineyard get too much water, other parts get too little)

Action Use NDVI to create irrigation zones, enabling differential irrigation to ensure appropriate irrigation applications in each part of vineyard.

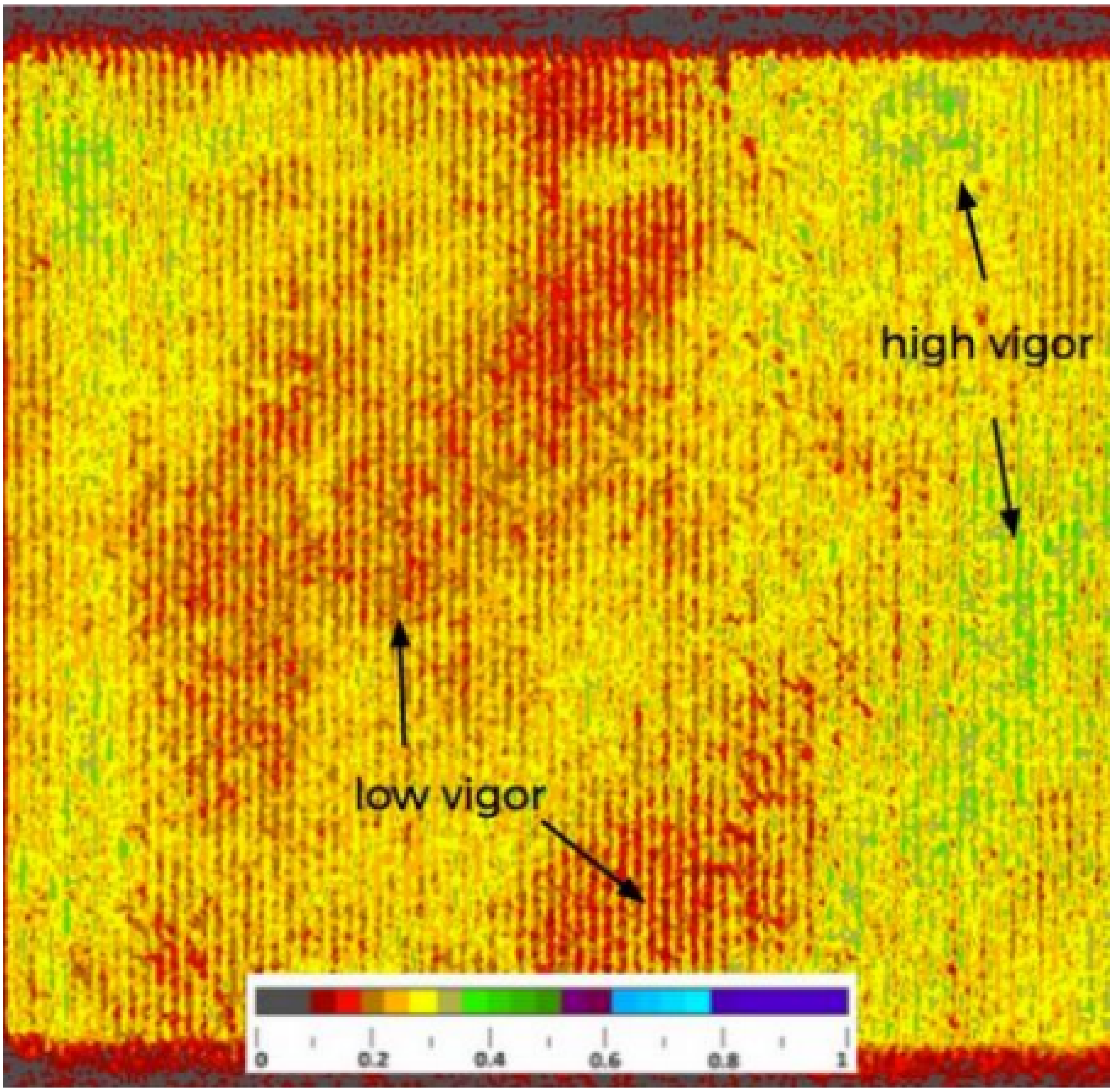


Figure 1.23: Uneven field vigor zone #1

Harvest zones

Situation Uneven field vigor results in mixed quality grape harvest.

Action Use NDVI to create harvest zones, enabling differential harvesting to avoid mixing high and low quality grapes.

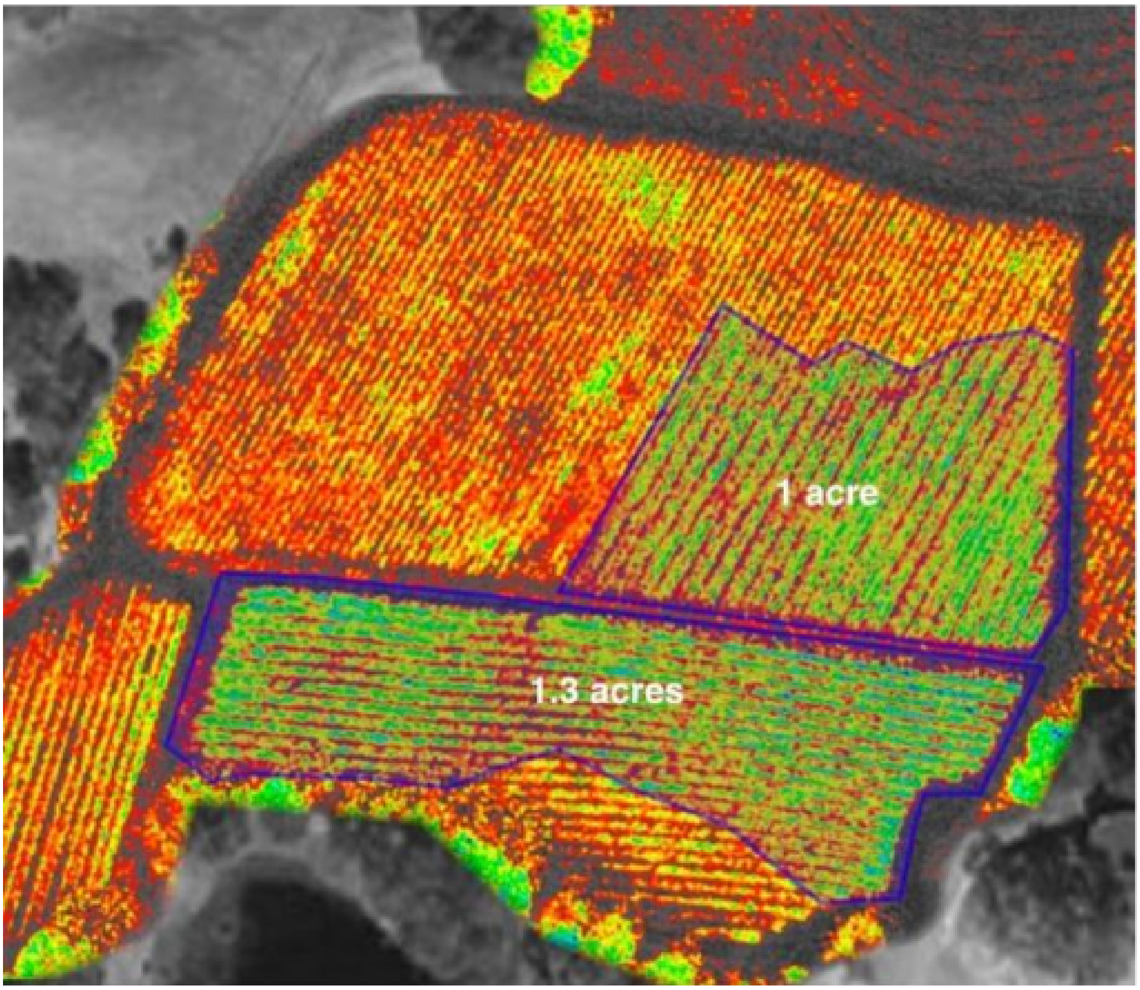


Figure 1.24: Uneven field vigor zone #2

Cover crops

Situation Uneven vineyard vigor results in sub-optimal cover crop planting decisions (i.e., cover crop based upon average vineyard needs as opposed to cover crops matching particular areas)

Action Create in-season vigor zones to inform off-season cover crop decisions

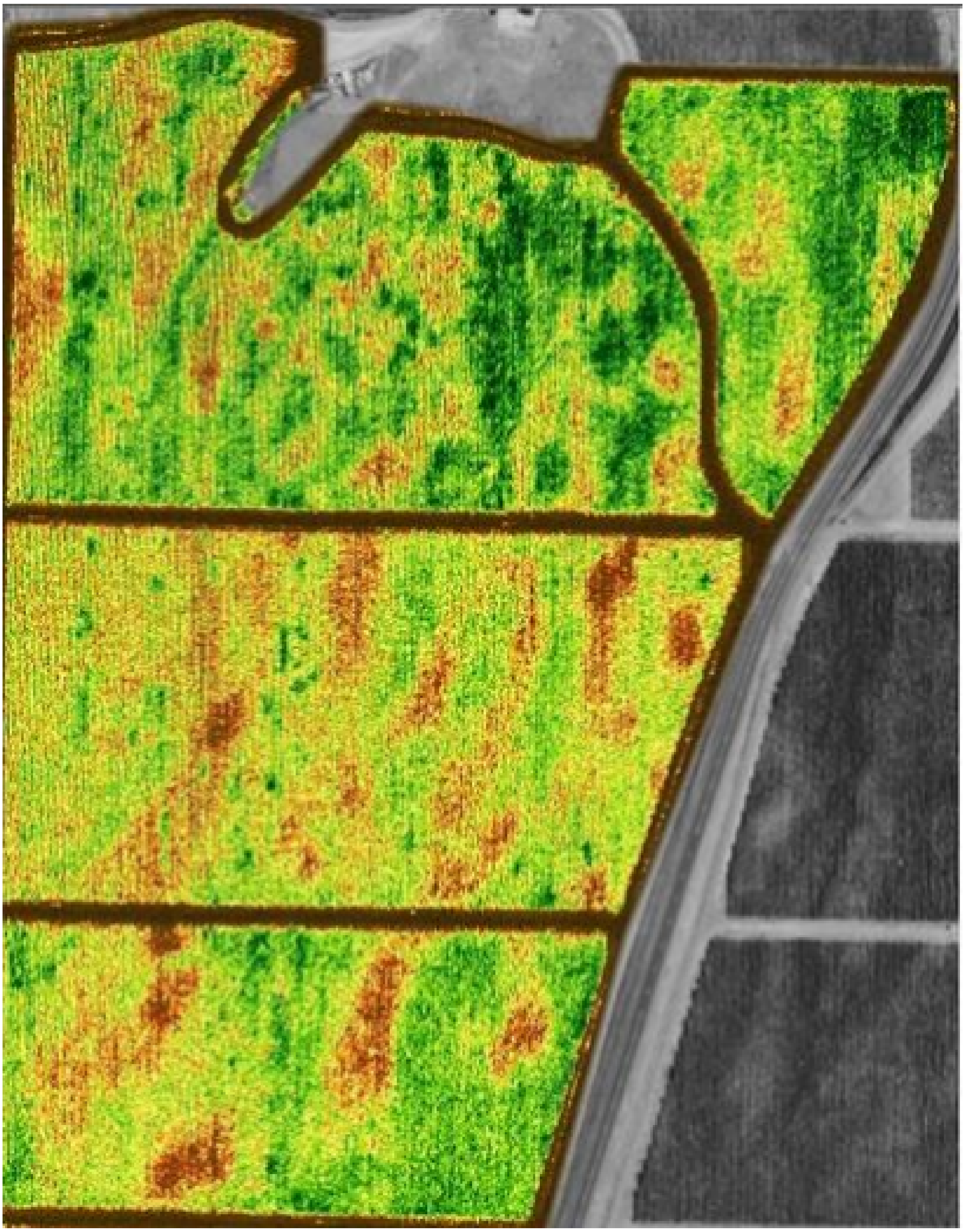


Figure 1.25: Uneven vineyard vigor zone

1.2.2 Using drones in Media and Entertainment

1.2.2.1 Aerial photography

In 2016 , An Egyptian company called "IFLY EGYPT" [11], started up which is specialized in developing UAVs used in aerial photography.they used drones in applications such as

- Football matches

Figure 1.26: Football match image taken by a drone

- Tourism industry

Figure 1.27: Cairo tower image taken by a drone

- Road traffic

Figure 1.28: Road traffic image taken by a drone

Challenges they have faced:

- permissions for using RC devices
- Exporting a lot of advanced equipment
- Maintenance of these equipment Local
- Developing for some equipment to meet the requirements

1.2.2.2 Advertising

Intel used the squadron of drones to advertise its logo

Figure 1.29: Intel image #1

Figure 1.30: Intel image #2

1.2.3 Using drones in Search and Rescue

1.2.3.1 Introduction

Drones aren't always mentioned in the same breath as saving lives, but a new report from one drone manufacturer says they should be.

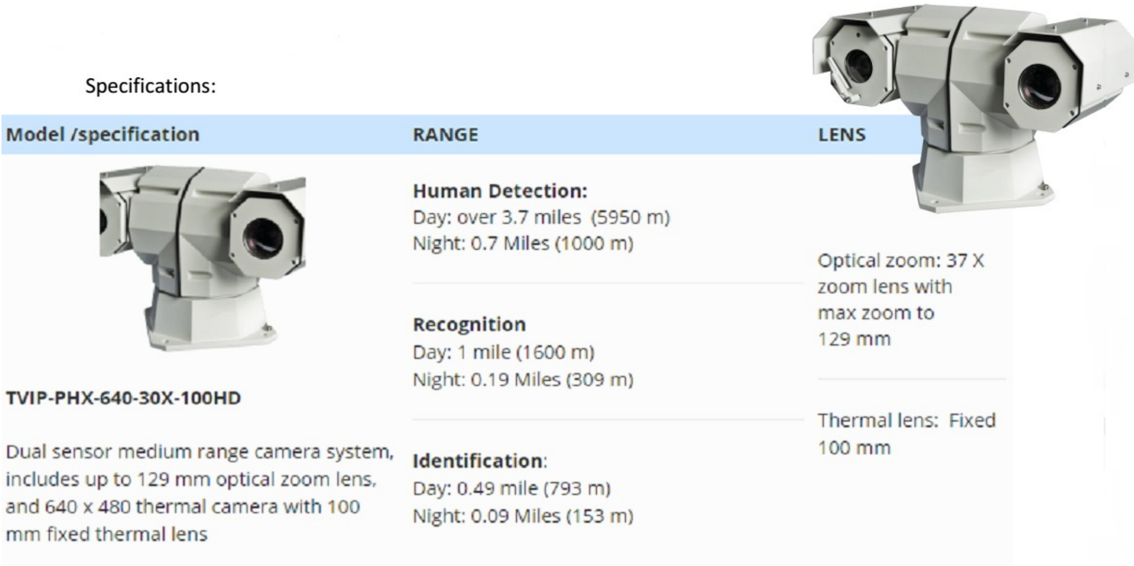
Civilian drones have been used to save at least 59 people in 18 different incidents around the world since 2013, DJI, a China-based company that manufacturers popular civilian drones, said in a statement on Tuesday. The company added that 38 of those individuals were saved within in the last 10 months thanks to rescue teams and civilians employing their unmanned aerial vehicles (UAV) to aid people facing life-threatening emergencies.

Now, DJI says a drone is saving nearly one person's life a week on average.

1.2.3.2 Saving and Rescue UAS

The mission The initial design is a fixed wing UAS with an IR camera for night vision. The UAS surfs the ocean and the Mediterranean Sea in order to search for any people stuck in the middle of the sea and rescue them. This can be done by installing the following devices:

- Long Range IR PTZ system

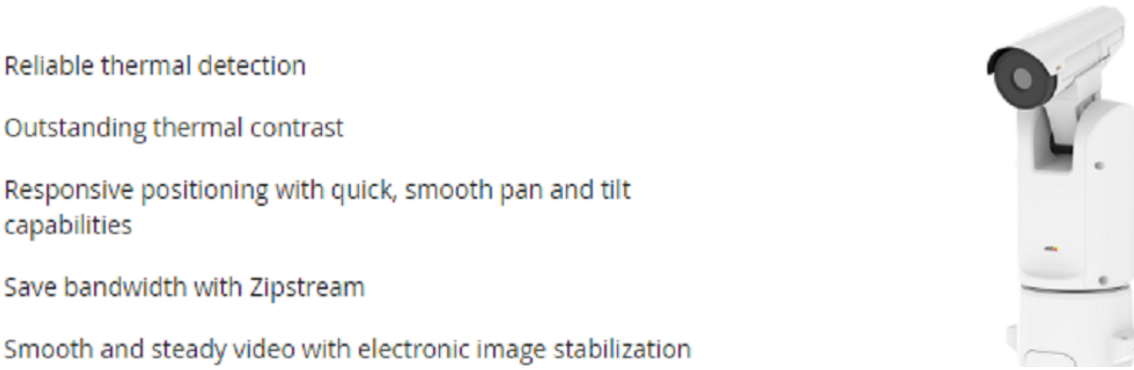


Specifications:

Model /specification	RANGE	LENS
TVIP-PHX-640-30X-100HD Dual sensor medium range camera system, includes up to 129 mm optical zoom lens, and 640 x 480 thermal camera with 100 mm fixed thermal lens	**Human Detection:** Day: over 3.7 miles (5950 m) Night: 0.7 Miles (1000 m) **Recognition** Day: 1 mile (1600 m) Night: 0.19 Miles (309 m) **Identification**: Day: 0.49 mile (793 m) Night: 0.09 Miles (153 m)	Optical zoom: 37 X zoom lens with max zoom to 129 mm Thermal lens: Fixed 100 mm

Figure 1.31: TVIP-PHX-640-100HD camera specifications

- AXIS Q8641-E PT Thermal Network Camera



Reliable thermal detection

Outstanding thermal contrast

Responsive positioning with quick, smooth pan and tilt capabilities

Save bandwidth with Zipstream

Smooth and steady video with electronic image stabilization

Figure 1.32: AXIS Q8641-E PT camera specifications

- AXIS Q8641-E lets operators choose between really slow or super-fast pan (from 0.05 to 120 degrees per second) and tilt movement (from 0.05 to 65 degrees per second). So they get smooth and jerk-free panoramic viewing when they need it and can respond quickly to events. The camera can be column-mounted, on poles or walls for a 360° panoramic view and a ground-to-sky view from -90° to +45°. It can withstand high winds when it's in motion of up to 47-meter per second (106 mph).

– Detection Ranges

	Focal length	Viewing angle	Detection			
	mm	Horizontal	Human: 1.8 x 0.5 m		Vehicle: 4 x 1.5 m	
			m	yards	m	yards
Detection (1.5 pixels on target)	35	10.7°	1028	1124	3153	3448
Recognition (6 pixels on target)	35	10.7°	257	281	788	862
Identification (12 pixels on target)	35	10.7°	129	141	394	431

Table 1.2: AXIS Q8641-E detection ranges

– This camera can be a better option as it has a local seller in Egypt. As the camera belongs to Axis communications and has a seller "Quantum Digital Technologies, Cairo", "HitekNofal Solutions, Cairo" and "C&CC, Cairo".

Types of UAS that can be used in search and rescue

Fixed Wing UAS The first trial maybe a fixed wing UAS able to carry the payload of the camera system, compatible with the battery and having a GPS system to detect the one drowning in the sea and send its location to The responsible Authority for saving him.

Multi-Rotor Drone This design can be taken into consideration as it's easy to manufacture. This option is a better one.

Another Function may be added to this Multi-Rotor Drone which is dropping life vests and ropes to people stuck in the sea like in the following picture.

Figure 1.33: Dropping life vests drone

1.2.3.3 Firefighting Drones

In search and rescue operations, drones allow greater coverage of a search area – and thermography allows rescue teams to work through the night, significantly increasing the potential for success. Thermal imaging cameras give teams the power to "see in total darkness," says FLIR, the global leader in thermo-graphic imaging sensors. Added to that is the ability to discern figures difficult to find with traditional cameras even in daylight- like one stranded hiker lost against the backdrop of a snowy field. This capacity is one of several reasons that law enforcement organizations around the world are using drones. Firefighting may provide one of the most compelling applications for drones equipped with thermal imaging equipment. From New York City's famous FDNY to volunteer departments in small towns around the country, fire departments are utilizing drone technology to save structures and victims, and minimize risk to firefighters. The aerial perspective through a thermal imaging camera allows teams to pinpoint hotspots, identify victims on the scene, and quickly establish a plan of attack. It provides a level of visibility in the midst of a fire that is impossible with the naked eye or traditional cameras. (You can see how a fire looks through the lens of one of these thermo-graphic tools here – experiencing a firefighters view through dark and smoke.) Drones not only make firefighters more effective – they keep them safe.

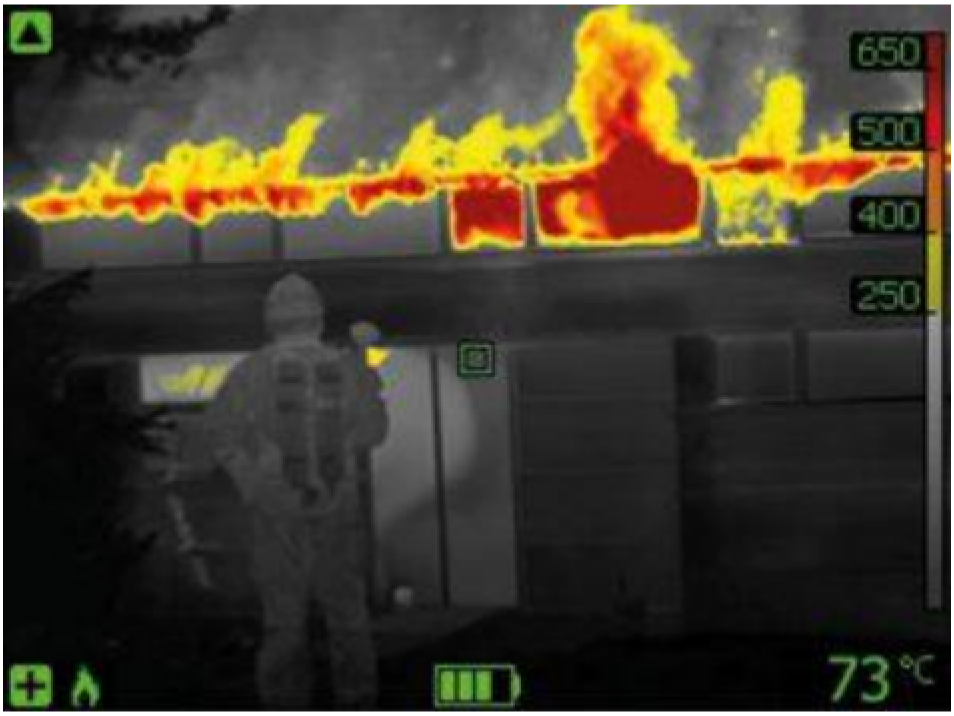


Figure 1.34: Thermal image taken by a Drone

Main components Drones may have the same cameras mentioned above or more accurate thermal cameras for optimizing its missions. But it may be designed to be Multi-Rotor Drone in order to be more flexible to fly above the burnt areas.

1.2.4 Using drones in Disaster Relief and Emergency Response

1.2.4.1 Introduction

Aerial drones are one of the most promising and powerful new technologies to improve disaster response and relief operations. Drones naturally complement traditional manned relief operations by helping to ensure that operations can be conducted safer, faster, and more efficiently.

When a disaster occurs, drones may be used to provide relief workers with better situational awareness, locate survivors amidst the rubble, perform structural analysis of damaged infrastructure, deliver needed supplies and equipment, evacuate casualties, and help extinguish fires among many other potential applications.

In advance of an emergency, drones are able to assist with risk assessment, mapping, and planning [12]. When individuals, businesses, and communities are able to understand and manage risks and plan effectively, they reduce overall damage and losses. Rebuilding and recovery are then able to begin more quickly and ultimately strengthening the resiliency of communities.

Drones have long been described as optimally suited to perform the "3-D" missions, often described as dirty, dull, and dangerous. They can provide needed aerial data in areas considered too hazardous for people on the ground or for manned aircraft operation, such as sites with nuclear radiation contamination or in close proximity to wildfires. Drones can also deliver needed supplies and relay Wi-Fi and cellular phone service when communications are needed the most.

Disaster relief and emergency response (DRER) efforts are inclusive of all actions by first responders and subsequent aid efforts during and immediately following a catastrophic event which threatens human life.The primary purpose of DRER efforts is to save human lives. Secondary purposes of DRER efforts are to preserve and maintain the environment, protect property, keep the peace, and uphold governmental authority.

UAV systems have the potential to improve the effectiveness of DRER efforts by enhancing first responder.

Modern manned DRER systems include ground vehicles, conventional aircraft, and rotorcraft capabilities and providing advanced predictive capabilities and early warning. A wide variety of system types of all sizes with varying capabilities already exist with even more under development.

Disasters or emergencies for which DRER UAV systems could be implemented include: severe storms, tornados, hurricanes, wild fires, tsunamis, floods, earthquakes, avalanches, civil disturbances, oil or chemical spills, and urban disasters.

Civil unmanned aerial vehicle systems have potential to augment disaster relief and emergency response efforts. Optimal design of aerial systems for such applications will lead to unmanned vehicles which provide maximum potentiality for relief and emergency response while accounting for public safety concerns and regulatory requirements.

1.2.4.2 Major Usage

Reconnaissance and Mapping The need for regular mapping of disaster-prone areas cannot be overstated. Flood maps help coordinate disaster response eff orts after events like the Superstorm Sandy storm surge; 3D topographical mapping can help identify areas prone to mudslide; high-resolution visual imaging can help first responders flag critical infrastructure that needs to be secured immediately after a disaster; and advances in remote sensing technology have opened new possibilities in developing early warning signs for potential disasters. For example, British researchers operating in Malaysia have used drones to map patterns of deforestation that have been correlated with increased incidences of malaria.

Maps constructed quickly in the wake of a disaster are also useful tools for identifying and assessing damage, especially when combined with images of the area before a disaster. For this to be most efficacious in assisting relief operations, "before" maps must be very recent, while "after" maps must be created as swiftly as possible.

Unfortunately, in the aftermath of a disaster, mapping may take too long using satellites or traditional manned aircraft. Satellite imaging technology cannot currently penetrate cloud cover, often leading to delays in image capture after extreme weather events.

Structural Integrity Assessment Natural disasters such as earthquakes, hurricanes, tornadoes, tsunamis, and floods, as well as man-made disasters such as explosions and arson, can all cause immense damage to the structural integrity of buildings and infrastructure. Even small-scale events can cause serious damage. For example, the 2011 Virginia Earthquake, though measuring only 5.8 on the Richter scale, caused significant structural damage to such famous landmarks as the Washington Monument and the National Cathedral.

Assessing structural damage after a disaster comes with many potential risks. Assessors may have to enter buildings in danger of collapse or access hard-to-reach places like the undersides of bridges. Drones have proven their usefulness in assessing structural damage over a wide area, locally, and even in building interiors.

Chemical, Biological, Radiological, Nuclear, or Explosive (CBRNE) Events Heavy industry and power generation relies on hazardous chemicals and fuels, including fi ssile material to create nuclear power. Malfunctions in factories or power plants, accidents while transporting hazardous materials, terrorism and criminal sabotage all have the potential to create unexpected chemical, biological or nuclear disasters. These devastating events require fast and eff ective disaster response and relief eff orts, but by their nature are extremely unsafe for relief workers. Characteristics of CBRNE events are: •Toxic / radioactive / explosive environments.

- Toxic / radioactive / explosive environments.
- Unprepared / disrupted surfaces.
- Rapidly changing environmental situations.
- Lack of information and data on the extent of the disaster.

Drones significantly reduce human exposure to unsafe environments while providing continuous monitoring and data validation in the most extreme conditions. Sending drones into a CBRNE area can help rescue workers quickly and safely locate sources of contamination/danger and the scope of the damage, providing invaluable situational awareness. Drones can also be used to repair damage, quickly deliver needed equipment to disaster teams, and apply chemical retardants or dispersants. Additionally, most drones can be deployed from unimproved locations, ensuring that even if airfields are not present or are unusable, aircraft can still be deployed to the area.

While drones have been used primarily in post-CBRNE disaster damage assessment and establishing situational awareness, the uses of drones in these environments are nearly endless.

For example, drones could have been used to distribute goods to the family of Thomas Duncan, the man infected with the Ebola virus in Liberia, who returned to Dallas, Texas, in fall 2014.

Drones have many uses in the preparedness and prevention stages of disaster, as well. For instance, drones fitted with methane sniff ers could detect a gas leak in a storage tank before it ignited.

Search and Rescue Operations Many dynamic tactical challenges accompany search and rescue operations [13]. Searching for people or wreckage over vast areas like deserts, oceans, rugged mountainous and forested terrain can be very time consuming and difficult. This can lead to crew fatigue, decreasing their effectiveness in searching and increasing the likelihood of pilot error. Furthermore, once survivors are located, many rescue / evacuation operations must be carried out in hazardous environments (CBRNE, low visibility, rugged terrain, etc.). The use of unmanned systems in these situations allows operations to be conducted without exposing a flight crew to unnecessary danger. Search and rescue operations often embody the “3-D” model (Dull, Dirty, Dangerous) of missions best suited to drones.

Insurance Claims Response and Risk Assessment Insurance companies play an invaluable role in assisting disaster relief efforts. When people lose their homes and possessions and when businesses stuff er property damage and business interruption, insurance companies are there to provide them with the material support they need to begin the rebuilding process. Insurance coverage can help disaster-stricken areas recover much more quickly and comprehensively than would have been possible otherwise. For these reasons, it is imperative that insurance companies act as eff actively and efficiently as possible in the wake of a disaster. Insurance companies could use drones to fly over an affected area, assessing damage to insured property, developing situational awareness for deploying additional claims adjusters on the ground, and supporting the claims response process. Using drones will also reduce the inherent dangers of inspecting damaged properties. Drones provide more options to review properties, which otherwise would be inaccessible due to safety concerns.

Logistics Support The damage to infrastructure that occurs after major disasters is often one of the most signifi cant obstacles to effi cient disaster relief. Blocked roads, damaged rail, and destroyed sea and airports can severely curtail disaster recovery by delaying delivery of needed supplies and equipment.

Drones provide an alternative for logistical support after a disaster. Drones can fly above destroyed infrastructure, and many, particularly rotary-wing craft, do not require runways for takeoff.

Drone logistics support will also help disaster responders directly. Any extra time that disaster responders can devote to actively mitigating a disaster or searching for and rescuing survivors will save lives and reduce costs. Many rescue workers currently devote substantial time to establishing logistical support for other responders, ferrying equipment and essential supplies like food and water. Drones can help speed up this process.

1.2.4.3 Advantages in Disaster Relief and Emergency Response:

- Drone technology can reduce disaster worker exposure to unnecessary danger:
  - Drones function in environments that are unsafe for humans.
- Drones enhance the effectiveness of responders
  - In addition to relieving disaster responders from some of their most dangerous duties, drones can perform dull and dirty tasks to allow responders to focus on more important matters.
- Drones provide unique viewing angles at low altitudes not possible from manned aircraft
  - For example, a team from several European universities, called NIFTi, used two small rotary-wing drones to assess damage to cathedrals in Mirandola, Italy, after an earthquake in 2012. Such an assessment is impossible with manned systems.
- Drone technology is highly deployable
  - Drones, particularly small models, can be launched in a variety of environments without the need for a runway.
- Drone technology is cost-efficient
  - While a robust drone system can require significant upfront capital cost, drones are still often cheaper than manned aircraft to purchase and operate. Furthermore, by developing relationships with drone service companies, emergency response organizations can pay only for the tools that they need before and after disasters, lowering costs.

1.2.5 Using drones in Wind Turbine Inspection

Wind Turbine Inspections involve identification of defects such as: Dents, Cracks, Delamination, Gel-coat degradation, Paint peel-off, Lightning Strike damage, Lightning Receptor damage, Vortex Generator damage, Fiber Wrinkles, Manufacturing anomalies, installation damage, etc.

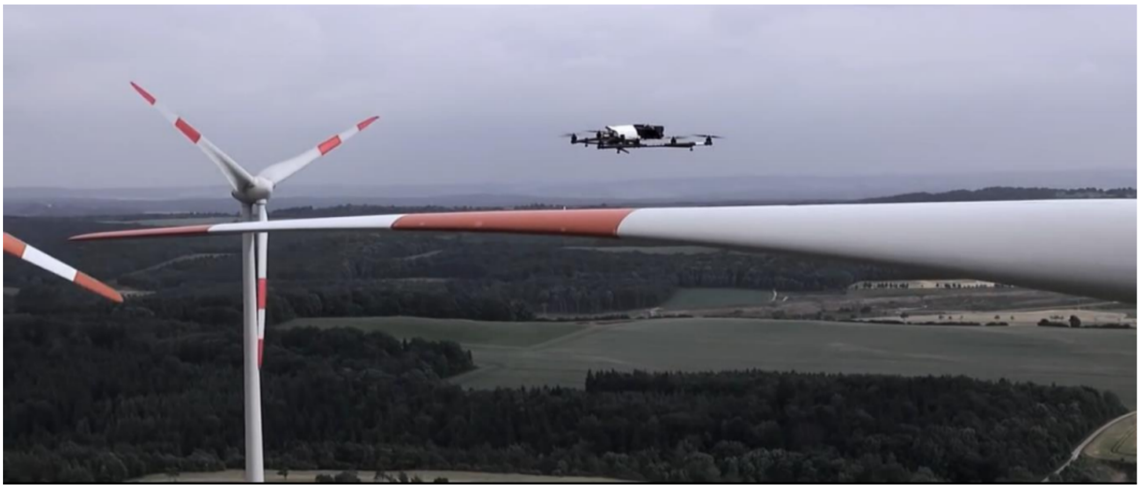


Figure 1.35: Wind Turbine inspection

1.2.6 Using drones in Other Applications

- Meteorological Monitoring (Humidity – Wind – Pressure – Temperature - .....) in various locations to get a Meteorological map
- Police or Military reconnaissance Especially in mountainous areas
- Industrial roof inspections
- Surveying & Mapping
- Solar panels inspections
- Civil inspection
- Pipeline and power line inspections

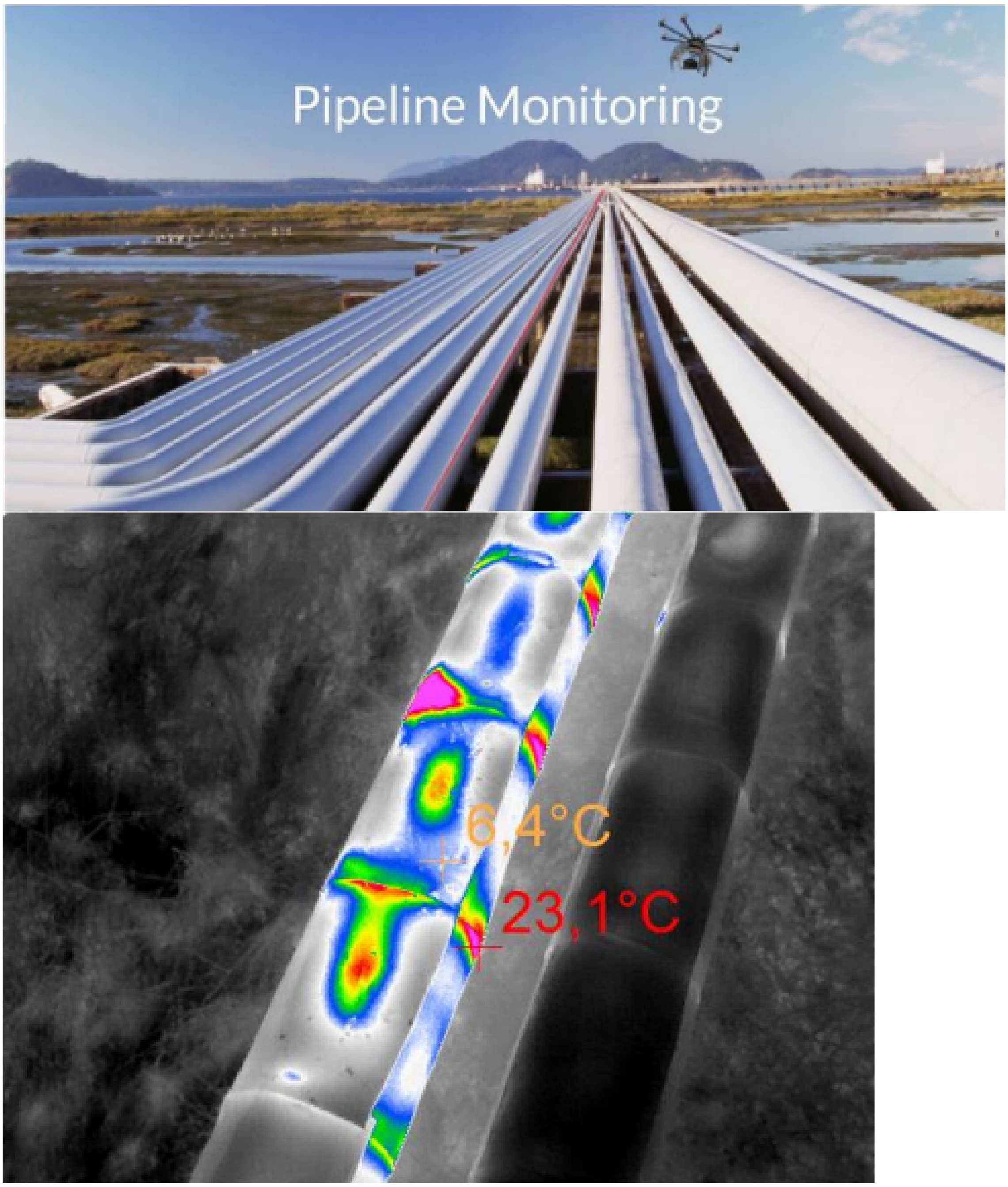


Figure 1.36: Pipeline inspections

- Tunnels inspections Especially narrow ones
- Racing Besides it can be integrated with VR (virtual reality)

- Internet access(Google project)

1.3 Conclusion

We settled on precision agriculture field as it has so mush potential and many befits.

2 Autopilot Overview

2.1 Introduction

The basis for autopilot system operation is error correction. When an aircraft fails to meet the conditions selected, an error is said to have occurred. The autopilot system automatically corrects that error and restores the aircraft to the flight attitude desired by the pilot. There are two basic ways modern autopilot systems do this. One is position based and the other is rate based. A position based autopilot manipulates the aircraft's controls so that any deviation from the desired attitude of the aircraft is corrected. This is done by memorizing the desired aircraft attitude and moving the control surfaces so hat the aircraft returns to that attitude. Rate based autopilots use information about the rate of movement of the aircraft, and move control surfaces to counter the rate of change that causes the error. Most large aircraft use rate-based autopilot systems. Small aircraft may use either.

Any autopilot consists of three different things

- Guidance system
- Control system
- Navigation system

These systems aim to make the any aircraft full autonomous.

2.2 Components of an Autopilot System

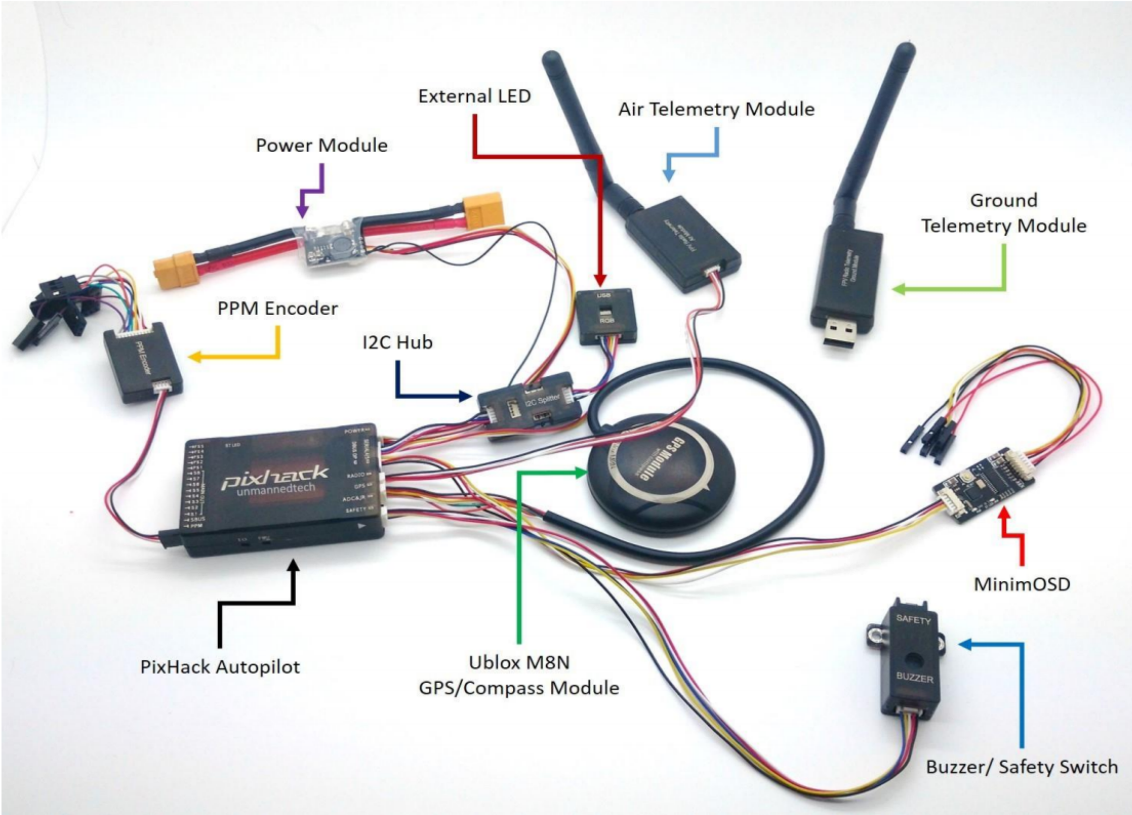


Figure 2.1: Components of an Autopilot System

2.3 Professional Autopilot's Definitions

Professional Autopilots such as ArduPilot and Pixhawk Autopilot defined theses definitions (modes) so that other companies or individuals working in the same field follow their standard of Autopilot

Basic Autopilot control modes

Stabilize Mode

Stabilize mode allows you to fly your vehicle manually, but self-levels the roll and pitch axis.

- Pilot's roll and pitch input control the lean angle of the copter. When the pilot releases the roll and pitch sticks the vehicle automatically levels itself.
- Pilot will need to regularly input roll and pitch commands to keep the vehicle in place as it is pushed around by the wind.
- Pilot's yaw input controls the rate of change of the heading. When the pilot releases the yaw stick the vehicle will maintain its current heading.
- Pilot's throttle input controls the average motor speed meaning that constant adjustment of the throttle is required to maintain altitude. If the pilot puts the throttle completely down the motors will go to their minimum rate and if the vehicle is flying it will lose attitude control and tumble.
- The throttle sent to the motors is automatically adjusted based on the tilt angle of the vehicle (i.e. increased as the vehicle tilts over more) to reduce the compensation the pilot must do as the vehicle's attitude changes.

Altitude Hold Mode

In altitude hold mode, Copter maintains a consistent altitude while allowing roll, pitch, and yaw to be controlled normally.

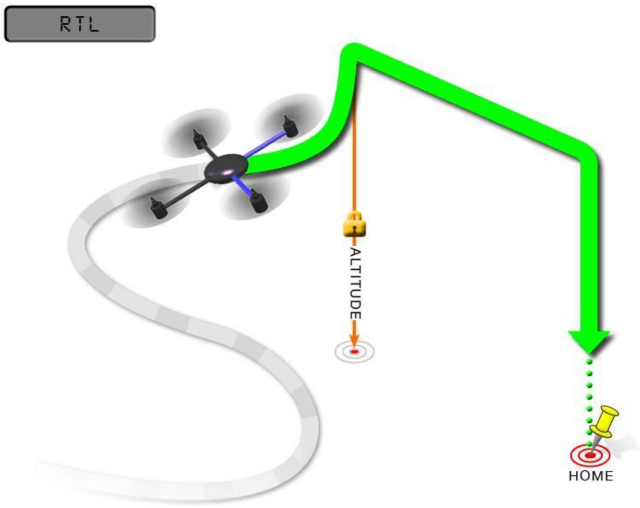
When altitude hold mode is selected, the throttle is automatically controlled to maintain the current altitude. Roll, Pitch and yaw operate the same as in Stabilize mode meaning that the pilot directly controls the roll and pitch lean angles and the heading.

Loiter Mode

Loiter Mode automatically attempts to maintain the current location, heading and altitude. The pilot may fly the copter in Loiter mode as if it were in a more manual flight mode but when the sticks are released, the vehicle will slow to a stop and hold position.

A good GPS lock, low magnetic interference on the compass and low vibrations are all important in achieving good loiter performance.

RTL Mode



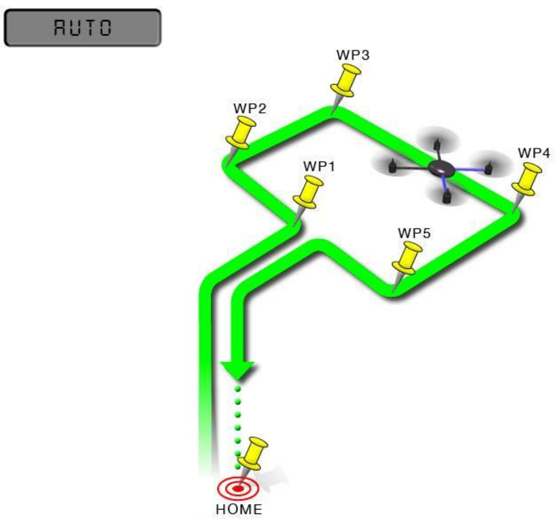
RTL mode (Return To Launch mode) navigates Copter from its current position to hover above the home position.

When RTL mode is selected, the copter will return to the home location. The copter will first rise to specified altitude before returning home or maintain the current altitude if the current altitude is higher than the specified altitude. The default value for the specified altitude is 15m.

RTL is a GPS-dependent move, it will command the copter to return to the home position, meaning that it will return to the location where it was armed. Therefore, the home position is always supposed to be your copter's actual GPS takeoff location, unobstructed and away from people.(barometer & GPS & sonar for 20 feets)

Agriculture modes

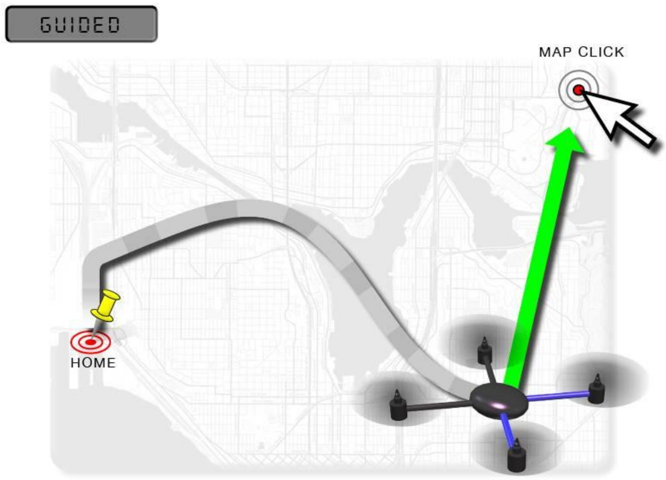
Auto Mode



In Auto mode, the copter will follow a pre-programmed mission script stored in the autopilot which is made up of navigation commands (i.e. waypoints) .

AUTO mode incorporates the altitude control from Altitude Hold mode and position control from Loiter mode and should not be attempted before these modes are flying well.

Guided Mode



Guided mode is a capability of Copter to dynamically guide the copter to a target location wirelessly using a telemetry radio module and ground station application.

Guided mode is not a traditional flight mode that would be assigned to a mode switch like other flight modes

Pilot point of view modes

Land Mode

LAND Mode attempts to bring the copter straight down and has these features:

- descends to 10m (or until the sonar senses something below the copter)

Position Hold Mode

The Position Hold flight is similar to Loiter in that the vehicle maintains a constant location, heading, and altitude but is generally more popular because the pilot stick inputs directly control the vehicle's lean angle providing a more "natural" feel.

Good GPS position, low magnetic interference on the compass and low vibrations are all important in achieving good loiter performance.

Simple and Super Simple Modes

"Simple" and "Super Simple" modes allow the pilot to control the movement of the copter from the pilot's point of view regardless of which way the copter is facing. This is useful for new pilots who have not mastered adjusting their roll and pitch inputs depending upon which way the vehicle is facing and for cases when the copter is far enough away that it's heading is not apparent.

- "Simple" and "Super Simple" modes can be used in combination with nearly all flight
- Simple Mode allows you to control the copter relative to the copters heading at takeoff and relies only on a good compass heading.
- Super Simple Mode allows you to control the copter relative to its direction from home (i.e. where it was armed) but requires a good GPS position.

Brake Mode

This very simple flight mode simply stops the vehicle as soon as possible using the Loiter controller. Once invoked, this mode does not accept any input from the pilot.

When switched on, Brake mode will attempt to stop the vehicle as quickly as possible. Good GPS position, low magnetic interference on the compass and low vibrations are all important in achieving good performance.

Photographing modes

Circle Mode

Circle will orbit a point located with specified radius in front of the vehicle with the nose of the vehicle pointed at the center.

Setting the radius to zero will cause the copter to simply stay in place and slowly rotate (useful for panorama shots).

Sport Mode

- It was designed to be useful for flying FPV and filming dolly shots or fly by because you can set the vehicle at a particular angle and it will maintain that angle.
- The pilot's roll, pitch and yaw sticks control the rate of rotation of the vehicle so when the sticks are released the vehicle will remain in its current attitude.
- The vehicle will not lean more than 45 degrees
- The altitude is maintained with the altitude hold controller so the vehicle will attempt to hold its current altitude when the sticks are placed with 10% of mid-throttle.
- It will climb or descend at up to 2.5m/s.

Follow Me Mode

Follow Me mode makes it possible for you to have your copter follow you as you move, using a telemetry radio and a ground station. (GPS dongle)

2.4 Guidance System

2.4.1 Introduction

Guidance is defined as: The process for guiding the path of an object towards a given point, which in general may be moving.

- Determines a path to follow based on commanded signals (waypoints – altitude - speed) by the operator.

- Many methods to make a guidance system depends on what the autopilot supposed to do (tracking a moving target which is time-dependent) or (follow a predefined path which is time-independent).
- The guidance system of any aerial vehicle must handle three dimensions. It will be decoupled into two parts:
  - Horizontal(East-West)
  - Vertical(altitude)

Guidance laws are composed of speed and steering laws, which can be combined in different ways to achieve different motion control objectives.but we must know about the different motion control scenarios in order to find what suits our application.

2.4.1.1 motion control scenarios

motion control scenarios are typically divided into the following categories: point stabilization, trajectory tracking, and path following.

- The control objective of a target-tracking scenario is to track the motion of a target that is either stationary (analogous to point stabilization) or that moves such that only its instantaneous motion is known, i.e., such that no information about the future target motion is available. Thus, in this case it is impossible to separate the spatio-temporal constraint associated with the target into two separate constraints.
- The control objective of a path-following scenario is to follow a predefined path, which only involves a spatial constraint. No restrictions are placed on the temporal propagation along the path. However, the control objective of a path-tracking scenario is to track a target that moves along a predefined path (analogous to trajectory tracking), which means that it is possible to separate the related spatio-temporal constraint into two separate constraints. Often, the spatial constraint is considered more important than the temporal constraint, such that if both cannot be satisfied simultaneously, the spatial constraint takes precedence (i.e., to move along the path, albeit at a distance behind the target).
- The control objective of a path-maneuvering scenario is to employ knowledge about vehicle maneuverability to feasibly negotiate (or somehow optimize the negotiation of) a predefined path. As such, path maneuvering represents a subset of path following, but is less constrained than path tracking since spatial constraints always take precedence over temporal constraints.

There are three terminal guidance strategies will be presented in the following, namely line of sight, pure pursuit, and constant bearing.

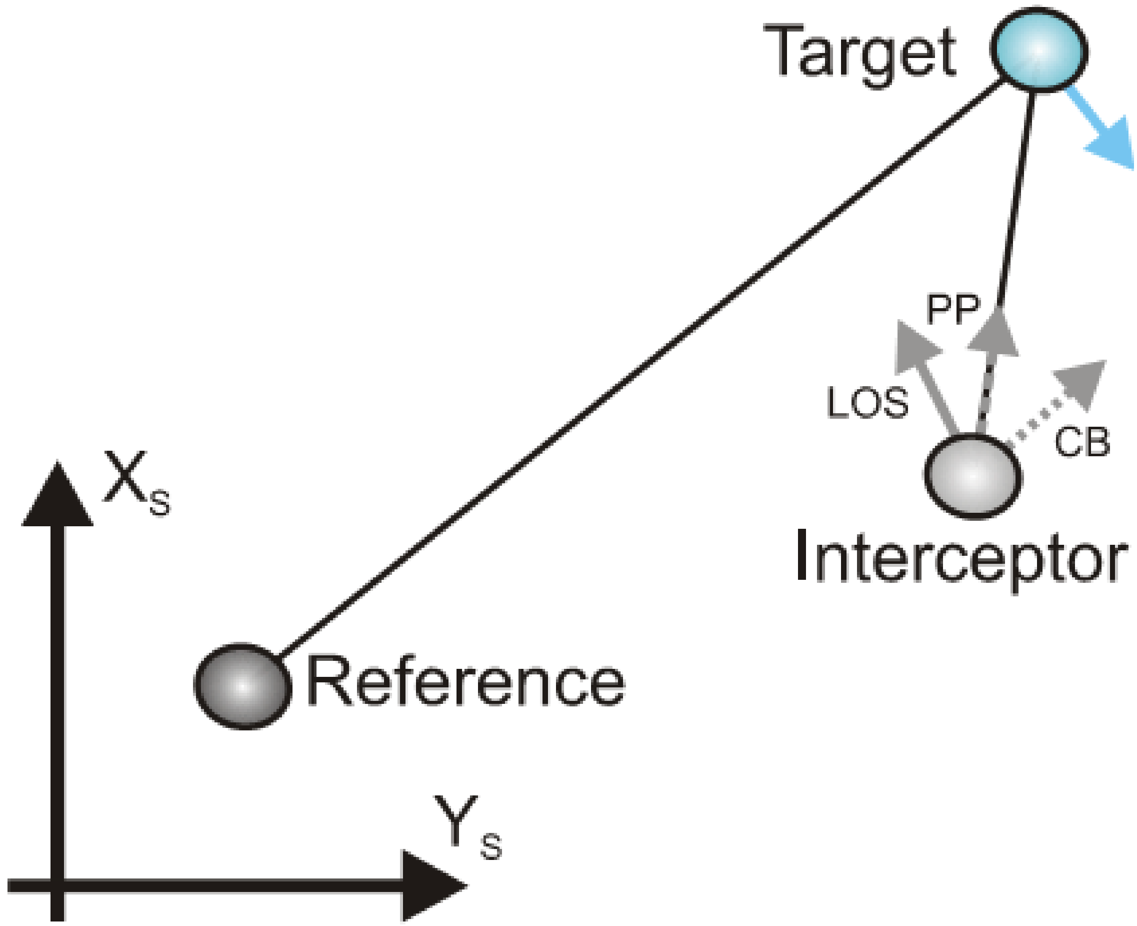


Figure 2.2: Guidance principles line of sight (LOS), pure pursuit (PP), and constant bearing (CB).

- Line of Sight Guidance

  Line of sight (LOS) guidance is classified as a so-called three-point guidance scheme since it involves a (typically stationary) reference point in addition to the interceptor and the target. The LOS denotation stems from the fact that the interceptor is supposed to achieve an intercept by constraining its motion along the line of sight between the reference point and the target.

- Pure Pursuit Guidance

  Pure pursuit (PP) guidance belongs to the so-called two point guidance schemes, where only the interceptor and the target are considered in the engagement geometry. Simply put, the interceptor is supposed to align its velocity along the line of sight between the interceptor and the target.

- Constant Bearing Guidance

  Constant bearing (CB) guidance is also a two-point guidance scheme, with the same engagement geometry as PP guidance. However, in a CB engagement the interceptor is supposed to align the relative interceptor-target velocity along the line of sight between the interceptor and the target.

conclusion

Int the end we know that the LOS guidance is what we want to use as in the ground control station is supposed to be used to specify way points and upload it the Guidance system.

2.4.2 Steering Laws for path following

In LOS guidance, There are a lot of Steering laws to use according to type of the path that is being followed

- Steering Laws for Straight Lines

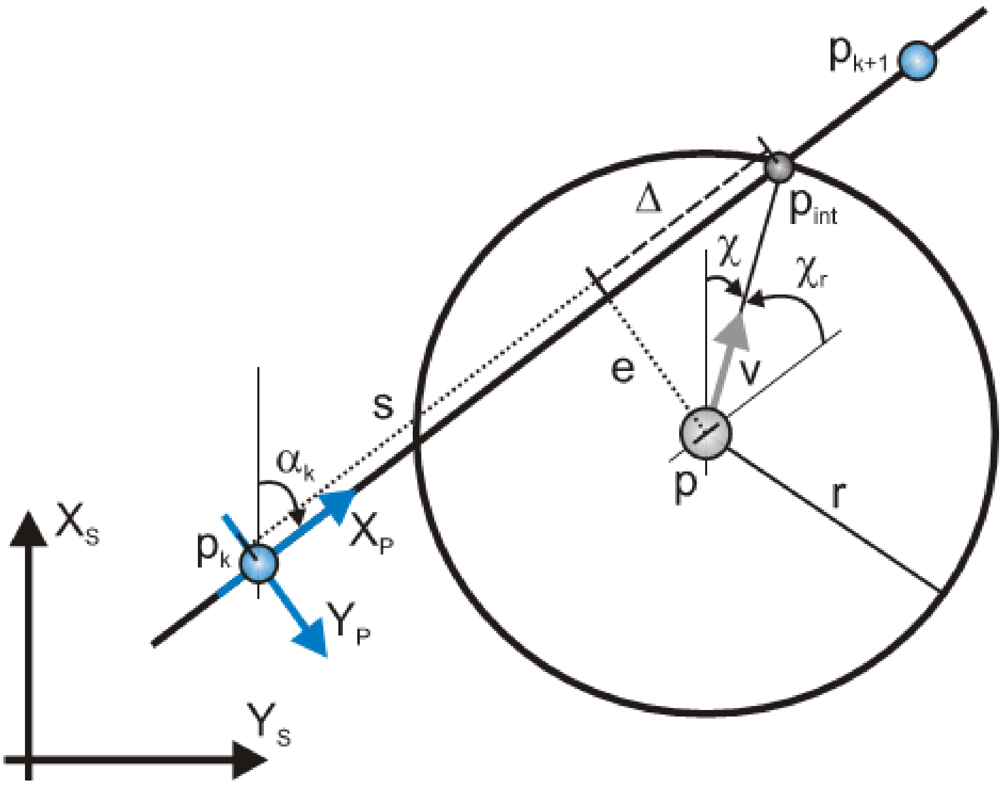


Figure 2.3: The main variables associated with steering laws for straight-line paths.

> Consider a straight-line path implicitly defined by two waypoints through which it passes. Denote these waypoints as p_k and p_{k+1} , respectively. Also, consider a path-fixed reference frame with origin in p_k.

Only the cross-track error is relevant since $e(t) = 0$ means that the vehicle has converged to the straight line.

$$e(t) = -[x(t) - x_K]\sin(\alpha_K) + [y(t) - y_K]\cos(\alpha_K)$$
$$\alpha_K := atan2(y_{k+1} - y_K, x_{k+1} - x_K)$$
$$\lim_{t\to\infty} e(t) = 0$$

- there are two methods to do so
  - Enclosure-Based Steering
  - Lookahead-Based Steering

the lookahead-based scheme has several advantages over the enclosure-based approach as it's is less computationally intensive than the enclosure-based approach.

- Lookahead-Based Steering

$$\Psi_R = \alpha_K - \arctan(K_P e)$$

where

K_p is just a gain

there are other of Steering laws for Piecewise Linear Paths , Circles and Regularly Parameterized Paths.

2.4.3 Circle of Acceptance

Circle of acceptance is a method for knowing when to switch to the next waypoint [9].

When the aircraft is inside a circle with radius R_{k+1} around the point $[x_{k+1}, y_{k+1}]$, as can be seen in the following figure

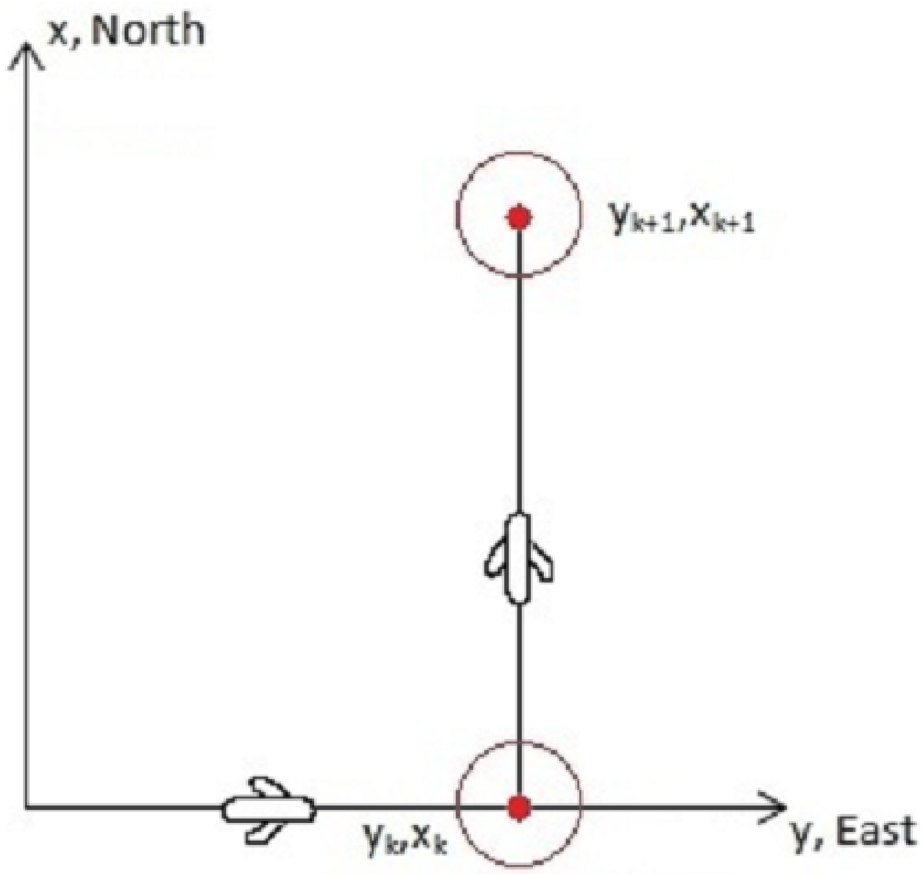


Figure 2.4: Navigation in x-y plane with circle of acceptance

The guidance system should change to the next waypoint. The position of the aircraft has to satisfy:

$$[x_{k+1} - x(t)]^2 + [y_{k+1} - y(t)]^2 \leq R_{k+1}^2$$

2.4.4 Altitude Guidance

First we must make sure that the multi rotor is stable then we work on controlling the altitude.

2.4.5 What we hope to do

The guidance system could be implemented and looks like the following figure.

- LOS is used for calculating desired heading angle
- the kinematic controller has been used for desired pitch angle
- a 1st order LP filter for speed.

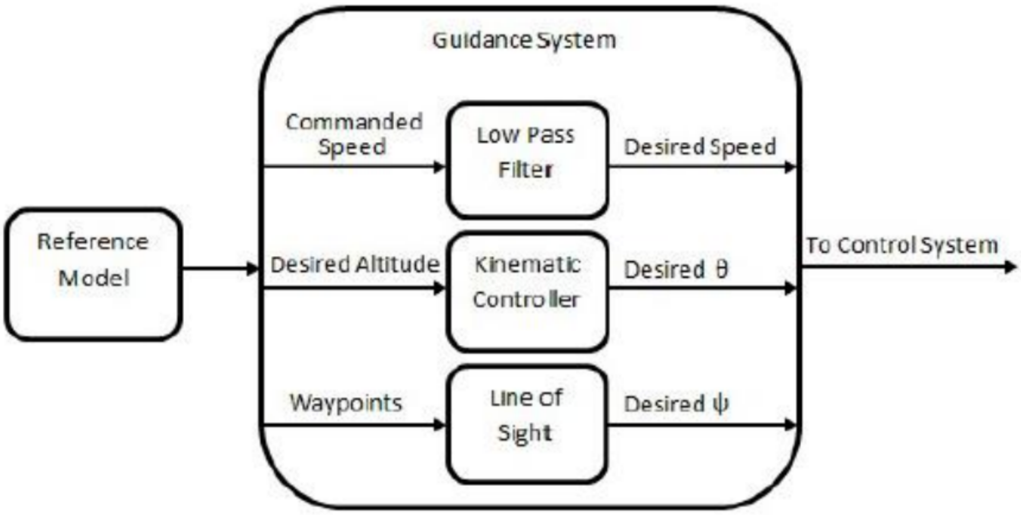


Figure 2.5: Block diagram of a guidance system[9]

and we hope we could create something like this

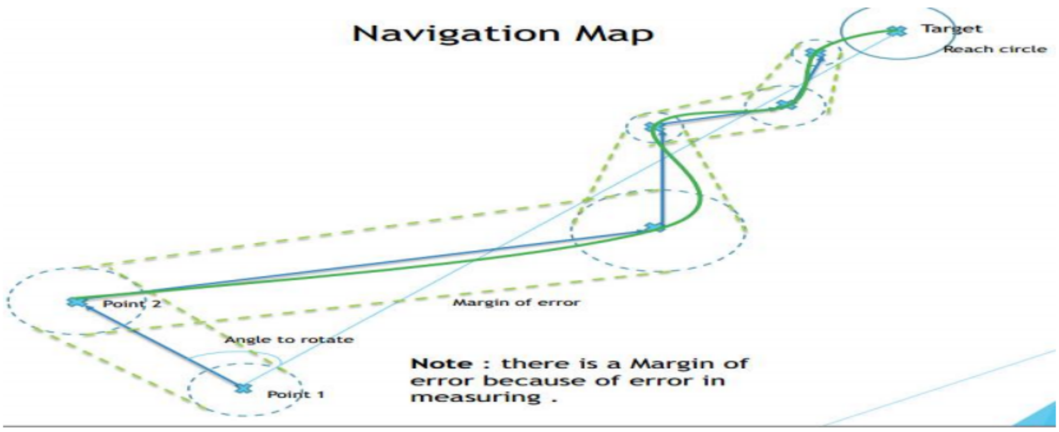


Figure 2.6: Navigation map

2.5 Control System

We'll design the control system using any design methods that we studied in the previous years.

here is a summery of these methods

2.5.1 PID Controller Design

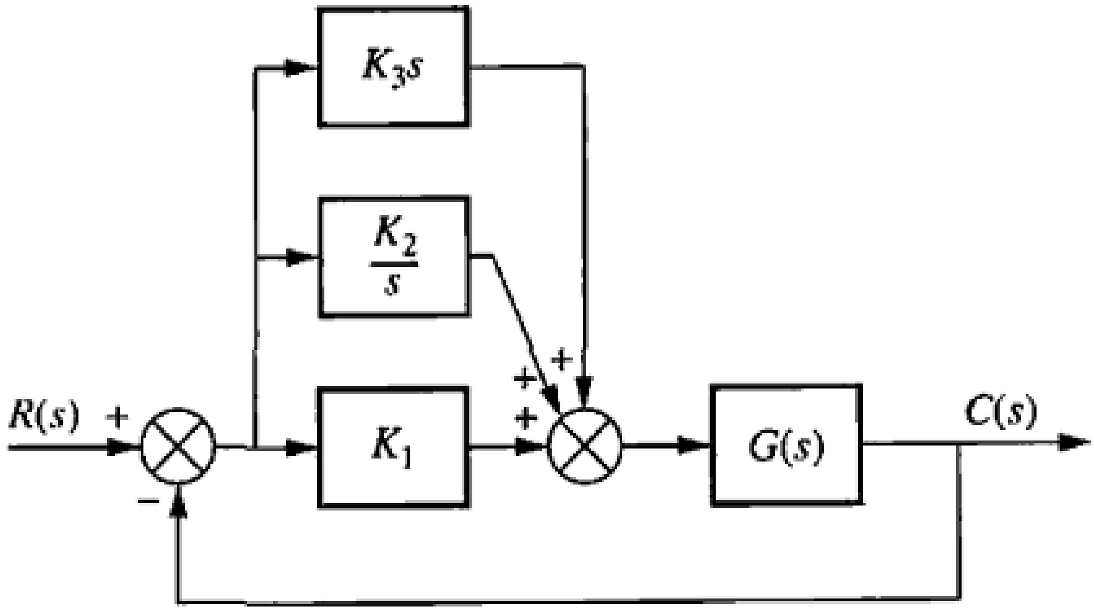


Figure 2.7: PID controller scheme

A PID controller transfer function is

$$G_c(s) = K_1 + \frac{K_2}{s} + K_3 s = \frac{K_1 s + K_2 + K_3 s^2}{s} = \frac{K_3(s^2 + \frac{K_1}{K_3}s + \frac{K_2}{K_3})}{s}$$

which has two zeros plus a pole at the origin. One zero and the pole at the origin can be designed as the ideal integral compensator; the other zero can be designed as the ideal derivative compensator.

2.5.1.1 Controller Design procedure[1]

The design technique consists of the following steps :

1. Model the system using Newton equations or Lagrange equations
2. Linearize around your operating point.
3. Take Laplace transform
4. Get open loop transfer function (G_{open})
5. Evaluate the performance of the uncompensated system to determine how much improvement in transient response is required.
6. Design a P controller to meet your requirement.
7. Simulate the system to be sure all requirements have been met.
8. If it doesn't meet.Change the type of the controller to PI controller
   a) $PI = K_p + \frac{K_i}{s} = K_p \frac{s+\frac{K_i}{K_p}}{s} = K_p \frac{s+zero}{s}$
9. Put the zero so that the phase at your required pole is -180 (Root Locus condition)
10. Get gain so that the open loop poles move to your required pole.
11. The new open loop transfer function is $G_{open_{new}} = \frac{G_{open}}{s}$
12. Simulate the system to be sure all requirements have been met.
13. If it doesn't meet.Change the type of the controller to PID controller
    a) $PID = K_p + \frac{K_i}{s} + K_d * s = K_d \frac{s^2+\frac{K_p}{K_d}*s+\frac{K_i}{K_d}}{s} = K_d \frac{(s+zero1)(s+zero2)}{s}$
14. Make each zero compensate half of the phase required
15. Simulate the system using nonlinear simulation.
16. If you increased the input and the response become unstable, you should linearize around a different operating point and consider using gain scheduling

2.5.2 State Feedback Controller Design

2.5.2.1 Pole Placement

- Assume that the single-input system dynamics are given b

  $$\dot{x} = Ax + Bu$$

  $$y = Cx + Du$$

  and D = 0.
- Recall that the system poles are given by eigenvalues of A.

- Want to use the input u(t) to modify the eigenvalues of A to change the system dynamics.

- Assume a full state feedback of the form:

$$u = r - Kx$$

where r is some reference input.

- Find the closed loop dynamics:

$$\dot{x} = Ax + B(r - Kx) = (A - BK)x + Br = A_{cl}x + Br$$

$$y = Cx$$

- Pick K so that A_{closed} has the desired properties.

- Note that it's not always easy, as the issue of the controllability must be checked.

2.5.2.2 Ackermann's Formula

- Ackermann's Formula gives us a method of doing this entire design process as one step.

$$K = \begin{bmatrix} 0 & ... & 0 & 1 \end{bmatrix} M_c^{-1} \Phi_d(s)$$

where

- $M_c = \begin{bmatrix} B & AB & ... & A^{n-1}B \end{bmatrix}$
- $\Phi_d(s)$ is the characteristic equation for the closed-loop poles, which we then evaluate for s = A.
- It's explicit that the system must be controllable because we are inverting the controllability matrix.

2.5.3 Flight Qualities

The flying qualities of an airplane are related to the stability and control characteristics and can be defined as those stability and control characteristics.

Unfortunately there is no flying qualities for multi-copters published in any text book as the main focus is manned airplanes so our design points be set according to our preferences.

2.6 Navigation System

As previously said, Guidance takes care of input to the system, inputs as waypoints and desired speed, and determine the desired path from the current location of the aircraft to the desired waypoint.

Guidance is often decoupled onto reference model and guidance system where reference model deals with commanded signals and guidance determines the path.

Navigation determines the location and altitude of the aircraft at a given time.

The control system ensures that the aircraft follows the desired path and altitude by manipulating the control surfaces.

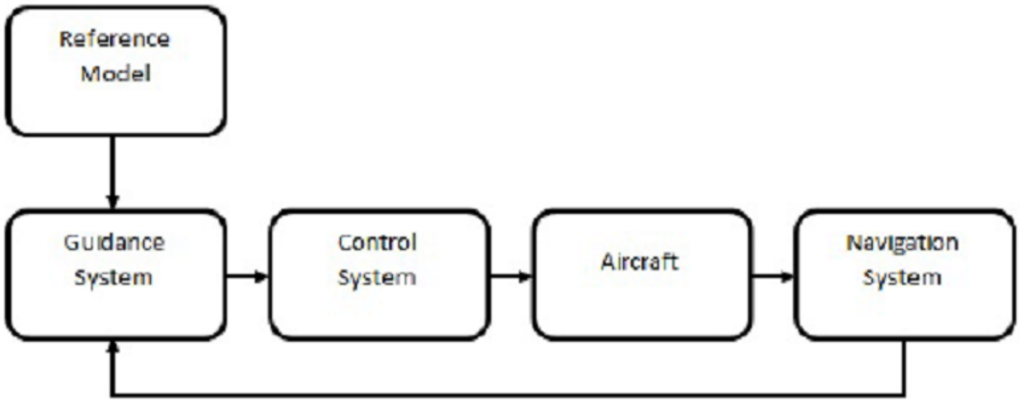


Figure 2.8: Block diagram of a guidance, navigation and control system

We should take advantage of the previous year work of INS as their work have been verified.

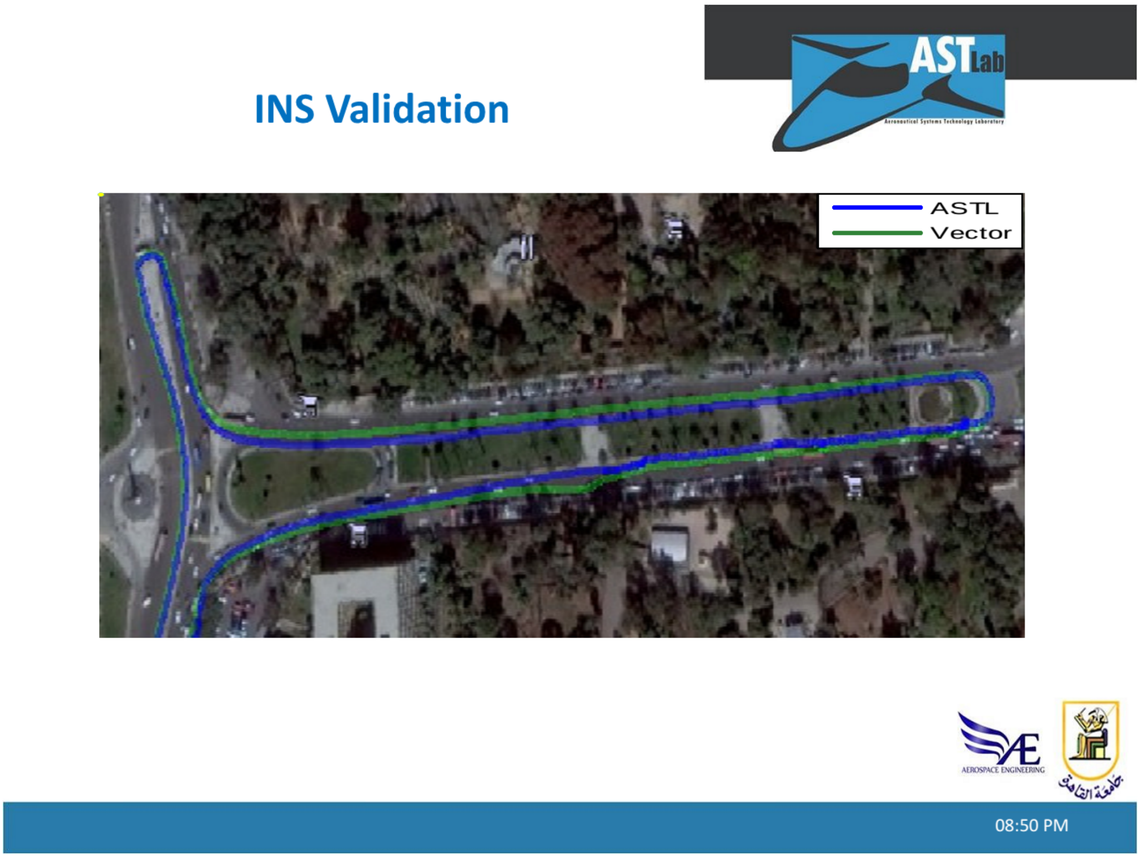


Figure 2.9: INS validation

2.7 Ground Control Station[2]

2.7.1 Introduction

A ground station is typically a software application, running on a ground-based computer, that communicates with your UAV via wireless telemetry. It displays real-time data on the UAVs performance and position and can serve as a virtual cockpit, showing many of the same instruments that you would have if you were flying a real plane. A GCS can also be used to control a UAV in flight, uploading new mission commands and setting parameters. It is often also use to monitor the live video stream from a UAV's cameras.

For Desktop, there is (Mission Planner, APM Planner 2, MAVProxy, QGroundControl and UgCS.

For Tablet/Smartphone, there is Tower (DroidPlanner 3), MAVPilot, AndroPilot and SidePilot that can be used to communicate with ArduPilot.

Now we are going to talk about Mission Planner as it's a full-featured ground station application for the ArduPilot open source autopilot project.

2.7.2 Capabilities

- Point-and-click waypoint entry
- using Google Maps/Bing/Open street maps/Custom WMS.
- Select mission commands from drop-down menus
- Download mission logles and analyze them Congure APM settings for your airframe
- Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator.
- See the output from APM's serial terminal • With appropriate telemetry hardware you can: Monitor your vehicle's status while in operation. Record telemetry logs which contain much more information the the on-board autopilot logs. View and analyze the telemetry logs. Operate your vehicle in FPV (rst person view)
- Auto grid You can also have the Mission Planner create a mission for you, which is useful for function like mapping missions, where the aircraft should just go back and forth in a lawnmower pattern over an area to collect photographs.
- MAVLink protocol defines a large number of commands that the mission planners uses
- Planning a camera mission • Setting Up Rally Points(Return yo home points)
- Radio Control Calibration in Mission Planner

User Interface

Figure 2.10: Mission planner user interface

Example of specifying way points

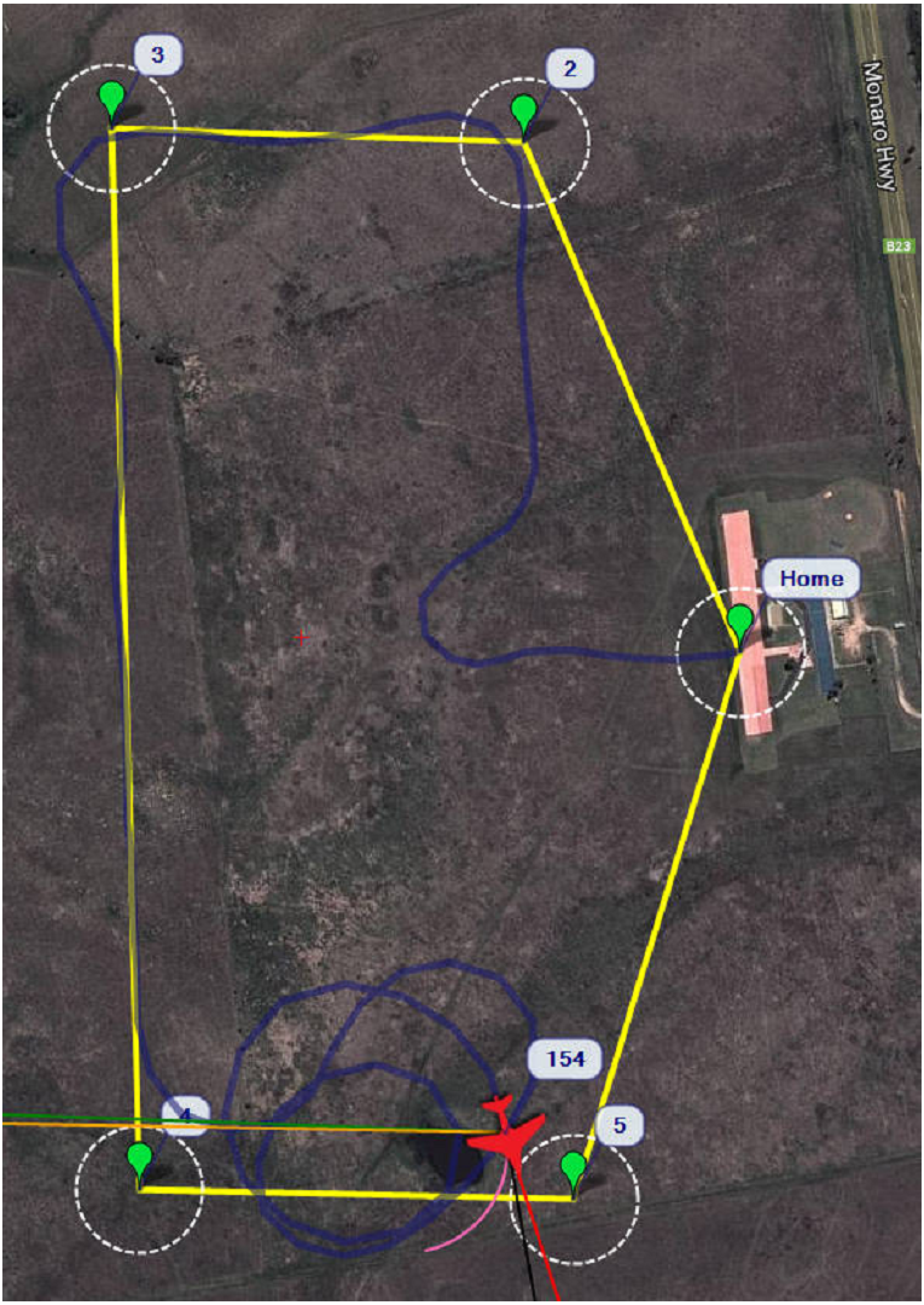


Figure 2.11: **Specifying way points**

GCS Flight Data Screen

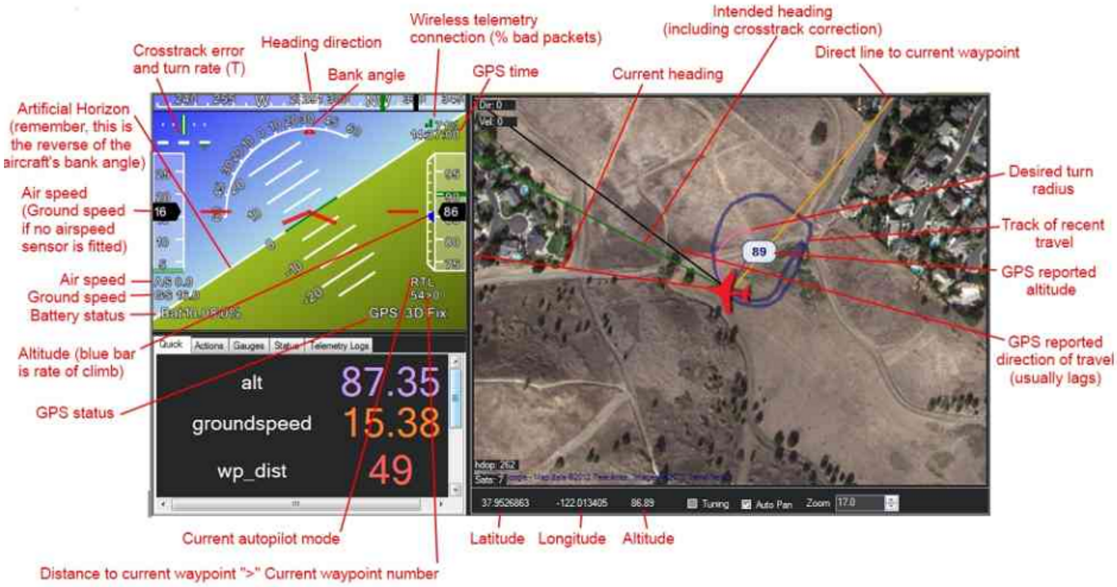


Figure 2.12: **GCS Flight Data Screen #1**

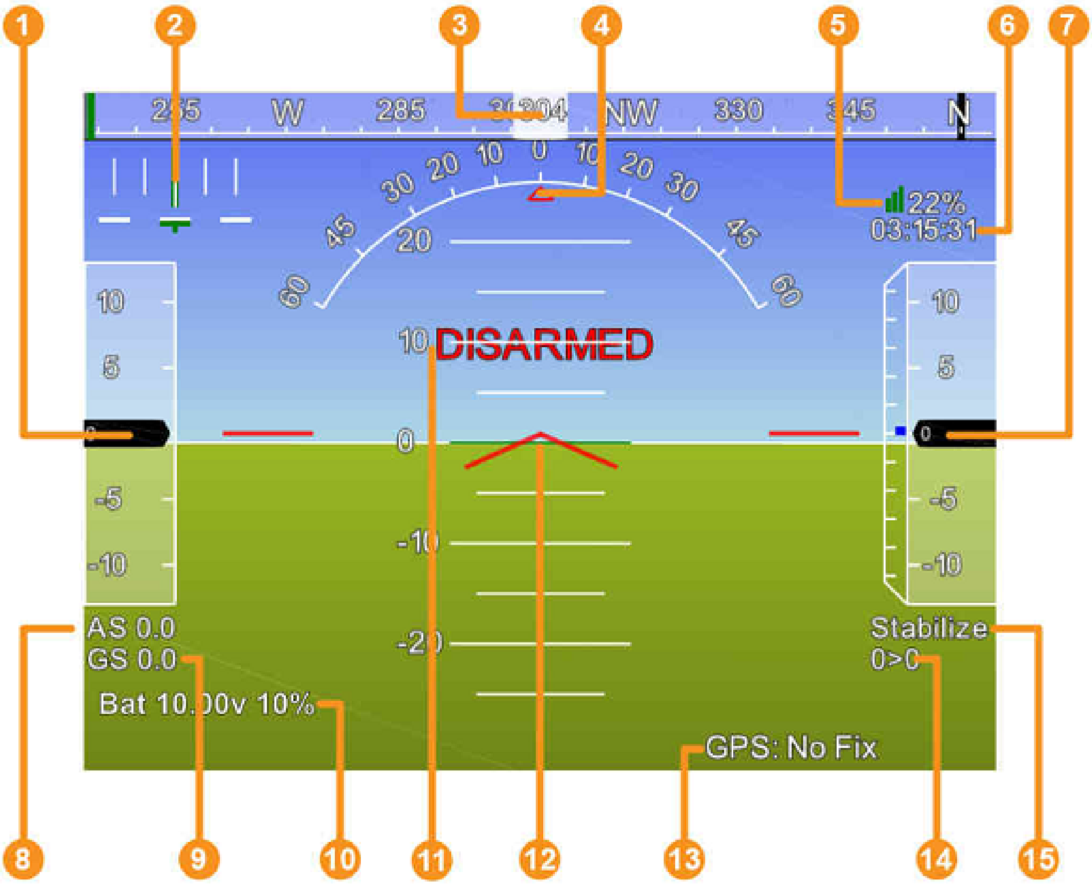


Figure 2.13: **GCS Flight Data Screen #2**

Where

1. Air speed
2. Cross track error and turn rate (T)
3. Heading direction
4. Bank angle
5. Wireless telemetry connection (% bad packets)
6. GPS time
7. Altitude
(blue bar is rate of climb)
8. Air speed
9. Ground speed
10. Battery status
11. Artificial Horizon

Typical log file

	A	B	C	D	E	F	G	H	I	J
1	Date	Time	mavlink_gps_raw_t.eph	mavlink_raw_imu_t.xmag	mavlink_raw_imu_t.ymag	mavlink_raw_imu_t.zmag	mavlink_attitude_t.yaw	mavlink_vfr_hud_t.airspeed	mavlink_vfr_hud_t.groundspeed	mavlink_vfr_hud_t.heading
2	02/05/2012	7:27:09	0	0	0	0	-2.744607	0	0	0
3	02/05/2012	7:27:09	0	0	0	0	-2.744607	0	0	202
4	02/05/2012	7:27:09	0	-82	64	289	-2.744607	0	0	202
5	02/05/2012	7:27:09	7.813966	-82	64	289	-2.744607	0	0	202
6	02/05/2012	7:27:09	7.813966	-82	64	289	-2.745121	0	0	202
7	02/05/2012	7:27:09	7.813966	-82	64	289	-2.745121	0	0	202
8	02/05/2012	7:27:09	7.813966	-85	61	289	-2.745121	0	0	202
9	02/05/2012	7:27:10	8.87957	-85	61	289	-2.745121	0	0	202
10	02/05/2012	7:27:10	8.87957	-85	61	289	-2.745434	0	0	202
11	02/05/2012	7:27:10	8.87957	-85	61	289	-2.745434	0	0	202
12	02/05/2012	7:27:10	8.87957	-82	62	289	-2.745434	0	0	202
13	02/05/2012	7:27:10	9.617817	-82	62	289	-2.745434	0	0	202
14	02/05/2012	7:27:10	9.617817	-82	62	289	-2.745587	0	0	202
15	02/05/2012	7:27:10	9.617817	-82	62	289	-2.745587	0	0	202
16	02/05/2012	7:27:10	9.617817	-86	62	288	-2.745587	0	0	202
17	02/05/2012	7:27:10	8.652532	-86	62	288	-2.745587	0	0	202
18	02/05/2012	7:27:10	8.652532	-86	62	288	-2.747233	0	0	202
19	02/05/2012	7:27:10	8.652532	-86	62	288	-2.747233	0	0	202
20	02/05/2012	7:27:10	8.652532	-86	62	287	-2.747233	0	0	202
21	02/05/2012	7:27:11	6.307695	-86	62	287	-2.747233	0	0	202

Figure 2.14: Typical log file

2.7.3 What we hope to do

- Connecting GCS software with the autopilot and making configuring waypoints and upload them to the aircraft through the communication system.

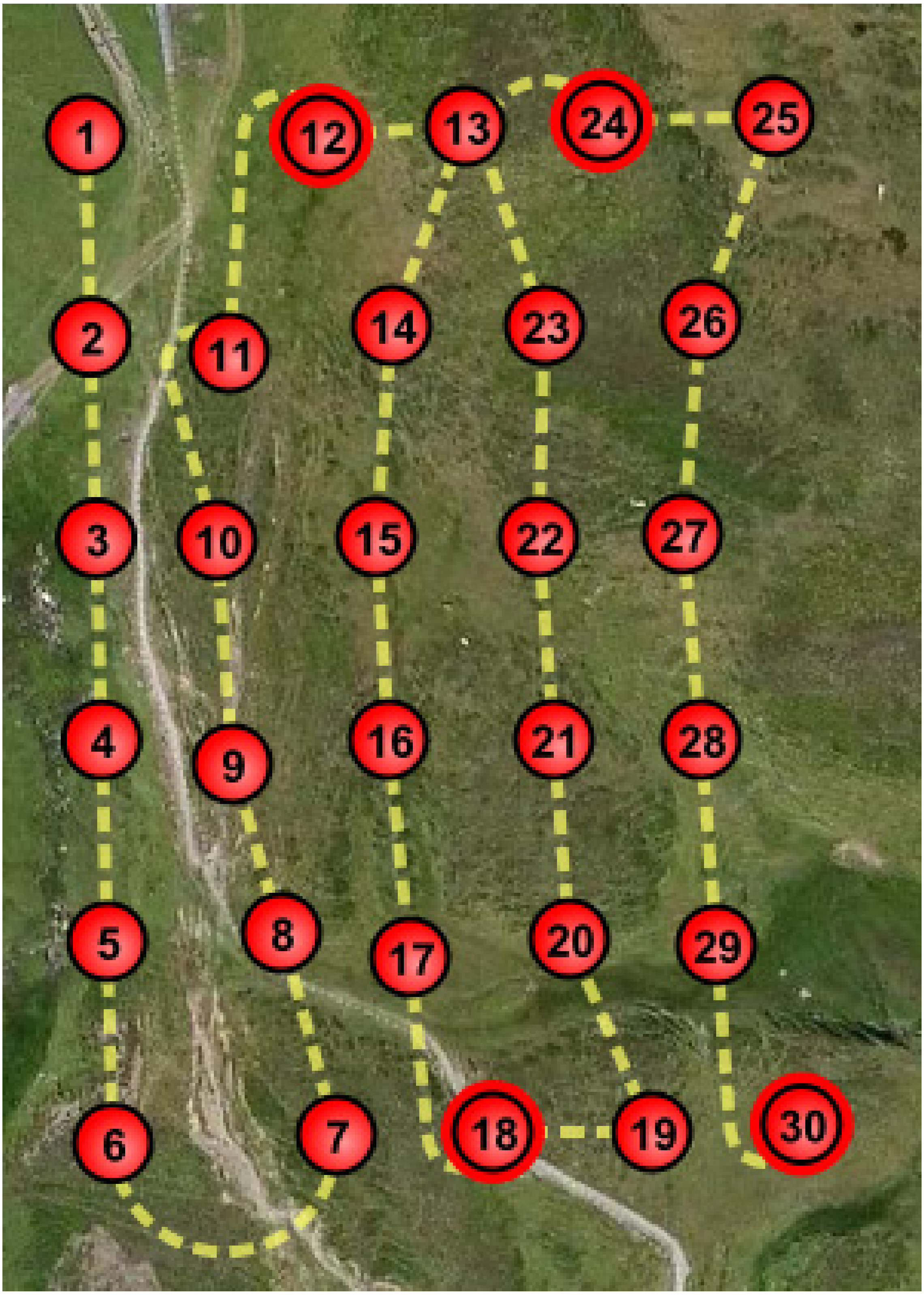


Figure 2.15: Waypoints specified map

2.8 Telemetry

2.8.1 Introduction

Telemetry is what you use to send and receive data between your drone and your ground station. Adding telemetry to your drone is very useful, but is not always necessary.

Telemetry modules are the actual radio devices that transmit and receive the data. You will have one onboard your drone, and one on the ground plugged onto your ground station device. The most important thing when using telemetry modules for your given autopilot, is that they will often need to be paired together so they can communicate.

Figure 2.16: Telemetry module

3 Drones in Precision Agriculture

Drones can to capture aerial images of the crops or spraying fertilizers.

3.1 Aerial Images Applications[3]

We try to answer the question of "What we gonna extract from the aerial photos that will be taken by a camera ?"

The answer must depend on the type of sensor attached to the camera.

3.1.1 Enhanced Normalized Difference Vegetation Index

- Supported Sensors: BGNIR
- Description: ENDVI is a close equivalent and modified version of NDVI, designed for low altitude monitoring systems, such as UAVs. ENDVI is an indicator of live green vegetation, and can be used for crops in all growth stages.

3.1.2 Green Normalized Difference Vegetation Index

- Supported Sensors: BGNIR
- Description: GNDVI is a modified version of the NDVI to be more sensitive to the variation of chlorophyll content in the crop. It is useful for assessing the canopy variation in biomass, and is an indicator of senescence in case of stress or late maturity stage. This index can be used to analyze crops in mid to late growth stages.

3.1.3 Difference Vegetation Index[4]

- Supported Sensors: RGNIR
- Description: DVI is a simple vegetation index, and distinguishes between the soil and vegetation. This index can be used for crops in all growth stages.

3.1.4 Field Uniformity Tool

- Supported Sensors: BGNIR, RGNIR, RGB

- Description: The Field Uniformity Tool makes it possible to quantify plot-level statistics on plant count, height, vigor, leaf area and canopy cover. Drawing data from your other licensed algorithms (Row-Based Plant Counting Tool, Plant Height, Canopy Cover, Leaf Area and Vegetation Indices) , it calculates the maximum, minimum, mean and standard deviation for each plot or user-defined grid cell.

3.1.5 Optimized Soil Adjusted Vegetation Index

- Supported Sensors: RGNIR
- Description: OSAVI is a simplified version of SAVI to minimize the influence of soil brightness. This index is recommended to analyze crops in early to mid growth stages, in areas with relatively sparse vegetation where soil is visible through the canopy.

3.1.6 Green Leaf Index

- Supported Sensors: RGB
- Description: GLI was designed to adjust for the greeness and yellowness of the crop, and was designed for low altitude monitoring systems, such as UAVs. This index can be used for crops in all growth stages.

3.1.7 Visual NDVI

- Supported Sensors: RGB
- Description: Visual NDVI, also known as NGRDI, is an indicator of surface greenness and it is an index to detect live green plant canopies. This index can be used to analyze crops in all growth stages.

3.1.8 Visible atmospherically resistant index

- Supported Sensors: RGB
- Description: VARI was designed to introduce an atmospheric correction and is a good index to estimate the vegetation fraction from the visible range of the spectrum. This index can be used to analyze crops in all growth stages.

3.1.9 Conclusion

We concluded that a single image can give different information whether it's RGB image or NIR image but NIR is more valuable as vegetation stress occurs in the NIR region first.

3.2 Multi-Spectral Cameras

The following cameras are mainly used in precision agriculture.

3.2.1 Parrot SEQUOIA [5]

Figure 3.1: Parrot SEQUOIA

Sequoia captures information from both visible and invisible light, providing data to optimally monitor the health and vigor of your crops.

Price: $3500 USD

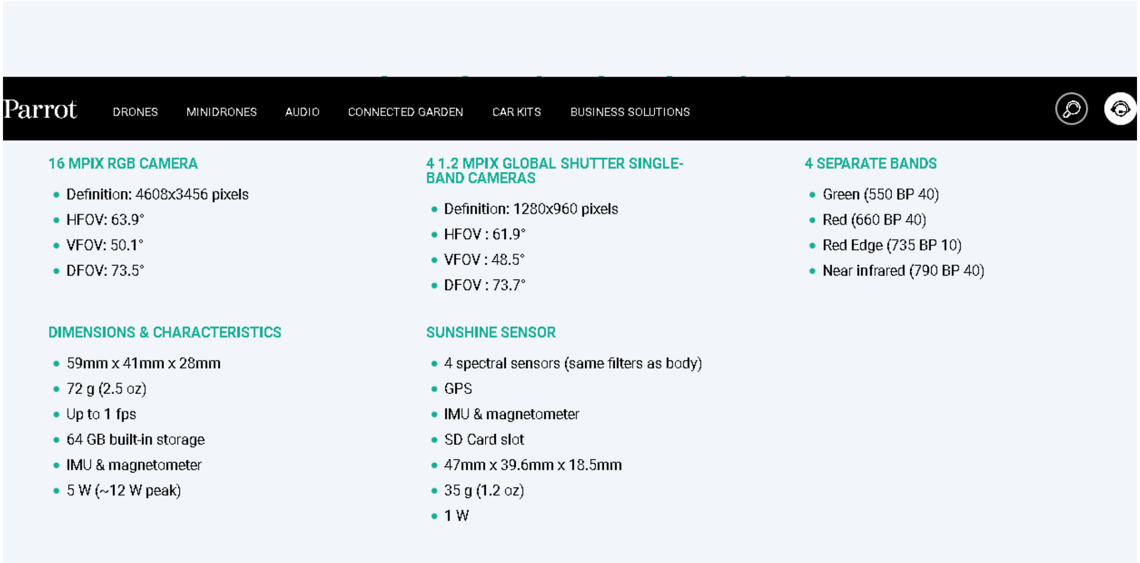


Figure 3.2: Parrot SEQUOIA's specifications

3.2.2 MicaSense RedEdge[6]

Figure 3.3: MicaSense RedEdge

RedEdge is a rugged, built-to-last, professional multispectral sensor that captures specific wavebands needed for accurate plant health analysis. With various integration options, it's also one of the most flexible solutions on the market. Additionally, optimized GSD, a downwelling light sensor, a low power requirement, and a global shutter for distortion-free images make this sensor the multispectral powerhouse.

Price: $5195 USD

Weight:	180 grams (6.3 oz.) (including DLS and cable)
Dimensions:	12.1 cm x 6.6 cm x 4.6 cm (4.8 in x 2.6 in x 1.8 in)
External Power:	5.0 V DC, 4 W nominal (8 W peak)
Spectral Bands:	Blue, green, red, red edge, near IR (global shutter, narrowband)
RGB Color Output:	3.6 MP (global shutter, aligned with all bands)
Ground Sample Distance (GSD):	8 cm per pixel (per band) at 120 m (~400 ft) AGL
Capture Rate:	1 capture per second (all bands), 12-bit RAW
Interfaces:	Serial, Ethernet, WiFi, External Trigger, GPS
Field of View:	47.2° HFOV
Custom Bands:	400nm - 900nm (QE of 10% at 900nm)

Figure 3.4: MicaSense RedEdge's specifications

Sequoia and RedEdge are both powerful multispectral sensors with the capability to yield accurate and calibrated results [?]. Sequoia is simple to operate, fully capable yet lightweight and cost-effective. The additional band (blue), improved GSD, and multiple integration options make RedEdge an ideal solution for research and advanced integrations.

3.2.3 The Sentera Double 4K[7]

The Sentera Double 4K is a small, fully customizable twin-imager sensor that is universally compatible with any UAV.

Fitting in the footprint of a GoPro® HERO 4, the rugged, high-throughput Double 4K Sensor is designed for use in harsh environments with configuration options that make it ideal for use in agriculture and infrastructure inspection applications.

The camera is capable of capturing high-megapixel color stills, near-infrared (NIR), and normalized difference vegetation index (NDVI) data, and 4K video.

Price: \$1999-\$2949 USD

Figure 3.5: The Sentera Double 4K

3.2.4 Comparison Between Multi-Spectral Cameras

Camera	Number of bands	RGB color outputs	Light sensor	Price	Weight	Power usage
MicaSense RedEdge	5 bands (Blue, Green, Red, Red Edge, Nearinfrared)	(Global shutter)3.6 MP	✓	5900$	180 grams (with DLS and cable)	4 W nominal, 8 W peak
Parrot Sequoia	4 bands (Green, Red, Red Edge, Nearinfrared)	(Rolling shutter)16 MP	✓	3500$	135 grams (with Sunshine Sensor and cable)	8 W nominal, 12 W peak
SENTERA QUAD SENSOR	6bands	10.5MP	Need additional one	5,499$~5,599$	126 grams	<10W
SENTERA DOUBLE 4K AGRICULTURE SENSOR	Spectral Bands: (Blue-Green - Red- Red Edge Near Infrared)	12.3MP	Need additional one	$2,499~ $4,299	80 grams	8W typical / 12W maxim um

Table 3.1: Comparison between multi-spectral cameras

We can see that the price of any professional cameras is so high. but you can overcome this by buying a consumer camera and convert to NIR camera through NIR filter in front of its lenses .Nevertheless this modified camera is in the same level as other professional cameras due to additional hardware and their specific user online help.

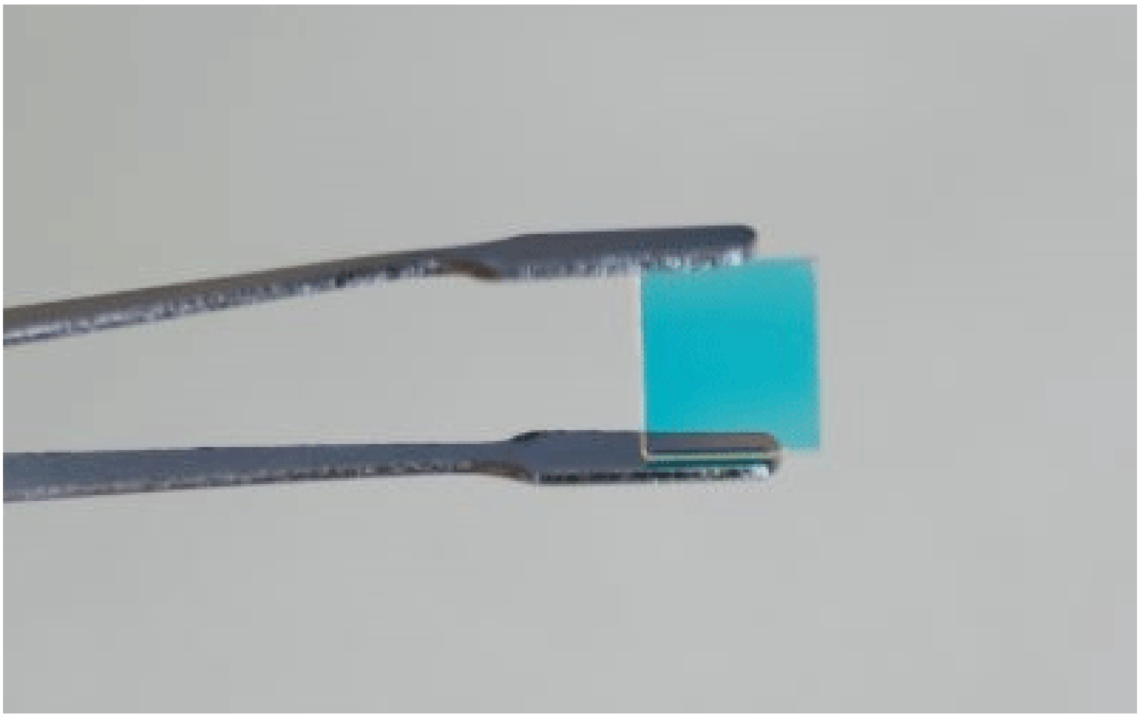


Figure 3.6: NIR filter

3.2.5 Consumer Camera Vs Professional Multi-Spectral Camera

	Consumer camera	**Professional multispectral camera**
Calibration	needs to be calibrated (ISO,Aperture,shutter speed)	A real and calibrated NDVI camera will account for differences in lighting and maintain consistent and comparable outputs between multiple visits to the same site, regardless of lighting.
Both need	calibrated against reflectance panels	calibrated against reflectance panels
Cost (approx)	400$	3500$ ~7000$

Table 3.2: Consumer camera vs professional multi-spectral camera

3.2.6 Recommended Consumer Camera and Filters

- Canon SX260, SX280, S100, S110, and S120

  They are are used by companies such as Agribotix, Sensefly, Roboflight, Quest UAV etc. To simplify operation.

  Camera SX260HS, as this has an on-board GPS, allowing for captured image to be geo-tagged with GPS coordinates. This can help with the image processing later\

  price : $399.00 and it can be bought from any supplier in Egypt.

  filter

  - Custom NGB Filter Glass for DIY SX260, SX280, S100, S110, and S120 Camera Conversions.
  - Price: $89.00

3.3 Hyper-Spectral Cameras

Corning micro HSI 410 SHARK Hyperspectral Sensor for UAV Drones

Corning Hyperspectral Imaging provides hyperspectral sensors and full hyperspectral systems for all applications including precision agriculture, industrial, environmental monitoring, mining, and mineralogy. Corning's microHSI™ family of hyperspectral sensors and systems combine the lowest size, weight and power (SWaP) in the industry with uncompromising performance, enabling deployment for challenging applications in limited payload and/or size constrained environments.

A few of the 410 SHARK's innovative features include:

- First complete, coherent HSI sensor system designed specifically for small UAS/UAV drones
- System includes:
  – visNIR microHSI™ 410 sensor
  – Lens
  – GPS/Inertial navigation system (INS)
  – Microprocessor control
  – Data acquisition and storage

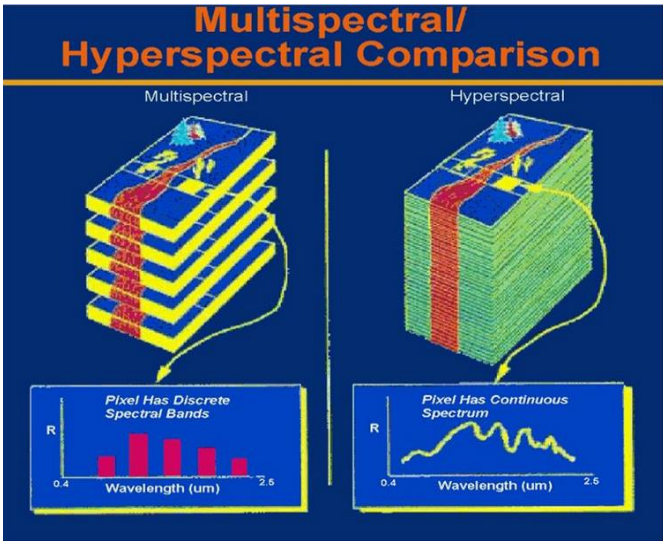
- Dimensions: 136.4 x 87.4 x 70.4mm (with lens) / 95.8 x 87.4 x 70.4mm (without lens)
  • Weight: 730 grams
- Web interface for system management and control
- Flight planning and execution software enables preprogramming of image collection plan
  - Automated waypoint operation, frame rate, binning, selectable image recording options
- Operating and maintenance documentation
- API interface (upon request)
- Designed for *minimum* 30 minute operating/recording time.
  - Consistent with performance of most small UAS
  - Hot-swap battery optional; larger battery available
- For more effective data management, the user can choose to collect the entire 155 band hyperspectral image cube, or only the spectral bands needed for a specific mission or application.
- Digital Elevation Maps (DEM) can be loaded into the system pre-flight for the area to be imaged to improve image georegistration during post-processing.

Hyperspectral vs. Multispectral Imaging Technology

- **Hyperspectral imagers** cover many dozens to hundreds of spectral bands contiguously
- **Multispectral imagers** cover a selected set of bands non-contiguously
  - Spectral information critical for characterization, research and development of specific applications may be missing.

Number of spectral bands is insufficient to address multitude of developed and proven applications and indices

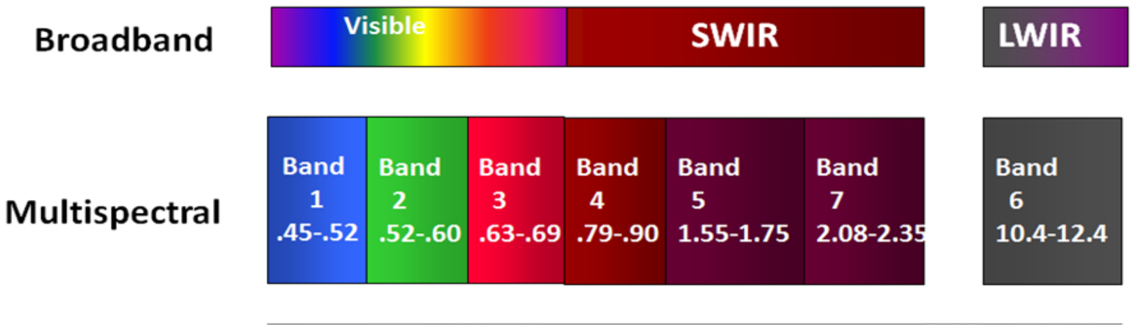
Why Hyperspectral Over Multispectral for Precision Agriculture?



- Agricultural market demand for hyperspectral sensor systems is growing to address a growing catalog of vegetation indices used for vegetation/crop analysis and diagnostics.
  - There are currently over proven 65 vegetation indices, and growing
- New crop specific, application specific indices are being developed and introduced each year.

- Multispectral sensor systems can utilize only a small subset of indices, and cannot take advantage of new indices as they are introduced.

Hyperspectral sensors enable the research and development of new vegetation indices – multispectral sensors do not.



3.4 Thermal Cameras

From $1,199.20

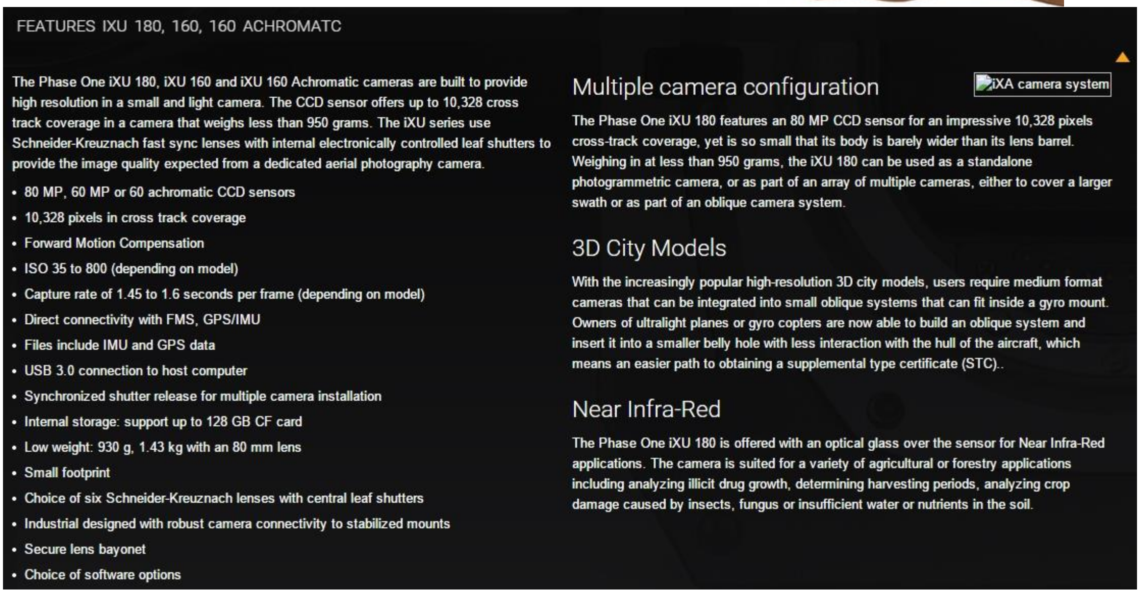
FLIR VUE SPECIFICATIONS

Overview		
Thermal Imager	Uncooled VOx Microbolometer	
Resolution	640x512	336x256
Lens Options	9 mm; 69° x 56° 13 mm; 45° x 37° 19 mm; 32° x 26°	6.8 mm; 44° x 36° 9 mm; 35° x 27° 13 mm; 25° x 19°
Spectral Band	7.5 - 13.5 µm	
Full Frame Rates	30 Hz (NTSC); 25 Hz (PAL) ***US only, not for Export***	
Exportable Frame Rates	7.5 Hz (NTSC); 8.3 Hz (PAL)	
Physical Attributes		
Size	2.26" x 1.75" x 1.75" (57.4 x 44.4 mm x 44.4 mm) (including lens)	
Weight	3.25-4 oz (92.1 – 113.4 g) (configuration dependent)	
Precision Mounting Holes	Two M2x0.4 on each of two sides & bottom One 1/4-20 threaded hole on top	

3.5 High Resolution Cameras

Phase One iXu Aerial Camera System

71,500$ to 93,500$



FEATURES IXU 180, 160, 160 ACHROMATC

The Phase One iXU 180, iXU 160 and iXU 160 Achromatic cameras are built to provide high resolution in a small and light camera. The CCD sensor offers up to 10,328 cross track coverage in a camera that weighs less than 950 grams. The iXU series use Schneider-Kreuznach fast sync lenses with internal electronically controlled leaf shutters to provide the image quality expected from a dedicated aerial photography camera.

- 80 MP, 60 MP or 60 achromatic CCD sensors
- 10,328 pixels in cross track coverage
- Forward Motion Compensation
- ISO 35 to 800 (depending on model)
- Capture rate of 1.45 to 1.6 seconds per frame (depending on model)
- Direct connectivity with FMS, GPS/IMU
- Files include IMU and GPS data
- USB 3.0 connection to host computer
- Synchronized shutter release for multiple camera installation
- Internal storage: support up to 128 GB CF card
- Low weight: 930 g, 1.43 kg with an 80 mm lens
- Small footprint
- Choice of six Schneider-Kreuznach lenses with central leaf shutters
- Industrial designed with robust camera connectivity to stabilized mounts
- Secure lens bayonet
- Choice of software options

Multiple camera configuration

iXA camera system

The Phase One iXU 180 features an 80 MP CCD sensor for an impressive 10,328 pixels cross-track coverage, yet is so small that its body is barely wider than its lens barrel. Weighing in at less than 950 grams, the iXU 180 can be used as a standalone photogrammetric camera, or as part of an array of multiple cameras, either to cover a larger swath or as part of an oblique camera system.

3D City Models

With the increasingly popular high-resolution 3D city models, users require medium format cameras that can be integrated into small oblique systems that can fit inside a gyro mount. Owners of ultralight planes or gyro copters are now able to build an oblique system and insert it into a smaller belly hole with less interaction with the hull of the aircraft, which means an easier path to obtaining a supplemental type certificate (STC)..

Near Infra-Red

The Phase One iXU 180 is offered with an optical glass over the sensor for Near Infra-Red applications. The camera is suited for a variety of agricultural or forestry applications including analyzing illicit drug growth, determining harvesting periods, analyzing crop damage caused by insects, fungus or insufficient water or nutrients in the soil.

3.6 Images Analysis Software

3.6.1 Software On Server [3]

There are some websites that offer some tools on their server for free.

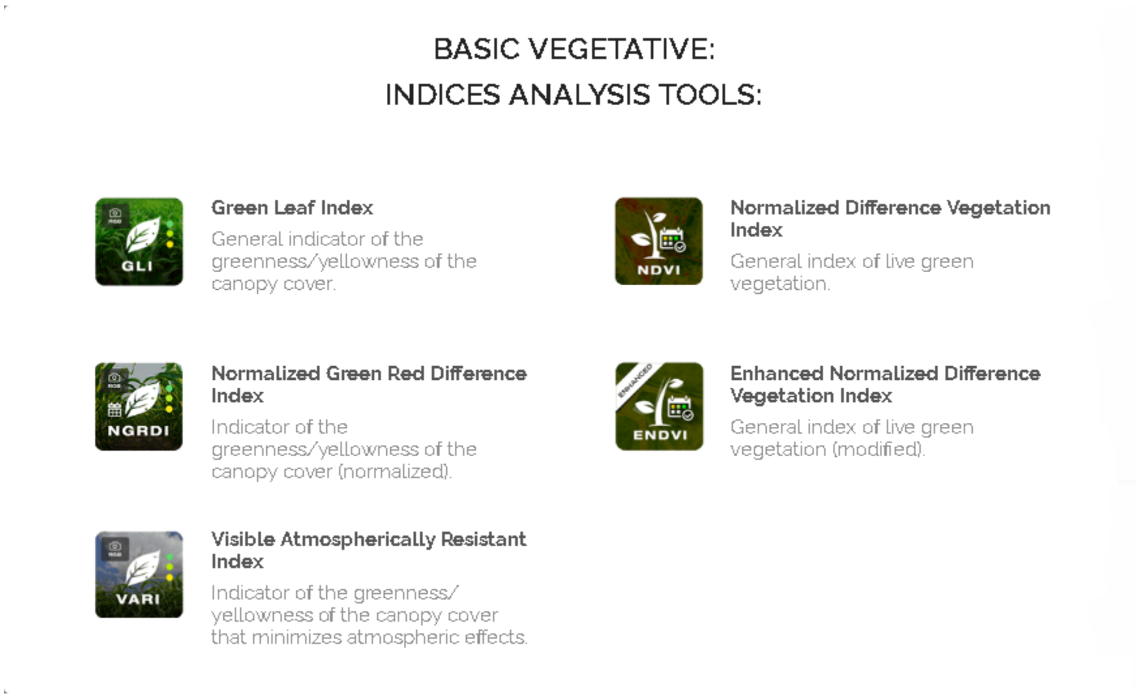


Figure 3.7: Basic free services

Other services are availabl according to their price plan.

	FREE	STANDARD	STANDARD +	BUSINESS
	$ 0 /MO	$ 95 /MO	$ 240 /MO	$ 450 /MO
CLOUD-BASED 2D/3D MAPS (Any Resolution)	5/mo Visual Only	10/mo	10/mo	50/mo
STORAGE	300 GB	450 GB	450 GB	Unlimited
EXPORT	✓	✓	✓	✓
PRECISIONVIEWER Instant Data Review	✓	✓	✓	✓
VOLUMETRICS	✓	✓	✓	✓
UNLIMITED BASIC VEGETATIVE INDICES learn more	✓	✓	✓	✓
UNLIMITED ADVANCED VEGETATIVE INDICES learn more	✗	✓	✓	✓
OFFLINE IMAGE PROCESSING	✗	✗	✓	✓
MULTIPLE USER ACCESS	✗	✗	✗	✓
ADD-ON ADVANCED ANALYSIS TOOLS learn more	$4.99-$19/mo	$9.99-$29/mo	$9.99-$29/mo	$49-$149/mo
	GET STARTED	GET STARTED	GET STARTED	GET STARTED

Figure 3.8: Price plan

3.6.2 Desktop Application

There are some software that can run on your mahine.

- ArcGIS
  - ArcGIS Desktop Basic- Visualize, build maps, edit data, import CAD, perform data conversions, generate maps, query data. Cost is $1,500 for a single use license / $3,500 for concurrent.
  - ArcGIS Desktop Standard- Allows everything found in the basic version but allows additional capabilities for multi-user platforms and editing enterprise level geodatabases. This level is required to take advantage of many custom

editing tools published by esri. Cost is $7,000 for a single use or concurrent license.

- Envi
  - ENVI image analysis software uses scientifically proven analytics to deliver expert-level results.

3.6.3 Build our own software

We could use any image processing packages to analyze any image and compute the desired vegetation index as any index has their own formula such as

- Normalized difference vegetation index (NDVI)

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

- Global environmental monitoring index (GEMI)

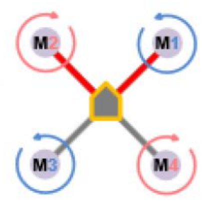
$$eta = \frac{2\left(NIR^2 - Red^2\right) + 1.5 * NIR + 0.5 * Red}{NIR + Red + 0.5}$$

$$GEMI = eta\,(1 - 0.25 * eta) - \frac{Red - 0.125}{1 - Red}$$

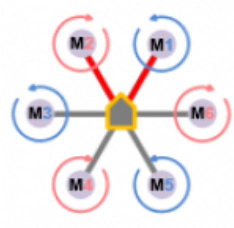
4 Mechanical Design

Mechanical Design:

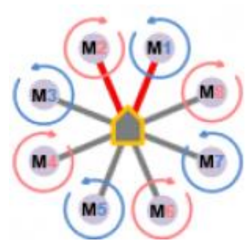
No. of Rotors:



Quadcopter: This is by far the most common type of frames that you see within the RC drone industry. It has four arms, each of which are connected to a single motor. Not only is it the simplest type of frame design you'll find, but it's also one of the most versatile. This is why popular drone models like the DJI Phantom 3 and the Parrot Bebop are all built using this exact frame configuration.



Hexacopter: As its prefix implies, a hexacopter ("hex" = six) is a type of drone setup in which there are six arms. Each arm is connected to a single motor. Generally speaking, these types of setups are reserved for flyers who are interested in doing some serious aerial photography. They can exist in one of two different "layouts": one in which the front of the body is located between two motors, and one in which the front of the body is located directly behind a single motor.



Octocopter: Last but certainly not least on this list is the octocopter. With this frame setup, there are eight arms, each of which are connected to a single motor. As you can imagine, there's a huge amount of thrust being produced with this type of setup. But as the old saying goes, "With great power, comes great responsibility". If you decide to go with this type of frame setup, which I don't recommend if you're a beginner, then you have a long, challenging road of ahead of you. For the most part, these types of RC drone setups are reserved for people who know what they're doing. When learning how to build a drone for the first time, stick to a simpler model, like the quadcopter or tricopter setup.

	Pros	Cons
Quadcopter	One of the biggest benefit to using a quadcopter frame is that nearly all of the flight controllers on the market today can work with this type of design. It's also one of the simplest designs you can use, which is perfect if you're learning how to build a drone for the first time.	No frame design is perfect – not even the quadcopter. A drawback to using this frame type is that if one motor or propeller fails, the remaining motors/propellers won't be able to compensate, resulting in a crash.
Hexacopter	One of the main benefits to a hexacopter frame is that you'll be able to deliver	In general, building a hexacopter is going to be more expensive than

	more thrust. This comes in handy for lifting heavier payloads. Also, if one motor fails, then there's still a chance that the drone can land safely rather than crashing. Another great advantage to this design is that nearly all flight controllers support this type of frame setup	building say, a triocpoter or quadcopter. This is due to the larger number of parts required to make it fly. Also keep in mind that more parts equals more weight, so in order to achieve the type of thrust you'll need to get a hexacopter in the air, a larger battery will be required.
Octocopter	The high amount of motors present means more thrust, which subsequently means it can lift heavier things. Another great advantage to this type of design is that if one motor fails, the drone can probably still make it to the ground safely rather than crashing.	As you've probably guessed, more motors equals a more expensive build, as well as a larger battery pack. For the most part, people who build larger octocopters are interested in serious aerial photography and/or videography.

Checking the products available online:

For Agriculture:

Name	No. of rotors	Battery	Time	Payload	Dimensions
RJX Agricultural Sprayer	4	12S(44.4V)/ 16000Mah	15-25 min.	10 kg	1800 x 1800 x 480 mm
DJI Matrice 100	4	22.2 V/4500 mAh	13 min.	1 kg	996 x 996 x 218 mm
X4-10	4	44.4V/1000 0mAh	14 min.	10 kg	1148*1148*453mm (arm unfolded, without propeller)
BapUp Odyssey 3	8		20 min.	10 kg	1369.06 x 500.38 x 1369.06 mm
DJI AGRAS MG-1	8	12000 mAh	10-24 min.	10 kg	1471 x 1471 x 482 mm

Name	No. of rotors	Battery	Time	Payload	Dimensions
DJI Phantom P3-STANDARD	4	15.2 V /4480 mAh	25 min.	-	304.8 x 304.8 x 177.8 mm
Freefly Systems ALTA UAV	6	6S / 22.2V	17-30 min.	6.8 kg	1533 x 1533 x 318 mm
MAHATMA	8		20-30 min.	10 kg	1998.98 x 1998.98 x 850.9 mm
Freefly Systems ALTA UAV	8	6S / 22.2V	13-20 min.	9.1 kg	1720 x 1720 x 360 mm

For Shipping & Photography:

Figure 5: DJI AGRAS MG-1


Figure 4: DJI Matrice 100


Figure 3: Bap Up


Figure 2: X4-10


Figure 1: Phantom 3 Standard

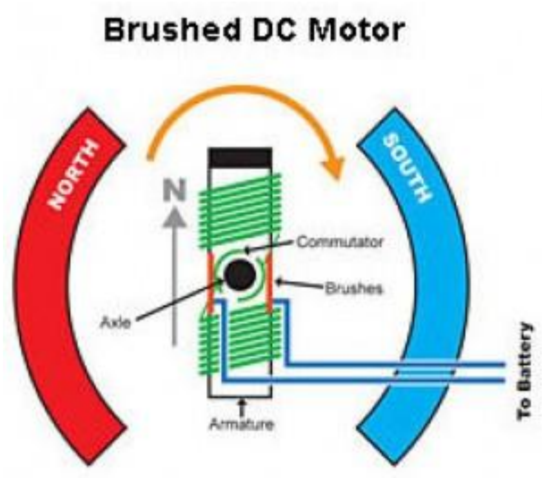
Figure 4.1: Different professional multi-copters[10]

Common Types of Materials Used For Drone Frames:

Wood: If you're trying to build a drone as cheaply as possible, then consider using a wooden frame. It's certainly one of the most inexpensive. One reason why I love wooden frames is because if something breaks, you can quickly and easily replace it. If you're going to use wood for your drone's frame, then make sure that it doesn't have any areas that are warped or twisted.
Carbon Fiber: carbon fiber is very tough and extremely lightweight. It's this combination that will make your RC drone fly better and consume less energy. Remember that carbon fiber impedes RF signals, so make sure that you keep this in mind when you're mounting important electronic components (like an antenna for example).
Plastic: Most commercial RC drones that you buy today come with plastic frames. 3D printed molded plastic frames have become an incredibly popular amongst DIY drone enthusiasts. Generally, using a 3D printer to create a perfectly shaped plastic frame is something that only works on smaller drones. When using plastic sheets (not 3D printed shapes or objects), you can strategically use them on your landing gear or for the cover of your drone.
Aluminum: Aluminum can also be used when building your frame. It's lightweight (though not as lightweight as carbon fiber), flexible, and is relatively easy to work with. You can use aluminum to build the entire frame, or simply use the material to supplement certain parts of the frame (arms, landing gear, etc.). Another benefit to aluminum frames is that this type of material is both inexpensive as well as readily accessible.

Motors:

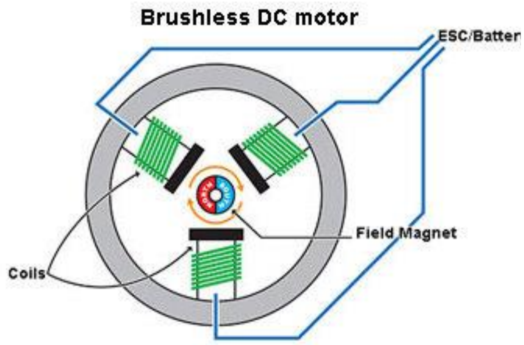
Brushed Motors: Like all RC motors, brushed motors contain windings (coil) and magnets. With this particular type of RC motor, the magnets remain FIXED while the coils SPIN. Generally speaking, brushed motors are quite popular amongst smaller, inexpensive model quadcopters (like the Syma X5C or Cheerson CX-10).One potential downside to this type of motor is that the brushes can wear out rather quickly, so their lifespans tend to be less than that of a brushless motor. Obviously, there are exceptions, but this tends to be the general rule.



Brushless Motors: Brushless motors act in the exact opposite manner: their COILS remain fixed while their MAGNETS are spun. As its name implies, a brushless motor does not contain any brushes, which can actually lead to the longevity of the RC motor. Here are a very common types of brushless DC motors that you'll encounter:

***Inrunner**:* These types of brushless motors have coils that are fixed on the outer casing, while the mobile magnets spin on the inside of the casing.

***Outrunner**:* As you can probably guess, these types of brushless motors have their magnets on the outer casing, and are spun around the fixed coils that are located within the middle of the motor casing.



Propeller:

All multi-rotor RC aircrafts use propellers (not to be confused with helicopter blades) to achieve lift. Propellers attach to the drone's motors. When the motor spins, so do the propellers. Similar to drone frames, propellers can be made from a wide variety of materials, as well as exist in many different sizes.

The majority of RC drones come with three-bladed or two-bladed propellers, with the most common setup being two. Smaller blades (those with smaller diameters) tend to be easier to slow down and speed up, which comes in handy if you're interested in doing acrobatic flights. Larger blades, or those with larger diameters, are better-suited for more stable flights since it's harder to speed up or slow down the blades.

All propellers that you use to build a drone come designed to spin in one of two ways:

Clockwise (CW)
Counterclockwise (CCW)

Obviously, it's important that you be able to tell which part of the propeller is supposed to face upwards and which part of the propeller is supposed to face downwards.

Materials Used to Make Propellers:

Plastic: Plastic is by far the most popular choice for propellers in the multi-rotor industry. This is mainly due to their low cost and respectable durability. Unfortunately, plastic propellers do have their downsides. For example, when you crash, it's very likely that, without a prop guard, you'll damage your propellers (even with prop guards there's a chance you can damage them). The good news is that plastic propellers are dispensable, so you can break the again and again without worrying about spending a lot on new ones.

Wood: Due to the intricate machining required to produce wooden propellers, they will cost much more than plastic. On a good note, wooden propellers tend to be very durable. They won't bend, and tend to remain in pretty good condition after light crashes. While they're not common in the RC drone industry, you can still find them in various RC planes.

Carbon Fiber: If you're looking for something that's super-high quality and that won't break, then consider using carbon fiber propellers when building a drone. Just note that you will be paying top dollar for these propellers. What I love about carbon fiber propellers is that they are very hard to break, and offer much more flex than a standard plastic propeller.

Safety

Prop Guards:

A “prop guard” is the thing that surrounds the propeller and prevents it from coming in contact with anything from the outside environment. When learning how to build a drone, I would definitely keep prop guards in mind. If you’ve never flown before, chances are good that you’re going to crash…a lot. And the best way I can think of to protect your props is to use a prop guard. RC quadcopters like the UDI U818A or FQ777-124 Pocket Drone come with removable plastic prop guards. Just keep in mind that they’re not perfect, and do come with their own set of drawbacks:

They add weight to your drone, which can decrease overall flight time.
They only work for “light” crashes.
They can contribute vibration of your RC aircraft.

Collision Tolerant:

Carrying its own protective frame, the drone is collision-tolerant. This means you can access the tightest spaces without any risk of crashing. No need to focus on avoiding obstacles, the drone bounces off and roll on them to find its way. You can fly close or even in direct contact with humans without any risks of injuries.

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