MASTER's THESIS – RENEWABLE ENERGY MANAGEMENT

Cologne University of Applied Science – Institute for Technology and Resources

Management in the Tropics and Subtropics

MONITORING AND MAPPING SOLUTIONS USING SENSOR NODES AND DRONES

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Abbreviations

API	Application Programming Interface
CSV	Comma Separated Values
EM	Electromagnetic
FPV	First Person View
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSD	Ground Sampling Distance
GSM	Global System for Mobile
NDVI	Normalized Difference Vegetation Index
RC	Remote Controller
SDK	Software Development Kit
UAV	Unmanned Aerial Vehicle
WSN	Wireless Sensor Network

1 Abstract

Researchers are always looking for innovative ways to collect the environmental data and ease the process of data collection on the field. Advancement in sensor technologies and drones has led to easy technological access to design custom solutions even with basic electronics and technical knowledge. This paper documents, construction and working of "ITT Smart Sense", which is a low power, easy to use and cost effective environment monitoring system using wireless sensor network that runs autonomously on battery power for an extended period of time. Along with that, a UAV based platform, titled "ITT Smart Sense Fly", focused on environmental monitoring and scientific research and is tailored to the needs of researchers has been proposed in this paper. This platform is comprised of an autonomous unmanned aerial vehicle (UAV)/Drone with a camera sensor, an autopilot mobile app for mission planning and other required Photogrammetry tools. The drone navigates over the area of interest based on a pre-programmed flight plan and captures a series of photographs using the on-board camera. The collected image data set is processed to create orthomosaics, high resolution maps and 3D point cloud. The proposed solutions were demonstrated with three distinct case studies.

Keywords: Wireless Sensor Network, UAV, Environmental Monitoring, photogrammetry, data collection, image acquisition, orthomosaic, image processing, aerial survey, mapping, solar panel detection

2 Introduction

2.1 Problem Statement

A sound natural resources management depends on the availability of reliable scientific data. Data collection is the preliminary step in an environmental research. Data collection is defined as the systematic approach to gathering and measuring information from a variety of sources to get a complete and accurate picture of an area of interest (Techtarget, 2017). A good, reliable and qualitative data is absolutely necessary for successful research, accurate results and correct conclusions. Researchers often spend a lot of time (several weeks, months, sometimes years) in data collection. The plug-and-play type monitoring equipment available in the market is usually expensive and adds up considerable costs to a project.

The scientists and researchers are looking for a smart monitoring solution with good accuracy that is easy to set up, time efficient, easily customizable, and most importantly, cost-effective. This enables them to focus on the analysis and assessment of measured environmental data rather than spending thousands of euros on buying expensive monitoring equipment and/or spending a significant amount of time in setting up an environmental monitoring system by custom design and development.

The main goal of this thesis is to provide cost-effective and time efficient environmental monitoring solutions for students, environmentalists, and researchers using wireless sensor networks (WSN) and drones by leveraging latest advancements in technology.

2.2 Objectives

- Design and development of robust and reliable environmental monitoring solutions using wireless sensor nodes and drones.
- Development of an *in situ* based monitoring platform and a UAV based monitoring platform
- Design the architecture of a wireless sensor network.
- Development of a data collection framework for environmental monitoring using drones, that can be replicated anywhere in the world, independent of the location.
- Development of ITT Smart Sense Fly mobile app for conducting autonomous flight surveys and capture images. This app is used to control an autonomous UAV, suitable for monitoring and inspection of wide range of field applications like on agricultural fields, water bodies like rivers and lakes, solar farm etc.
- Processing the image dataset collected from drone flight surveys.
- Demonstration of developed solutions using selected case studies.

3 Motivation

In situ measurements and remote sensing are two popular, state-of-the art data collecting approaches that are widely adopted by researchers across the world.

In situ measurements are taken directly on the field using instrumentation line handheld devices, or sensor nodes. Unlike satellite remote sensing data, *in situ* measurement samplings are flexible and often more accurate.

High precise and accurate sensor devices are expensive to build. On the other hand cheap sensor devices are mostly meant for hobby purpose, less accurate, and may not be reliable for research purposes. So developing innovative sensor devices that are accurate enough for the research purpose and low cost would be helpful for researchers. This has been one of the strongest motivations for writing this thesis and development of ITT Smart Sense Box.

Jensen defined remote sensing as the science and art of obtaining information about area, object, or phenomena through the analysis of data acquired by device that is not in contact with the area or phenomena under investigation (Jensen, 2007). Data analysis using remote sensing offers many advantages like easy data acquisition at different scales and resolutions, provides information in areas where ground based measurements are difficult or impossible, a single remotely sensed image can be analyzed and interpreted for different purposes and applications. However, sometimes it could be expensive to use remote sensing data for smaller areas and requires specialized training for image analysis. Moreover, the sampling rate of remote sensing data is linked to the repeat cycles of the satellites.

UAV/drone based airborne data acquisition has received a lot of attention in recent years. Researchers from Saudi Arabia have developed UAV based flash flood monitoring using Lagrangian trackers (Abdelkader, et al., 2013). Italian researchers used UAVs to evaluate multispectral images and vegetation indices for precision farming applications (Candiago, et al., 2015). UAVs, with their tiny footprints, permit remote data acquisition in dangerous environments and/or inaccessible locations such as deep forest, volcanoes, deserts etc. They provide cloud free remote data more rapidly and at lower cost compared to piloted aerial vehicles or satellites (Candiago, et al., 2015).

Recent innovations in the drone technology have enabled some of the leading drone manufactures to release application programming interfaces (API) and software development kits (SDK) for drones. These APIs help piloting the drones programmatically, create custom navigation missions, and come with a rich feature set like waypoint navigation, live video feed, gimbal camera control etc. Current drone piloting apps that are available in the market place does not allow customization and are not designed to fit every research topic. So, the development of own application can help in rapid data collection using UAVs. One of the goals of this thesis is to provide a framework and reference for researchers on how to adopt drone APIs for their research topics and develop their own solutions according to their needs. For example, an automated river water level detection system can be developed by modifying the ITT Smart Sense Fly mobile app.

Coupling the *in situ* measurements with remote sensing data can improve quality of collected data and research outcomes. This integrated in situ and UAV remote sensing approach has been used by Tung-Ching Su to monitor water quality of reservoirs. The data collected by UAV carrying RGB and NIR sensors were coupled with *in situ* measurements to map trophic state of Tain-Pu reservoir (Su & Chou, 2015). Researchers at University of Colorado Boulder, as part of Project Drought, are using UAVs to collect soil moisture data at 5-20 cm depth with 15 meter resolution to complement 5-cm depth, 40-km resolution NASA Soil Moisture Active Passive satellite data (Project Drought, 2017).

4 Methodology

A comprehensive literature review and background research was performed on numerous state-of-the-art wireless sensor devices that exist in the market as well as the early research stage sensor devices. Then architecture of the wireless sensor network, i.e. the sensor nodes (ITT Smart Sense Boxes) communicating to server via mobile network, has been designed. All the necessary hardware components like microcontroller, GPRS module, battery and required sensors were chosen before constructing the actual sensor device. As the sensor devices will be typically deployed in the fields on open air and operate autonomously, they should be capable of withstanding harsh weather conditions like rain, snow, hail etc. So the state-of-the art enclosure components with good form factor were chosen during the construction of the device. The ITT Smart Sense web portal was then deployed on the university's webserver. The sensor device communicates to webserver through FTP protocol. Afterward, the testing of entire system was done and encountered bugs were fixed. Then a comprehensive instruction manual has been prepared. Finally, a case study on ITT Smart Sense box was implemented at ITT's Kalk building to demonstrate the developed solution.

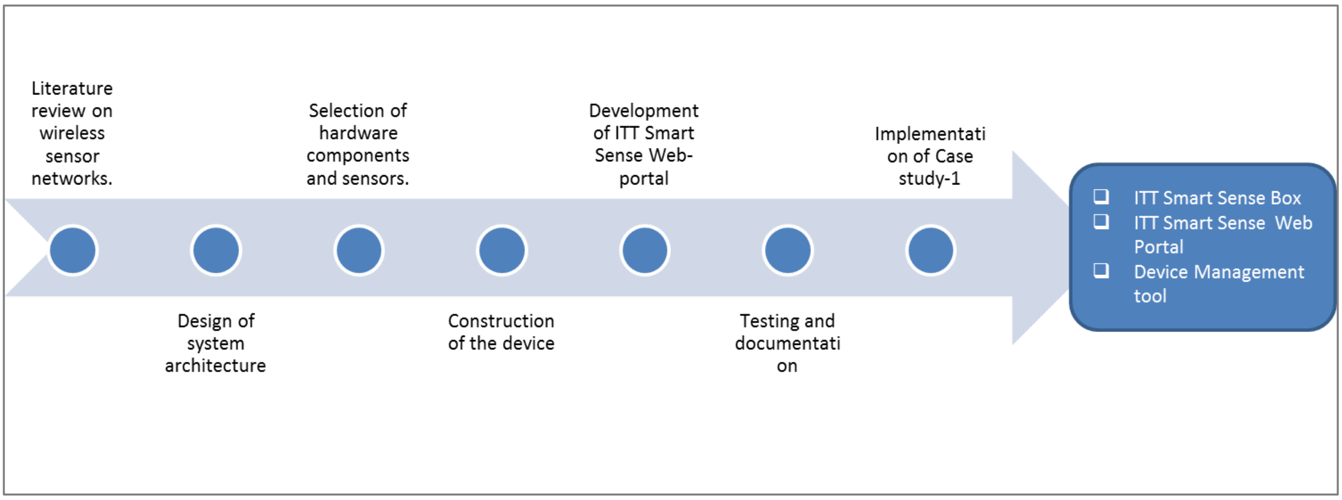


Figure 1: Methodology used for development of ITT Smart Sense Box

The Drone technology is advancing day by day at rapid speed. An extensive online research has been done to select state-of-the-art drones available in the market that can be tailored to the needs of researchers and environmental monitoring. Afterward, a robust, rational and replicable workflow has been designed. All the necessary apps, algorithms were then developed and required software tools were installed at workstation that would fit the designed workflow. Soon after that, the ITT Smart Sense Fly mobile app was tested both on the simulator as well as on the field on several instances to improve precision and accuracy of the flights. The field testing was challenging because of faraway test locations and unpredictable weather conditions. All the components of the system were then tested rigorously. Finally, a couple of case studies on the proposed concept were implemented at chosen locations.

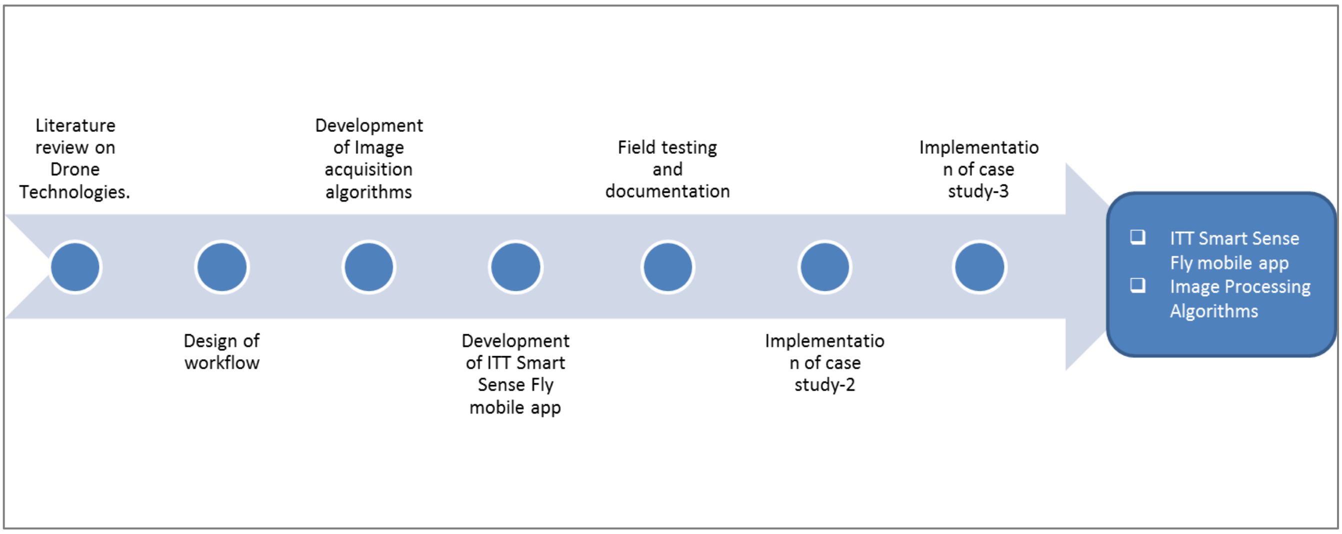


Figure 2: Methodology used for implementation of ITT Smart Sense Fly platform

5 Development of Smart Sense Devices and Tools

The details of developed tools and applications of the proposed monitoring platforms (ITT Smart Sense Box and ITT Smart Sense Fly) are presented in this chapter.

5.1 ITT Smart Sense Box

ITT Smart Sense Box is an autonomous sensor device to monitor physical or environmental conditions, such as temperature, humidity, soil moisture, etc. A typical sensor device consists of a microcontroller unit, a battery, a GSM/GPRS module (or a radio module) and a set of sensors. The microcontroller unit act as brain of the device which interprets the electrical signals of sensors and convert into numerical measurements. The GSM module transfers the sensor measurements to a webserver over mobile communication. The entire device is powered by a battery for continuous and autonomous operation.

Figure 3: ITT Smart Sense Box

The Smart Sense Box has three variants which are categorized based on the area of application.

- ITT Smart Sense Agriculture
- ITT Smart Sense Water
- ITT Smart Sense Weather

Smart Sense Agriculture is designed for agriculture monitoring and provides a continuous recording of important soil parameters such as soil moisture, soil temperature, and ambient temperature. Moreover, it is possible to connect additional sensors for measurement of solar radiation, UV radiation, and tree-trunk diameter. This device can also be used by farmers to maximize crop yields by utilizing a minimal quantity of water, fertilizer and other natural resources.

Smart Sense Water device can be used for measuring water quality parameters like electrical conductivity, water temperature, pH, dissolved oxygen (DO). This device can be installed in lakes, ponds, rivers and various other water bodies to measure and monitor water quality parameters.

Smart Sense Weather is developed for monitoring general climatic and weather parameters such as temperature, humidity, atmospheric pressure, wind speed with direction, and rainfall.

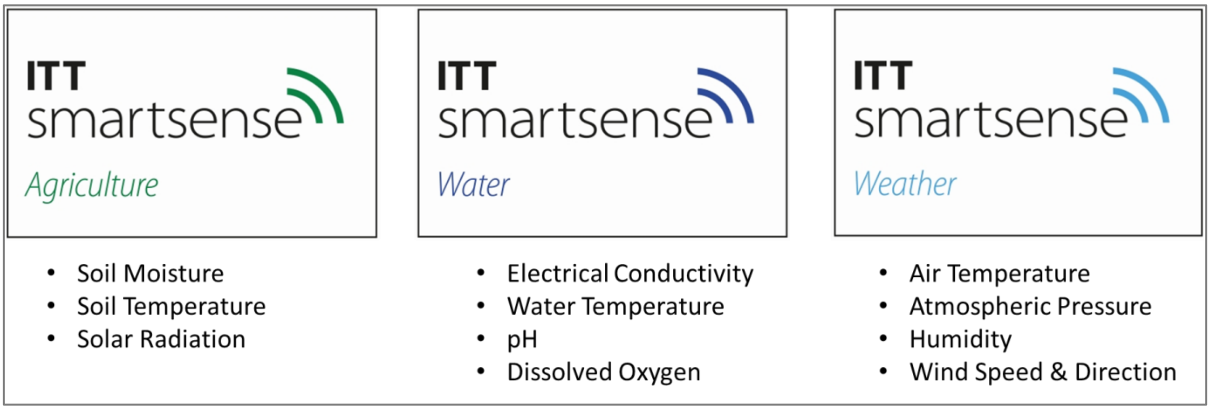


Figure 4: ITT Smart Sense variants with logos and monitoring parameters

5.1.1 System architecture

The ITT Smart Sense Box with connected sensors is installed on site at location of interest. The box collects the sensor measurements, logs the data locally with in device storage and also uploads the data to a webserver over internet using cellular communication (GSM) network. The "ITT Smart Sense Web portal" that sits on top of the web server, facilitates the easy access of uploaded sensor measurements to end users.

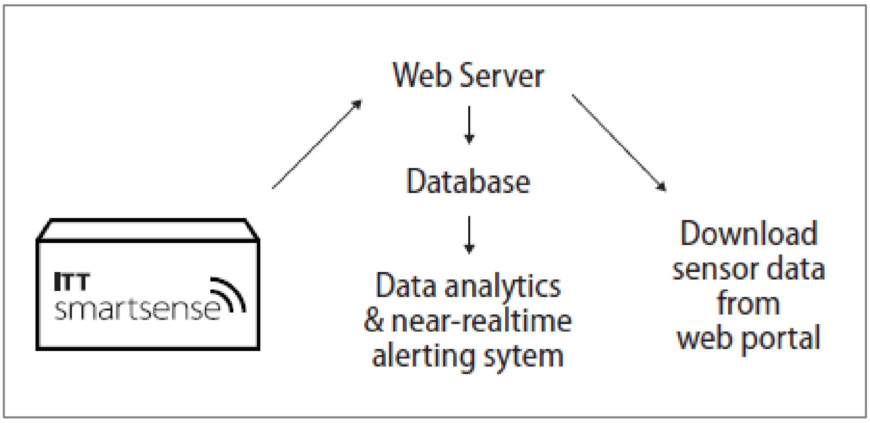


Figure 5: ITT Smart Sense platform architecture

5.1.2 Features of the device

- Long operating/battery life (approx. 2 years) – Solar Panel attached to the device recharges battery during daytime, helps to maintain long operating life and autonomous operation.
- Less/ almost no maintenance.
- Low battery alerts – Sends an SMS to the user when the device battery reaches under 20 percent.
- Device offline alerts – Alerts the user when device went offline for long period of time and stopped uploading the measured data.
- In-built data logger with in the device – Thanks to the memory card attached to device, the measurements are stored as a backup.
- IP67 Weather proof protection – The device can withstand harsh weather conditions like rain, wind, snowfall etc.
- Easy swapping of the sensors – possibility to swap or replace one sensor with another sensor when needed.

5.1.3 Construction of device

Four major components namely, microcontroller boards, battery, sensors, communication module, are required for successful construction of a sensor device. Several state-of-the-art microcontroller platforms, sensor technologies and communication options have been considered during the designing and planning phase. Other auxiliary components like enclosure, mounting components, switches, connectors, wiring components, spacers, solar panel, were chosen later to make the device robust and practical.

5.1.3.1 Microcontroller Board

A microcontroller is a single printed circuit board (PCB) that provides all necessary electronic circuitry like microprocessor, I/O circuits, RAM storage memory and all necessary integrated circuits (ICs) to be able to interpret electrical signals from sensors (Brennan, 2017). Several state-of-the-art microcontroller boards like Arduino, Raspberry Pi, Mayfly, Waspmote, were tested to select the most suitable board for the purpose. Arduino is an open source electronics board based on easy-to-use software and simplified hardware (Arduino LLC, 2017). It has an extensive collection of hardware and software for building sensor devices. However, the board itself is very minimal and requires many extensions like SD card, power management, etc to make it work as full-fledged device. This adds-up a considerable amount of complexity to the device. On the other hand, Raspberry Pi is a mini Linux computer with good form factor and powerful memory options (Raspberry Pi, 2017). But it consumes lot of energy which makes it hard to run the device autonomously without adequate continuous power supply. As the sensor stations are usually installed in remote locations where there is not access to a power source, using energy intensive board is not an ideal choice.

Finally, Waspmote has been chosen as a suitable microcontroller board for the sensor device. Waspmote has rich feature set like ultralow power consumption, seamless support for more than 120 sensors, and 16 radio technologies, open source SDK and API (Libelium, 2017). It has good accuracy and precision of measurement that makes it a best choice for the purpose of building a reliable remote sensor stations.

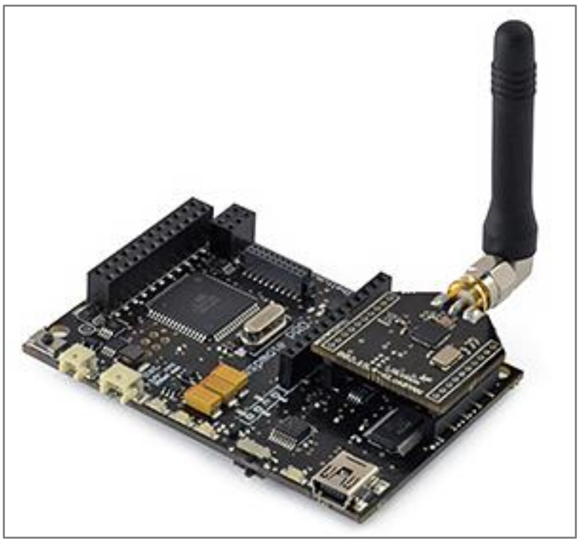


Figure 6: Waspmote Microcontroller Board from Libelium. Source: (Libelium, 2017)

Table 1: General characteristics of Waspmote board v3.

Microcontroller:	ATmega1281
Frequency:	14.74 MHz
SRAM:	8 kB
EEPROM:	4 kB
FLASH:	128 kB
SD card:	2 GB
Weight:	20 g
Dimensions:	73.5 x 51 x 13 mm
Temperature range:	[-30 ºC, +70 ºC]*
Clock:	RTC (32 kHz)
Power consumption	On: 17 mA Sleep: 30 µA Deep Sleep: 33 µA Hibernate: 7 µA
Input / Output	7 analog inputs, 8 digital I/O 2 UARTs, 1 I2C, 1 SPI, 1 USB
Electrical characteristics	Battery voltage: 3.3-4.2 V USB charging: 5 V - 480 mA Solar panel load: 6-12 V - 300 mA

Source: (Libelium, 2017)

5.1.3.2 Communication module

The environmental monitoring stations are generally placed in a remote location, makes it is hard to access the collected sensor measurements. So there has to be a reliable communication module which transfers the measured sensor data to desired location. Keeping the global context and deployment in mind, the internet provides best accessibility across the world. The cellular telecommunication networks provide radio and internet coverage to wide geographical area on the globe. Hence, GSM/GPRS communication module has been chosen as part of construction of ITT Smart Sense box.

5.1.3.3 Power Supply

The electronic components, including sensors cannot operate without electrical power source. A reliable power supply is required for smooth and autonomous operation of the device. A high power capacity of about 6600mah rechargeable battery has been chosen for powering ITT Smart Sense Box.

5.1.3.4 Supported Sensors

Though Waspmote platform supports 120+ sensors, only certain sensors (which are important and most widely used), were tried and tested during construction of device due to the time limitation. It is possible to use the sensors that are not mentioned below. However, at the moment, the Smart Sense Device Management tool does not support the generation of required sketch (programming code) of untested sensors. However the support can be added by modifying the source code of the Smart Sense Device Management tool.

Temperature, humidity and pressure sensor (BME280):

The BME280 is as combined digital humidity, pressure and temperature. The humidity sensor provides fast response time and high overall accuracy over a wide temperature range. The pressure sensor is an absolute barometric pressure sensor with extremely high accuracy and resolution with lower noise (Libelium, 2017).

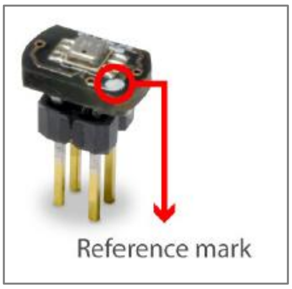


Figure 7: BME280 Sensor. Source: (Libelium, 2017)

Specifications:

Temperature Measurement:

- Operational range: -40 ~ +85 ºC
- Full accuracy range: 0 ~ +65 ºC

Humidity Measurement:

- Measurement range: 0 ~ 100% of Relative Humidity
- Accuracy: < ±3% RH (at 25 ºC, range 20 ~ 80%)

Atmospheric Pressure Measurement:

- Measurement range: 30 ~ 110 kPa
- Operational temperature range: -40 ~ +85 ºC

Soil moisture sensor (Watermark):

The Watermark sensor is a resistive type sensor consisting of two electrodes highly resistant to corrosion embedded in a granular matrix below a gypsum wafer. The resistance value of the sensor is proportional to the soil water tension, a parameter dependent on moisture that reflects the pressure needed to extract the water from the ground (Libelium, 2017).

Figure 8: Watermark soil moisture sensor. Source: (Libelium, 2017)

Specifications:

- Measurement range: 0 ~ 200 centibars or kPa
- Frequency Range: 50 ~ 10000 Hz approximately

Soil temperature sensor (DS18B20)

The DS18B20 is a digital thermometer that provides Celsius temperature measurements with good accuracy. (Libelium, 2017).

Figure 9: DS18B20 Soil temperature sensor. Source: (Libelium, 2017)

Specifications:

- Measurement range: -55 ~ 125 ºC
- Accuracy: ±0.5 °C accuracy from -10 °C to +85 °C

Weather station (WS-3000)

This weather station consists of three different sensors, namely, an anemometer, a wind vane and a pluviometer. The anemometer consists of a reed switch normally open, but closes for a short period of time when the arms of the anemometer complete a 180º angle. So, the output is a digital signal whose frequency is proportional to the wind speed. The wind vane consists of a basement that turns freely on a platform endowed with a net of eight resistances connected to eight switches that closed when a magnet in the basement acts on them, thereby allowing distinguishing up to 16 different positions (directions). The pluviometer consists of a small bucket (tipping bucket) that, once completely filled (0.28 mm of water approximately), closes a switch, emptying automatically afterwards (Libelium, 2017).

Figure 10: Weather Station. Source: (Libelium, 2017)

Specifications:

Anemometer:

- Sensitivity: 2.4km/h / turn
- Wind Speed Range: 0 ~ 240km/h

Pluviometer:

- Bucket capacity: 0.28 mm of rain

Temperature Sensor (Pt-1000)

The Pt-1000 is a resistive sensor whose conductivity varies in function of the temperature (libelium smart water, 2017).

Figure 11: PT1000 Water temperature sensor. Source: (Libelium, 2017)

Specifications:

- Measurement range: 0 ~ 100 ºC
- Cable length: 150 cm

Conductivity sensor:

The conductivity sensor is a two-pole electrode type sensor whose resistance varies in function of the conductivity of the immersed liquid. The conductivity of electrodes is proportional to the conductance of the liquid (libelium smart water, 2017).

Figure 12: Water conductivity sensor. Source: (Libelium, 2017)

Specifications:

- Sensor type: Two electrodes sensor
- Electrode material: Platinum
- Measuring Units: micro-Semmens/ cm

pH sensor:

The pH sensor is a combination electrode that provides a voltage proportional to the pH of a solution (libelium smart water, 2017).

Figure 13: pH sensor. Source: (Libelium, 2017)

Specifications:

- Sensor type: Combination electrode
- Measurement range: 0~14 pH
- Operating Temperature: 0~80 ºC

Dissolved Oxygen sensor

Dissolved Oxygen sensor is a galvanic cell type electrode that provides an output voltage proportional to concentration of dissolved oxygen in the solution (libelium smart water, 2017).

Figure 14: Dissolved Oxygen sensor. Source: (Libelium, 2017)

Specifications:

- Sensor type: Galvanic cell
- Measurement range: 0~20 mg/L
- Accuracy: ±2%

5.1.3.5 Component Assembly

A detailed step-by-step instruction document containing assembly of all required components and calibration of certain sensors of the ITT Smart Sense Box has been prepared.

5.1.4 ITT Smart Sense Web Portal

As discussed in previous sections, the sensor stations are usually deployed in remote locations and the measured data has to be easily accessible to stakeholders. In order to facilitate easy access over internet, ITT Smart Sense Web Portal has been developed. The portal is located over URL: http://itt-smartsense.info

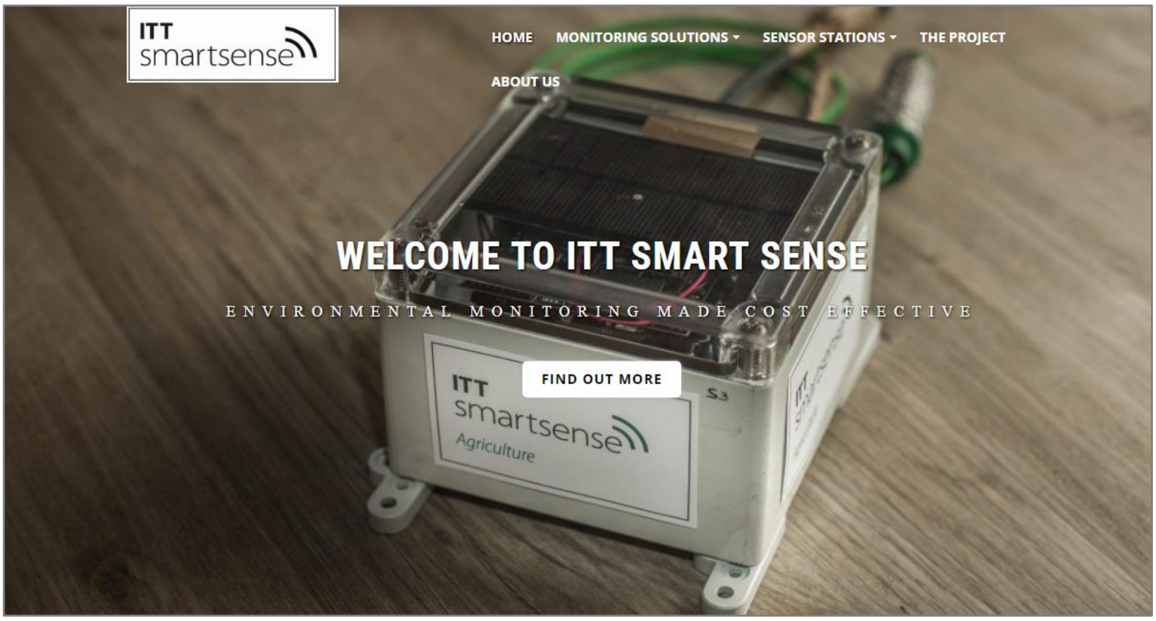


Figure 15: ITT Smart Sense Web Portal.

Authorized users can login to the web portal, view and download the sensor data. Each ITT Smart Sense Box has respective webpage in the portal with information about the device and uploaded sensor measurements. The sensor measurements are stored in ".csv" file format. Viewing and editing CSV files is supported by Microsoft office, open office or any other text editors.

station-1 data

Device Info:
Station Name: Smart Weather Monitor Test device
Location: Cologne, Germany
Geo-coordinates: 12.33435 E, 19.344324 N
Station Type: Smart Water Monitoring
Connected Sensors: Temperature, Soil Moisture
Data Upload interval: Every 24 hours
Sensor Reading Interval: Every 6 hours
Number of Readings per file: 100
Device Installed on: 12.06.2016 12:00 PM
Device Microchip ID: 123 453 112
Device ID: Ag1
Device Phone Number: +91-9999991234
Client Institution Name: ABC
Institution Address:
Contact Person: Mr. XYZ
Contact Email ID: xyz@email.com
Sensor Data Frame columns: DeviceID, Reading Serial Number, Battery Level, Date, Time, Temperature, Humidity, Soil Moisture,
Pictures:

Sensor Data Files:

other info/ Notes:

View and Download Sensor Data file:

170507A

Search

DEVICEID	SEQNUMBER	BATTERYLEVEL	DAY	DATE	TIME	TEMPERATURE	HUMIDITY	SOILMOISTURE	SOILTEMPERATURE
ag1	161	73	Fri	17/05/07	13:02:06	4.6	na	8396.	na
ag1	162	73	Fri	17/05/07	19:03:26	7.9	na	8493.	na
ag1	163	73	Sat	17/05/08	01:04:45	9.0	na	8519.	na
ag1	164	73	Sat	17/05/08	07:06:04	9.4	na	8514.	na

Figure 16: Deployed sensor device information page in Smart Sense web portal.

5.1.5 ITT Smart Sense device management app

“ITT Smart Sense device management app” is a desktop software tool that generates appropriate programming code for the microcontroller and also communicates with backend FTP server to generate necessary files and folders where the measurements will be uploaded after the deployment of the device on the field. The user is presented with a couple of screens where he chooses sensors, measurement time interval, upload interval, and various other settings. At the end, the tool generates appropriate microcontroller code (programming sketch) according to configuration. It eliminates the necessity to learn complex software programming by the end user.

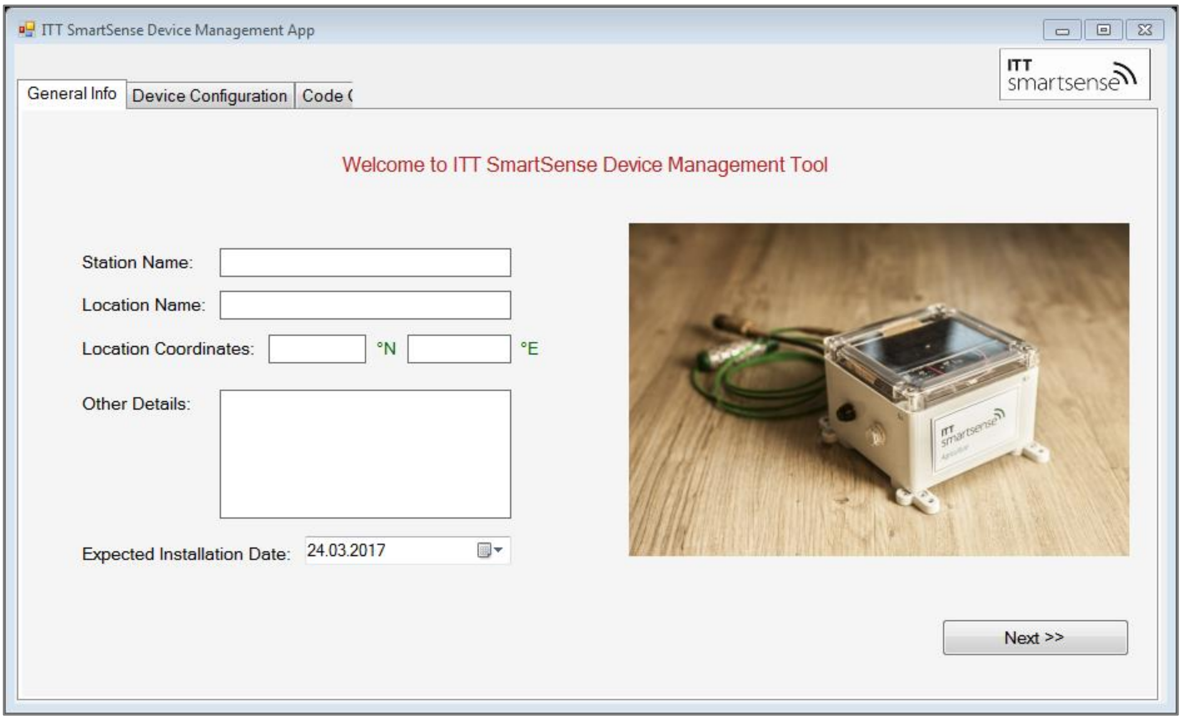


Figure 17: ITT SmartSense Device Management Tool.

5.1.6 Potential applications

The government organizations, municipalities, environmental agencies can use ITT Smart Sense across wide range of monitoring applications. Smart Water variant can be used to monitor water level variations in dams, rivers and reservoirs, water quality monitoring in fish farms and ponds, chemical leakage detection in rivers etc. Smart Agriculture version of ITT Smart Sense can be used in green houses to control climatic conditions to maximize the production of fruits and vegetables, precision agriculture, prediction of yield and various other applications. Wind measurement stations, forecasting of floods and droughts, are some of potential applications of Smart Weather variant.

5.2 ITT Smart Sense Fly

ITT Smart Sense Fly is an Unmanned Aerial Vehicle (UAV) based solution to capture aerial photographs of a study region using camera and other sensors. This solution enables researchers, scientists, and students to capture pictures using selected drones without having to learn how to pilot the drone. An elegant mobile app that can run on any android phone or tablet has been developed to auto pilot the drone.

Figure 18: ITT Smart Sense Fly logo

5.2.1 Selection of a UAV/Drone

The Drones come in all sizes, shapes and prices. There are hundreds of models of drones available in the market. So it is important to pick the right drone according to intended field of application. The following general criterion has to be considered for the selection of a drone suitable for scientific research and development purpose.

- ✓ **High flight endurance** – Flight endurance is the maximum length of the time that an aircraft/UAV can spend in hovering. The higher the endurance, the farther it can travel. For example, a drone has to have a flight time (endurance) of at least 15 minutes in order to travel 4.5 kilometers at 5 m/s (18 km/h).
- ✓ **High Payload** – The payload is the additional weight, a drone or unmanned aerial vehicle (UAV) can carry. Cameras, gimbals, LiDAR are some of the payloads a drone often carries. A drone with higher payload capacity can carry heavy cameras. A payload capacity of 500 grams to 800 grams is sufficient to carry most of the widely used camera models. Usually, the flight endurance decreases with increased payload.
- ✓ **Range** – The radio range determines how far and how high a drone can travel. A radio range of 1-2 kilometers is recommended for commercial applications.
- ✓ **Battery Life** – Battery life is directly linked to flight endurance. The higher the battery life, the higher the endurance. Most of the state-of-the-art drones have a battery life of 15 – 25 minutes flight time (James, 2017).
- ✓ **Support multiple cameras** –Some drones support attaching more than one camera at same time (Popper, 2016). For example, inspection of solar panels for detection of hotspots requires a regular RGB camera along with an infrared camera.
- ✓ **Industrial Grade -** Commercial and military grade drones are rugged, robust, and can able to run even in rain and freezing temperature. In certain research areas, like regions close to northern hemisphere or mountainous regions may require industrial grade drones to capture the aerial footage.

- ✓ **Ability to stream live video footage –** Some research applications like monitoring of flood plains or inspection of river basin requires first person view (FPV) of drone. In other words, live streaming of video footage.
- ✓ **Advanced Control options with fail safe mode** – Advanced control options like auto takeoff and landing, attitude mode, controlling with mobile apps can make the pilot's job easier. Bad weather conditions, especially high-speed wind, can make the flight difficult. The drone should have a mechanism (fail safe mode) to handle such unexpected situations and automatically land at safe location.
- ✓ **Price** – Prices of drones vary between as low as 20 EUR to as high as 2,00,000 EUR.
- ✓ **After sales and customer support**

An extensive online research and literature review has been performed in order to select the best drone(s) according to above mentioned selection criteria. "DJI Matrice 100" quadcopter has been chosen for the proof-of-concept. DJI is one of the leading drone manufacturer by capturing an approximately 70% of drone market (Joshi, 2017). DJI Matrice 100 is a fully programmable and autonomous industrial grade drone. The drone has a flight time of 22 minutes, 17 minutes, 13 minutes with no payload, 500grams payload and 1kg payload respectively (DJI, 2016). It can fly with a maximum speed of 17m/s in GPS mode at no payload and no wind condition. It has advanced control options with fail safe mode and also supports multiple cameras. The drone can travel within the radius of two kilometers and a maximum flight altitude of three kilometers.

Figure 19: DJI Matrice 100 drone. Source: (DJI, 2016)

5.2.1.1 Major components of a drone

A drone uses several real-time measurements from sensors like accelerometer, gyroscope, magnetometer, barometer, GPS sensor, in order to hover at a defined (rather instructed) spot. If a drone has to navigate from Point A to Point B, it does so, using GPS sensor to identify those two actual location coordinates (of point A and point B) on the ground. Traditionally, drones are controlled using remote controllers (RC). However, in recent days, most of the drones can be controlled using smart phones or tablets with necessary apps installed.

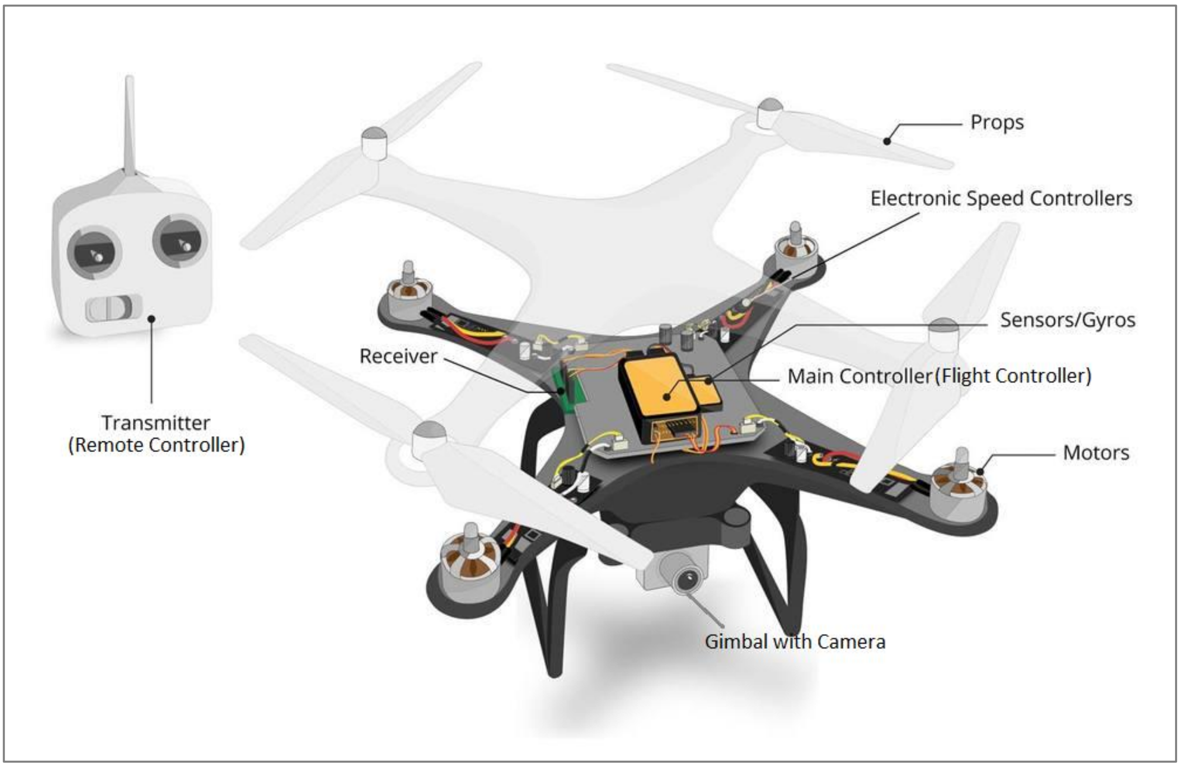


Figure 20: Main Components of a drone. Source: (Arc Aerial Imaging, 2017)

Flight Controller:

A flight controller is the brain of aircraft, which is basically an integrated circuit board with built-in sensors, and necessary control mechanism to regulate speed of the motors in order to keep the drone/UAV in the air (Oscarliang, 2014). Recent developments in technology have enabled flight controllers to drive the drones autonomously in autopilot mode. DJI A2, DJI Naza, Pixhawk are some of popular flight controllers that are available in the market.

Motors and Propellers:

Motors and Propellers are like engine and wheels of a car, which drive the drone. Usually propellers of the drone have to be detached from motors after every flight.

Figure 21: Lumenier Rx2206 motor and propeller. Source: (Quad Questions, 2017)

Remote Controller:

The remote controller (RC) provides the ability to pilot the drone. Though the drones are capable of piloting autonomously, remote controllers are necessary to communicate with the drone during the flight, view the video, and trace the real-time location of the drone through flight telemetry. RCs are extremely important to take control of the drone in-case of emergency situations.

Figure 22: DJI Remote Controller for Phantom drone. Source: (Drones Made Easy, 2017)

Gimbal/Stabilizer:

The drone gimbal is a pivoting mount that rotates about the x, y, and z axes using motors to provide stabilization and pointing of cameras and/or other sensors. It absorbs the vibrations, shakes and stabilizes the motion during the flight. A typical 3-axis gimbal can stabilize as well as rotate the cameras in all the three axes, i.e. pitch, roll, and yaw.

Figure 23: 3-axis gimbal with a camera. Source: (Adorama, 2017)

5.2.2 Electromagnetic spectrum and Selection of Camera

The selection of a camera depends on type and field of application. The payload (weight), shape, control mechanism of camera are also to be considered during the selection process. Sometimes it is tricky to find a suitable drone that can carry the chosen camera. Gremsy T1, Gremsy T3, Ronin Mx are some of the gimbals and camera stabilizers that are compatible to carry most of the standard cameras and fit to most of the commercial drones.

5.2.2.1 Electromagnetic spectrum

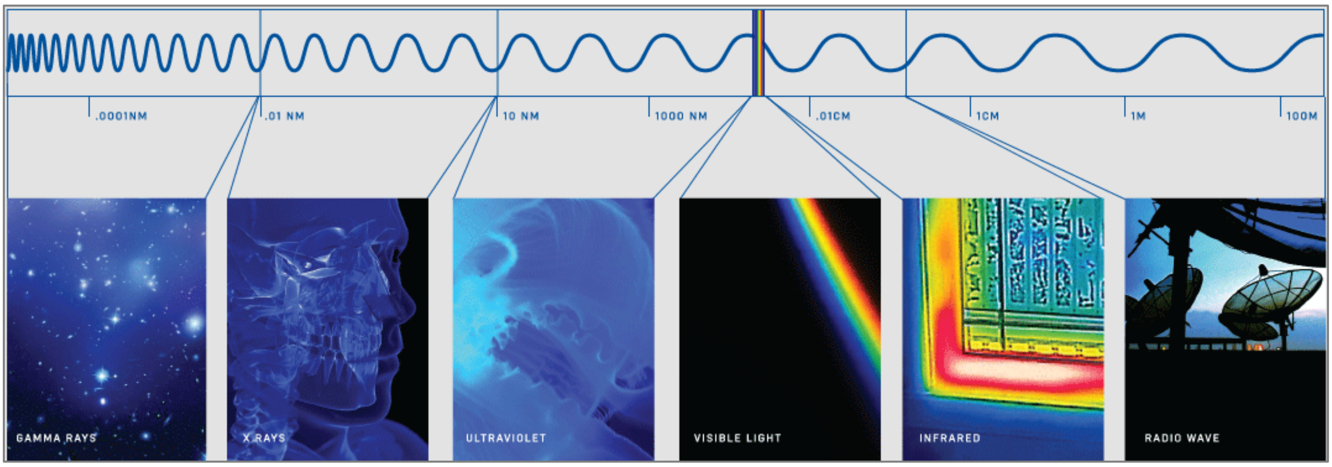


Figure 24: Electromagnetic spectrum. Source: (Flir, 2016)

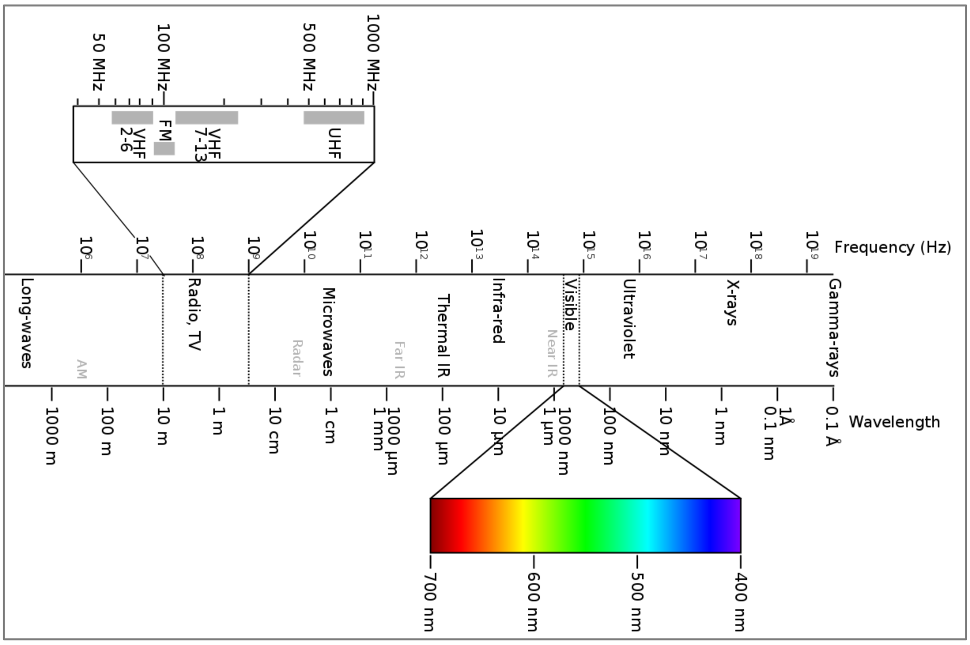


Figure 25: Electromagnetic spectrum with wavelength and frequency range for class. Source: (Blacus, 2012)

The electromagnetic spectrum is divided into eight main classes, namely, Gamma radiation, X-ray radiation, Ultraviolet radiation, visible radiation, Infrared radiation, Terahertz radiation, Microwave and Radio waves. Among these, the visible radiation and the infrared radiation are most widely used for environmental research and remote sensing applications. Infrared radiation in the electromagnetic spectrum covers the range from 1mm to 750nm and can be further divided into Far-infrared, Mid-Infrared, and Near-Infrared. The visible radiation wavelength spans from 400nm to 700nm. The most widely used spectral bands and their use in remote sensing applications is given in Table 2.

Table 2: Widely used spectral bands of EM spectrum and their usage in remote sensing applications

Spectral Band	Wavelength (micrometer)	Application
Blue	0.452 - 0.512	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation
Green	0.533 - 0.590	Emphasizes peak vegetation, which is useful for assessing plant vigor, Sediment-laden water, delineates areas of shallow water
Red	0.636 - 0.673	Discriminates vegetation slopes
Near Infrared (NIR)	0.851 - 0.879	Emphasizes biomass content and shorelines (Vegetation boundary between land and water, and landforms)
Short-wave Infrared	1.566 – 3.0	Discriminates moisture content of soil and vegetation; analyzing soil moisture content
Thermal Infrared	7.5-14.0	Thermal mapping
Far Infrared	20.8-23.5	soil, moisture, geological features, silicates, clays, and fires

Source: (USGS, n.d.)

5.2.2.2 Spectral Cameras

CMOS and CCD are most commonly used image sensors for state-of-the-art digital cameras. The image sensor present in the camera constitutes a grid of several million squares called “pixels”. These pixels measure the color and brightness of the light incident on them and store the measurements to create so-called a digital photograph. In other words, a digital photograph is a group of several millions of numbers. The pixels in regular digital camera (also called RGB camera), captures only visible radiation in electromagnetic spectrum, like a human eye. But there are other types of cameras exist which respond to other radiation wavelengths. For example, thermal imaging cameras capture infrared radiation.

Regular RGB Cameras:

Red, Green and Blue are primitive colors. These colors can be mixed in several ways to reproduce a broad array of colors. Most of the drones come with a regular RGB camera. These cameras are used for land-use classification and planning, geological mapping, object identification etc. These cameras are relatively inexpensive compared to other types of cameras.

Infrared Cameras:

Most common Infrared cameras are Thermal Imaging cameras. Drones carrying thermal cameras are used in inspection of powerlines, detection of hotspots in solar farms, search and rescue missions etc. However, there are other types of Infrared cameras like NIR cameras which are used mostly in precision agriculture and water research applications. Flir Vue Pro, Zenmuse Z3, WIRIS are some of the IR cameras specially designed to work with drones.

Multispectral Cameras:

Unlike regular RGB cameras and Thermal Imaging cameras, the multispectral camera can capture multiple spectral bands (Blue, Green, Red, Red-Edge, Near Infrared, Far-Infrared etc.). It means it can capture both visible and invisible images. These cameras are widely used in agriculture to Identify pests, disease and weeds, Provide data on soil fertility, estimation of crop yield etc. An NDVI camera is a special type of multispectral camera with Green, Red and NIR spectral bands used for measurement of NDVI on the agricultural field. MAPIR Survey 2, Parrot Sequoia, Tetracam ADC Lite, Sentera are some of notable cameras designed for UAVs.

Figure 26: Sequoia Multispectral UAV sensor for agricultural applications. Source: (Corrigan, 2017)

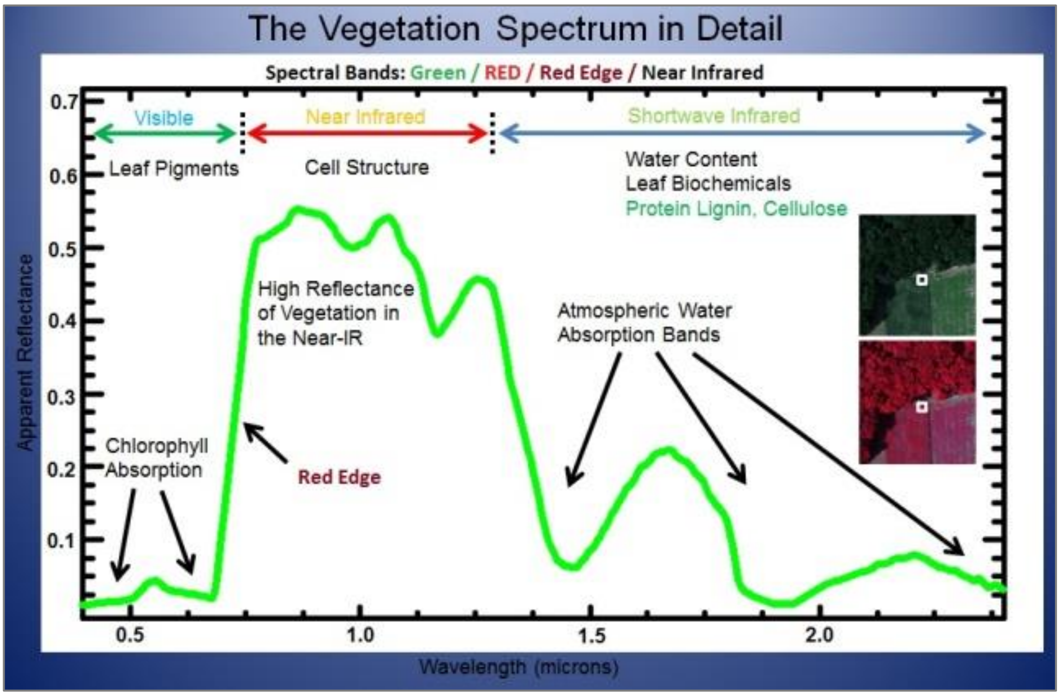


Figure 27: Vegetation Spectrum. Source: (Markelowitz, n.d.)

Hyperspectral Cameras:

The spectral resolution is the main factor that distinguishable factor between hyperspectral imagery and multispectral imagery. The hyperspectral camera captures more narrow bands than multispectral in the same portion of the electromagnetic spectrum, based on spectral responses. The hyperspectral cameras are used in precision agriculture, soil moisture measurement, invasive weed mapping, tracking pollution levels, livestock monitoring and various other applications.

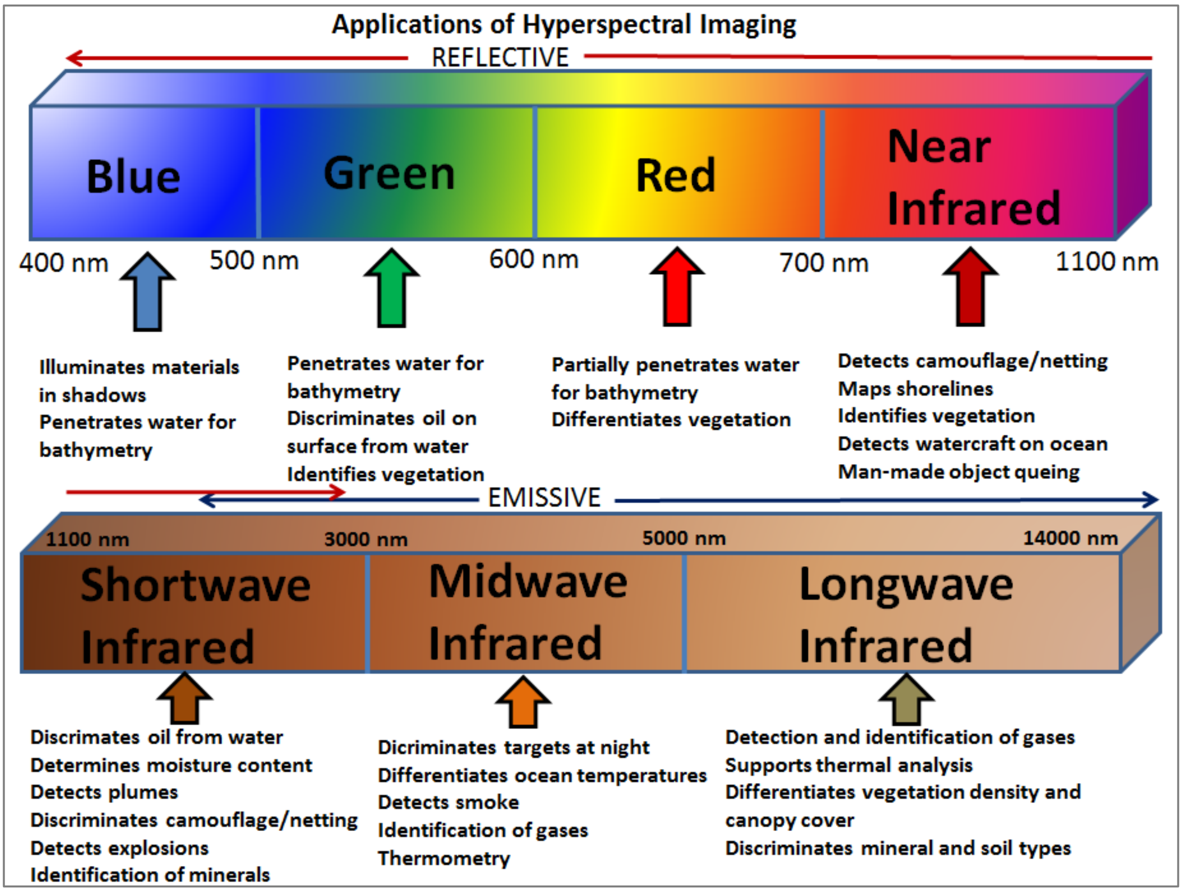


Figure 28: Applications of Hyperspectral Imaging. Source: (Markelowitz, n.d.)

5.2.3 The ITT Smart Sense Fly App

The ITT Smart Sense Fly app is a mobile application that allows the user to create flight plans to capture the image data. The app can run on an android phone or a tablet (recommended). The app pilots and controls an autonomous drone according to the preconfigured algorithm. The app is the perfect tool to automatically capture image data for optimal 2D and 3D maps and models. The user doesn't have to learn how to pilot a drone in order to use the drone for capturing aerial photographs and video. So the app facilitates the collection of image data easily and quickly. The researchers and students can concentrate on analyzing the collected data rather than spending months (sometimes years) in data collection.

Figure 29: ITT Smart Sense Fly android app - main screen

The app was developed using DJI Android Software Development Kit (SDK) in Android Studio. The DJI SDK version 3.2 was running during the development of this app. The app is compatible with various models of DJI drones, like Phantom 3, Phantom 4 series, DJI Matrice 100, Matrice 600, and Inspire series.

5.2.3.1 Features of the App

- Operate the drone in Auto pilot mode
- Displays current location of drone
- Possibility to configure flight parameters like flight speed, altitude, front overlap, side overlap etc.
- Automatic takeoff and landing
- Automatic generation of optimum flight path in selected region
- Voice Alerts
- Supports multiple types of cameras
- Rotate flight direction
- Save Flight data at the end of each mission
- Emergency landing button
- Trace the actual flight taken by aircraft during the mission

5.2.3.2 Using the App

The ITT Smart Sense Fly app has an intuitive user interface with couple of major screens. The sequence of steps to pilot the drone using the app is given below.

1. The user selects the region of interest by placing the markers on map section on the main screen.
2. Adjusts the flight settings by tapping on “Flight Settings” button.
3. Taps any of the four “flight plan buttons” available.
4. Taps “Start” button to start the mission.

5.2.4 Development of Image Acquisition Algorithms

The ITT Smart Sense Fly app uses a couple of algorithms for the generation of optimized flight route and to send instructions to the drone to shoot photographs or a video at the desired locations. These algorithms were developed using some of the fundamental concepts of physics, trigonometry, and photogrammetry.

5.2.4.1 Grid Flight Path Generation Algorithm

The drone navigates in a defined path using the so-called Waypoint navigation system. A waypoint is a set of coordinates (geo-coordinates with altitude) that identify a specific point in the physical space (Hansen, 2016). The job of the Smart Sense Fly app is to map (or sketch) an optimized flight path with the waypoints.

A “Grid Type” Flight Plan is one of the most widely used techniques of aerial survey for generation of topographic maps and orthophotos (Gopi, 2007). A typical grid flight plan for an aerial survey is shown in Figure 30. The figure illustrates a grid flight plan represented with 14 waypoints (yellow circles) in total.

Computing the optimum flight route for the desired survey area and representing it in the form of waypoints is the core function of ITT Smart Sense Fly app.

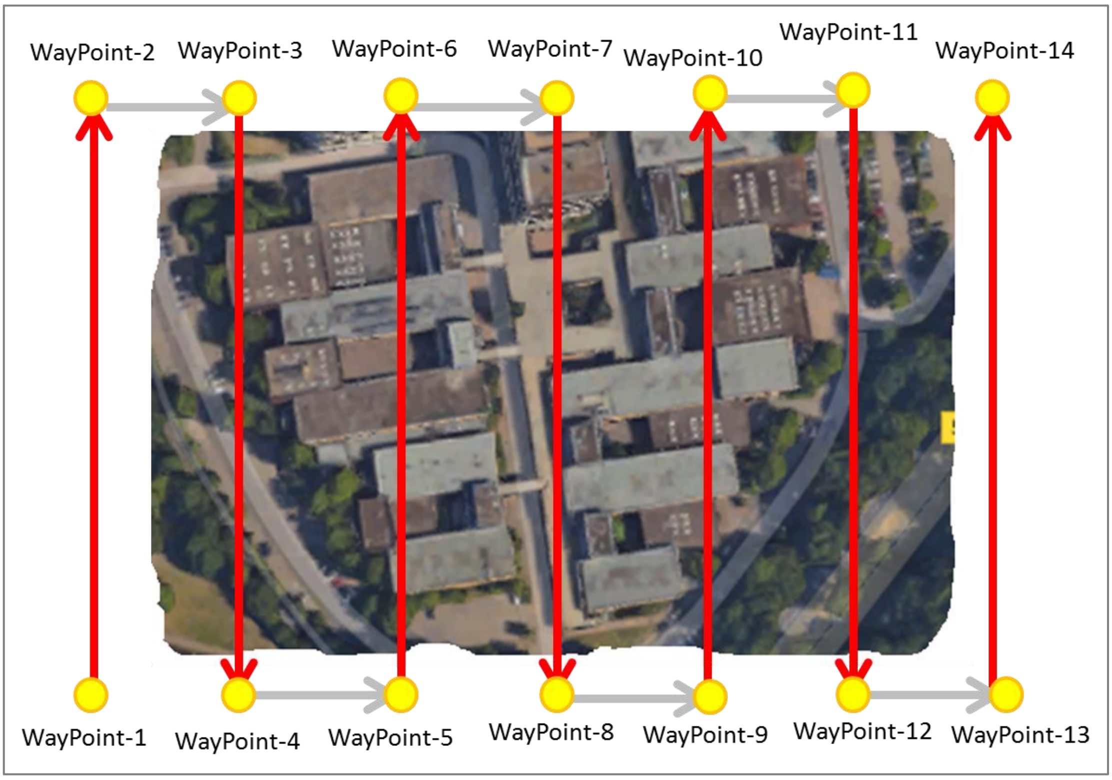


Figure 30: Grid flight plan of aerial survey mission with flight lines and waypoints

The ground footprint of an image (image ground coverage) captured by a camera lying orthogonal (±0˚ from nadir) to the ground and facing the ground, can be calculated by applying Pythagoras theorem (Pennsylvania State University, 2017):

$$\text{Width of footprint covered, Wg} = \left(\frac{A}{\text{Focal Len}}\right) \times Wc$$

$$\text{Height of footprint covered, Hg} = \left(\frac{A}{\text{Focal Len}}\right) \times Hc$$

Where, A = AGL= Altitude of camera or drone
Hc = Height of camera sensor
Wc= Width of camera sensor

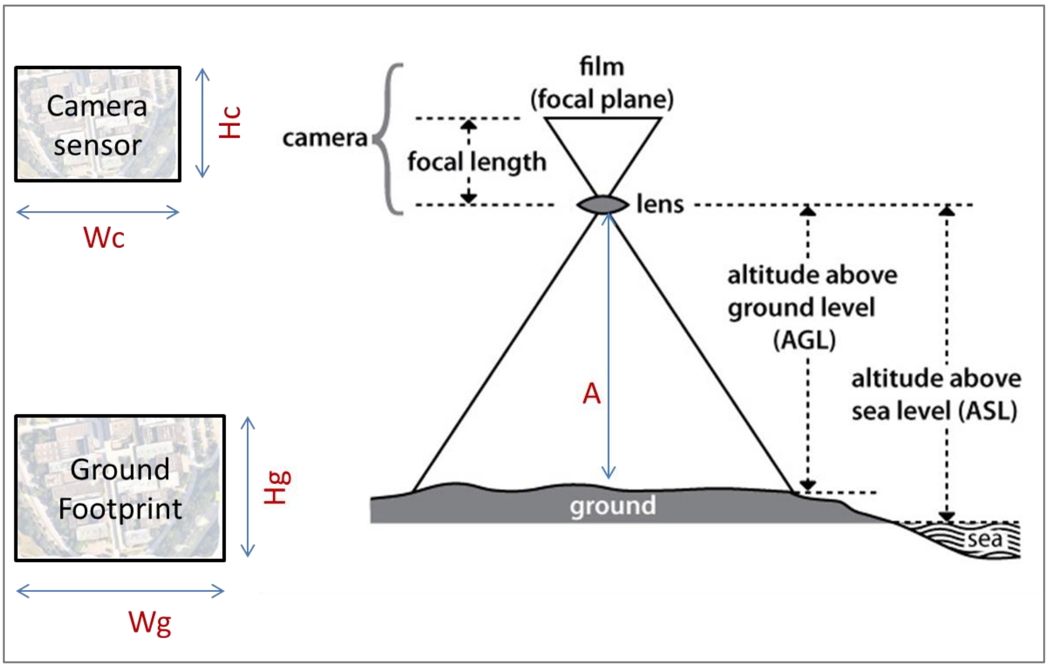


Figure 31: Ground footprint on camera sensor hovering at an altitude 'A' above ground level

Side-lap or Side overlap (as shown in Figure 32) is a term used in Photogrammetry to describe the amount of overlap that exists between the photographs captured from adjacent flight lines (Pennsylvania State University, 2017). The Figure 32 illustrates a drone taking two overlapping images. The distance in the air between the two adjacent flight lines (S) is called lines spacing. The side overlap is required to make sure that there are no gaps in the flight coverage during the aerial survey. It is measured as a percentage of total image coverage.

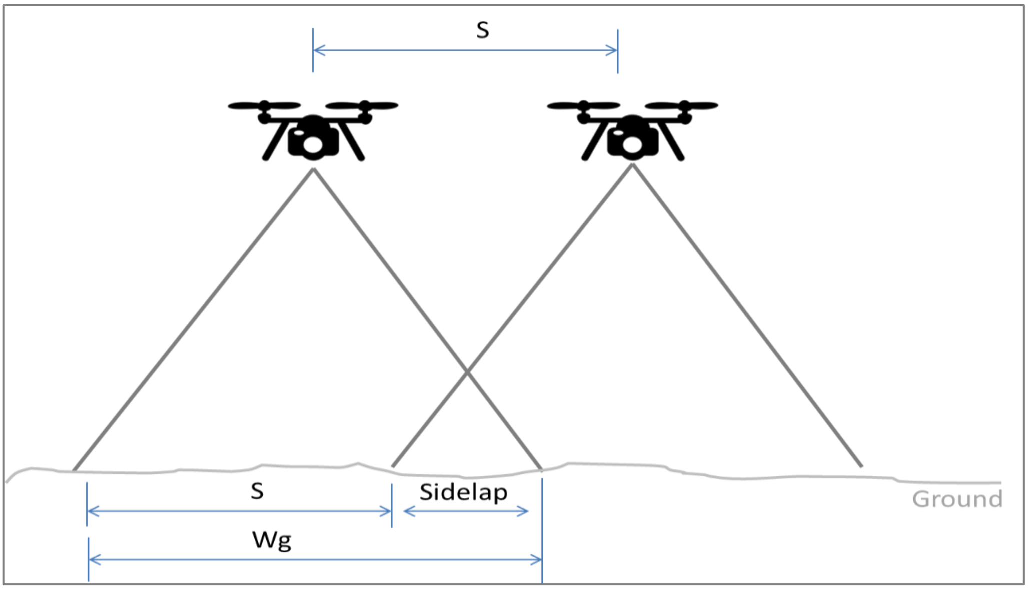


Figure 32: Area captured by a drone from adjacent flight lines with overlap

The grid flight plan generation algorithm was designed based on the three concepts mentioned above. The algorithm is represented in the form on flowchart given below.

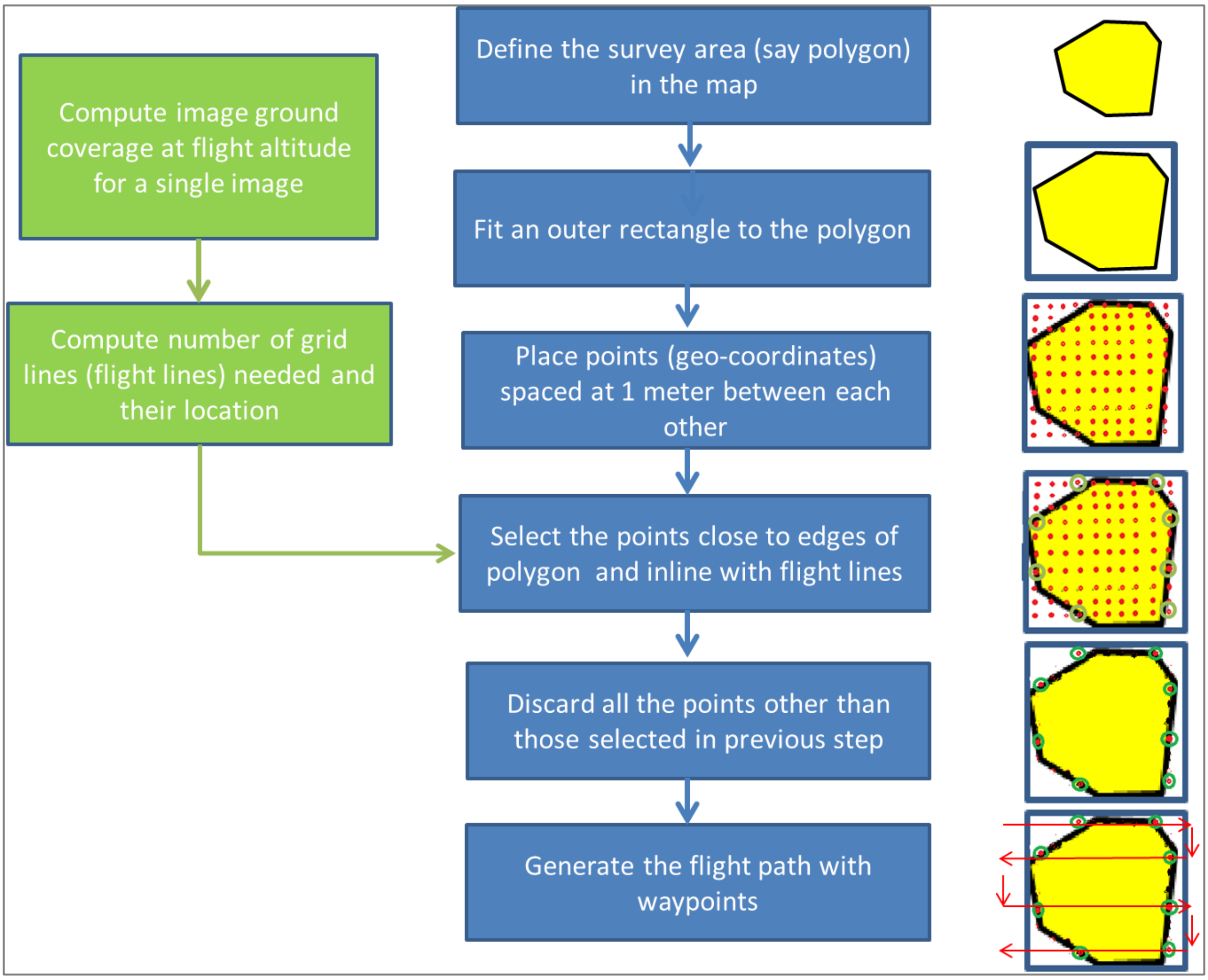


Figure 33: grid flight plan generation algorithm flowchart (left) and pictographic representation of the steps (right)

5.2.4.2 *Camera Trigger Algorithm*

"Forward lap" or sometimes referred as "in-track overlap" is a term in Photogrammetry to describe the amount of image overlap introduced (intentionally) between successive photographs along the flight line. Figure 34 illustrates a drone equipped with an aerial camera taking two overlapping photographs. The centers of the two photos are separated in the air with a distance "P".

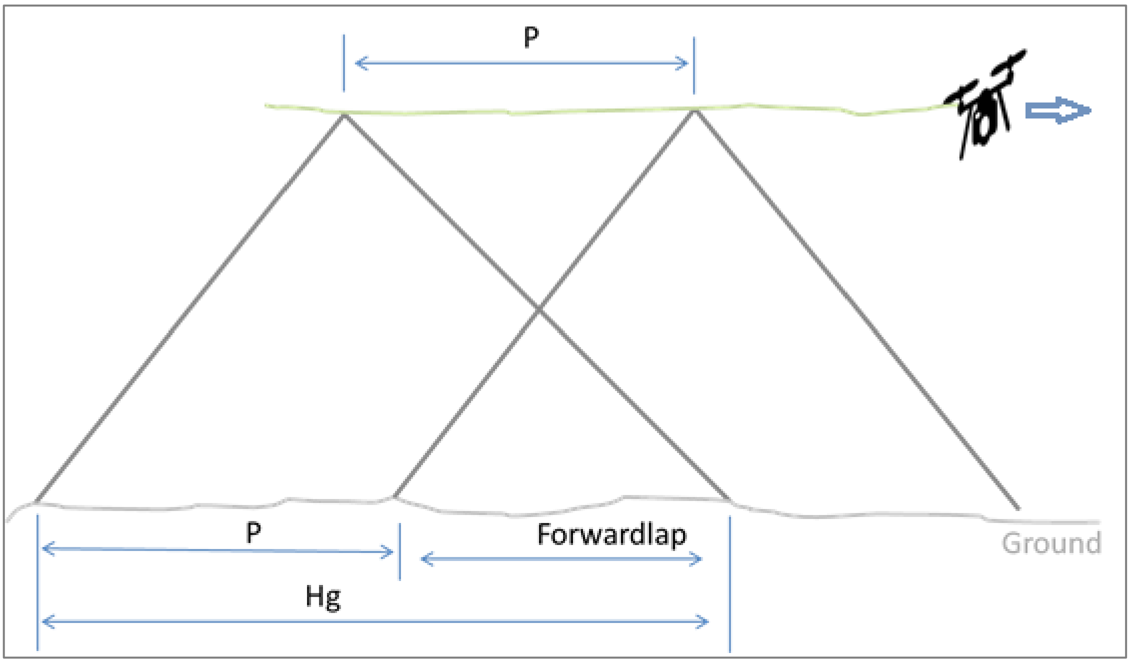


Figure 34: Area captured between the adjacent photographs with forward overlap

Depending on flight altitude, desired forward overlap, and speed of the flight, the Smart Sense Fly app computes the aerial distance required between the successive photographs (i.e. Air base, "P") and sends a command to the drone to shoot a photograph. In other words, the app instructs the drone to take a picture every time it moves the distance "P".

$$\text{Air base, } P = H_g - \left(H_g \times (\%\text{ Forward lap}) \right)$$

Where Hg is the height of footprint covered or image ground coverage height.

Using the equation above, the time interval between photographs can be calculated as,

$$t = \frac{P}{\text{Flight Speed}}$$

5.2.5 Potential Applications

- UAV-based landslide investigation.
- Ortho-mosaic and DTM processing of UAV-based images.
- Soil salinity stress detection, pest detection, weed detection and yield prediction.
- Maintenance and operation of solar power plants.
- Land surveying and classification.
- Flood propagation mapping, hydrological monitoring of sinkholes and other unconventional targets.

6 Case Studies

The developed solutions that are mentioned in the previous chapter (Chapter 5) were demonstrated using selected case studies, and their respective results are presented in this chapter.

6.1 Case study 1: Environmental Monitoring Station at ITT’s Kalk building

As a proof-of-concept (POC) an environmental monitoring station using ITT Smart Sense Box has been installed at ITT’s Kalk building. The monitoring station with temperature and soil moisture sensors has been deployed in the building. The Smart Sense Box has collected approximately 400 measurements in the span of 100 days. The device has withstood snow and rainfall. The battery charge was maintained, thanks to the solar panel. The performance of the device was as expected and did not run into any issues or malfunction.

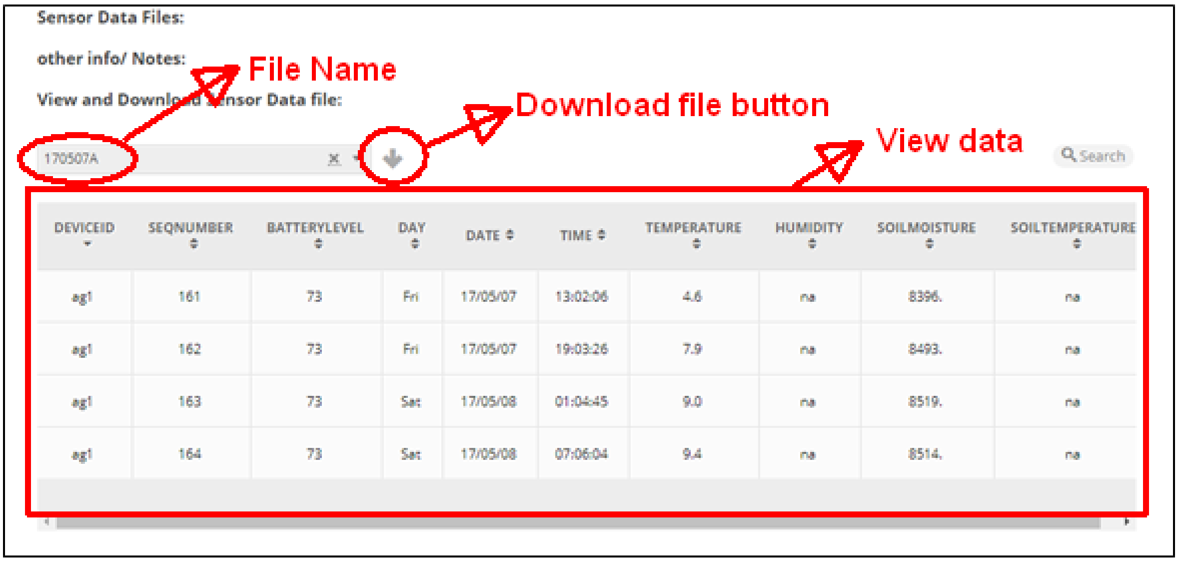
Figure 35: ITT Smart Sense Box installed at ITT's Kalk office

6.1.1 The Process of Deployment

From the inception to final installation of device on the field is done by following the instructions provided in "ITT Smart Sense Box deployment manual" document.

6.1.2 Accessing collected sensor data

The device has uploaded the measured sensor data daily, once in a day, to the web server. The data files can be accessed via ITT Smart Sense web portal. The sensor data is collected in the form .CSV files. These files can either be viewed online or downloaded by accessing the device webpage.



DEVICEID	SEQNUMBER	BATTERYLEVEL	DAY	DATE	TIME	TEMPERATURE	HUMIDITY	SOILMOISTURE	SOILTEMPERATURE
ag1	161	73	Fri	17/05/07	13:02:06	4.6	na	8396.	na
ag1	162	73	Fri	17/05/07	19:03:26	7.9	na	8493.	na
ag1	163	73	Sat	17/05/08	01:04:45	9.0	na	8519.	na
ag1	164	73	Sat	17/05/08	07:06:04	9.4	na	8514.	na

Figure 36: ITT Smart Sense web portal - device information page of installed device

The measured sensor data by the device during a day of the testing period is presented in Annexure 5.

6.2 Case study 2: Creation of Ortho-mosaic map and Digital Elevation Model of a landscape at Engelskirchen, Germany

An orthomosaic map is a grouping of many overlapping photographs of a defined area which are processed to create a new, larger image (called orthomosaic), a highly detailed, up-to-date map that is in true scale (Newstorymedia, 2017). By applying image processing techniques, the meta-information within an orthomosaic map allows analyzing several features and parameters, like volumetrics, point cloud, NDVI, object count and more.

A digital camera is attached to a drone/UAV (typically), pointed straight down (referred to as nadir imagery), and a series of overlapping photographs are captured along the flight path. Then these photographs are processed, stitched together, geometrically corrected (Orthorectification) using photogrammetry tool to create an orthomosaic map. The information of altitude and GPS location of images has to be provided to the photogrammetry tool during the stitching and orthorectification process.

6.2.1 Objective

The main objective of this case study is to create an orthomosaic map and Digital Elevation Model (DEM) of the selected study region by making use of some ITT Smart Sense tools.

6.2.2 Case study Region

The study region is located in the outskirts of Lindlar, Germany. The geographic information is given below.

- **Geo-coordinates:** 51° 1′ 0″ N, 7° 24′ 0″ E
- **Area:** 8.4 acres
- **Proximity:** 1.2 km E of Lindlar and 3.7 km N of Engelskirchen
- **UTM:** 32U 387772 5652897

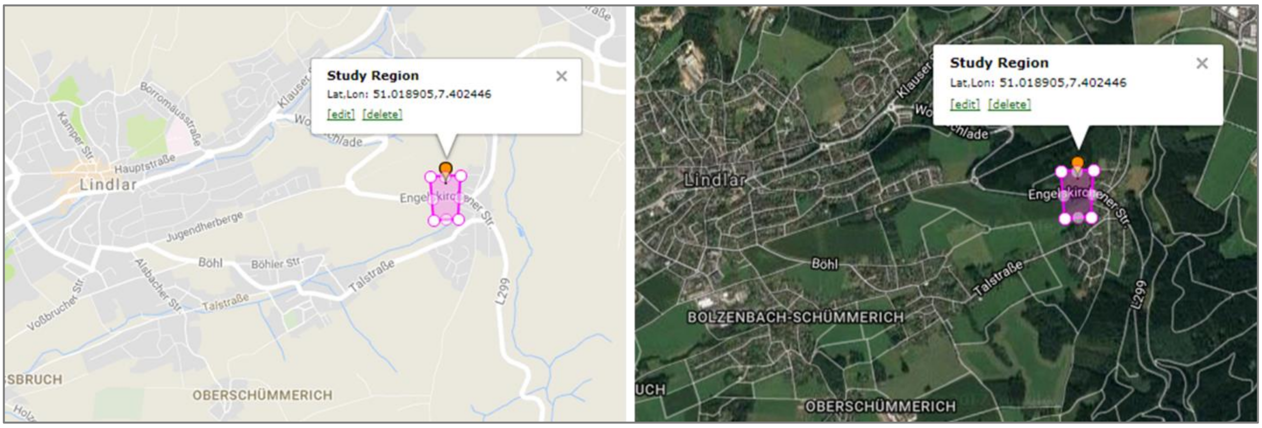


Figure 37: Study Region; Left - google map view, Right - satellite view

6.2.3 Implementation

6.2.3.1 Workflow

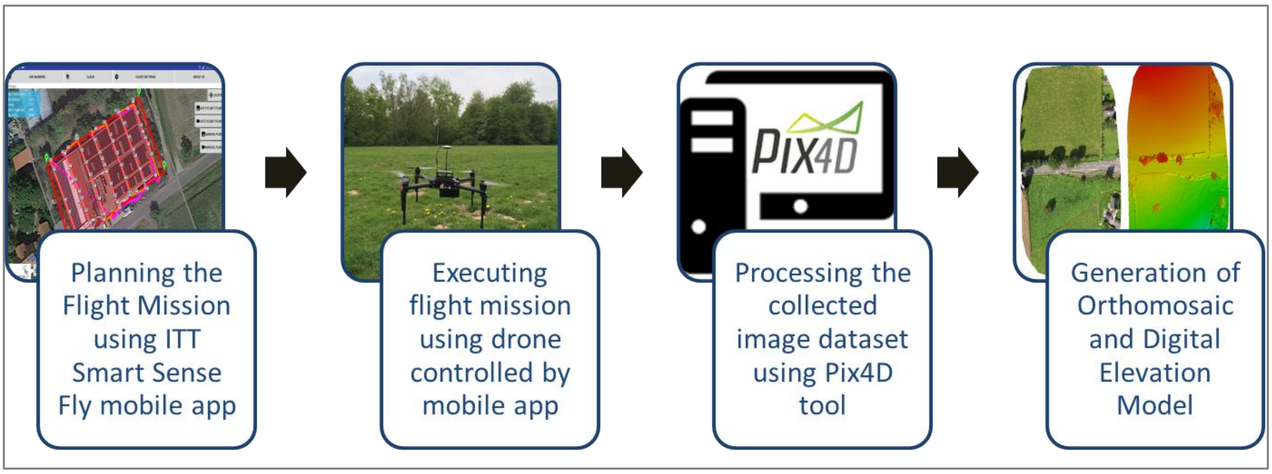


Figure 38: Case study implementation workflow

6.2.3.2 Planning the aerial survey mission

As explained in previous sections, ITT Smart Sense Fly mobile app can be used for planning an aerial survey. The same has been used for this case study. The camera settings were adjusted in the app according to chosen gimbal camera of drone, i.e. DJI Zenmuse X3. The altitude of the flight was adjusted according to desired ground sampling distance.

The Ground Sampling Distance (GSD) is the distance between the centers of two neighbouring pixel in the image on the ground (Aerial survey base, 2017). For example, a GSD of 10cm means that one pixel in the image represents linearly 10cm on the ground and area covered by a pixel is 100cm^2 (10*10). It is typically expressed as cm/pixel. The smaller the GSD, the higher the spatial resolution of the image, and the better the visible details. The GSD varies with flight altitude, focal length of camera and camera sensor. For a fixed focal length and a camera, the GSD increases with flight altitude. After trying several altitude inputs, the flight altitude of 40 meters has given the desired GSD of 2cm/pixel.

As discussed in previous sections, the overlap between images is required to make sure that there are no gaps in the flight coverage during the aerial survey. The recommended minimum overlap in general cases should be at least 60% side overlap and 75% forward overlap. In case of forests, dense vegetation and fields, 70% side overlap and 85% forward overlap (Pix4D, 2017). The selected study region has a general landscape with buildings, roads and trees, and so the overlap of 60% side overlap and 75% forward were chosen.

The settings of flight plan configuration are given in Table 3. The flight plan configuration window of ITT Smart Sense Fly is shown in Figure 39. Flight route generated in Photo Auto Flight Plan mode is shown in Figure 40.

Table 3: Flight settings configuration used for aerial survey

Setting Field	Value
Sensor Width	6.17 mm
Focal Length	3.56 mm
Image Resolution	4000 x 3000
Forward Overlap	75%
Side Overlap	60%
Flight Altitude	40 meters
Maximum Flight Speed	5 m/s

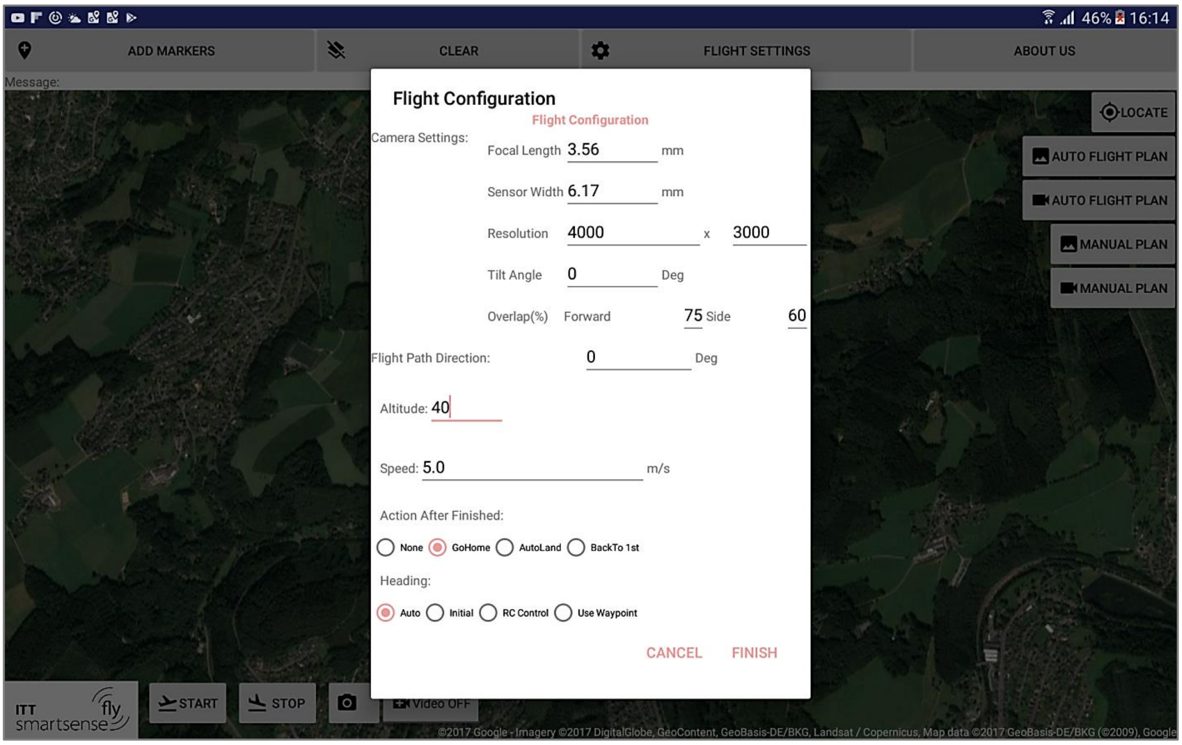


Figure 39: ITT Smart Sense Fly Flight Settings window

Figure 40: Flight route generated in "Auto Flight Plan" mode

6.2.3.3 *Executing the flight mission*

Weather conditions can considerably affect the performance of flight of the drone. Clear sky, sunny weather, light wind (<10 km/hr wind speed), and moderate temperature (25°c – 35°c)are ideal weather condition for flying the drone. Flying the drone under cloudy conditions, with no sufficient light, may lead to underexposed images and appear dark.

The aerial survey flight mission at study region was carried out in following weather conditions.

- **Time of the day:** 3pm
- **Wind speed:** 6 km/hour
- **Sky:** clear sky with no clouds
- **Temperature:** 30°c

Figure 41: Execution of flight mission using DJI Matrice 100 drone at the study location

The execution of flight mission was started by tapping “Start” button in the ITT Smart Sense Fly app. The DJI Matrice 100 drone had flown for about 12 minutes and captured 120 pictures. The captured pictures are presented in Annexure 1. The app has traced the actual flight route taken by drone during the flight as pink dots as shown in the Figure 42.

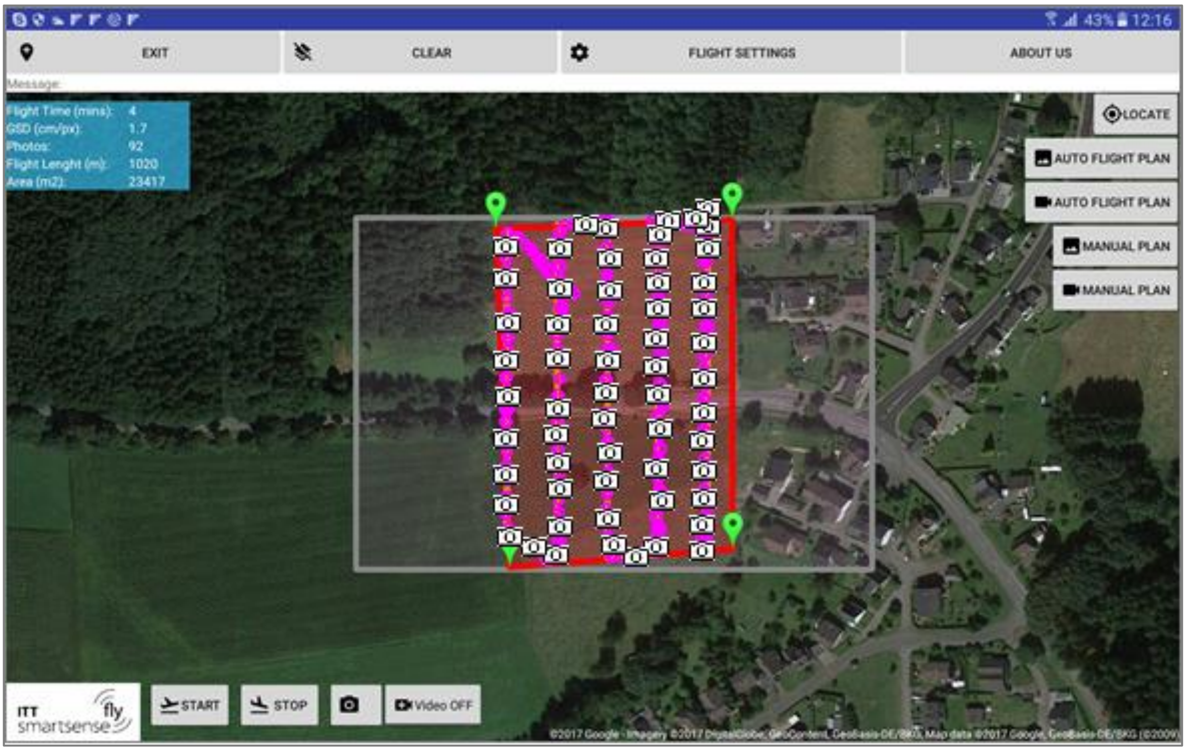


Figure 42: The trace of actual flight route taken by drone on the site

6.2.3.4 Processing collected imagery data

The collected image dataset from aerial flight mission has to be processed in order to create an orthomosaic map. The images are stitched together, orthorectified using photogrammetric image processing tool. The photo stitching is a method that glues images together and requires low number of key-points (usually less than 100). Key points are nothing but the common points between the images. Photo stitching alone (without need for orthorectification) works well only perfectly flat terrain surfaces and small datasets. However, for non-flat terrain surfaces and larger datasets, it can lead to artifacts where objects visible in several pictures do not align each other well (as shown in Figure 43). For considerably larger datasets, these kinds of errors accumulate over the whole dataset and leads to inaccurate measurements.

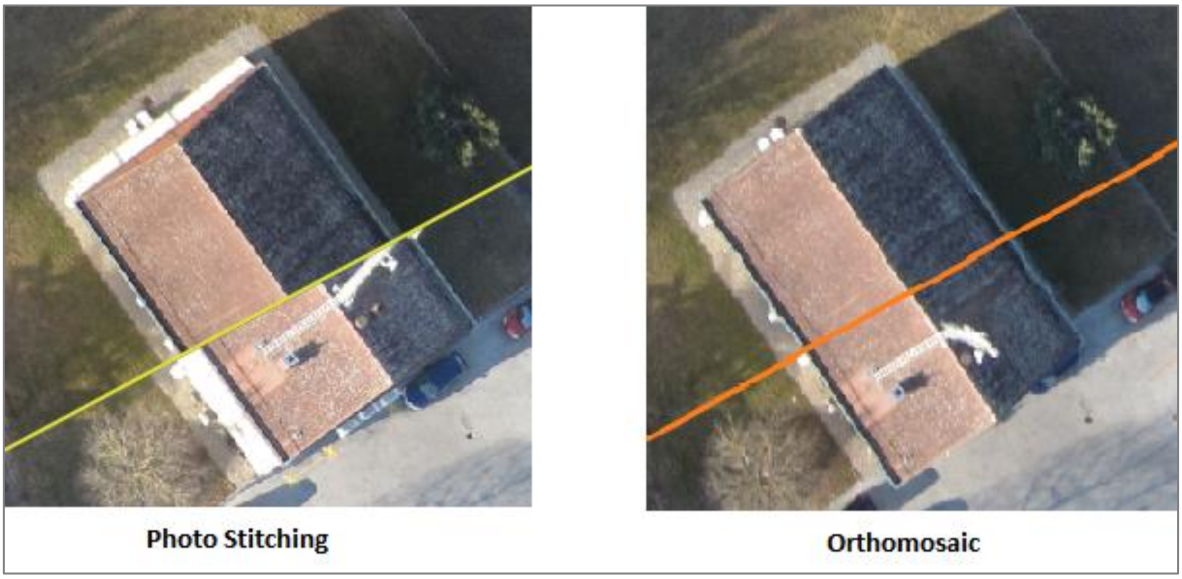


Figure 43: Photo Stitching vs Orthomosaic. Source: (Pix4D, n.d.)

Orthomosaics are generated based on orthorectification method, which removes the perspective distortions from the images using the DSM (Digital Surface Model). A high number of key-points (usually more than 1000) is required to generate the 3D model (that generates DSM). When key-points on different images are found to be the same, they are matched key-points. These matched key-points are the basis for construction of an orthomosaic. When there is high overlap between images, the common area captured is larger and more key-points can be matched together (Pix4d, 2017). The more the key-points, the more accuracy of computed mosaic. Hence, the high overlapping between the images is recommended in image dataset. Orthorectification handles all types of terrain, large datasets, as well as distances are preserved and therefore can be used for measurements.

After trying numerous photogrammetric image-processing tools for orthomosaic generation, “Pix4Dmapper Pro” software tool has been chosen for processing the image dataset collected at study region. The collected image dataset was imported to Pix4Dmapper Pro to create orthomosaic and digital elevation models of the region.

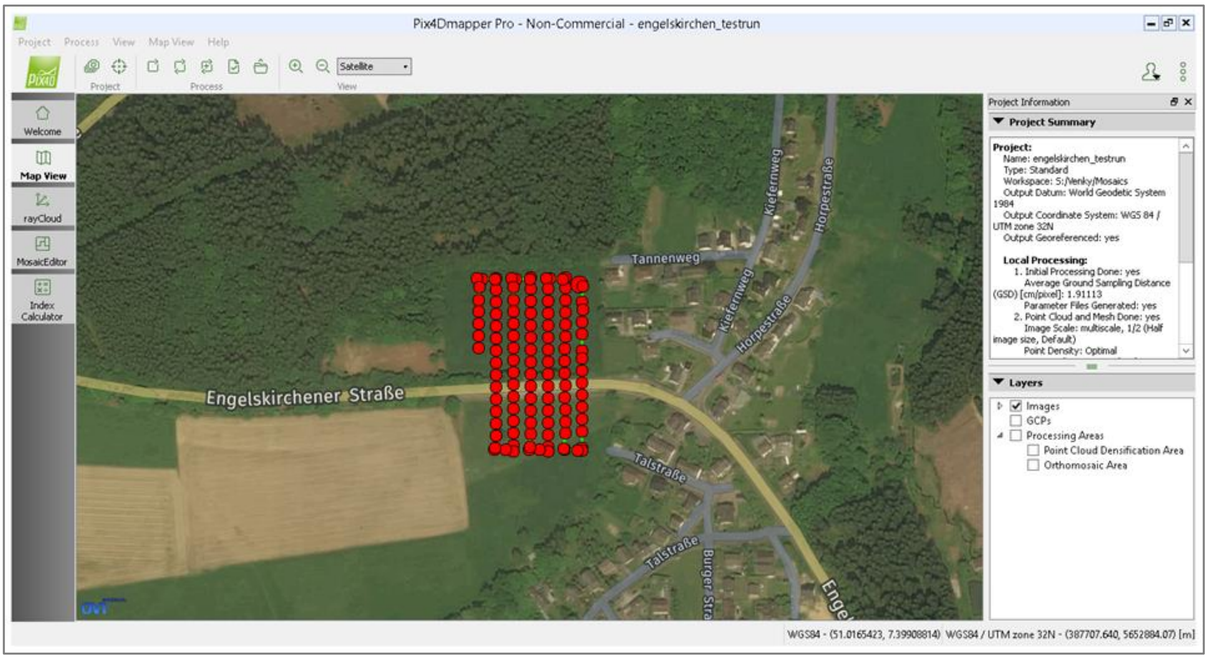


Figure 44: Map View screen of Pix4Dmapper Pro software

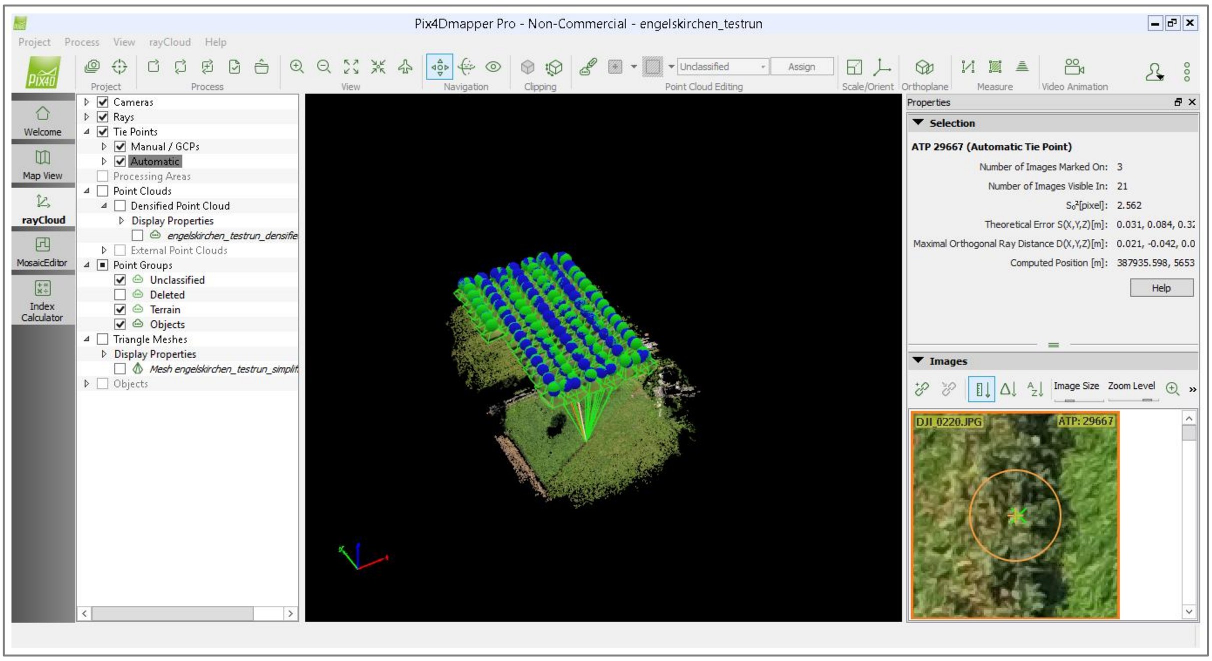


Figure 45: Ray cloud screen of Pix4Dmapper Pro software

The orthomosaic can be exported as “Google Map tails” and KML files. This enables to publish maps online easily. Besides creation of orthomosaics and DEMs, Pix4Dmapper can also generate 3D model, 3D textured mesh and Contour Lines.

6.2.4 Results discussion

The generated orthomosaic of the study region by Pix4Dmapper software is shown in Figure 46.

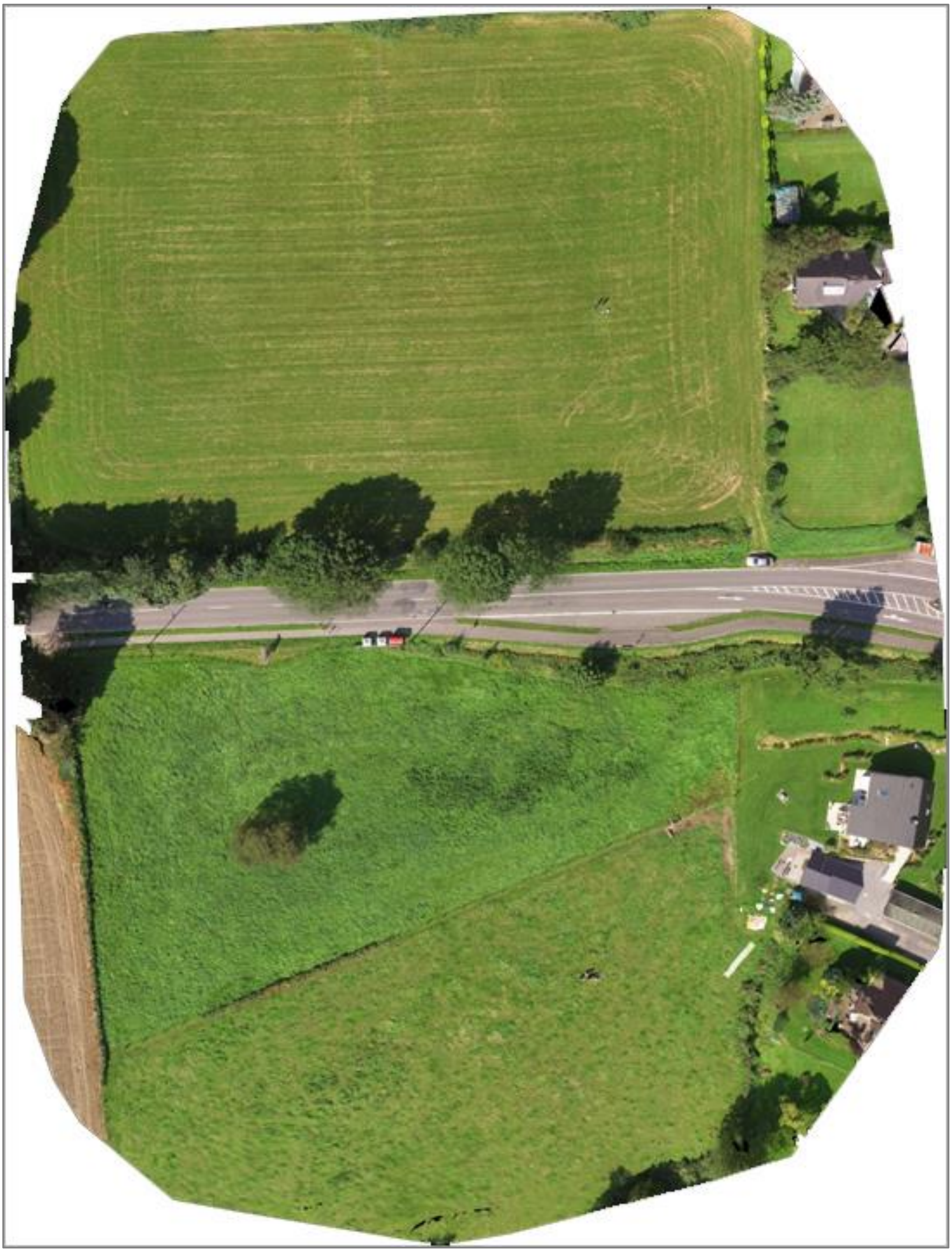


Figure 46: Orthomosaic of the region generated by Pix4D

Digital Elevation Model of the region is shown in Figure 47. The Dark red color represents higher elevation value of about 340 meters above sea level, while Green color represents lower elevation value of about 300 meters.

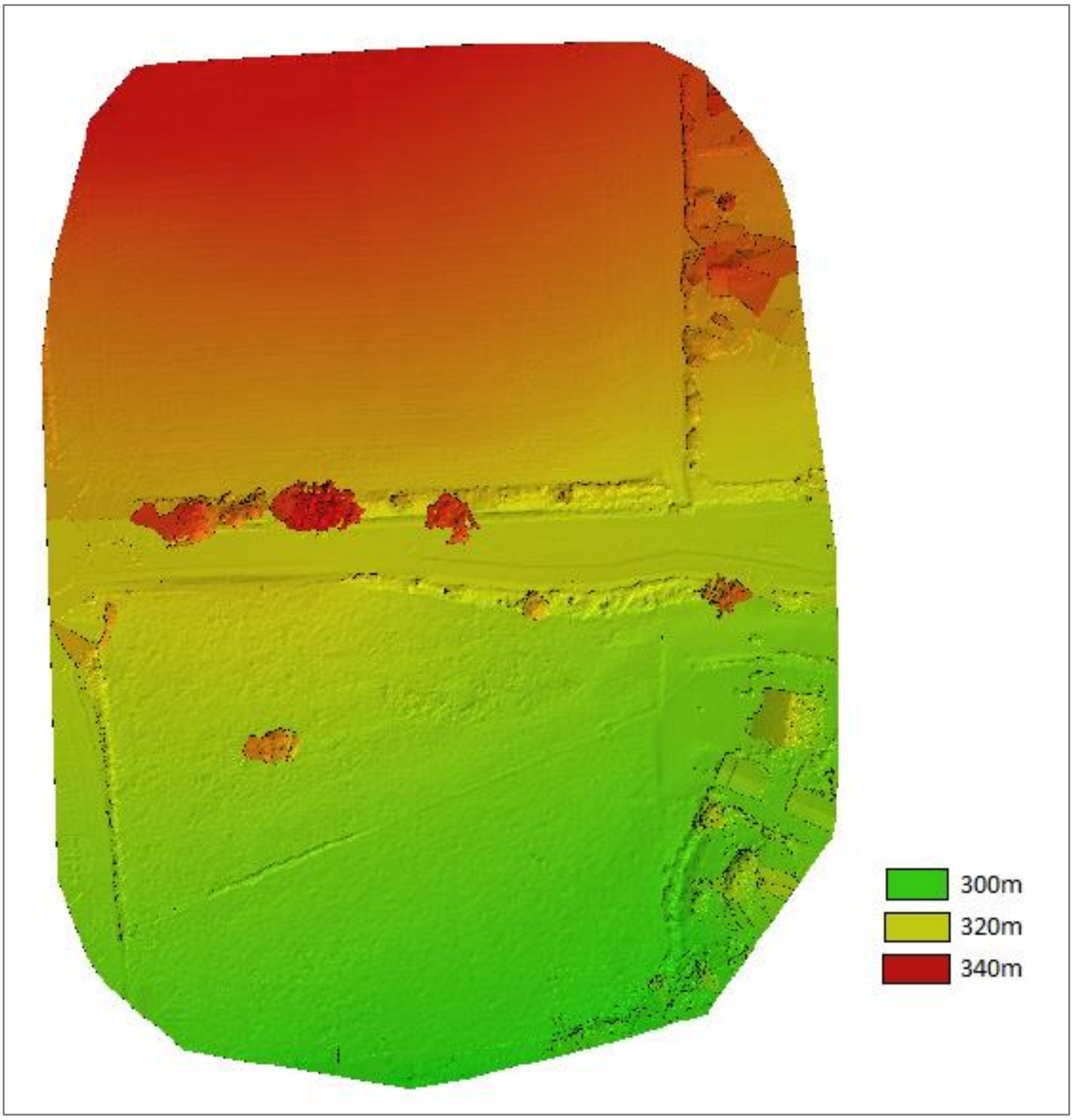


Figure 47: Digital Elevation Model of the region generated by Pix4Dmapper

Digital Terrain Model of the region is shown in Figure 48.

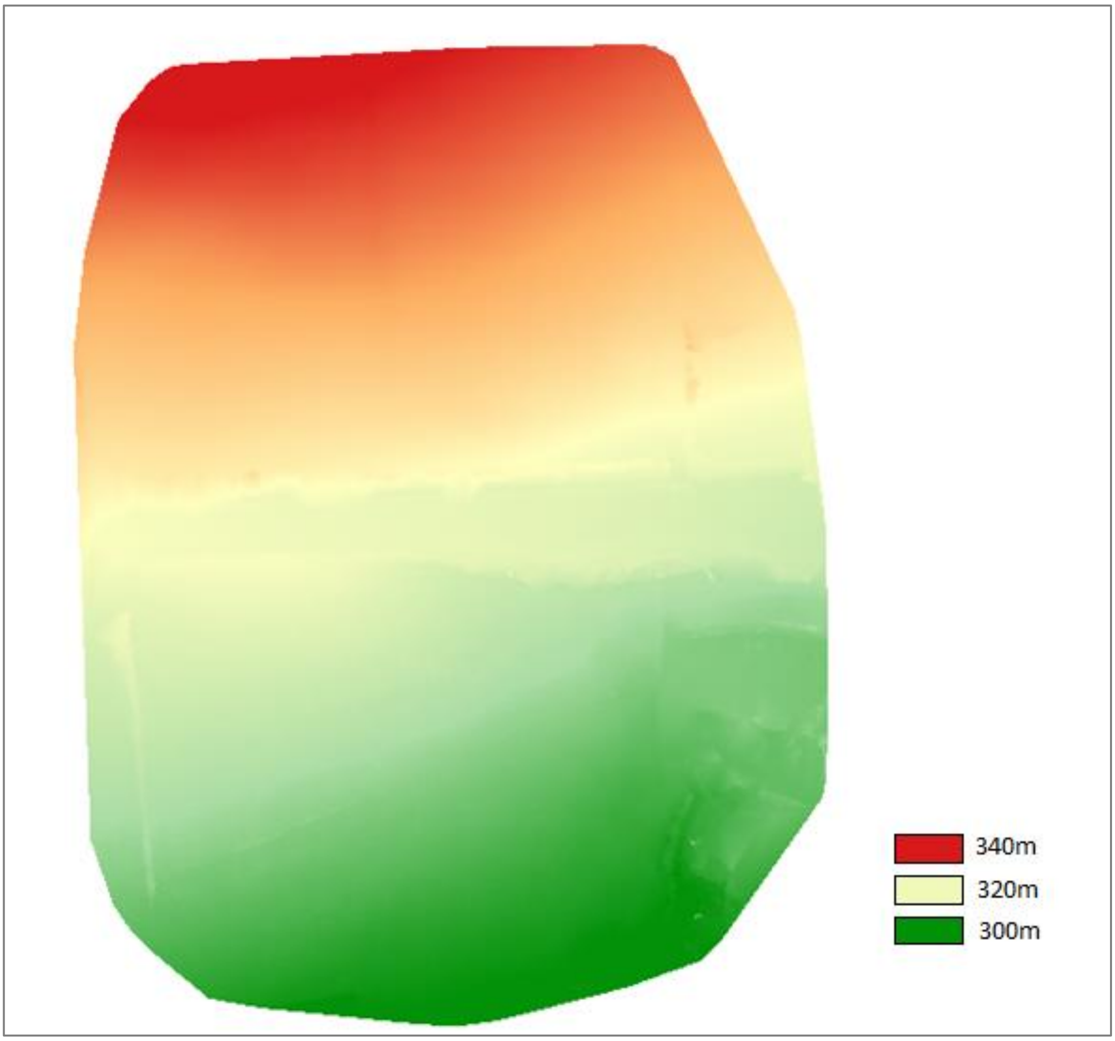


Figure 48: Digital Terrain Model of the study region

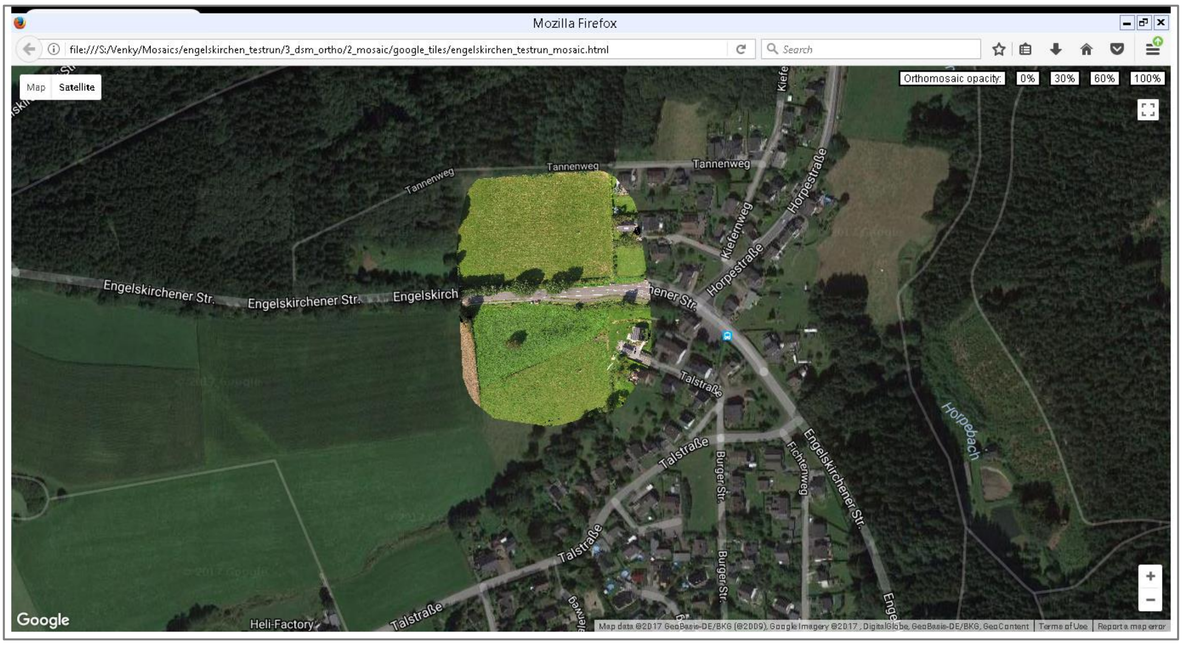


Figure 49: Google Map tail with orthomosaic of the study region.

6.2.5 Recommendations for generation of good orthomosaic maps

While drones are proving to be extremely useful tools for data, there are many restrictions that can adversely affect the quality of collected data. The recommendations for generating good orthomosaic maps are given below.

6.2.5.1 Weather Conditions

Weather conditions during the flight survey considerably affect the quality of captured photographs and their resultant orthomosaics. Higher wind speeds make it more difficult for the aircraft to hold its positioning and maneuver, which will result in shorter flight time and unequally spaced, irregular images. If the aircraft is heading in same direction as high speed wind, then the aircraft gains more speed than required, resulting in blurry images. So it is better to fly the drone with moderate speeds, that is, in between 4-6 m/s. Thick and dense cloud cover at the location during the flight may result in underexposed and darker images. So, it is recommended to conduct surveys during clear sky or in less cloud cover conditions. Also, the light conditions should not vary drastically during the flight. It is worth to mention that 9 am to 12 pm and 1pm to 4pm are the recommended times of the day for conducting the aerial survey.

6.2.5.2 Camera Settings

Improper camera settings may result in blurry, noisy, underexposed or over exposed images.

		
Blur due to slow shutter speed.	Noise due to high ISO sensitivity.	Overexposed or underexposed (wrong aperture and/or shutter speed).

Figure 50: Problems that may arrive due to wrong camera settings. Source: (Pix4D, n.d.)

The shutter speed, ISO and Aperture are the important parameters to consider while adjusting the camera settings. The shutter speed should be fixed and set to a medium speed (between 300 and 800), but fast enough to not produce blurry images. If the images are still blurry, either increase the shutter speed or reduce the speed of the flight. The ISO parameter should be set as low as possible (minimum 100). High ISO setting generally introduce noise into images and drastically reduce the quality of the images. The aperture should be set to automatic mode. Additionally, it is recommended to set focus mode to either Manual focus or Infinity (depending on camera model).

Table 4: Recommended camera settings for good and sharper images

Camera Parameter	Recommended Settings
Shutter speed	300 - 800
ISO	100, 200
Aperture	Automatic
Focus Mode	Manual

6.2.5.3 Large projects combining multiple flights

Usually, covering and mapping a large field (hundreds of acres) requires more than a single flight survey. For projects with multiple flight surveys, there should be sufficient overlap (at least 25%) between the flight plans and the conditions (weather conditions, sun direction, etc.) should be similar.

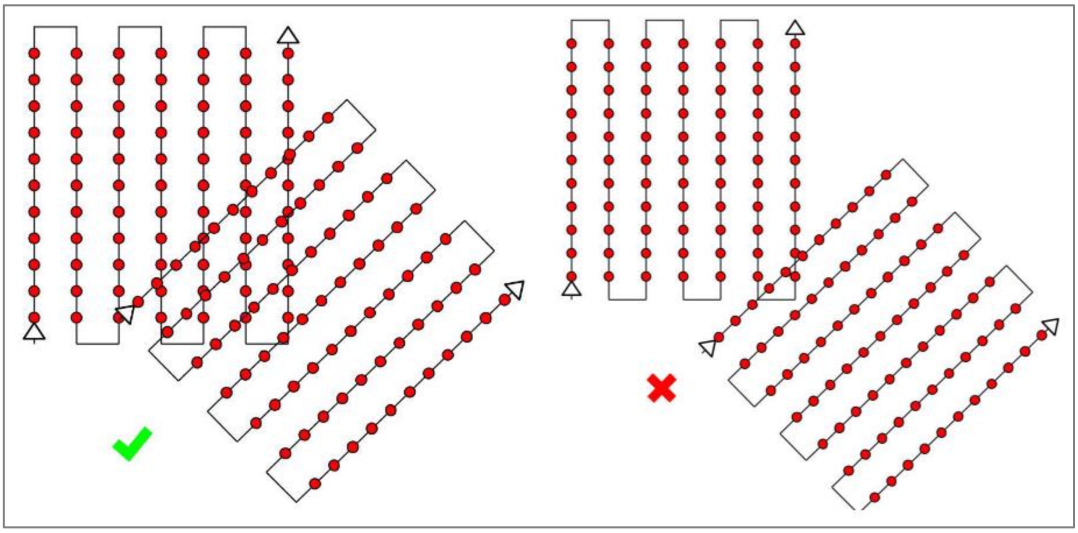


Figure 51: Picture indicating recommended overlap between two flight plans covering a large field. Source: (Pix4D, n.d.)

6.2.5.4 Other Recommendations

- It is recommended to choose more area than required while planning the flight survey on the app as the edges of the field/region suffers due to insufficient overlap.
- For projects with flight altitude above 50 meters, the camera lens between 22 mm and 80 mm focal length (in 35 mm equivalent) is recommended to ensure good GSD that will lead to higher accuracy results (Pix4D, n.d.).
- All the projects with flight altitudes below 20 meters during the test runs had generated poor quality ortho-maps. Hence, it is recommended not to choose flight altitudes below 20 meters.
- Using cameras with fixed focal length lens will usually result in sharper images with reduced noise.

6.3 Case study 3: Solar photovoltaic farm monitoring system using drone

PV power plants or solar farms require a regimen of continual monitoring, periodic inspection, scheduled preventive maintenance, and service calls (Soleenic, 2016). Improper maintenance may lead to unplanned outages, performance degradation of the entire plant. Sand storms, dust accumulation, bird droppings, and other deposits on solar panels lead to partial penetration of sunlight into solar cells, resulting in reduction of electricity generation and in some cases, local hotspots. Events like bad weather conditions, lightings, thunderstorms, and rapid temperature changes may result in panel cracking or panel breakage. In medium to large scale solar parks, with thousands of solar panels installed, it is often cumbersome and expensive to inspect the panels manually.

Drones/UAVs, with their tiny footprint, can provide quick, cost-effective monitoring and inspection activities of the solar farms. The drones, carrying regular RGB and Infrared cameras, can help in collecting the data to accurately spot malfunctions in solar panels. A comprehensive monitoring and inspecting solution can be developed using a set of workflows for identification of solar panels, identification of hotspots, dust accumulation etc. As a first step for developing such solution, a workflow for identifying thousands of solar panels installed in a PV park has been developed and addressed in this case study. In future, this workflow can be used as a reference for development of other workflows like hotspots identification workflow, dust accumulation estimation workflow, panels cracks identification workflow etc.

6.3.1 Objective

The main objective of this case study is to develop a workflow for identification of thousands of solar panels in a solar farm at the selected study region using drones and a set of software tools.

6.3.2 Study Region

The solar photovoltaic farm is located in Rütschenhausen, Germany with total area of three acres. Rütschenhausen is a village in the municipality of Wasserlosen, Schweinfurt district, Bavaria, Germany. The geographic and technical information of the solar farm is given below.

- **Geo-coordinates:** 50.062076° N, 10.060057° E
- **Area:** 3 acres
- **Place:** Rütschenhausen
- **Plant capacity:** 110 kWp
- **Type(s) of solar panels:** Thin film and Polycrystalline
- **Total number of panels installed:** Thin film – 1052 panels, Polycrystalline - 124

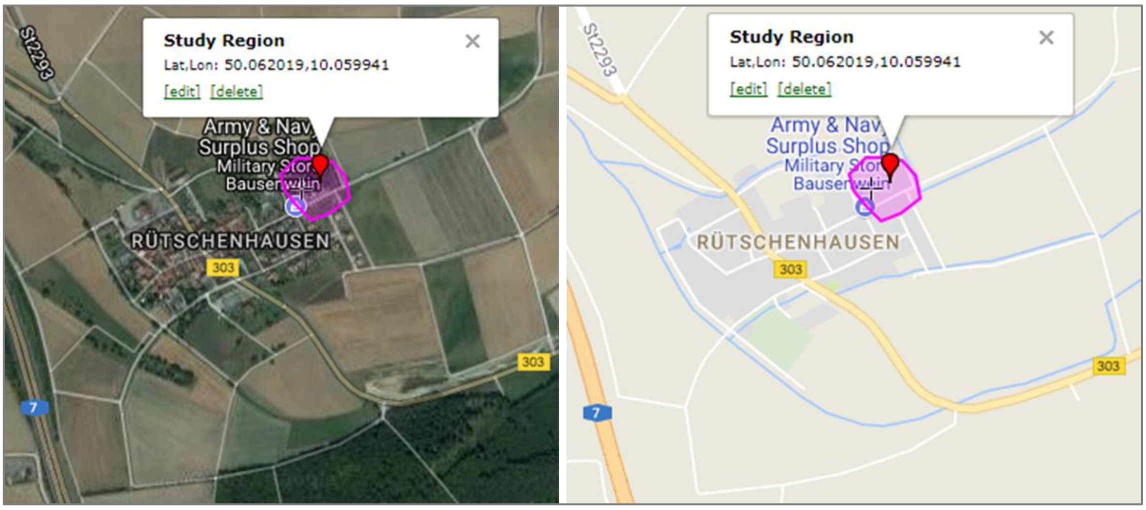


Figure 52: Solar Farm; Left - google map view, Right - satellite view

6.3.3 Implementation

6.3.3.1 Workflow

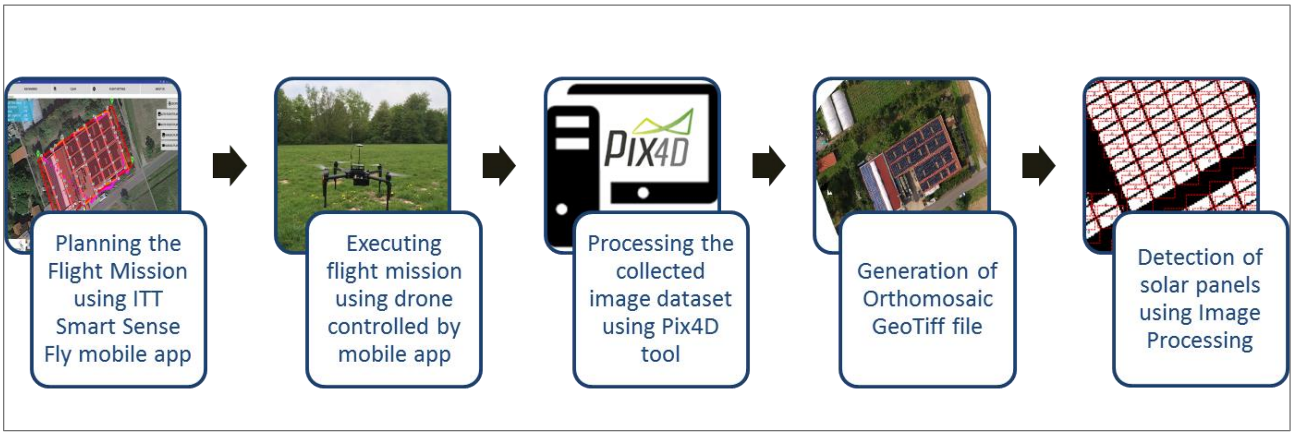


Figure 53: Solar farm monitoring workflow

6.3.3.2 Planning the aerial survey

The same process as of previous case study (6.2) was followed for planning the aerial survey. The boundaries of the solar farm were defined and a ground sampling distance of 1.25 cm/pixel (with flight altitude of 30 meters) was chosen. The flight plan was created in ITT Smart Sense Fly app. The settings of flight plan configuration are given in Table 5.

Table 5: Solar Farm flight mission settings used in ITT Smart Sense Fly app

Setting Field	Value
Sensor Width	6.17 mm
Focal Length	3.56 mm
Image Resolution	4000 x 3000
Forward Overlap	75%
Side Overlap	60%
Flight Altitude	30 meters
Maximum Flight Speed	5 m/s

6.3.3.3 Executing the flight mission

The aerial survey flight mission at study region was carried out in following weather conditions.

- **Time of the day:** 4pm
- **Wind speed:** 10 km/hour
- **Sky:** clear sky with no clouds
- **Temperature:** 32°c

The execution of flight mission was started by tapping "Start" button in the ITT Smart Sense Fly app. The drone had flown for about 8 minutes and has captured 72 photographs. The captured pictures are presented in Annexure 2. The trace of the actual flight route taken by drone during the flight is shown in the Figure 54.

Figure 54: The trace of actual flight route taken by drone on the site

6.3.3.4 Processing the collected image dataset

The collected image dataset from aerial flight mission was processed in Pix4Dmapper Pro tool and created an orthomosaic image of the solar farm. The generated orthomosaic (GeoTiff) is shown in Figure 55.

Figure 55: Orthomosaic of the PV installation at the study region

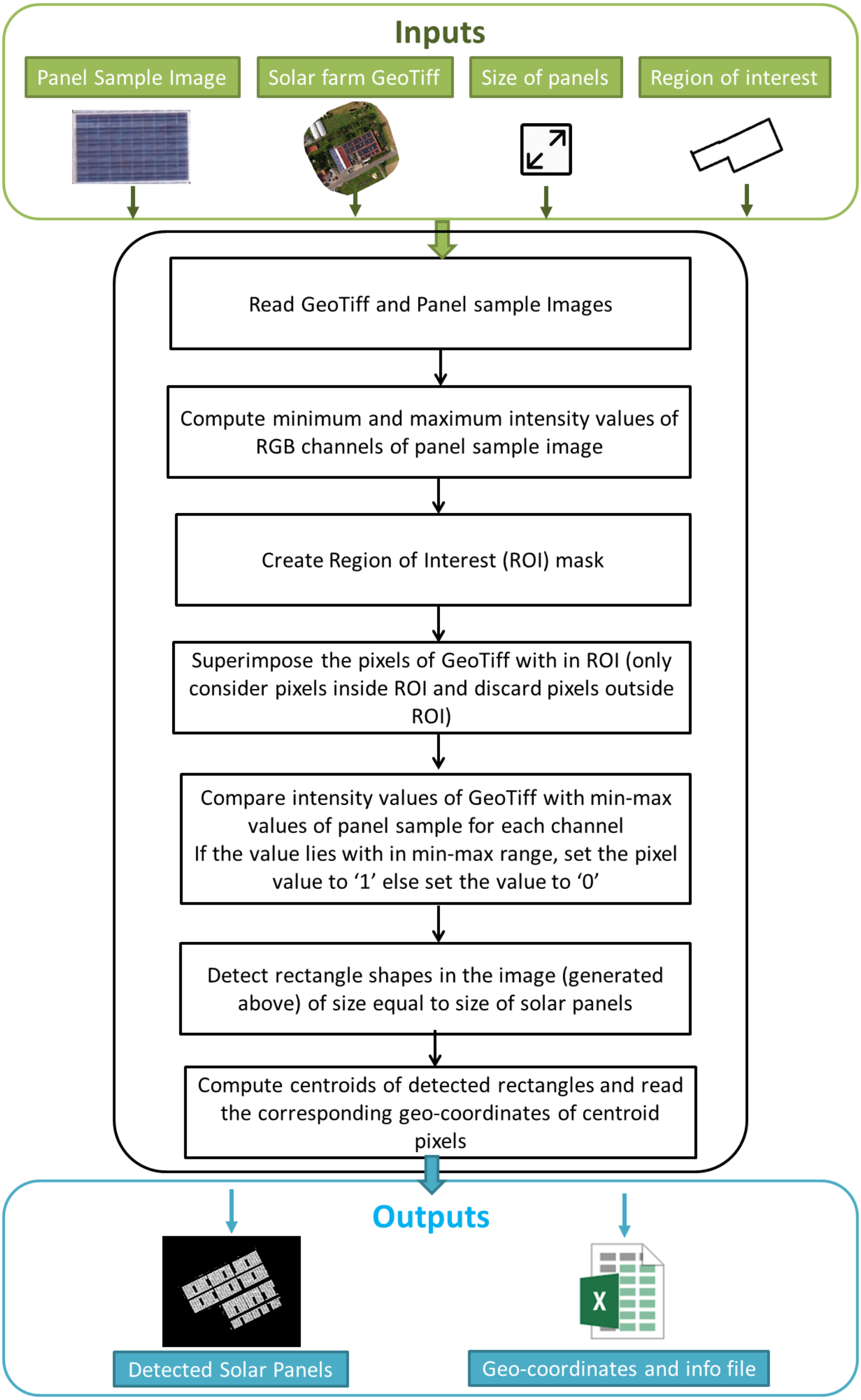
6.3.3.5 Detection of solar panels using image processing

Image processing is a method of conversion of an image into digital form and perform certain operations on it, in order to get an enhanced image or to extract useful information from it (Engineers garage, 2017). Image processing is particularly helpful to visualize the objects that are not visible to naked eye, identify patterns, distinguish objects, and even measure various physical parameters like length, volume, area, height etc. of objects present in an image.

In image processing, the images are processed using mathematical operations and signal processing techniques. Most of the image-processing techniques involve isolating the individual color channels (for example, RGB) of an image and treating them as two-dimensional signal and then applying standard signal-processing techniques and mathematical operations to them. The solar panels in a typical solar power plant have fixed shape and size. These features make the job of identification easier and with less computational power.

Solar Panel detection algorithm:

An efficient image processing algorithm was developed for detecting solar panels in the solar farm's orthomosaic (aka GeoTiff) that has been generated in previous step (Processing the collected image dataset). The algorithm was developed in MATLAB. The MATLAB implementation script of the algorithm is presented in Annexure 3. This script can be adapted to any other programming languages like Python, C++, or C# with appropriate image processing libraries to create a standalone tool. The flowchart of the designed algorithm is given below.



Inputs
Panel Sample Image
Solar farm GeoTiff
Size of panels
Region of interest
Read GeoTiff and Panel sample Images
Compute minimum and maximum intensity values of RGB channels of panel sample image
Create Region of Interest (ROI) mask
Superimpose the pixels of GeoTiff with in ROI (only consider pixels inside ROI and discard pixels outside ROI)
Compare intensity values of GeoTiff with min-max values of panel sample for each channel
If the value lies with in min-max range, set the pixel value to '1' else set the value to '0'
Detect rectangle shapes in the image (generated above) of size equal to size of solar panels
Compute centroids of detected rectangles and read the corresponding geo-coordinates of centroid pixels
Outputs
Detected Solar Panels
Geo-coordinates and info file

The solar farm GeoTiff mosaic, the sample image of solar panel contained in GeoTiff mosaic, typical size of the panels in the farm, and a particular region of interest in the GeoTiff (typically the pixel coordinates of the region where solar panels are concentrated) must be supplied as inputs to the algorithm. After processing the inputs, the algorithm outputs an image file highlighting all the detected solar panels and a CSV file consisting of geolocation data (latitude and longitude) of all detected panels.

6.3.4 Results discussion

The algorithm was implemented in MATLAB tool. After executing the written script and providing necessary inputs, the algorithm has detected the solar panels in study region with overall accuracy of 99.6%.

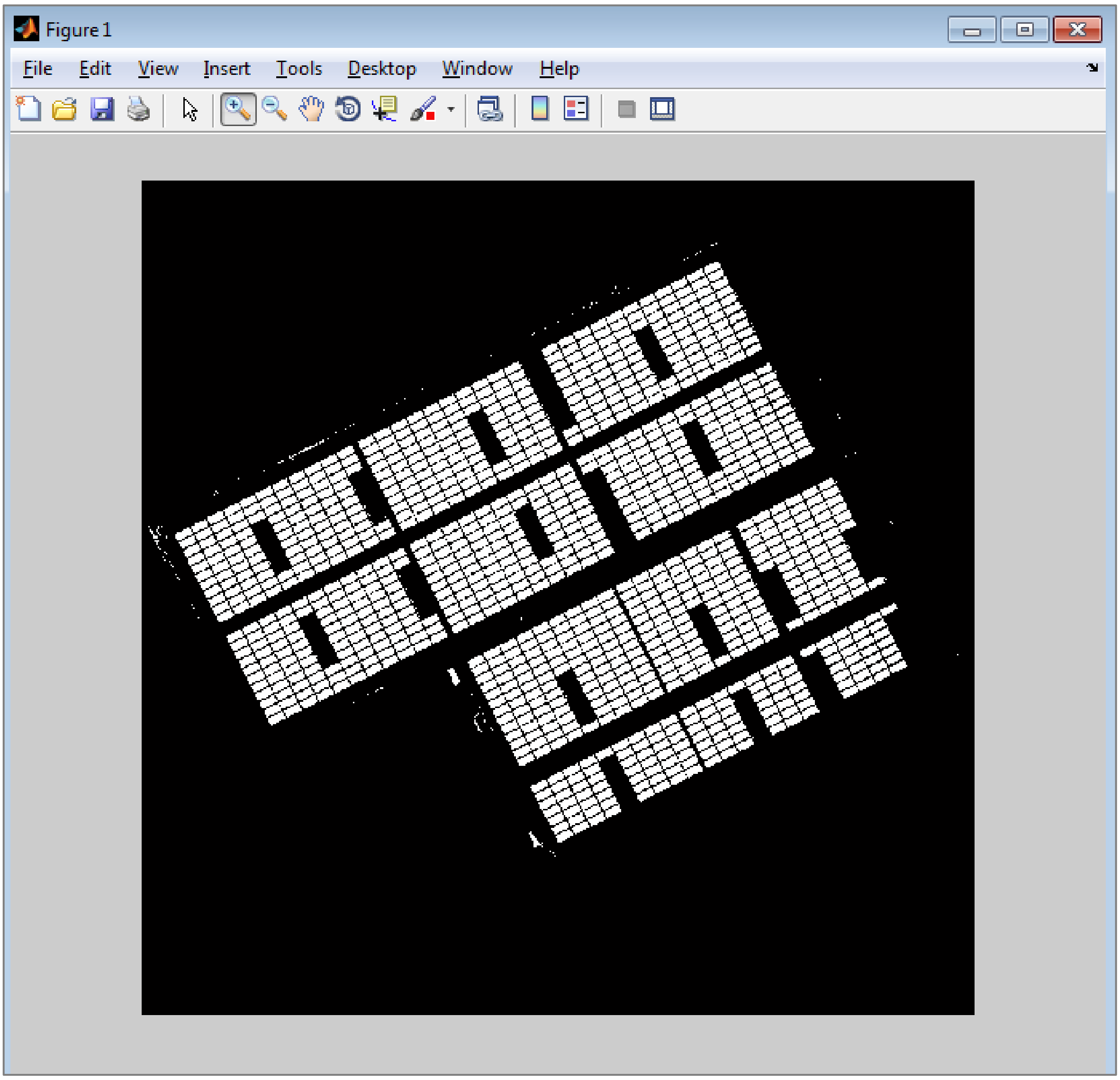


Figure 56: Output of algorithm in MATLAB for Thin film solar panels (The panels are highlighted in white)

The selected solar farm has two types of solar panels, thin film and polycrystalline. So, the algorithm was executed twice (one time for the detection of thin film solar panels and the second time for detection of polycrystalline solar panels). When thin film solar panel was provided as reference sample image, the algorithm has highlighted the pixels (that matched with reference image) of solar panels in white, as shown in Figure 56 . It has managed to detect all the thin film solar panels (1052 panels in total) correctly. However, it has falsely detected an object as solar panel (false positive).

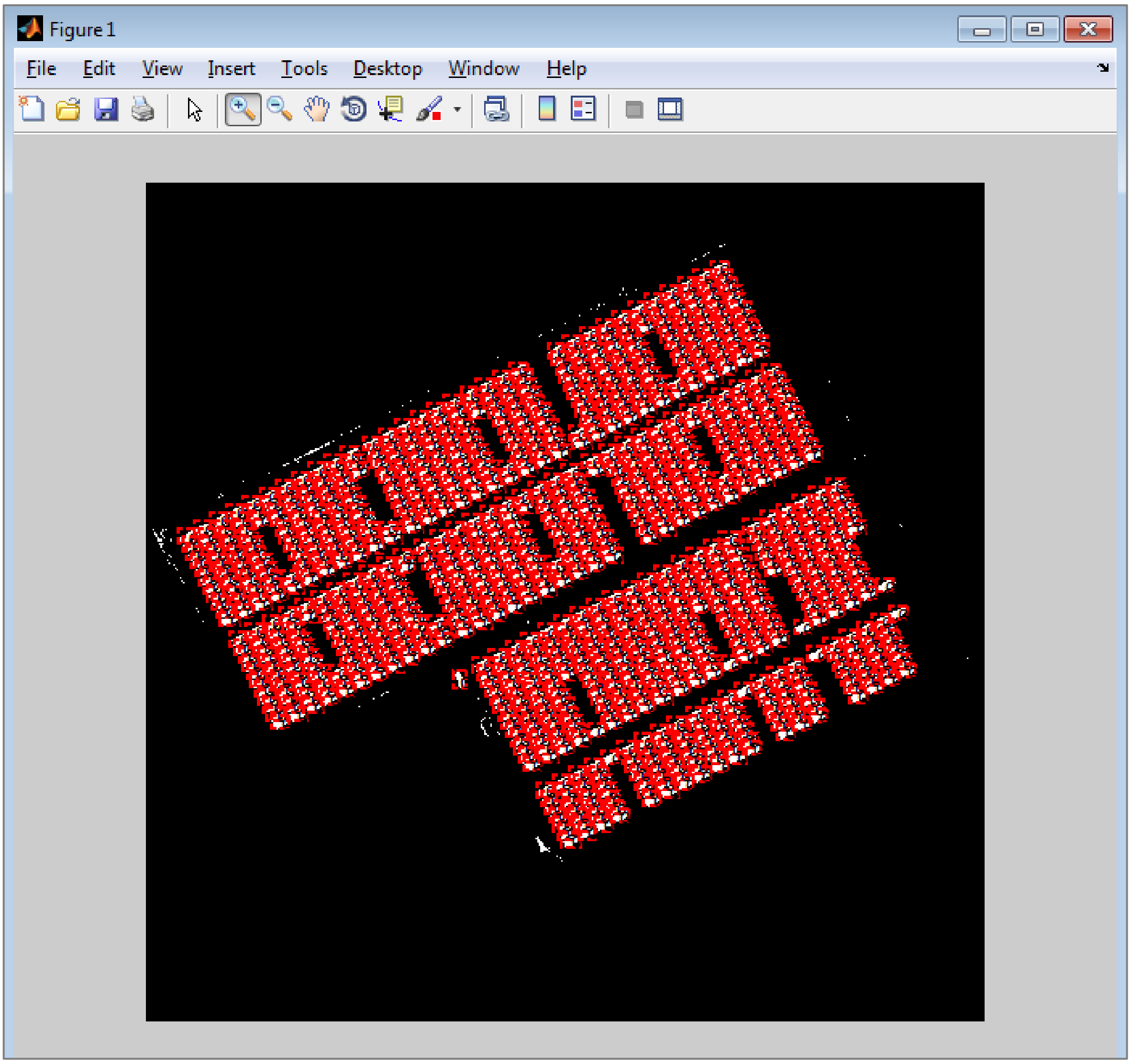


Figure 57: Output of algorithm in MATLAB for Thin film solar panels (The detected panels are highlighted in red boxes)

When the algorithm was executed for detection of polycrystalline panels, it has detected 120 panels out of 124 panels. Additionally, it has detected couple of false positives. The possible reason for failing to detect those four panels would be shading on solar panels due to trees.

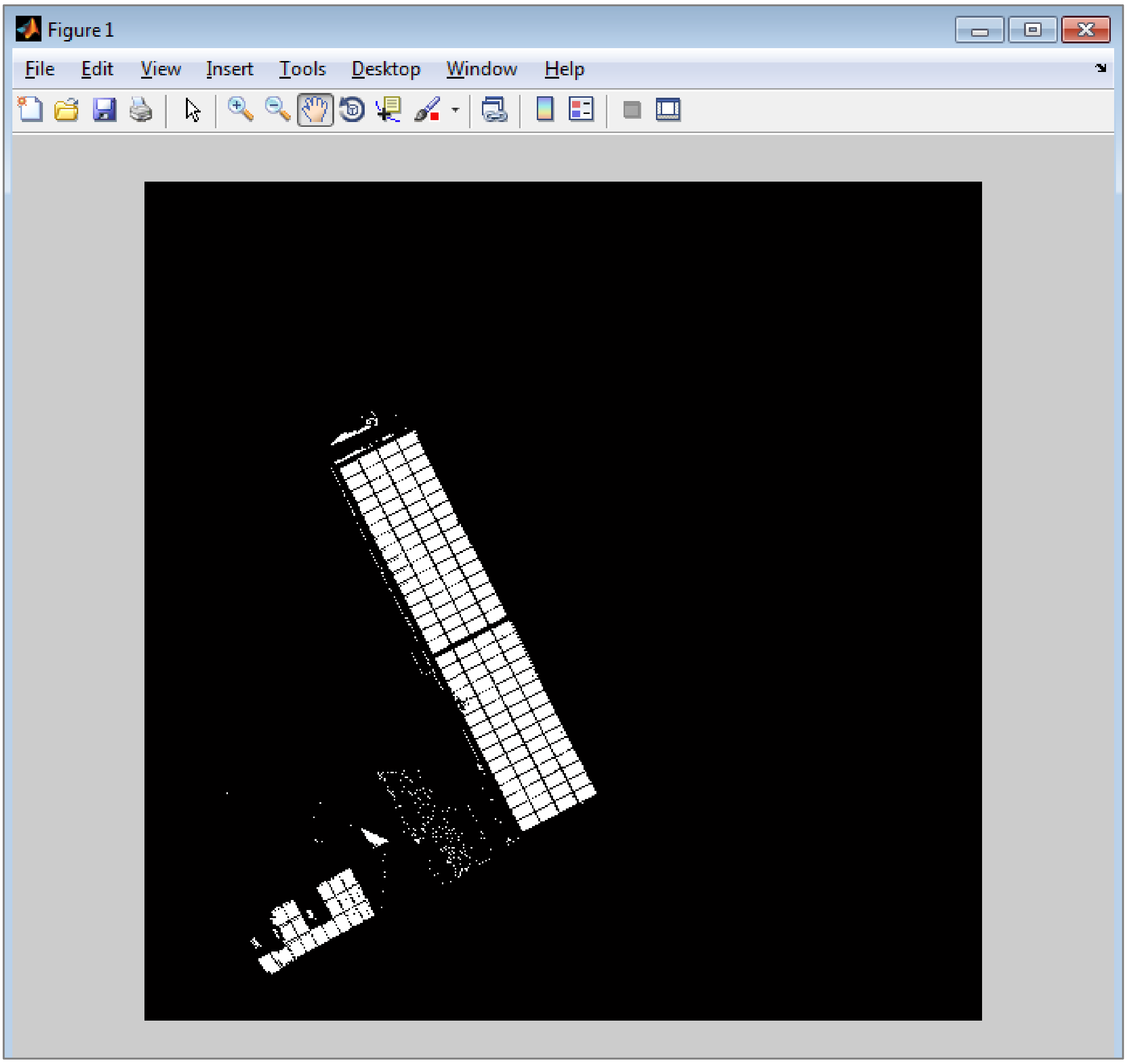


Figure 58: Output of algorithm in MATLAB for polycrystalline solar panels (The panels are highlighted in white)

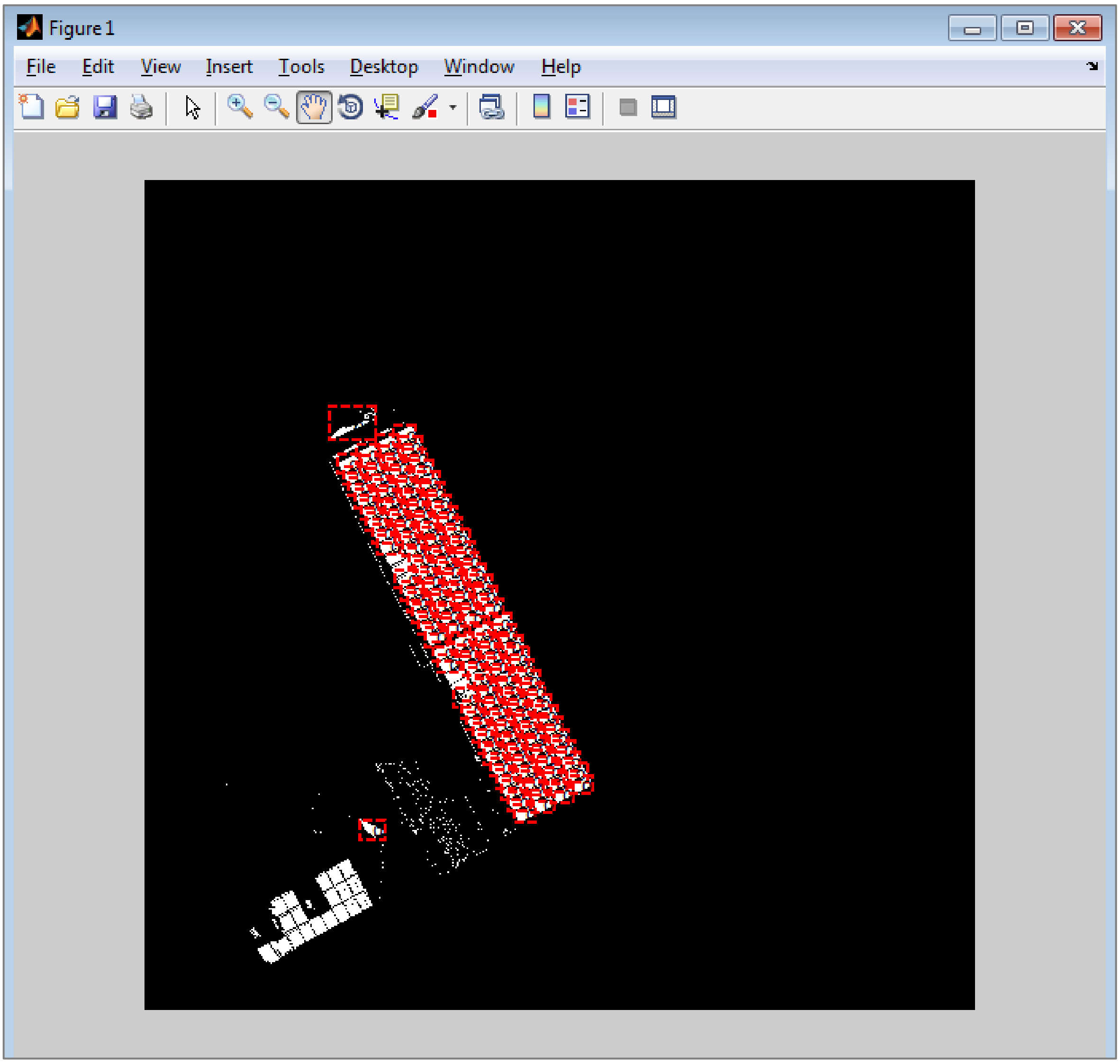


Figure 59: Output of algorithm in MATLAB for polycrystalline solar panels (The detected panels are highlighted in red boxes)

The summary of solar panel detection at the study region using proposed algorithm is given in the table below.

Table 6: Panel detection results summary

	Thin film solar panels	Polycrystalline solar panels
Number of panels	1052	124
Number of true detections	1052	120
Number of false detections	1	2
Accuracy	100%	97%

6.3.4.1 Advantages of proposed algorithm

The developed algorithm has good execution speed and is memory efficient. It has detected over 1000 solar panels in just under a minute. Since the algorithm is computationally less expensive, it can be run on the machines with decent system configuration. Region of Interest input avoids processing on unnecessary portion of the image and thereby reducing processing time.

6.3.4.2 Limitations of the algorithm

The algorithm is highly inaccurate when there is no considerable color variation between ground or panel background and solar panels. However, it is very unlikely event in case of a solar farm. Supplying improper reference solar panel image or size of solar panels can lead to highly inaccurate output.

7 Practical Issues and future work

7.1 Challenges

1. At the moment, it is cumbersome to access the measurement data stored in the memory card attached to the ITT Smart Sense device. This can be tiring to the user, when the device is operated in offline mode (i.e. without uploading data to webserver regularly) and the data has to be viewed frequently.
2. Most of the drones come with in-built camera. Attaching special or own cameras (for example, multispectral camera) to the drone is often difficult and sometimes impossible.
3. For case studies 2 and 3, several flights were carried out with various combinations. However only few flights successfully yielded expected results. When the pictures were captured at low altitudes (<20 meters), the generated orthomosaics had poor quality and inaccurate data.
4. The drone technology has to take some advancement in order to carry heavy cameras (>2 kilograms). Most of the drones that are available in market have maximum flight time of 20 minutes. So, multiple flights have to be carried out for covering larger areas.
5. Bad weather conditions like rain, snow, high wind speed affect the performance of flights negatively.

7.2 Drone Laws

Due to increasing privacy concerns and uncontrolled air-traffic, there are many legislations and government regulations that exist to restrict the use of drones in several regions. Special permissions are needed in order to fly the drones in restricted regions.

7.2.1 Drone laws in Germany

According to a news article published by the Federal Ministry of Transport and digital infrastructure (BMVI, 2017), the German Government introduced new laws concerning the use of drones in April 2017 (BMVI, 2017). These new laws will be enforced from October 2017. According to the new UAV laws,

- Any UAV/drone weighing more than 250 grams must be equipped with a permanently fixed identification plate with a fireproof inscription giving the name and address of the owner (Lufthansa Aerial Services, 2017).
- Special rules apply for drones weighing more than 2 kilograms. In order to operate the drones weighing more than 2 kilograms, the owners must prove that they have specialist knowledge (in operating drones) certified by Luftfahrt Bundesamt (Federal Aviation Office) or a drone pilot license.
- All drones over 5 kilograms require a special permit to fly from the regional authority
- Also, the flights above 100 meters always require a permit to fly from the regional aviation authority.

- Flying over no-fly-zones (near airports, hospitals, stadiums, industrial zones, police stations) is forbidden.
- Flying over nature reserves, national parks, rivers and navigation routes is forbidden as well.

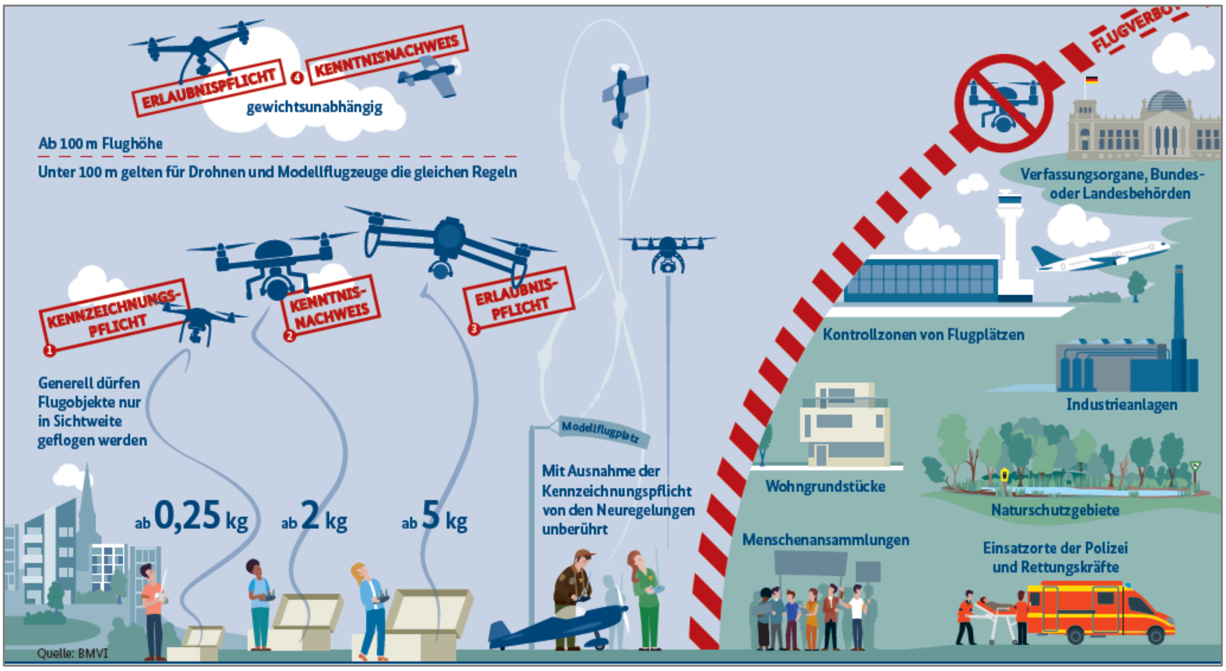


Figure 60: Infographic on new drone laws in Germany. Source: (Lufthansa Aerial Services, 2017)

7.3 Future work

- A handheld version of ITT Smart Sense Box would be a useful addition to researchers to record the measurements on the field immediately.
- Encryption of sensor data in the nodes has to be implemented in order to improve the data security.
- ITT Smart Sense Fly app currently supports only the cameras that are compatible with DJI drones natively. Support for custom cameras can be added by adding proper electronics on board.
- ITT Smart Sense Fly app currently supports DJI manufactured drones only. The app can be implemented for other drone manufacturers like Parrot and 3DR.
- Numerous image processing algorithms can be developed on top of ITT Smart Sense Fly platform to process images for analysis and detection of various objects of interest.
- Converted NDVI drone cameras offer a cost effective way to monitor crop health and key indices of plant growth. These cameras can easily be integrated into existing ITT Smart Sense Fly platform.
- Reliability and performance of the Panel detection algorithm has to be tested with more solar PV parks.
- Integration of ITT Smart Sense Box with ITT Smart Sense Fly platform will open the doors to new applications as well as improved accuracy of results.

8 Conclusion

ITT Smart Sense Box is robust and reliable environmental monitoring solution using wireless sensor nodes. The state-of-the-art sensors, electronics components and communication protocols have been used to construct the platform. Three variants of Smart Sense box have been designed according to their field of application. Smart Sense Agriculture is designed for agriculture monitoring of important soil parameters such as soil moisture, soil temperature, and ambient temperature and can support additional sensors to measure solar radiation, UV radiation and tree trunk diameter. The Smart Sense Water device is used for measuring water quality parameters like electrical conductivity, water temperature, pH, dissolved oxygen (DO). This device can be installed in lakes, ponds, rivers and various other water bodies to measure and monitor water quality parameters. Smart Sense Weather is developed for monitoring climatic and weather parameters such as temperature, humidity, atmospheric pressure, wind speed with direction, and rainfall. By following instruction manuals and how-to-videos of Smart Sense Box, anyone with basic electronics and computer knowledge can build a monitoring device.

On the other hand, ITT Smart Sense Fly, a drone based inspection and monitoring platform has been developed. A mobile app was developed to control an autonomous drone. This makes it easy to inspection and/or monitoring of agricultural fields, water bodies such as rivers and lakes, solar farms, wind farms etc. The developed solutions were demonstrated using three case studies. First case study was related to ITT Smart Sense Box and the remaining two were implemented using ITT Smart Sense Fly.

Concretely, environmental monitoring is a crucial to improve our understanding and interaction with the physical world. The proposed monitoring and inspection solutions, techniques and applications will help understanding the natural processes that are happening in the environment. They provide cost effective and reliable monitoring not only for researchers but also government institutions, environmental agencies and municipalities. The proposed tools can be used for monitoring and inspection of solar power plants, wind farms, estimation of available biomass for generation of bioenergy, soil salinity stress detection, pest and weed detection, yield prediction, landslide investigation, land surveying and classification, flood propagation mapping and various other applications.

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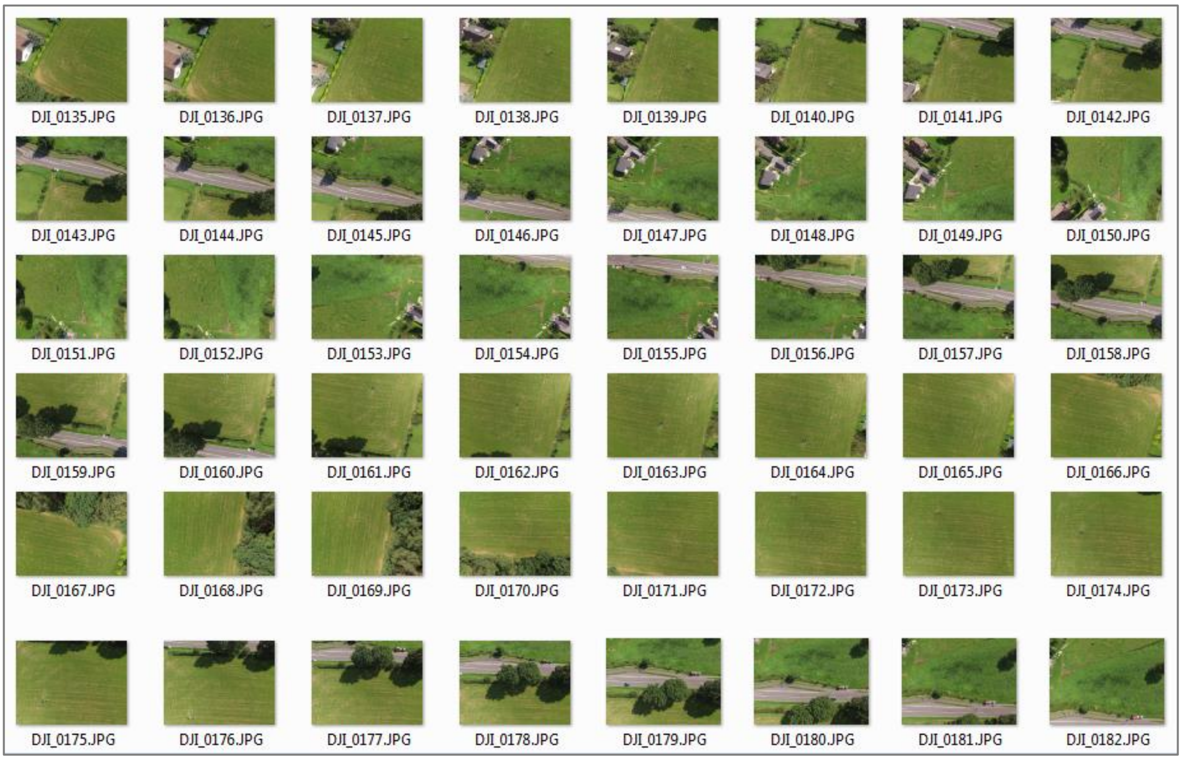
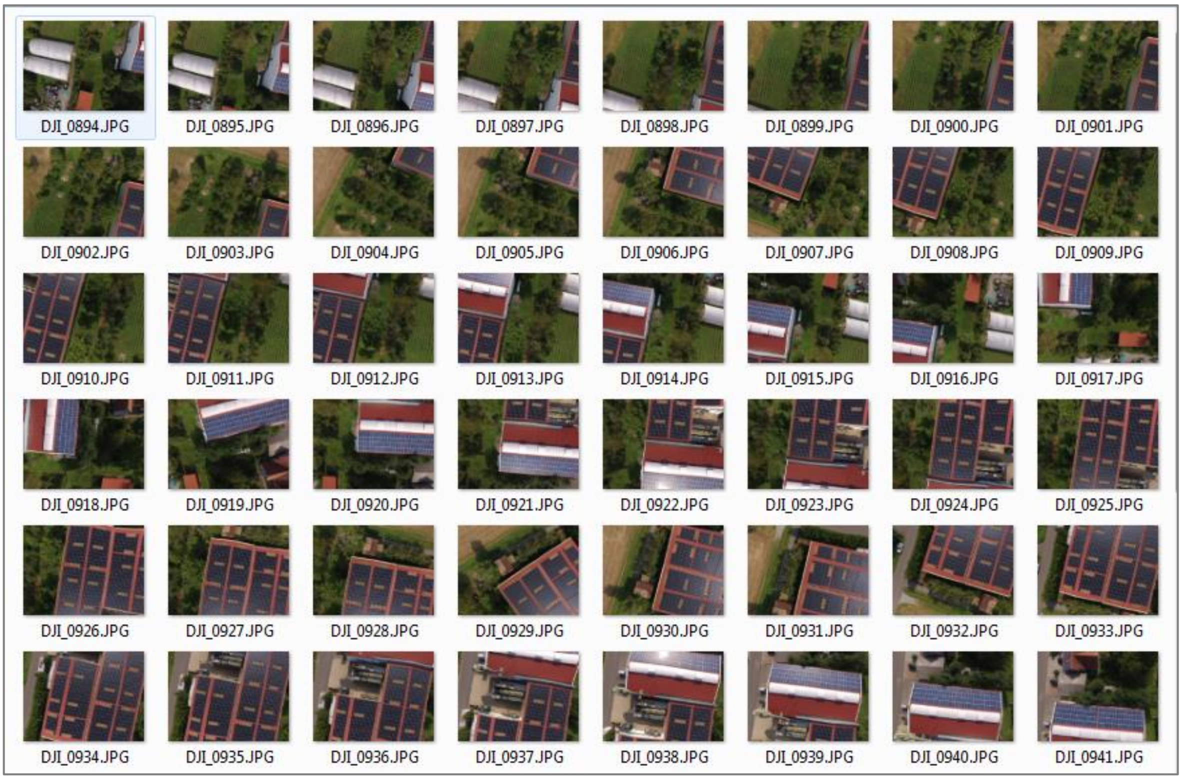
10 Annexures

Annexure 1: Some of the photographs captured at the study location of case study-2



Annexure 2: Some of the photographs captured at the study location of case study-3



Annexure 3: Solar panel detection program written in MATLAB

```
function PanelDetection(Img_JPG,Img_GeoTIF,panelMinSize,panelMaxSize,isRefImage,referenceImg,size_factor,roi_x,roi_y)
X = imread(Img_JPG); %read JPG version of orthomosaic. some image processing and quicker operations are easier with JPG version compared to GeoTiff
X = imresize(X,size_factor); %resize the image. so that, less noise and faster processing
roi = poly2mask(roi_x*size_factor,roi_y*size_factor,size(X,1),size(X,2)); %set region of interest
info = geotiffinfo(Img_GeoTIF); % read actual GeoTiff for retriving geo-coordinates from pixels
Blue_X=X(:,:,3); % seperate Blue Channel
Blue_X(~roi)=0; % consider only the portion with in region of interest
Green_X=X(:,:,2);
Green_X(~roi)=0;
Red_X=X(:,:,1);
Red_X(~roi)=0;
% convert into binary image with 0's and 1's. Pixel value of '1' means color range is with in reference panel image, '0' otherwise
%if reference image is not passed, consider generic color range of solar panels (this method is not recommended)
if(isRefImage==0)
Blue_X(Blue_X > 160) = 0;
Blue_X(Blue_X < 115) = 0;
Green_X(Green_X > 150) = 0;
Green_X(Green_X < 50) = 0;
Red_X(Red_X > 150) = 0;
Red_X(Red_X < 50) = 0;
%if reference image is passed, consider color range of reference image
else
RefImg = imread(referenceImg);
Blue_RefImg=RefImg(:,:,3);
Green_RefImg=RefImg(:,:,2);
Red_RefImg=RefImg(:,:,1);
Blue_Max=max(Blue_RefImg(:));
Blue_Min=min(Blue_RefImg(:));
Green_Max=max(Green_RefImg(:));
Green_Min=min(Green_RefImg(:));
Red_Max=max(Red_RefImg(:));
Red_Min=min(Red_RefImg(:));
%allow +-10% of color
Blue_X(Blue_X > Blue_Max*1.2) = 0;
Blue_X(Blue_X < Blue_Min*0.8) = 0;
Green_X(Green_X > Green_Max*1.2) = 0;
Green_X(Green_X < Green_Min*0.8) = 0;
Red_X(Red_X > Red_Max*1.2) = 0;
Red_X(Red_X < Red_Min*0.8) = 0;
 end
%consider pixels only in the ones in which all three channels are nonzeros
BandG=and(Blue_X,Green_X);
finalAnd=and(BandG,Red_X);
finalAnd=255*finalAnd;
%imshow(finalAnd);
Processed_rgb = cat(3,finalAnd,finalAnd,finalAnd);

bw = im2bw(Processed_rgb);

% find both black and white regions
stats = [regionprops(bw); regionprops(not(bw))];
% show the image and draw the detected rectangles on it
imshow(bw);
hold on;
% find the rectangles (solar panels) and also read their respective geo-coordinates and save it in csv file
for i = 1:numel(stats)
    if(stats(i).Area>=panelMinSize && stats(i).Area<=panelMaxSize)
    rectangle('Position', stats(i).BoundingBox, ...
    'Linewidth', 2, 'EdgeColor', 'r', 'LineStyle', '--');
c=stats(i).Centroid;
text(c(1),c(2),'o');
[x,y] = pix2map(info.SpatialRef, c(2)/size_factor,c(1)/size_factor);
[lati,lngi]=projinv(info,x,y);
dlmwrite('panelInfo2.csv',[stats(i).Area,double([lati,lngi])],'-append','precision',8)
    end
end
imsave;
```

Annexure 4: CSV file generated by the solar panel detection algorithm

	A	B	C
1	Size of Panel	Latitude	Logitude
2	144	50.062104	10.059748
3	145	50.062099	10.059751
4	149	50.062094	10.059755
5	146	50.062089	10.059759
6	150	50.062109	10.059763
7	154	50.062084	10.059763
8	144	50.062104	10.059767
9	150	50.062079	10.059767
10	152	50.062099	10.059771
11	145	50.062074	10.059771
12	151	50.062094	10.059775
13	152	50.062069	10.059775
14	151	50.062114	10.059779
15	149	50.062089	10.059779
16	145	50.062064	10.059779
17	146	50.062109	10.059783
18	153	50.062084	10.059783
19	150	50.062059	10.059783
20	148	50.062104	10.059787

Annexure 5: The measured sensor data by ITT Smart Sense Box on a certain day during the testing period

	A	B	C	D	E	F	G	H	I	J
1	DeviceID	SeqNumber	BatteryLevel	Day	Date	Time	Temperature	Humidity	SoilMoisture	SoilTempera
2	ag1	1	68	Sun	16/12/08	07:32:12	6.4	na	8587.	na
3	ag1	1	68	Sun	16/12/08	07:46:03	6.4	na	8473.	na
4	ag1	1	68	Sun	16/12/08	09:15:38	10.8	na	7620.	na
5	ag1	2	69	Sun	16/12/08	09:31:58	13.6	na	6836.	na
6	ag1	3	75	Sun	16/12/08	09:48:15	24.5	na	6443.	na
7	ag1	4	71	Sun	16/12/08	10:04:31	24.2	na	5940.	na
8	ag1	1	75	Sun	16/12/08	10:33:44	25.0	na	6302.	na
9	ag1	2	75	Sun	16/12/08	10:50:02	23.3	na	5839.	na
10	ag1	3	71	Sun	16/12/08	11:06:17	29.5	na	5114.	na

Declaration in lieu of oath

By

Venkatesh Pampana

This is to confirm my Master’s Thesis was independently composed/authored by myself, using solely the referred sources and support.

I additionally assert that this Thesis has not been part of another examination process.

Place and Date *Signature*