DEMETRA - 3D prEcision farMing using intErnet of Things and unmanned aeRiAl vehicles in greenhouses

DELIVERABLE D4.1

DEVELOPMENT OF UGV AND UAV SYSTEMS FOR INDOOR PRECISION AGRICULTURE APPLICATIONS

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Abstract

Describes the technical characteristics, the setup, the implementation and validation of the algorithms as described in T3.1 and T3.2. The report will include the performance findings on the SoTA Indoor Positioning Methods and Algorithms, the Multispectral Imagining System and the Soil Property Analysis.

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1 Concept and Objectives

The general objective of this project is the adaptation of existing technologies used in a precision agriculture (PA), into an indoor (greenhouse) prototype system which includes the use of both an unmanned ground and aerial vehicles (UGV and UAV). The term precision agriculture refers to the use of information technologies (IT) to help farmers manage the optimal growth of their crops thus ensuring profitability and sustainability. Furthermore, PA has also been known to help the environment by avoiding unnecessary spaying of pesticides as well as excessive use of water and fertilisers. The use of unmanned systems offers higher spatial resolution data compared to satellites. The real-time data of interest to the farmers and management tools/software includes soil properties such as moisture, compaction, salinity and nutrients (nitrogen (N), phosphorus (P) and potassium (K)), and crop monitoring which includes vegetation indexes such as Chlorophyll, Leaf Water, Ground Cover, Leaf Area, Normalised Difference Vegetation Index (NDVI), etc. UAVs have been used in PA for bird eye view, for insect identification using cameras and Lidars, and even actuators for autonomous spraying of pesticides, whereas the use of UGVs provides bottom-up capabilities identifying insects hiding under the leaves and for crop planting and harvesting. The innovation of this project is the UGV and UAV for indoor (greenhouse) PA applications where GPS signals are very weak or non-existent. In addition, this work will validate high-precision cm-level, 3D positioning techniques required for unmanned vehicle indoor localisation and navigation.

Related deliverables include 3.1 and 3.2.

- Deliverable 3.1 describes the concept, requirements and specifications of the technologies investigated in the project as well as the use case scenarios and the respective KPIs for the validation and verification of the system components and prototypes.
- Deliverable 3.2 on the other hand summarizes the results of the final testing carried out and compare them against the set KPIs. It will also include the final performance analysis against similar results reported in the literature as well as the applicability of the technology to be exploited in products/services.

This report describes the technical characteristics, the setup, the implementation and validation of the algorithms as described in T3.1 and T3.2. The report will include the performance findings on the SoTA Indoor Positioning Methods and Algorithms, the Multispectral Imagining System and the Soil Property Analysis.

2 Project Challenges

The project aims at agricultural application in the confined space of greenhouses using existing technologies and algorithms. As straight forward as it might sound, because of the abundance of sensors and solutions that are already used in precision agriculture applications as examined in the extensive literature review presented in Deliverable 3.1, it is worth noting the big difference and innovation of this project. Outdoor precision agriculture applications refer to vast farm lands which take advantage of GPS for localization and navigation. For those outdoor applications, GPS accuracy in the range of 1 and 2 meters is still acceptable due to the vastness of the farmlands. On the other hand, DEMETRA project proposes precision agriculture for Indoor, confined space of greenhouses, where GPS signals are obstructed and are unavailable. Hence, the **first challenge** DEMETRA needs to solve is the issue of **Indoor Positioning and Localization**. Furthermore, remaining on the same topic, the **second challenge** since UAVs will be used is that positioning needs to be **3-Dimensional positioning**. In addition, since the application is in the confined space of greenhouses, then the **third challenge** is the **accuracy** of 3D indoor positioning which is mandated to be in the **sub-meter range**. Furthermore, the **fourth challenge** is the requirement to use **small unmanned systems**, both ground and aerial vehicles (UGV and UAV respectively) because of the confinement of greenhouse dimensions.

The requirement of using small unmanned systems with strict payload constraints opens a new area challenges which come in the same package. The **fifth challenge package** includes the use of **small unmanned system applications** which require the **payloads** to be **compact**, **lightweight** and **low power**. Therefore, sensor integration and data acquisition should go through microcontrollers whereas processing hungry algorithms can also use Single Board Computers (SBC) suitable for small UAV applications. Due to the time constraint of the project, it is proposed to use commercially available navigation controllers (autopilots) which are compact and lightweight. However, this leads to the **sixth challenge** and the possibility that the commercially available **autopilots** will **recognise and accept converted and retransmitted GPS signals** for navigation.

Finally, taking into account all the challenges and challenge packages, the DEMETRA project, will include a **UGV and UAV** which will be able to **navigate through a confined indoor environment**. Both the UGV and UAV will also be equipped with **cameras for Insect Detection**. The UGV will provide bottom-up Insect Detection whereas the UAV birdeye view. In addition, the UAV will be equipped with **multispectral camera to provide vegetation indexing**. Finally, it would not have been a smart greenhouse if a Greenhouse Monitoring System was not included. The **Greenhouse Monitoring System** will include measurements and indications for **Temperature, Relative Humidity, Air Quality, Light Intensity, Soil Humidity and pH.**

The project concept is visualised in Figure 1, section 3.

3 Concept Visualization

The proposed concept is visualised on Figure 1 where the flowchart s given on Figure 2. The biggest challenge of this project is to achieve 3D indoor positioning for the navigation of the UAV and the UGV.

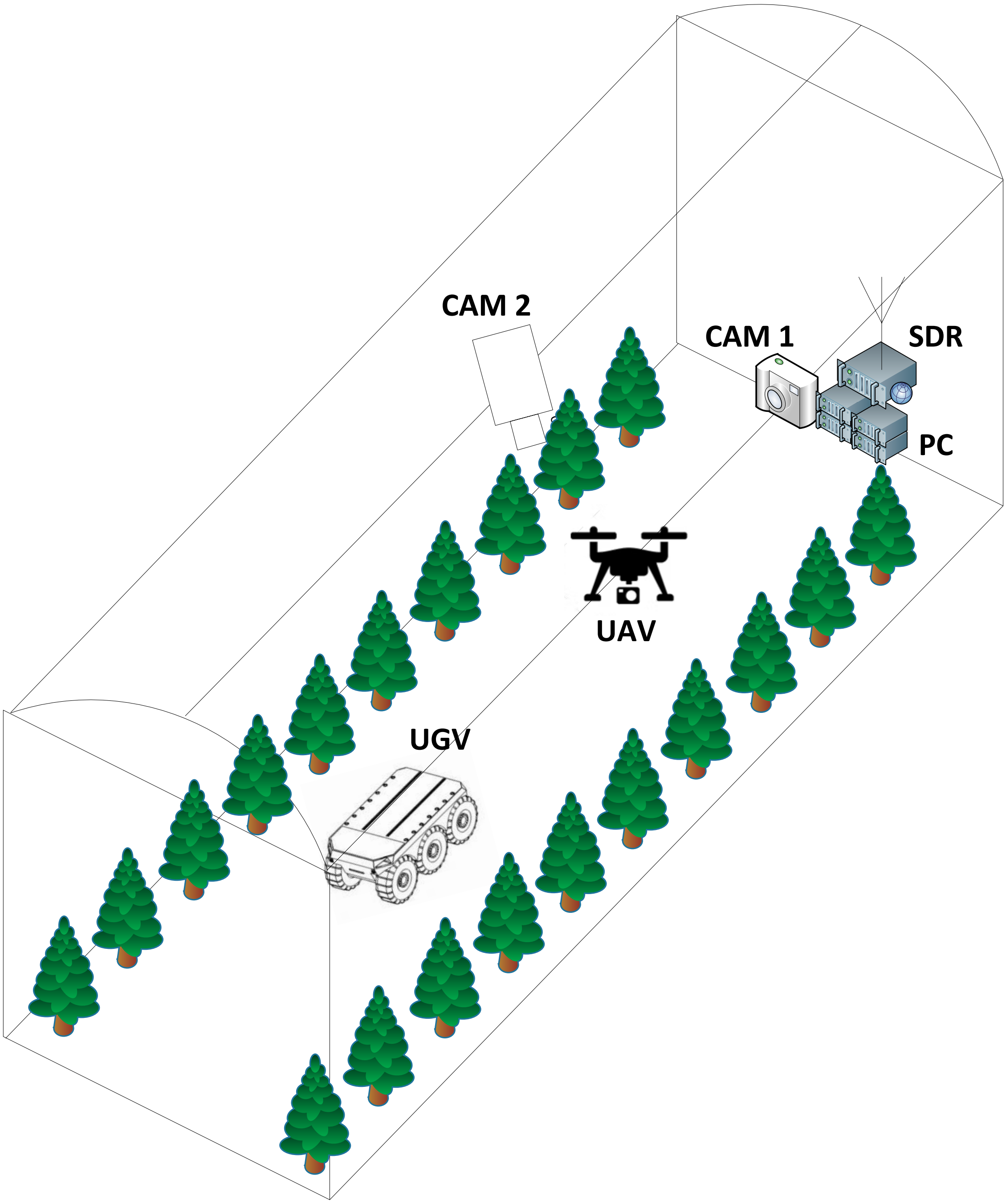

Figure 1: Greenhouse Indoor 3D Positioning using Cameras

Figure 1, shows a UGV and UAV navigating within the greenhouse indoor space. The positioning in this example is given by cameras. The advantage of cameras is that the unmanned systems can be detected and identified.

The cameras are stationary so that they can detect and identify the unmanned systems and calculate their local location within the space. It is suggested that one camera provides bird eye view and the second camera profile view of the space. The camera data acquisition and image processing is performed by a PC. When the local coordinates are calculated by the cameras then they will be converted to GPS protocol and retransmitted using Software Define Radio (SDR). The complete proposed operational flowchart is presented on Figure 2.

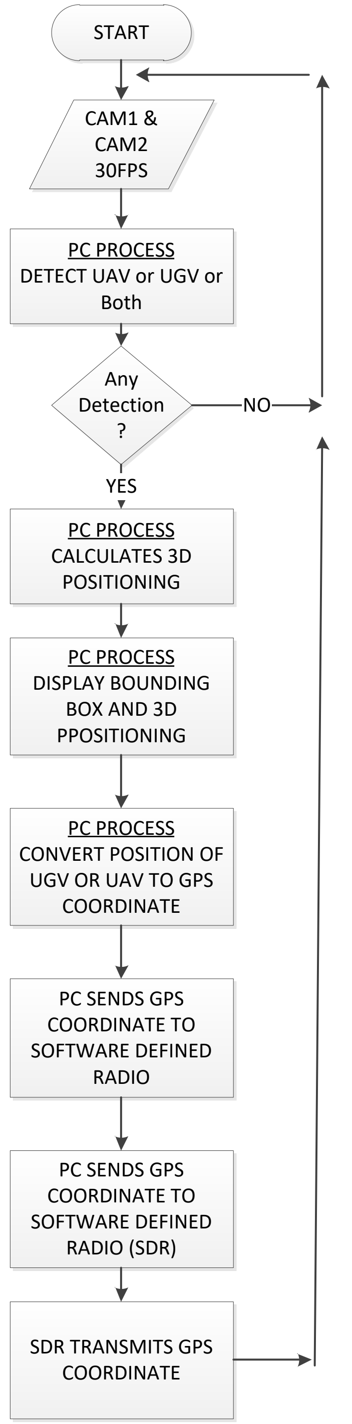

Figure 2: Proposed Operational Flowchart

The same operational flowchart would also serve the needs of when 3D indoor positioning is achieved via mmWave Radar Sensors as proposed on Figure 3.

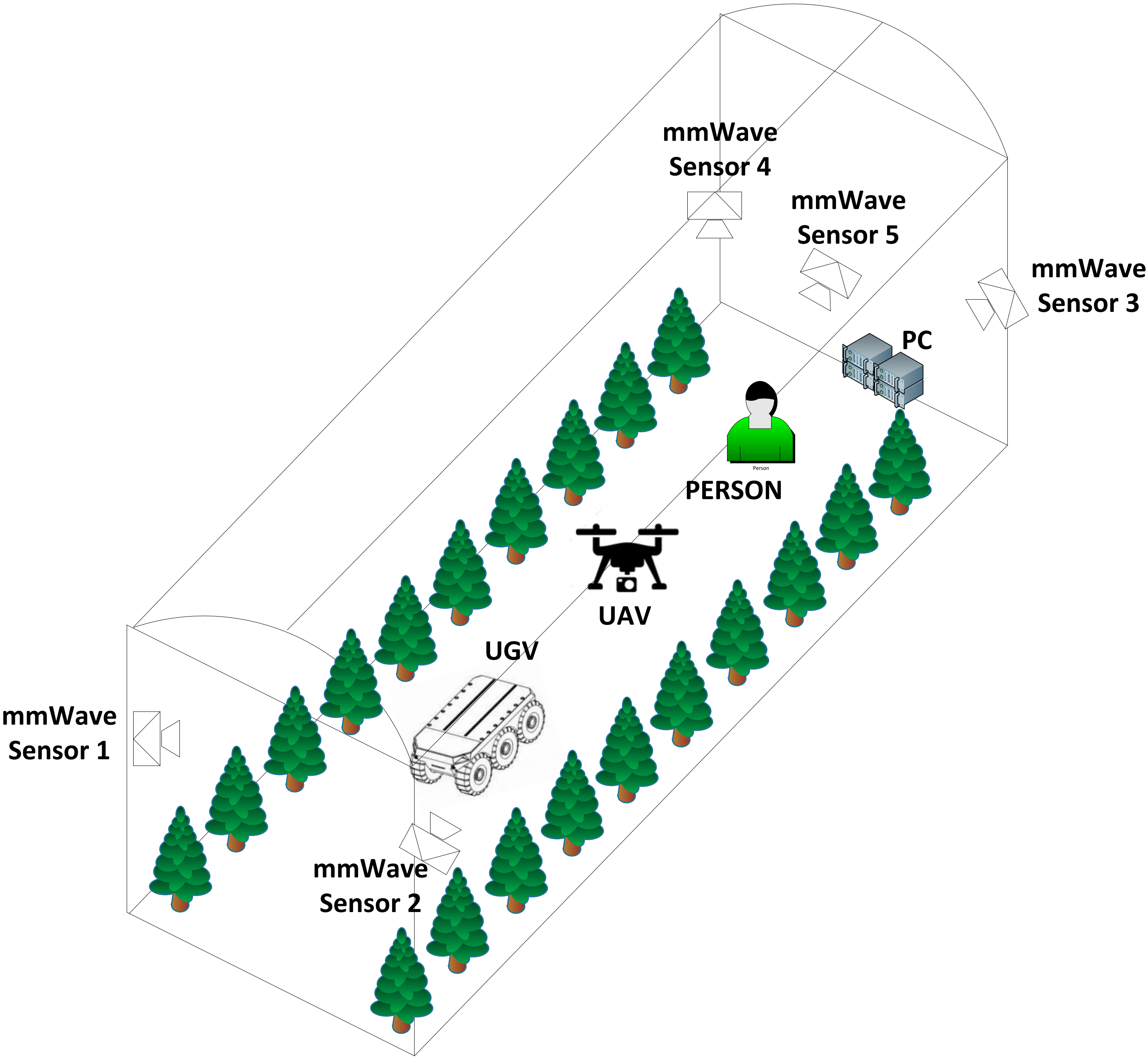

Figure 3: Indoor Positioning using mmWave Radar Sensors

As already have mentioned, mmWave radar sensors can detect objects but cannot identify them. With either technologies, mmWave or cameras, a very important **constraint** arises that **only one unmanned system can operate** at a time; either UGV or UAV. This constraint is due to the use of commercially available autopilots where both systems will receive the retransmitted GPS signal which is the location of one of the two. For future work, it is proposed that custom made controllers are used where with the retransmission the object ID is also attached to the transmission and the controller acts accordingly.

The proposed greenhouse monitoring system is presented on Figure 4. As can be seen it incorporates all the sensors to achieve the required measurements, Temperature, Relative Humidity, Air Quality, Light Intensity, Soil Humidity and pH. However, in addition to the required measurements the proposed system offers future improvements for more autonomy. Such improvements include sensors to monitor the water reservoir and actuators to control the water pump for autonomous watering and spraying. Actuators and Fans for autonomous temperature control by spraying water or opening and closing windows, etc. Finally, the monitor system could incorporate renewable systems such as a PV panel for automatic recharging of the battery. With the proposed improvements the possibilities are endless.

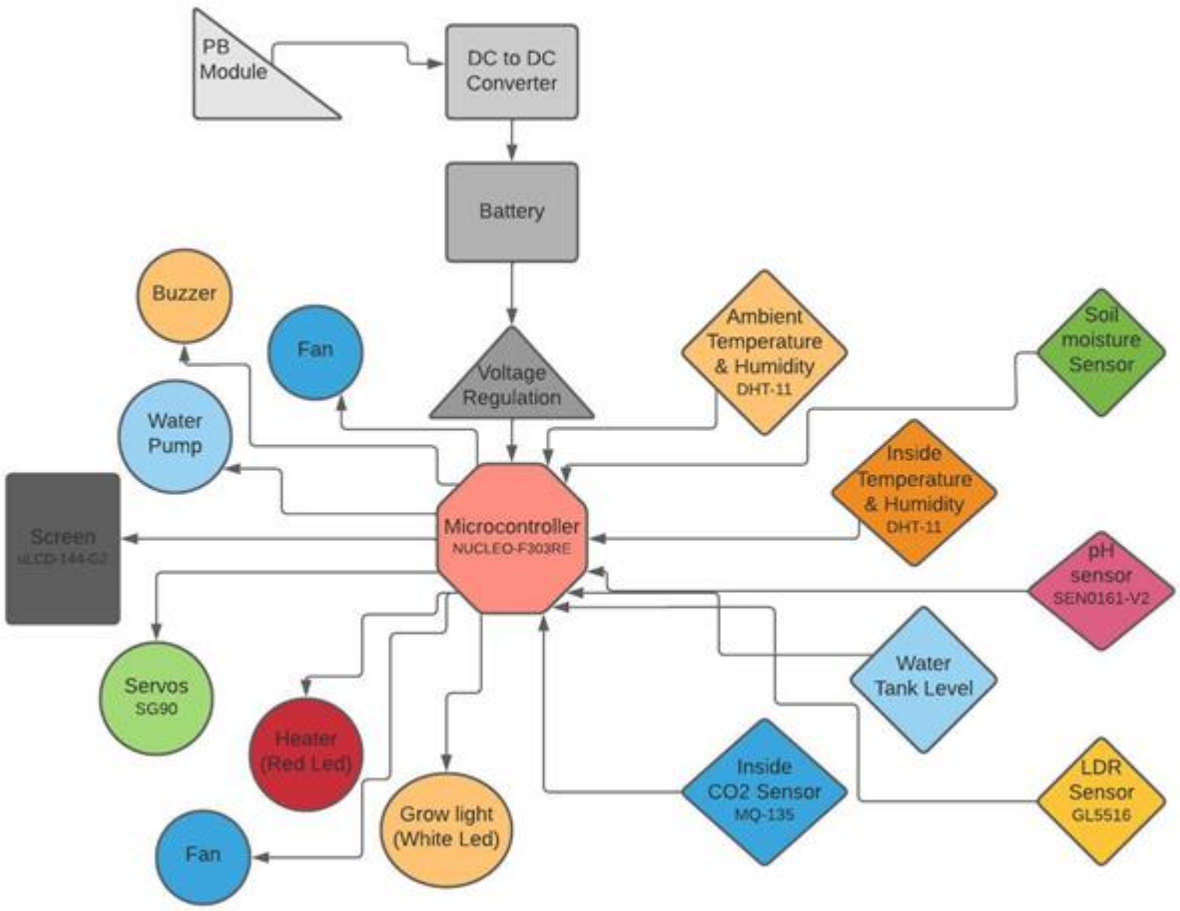

Figure 4: Proposed Greenhouse Monitoring System

4 Summary of all Proposed KPIs

Based on the proposed concepts for the DEMETRA project, systems and subsystems have been identified and individual KPIs have been set. The set KPIs meet or improve the state of the art which were identified by resent literature for precision agriculture applications.

4.1 Greenhouse Monitoring System

The greenhouse monitoring system should have the following characteristics:

- Temperature with accuracy of ±2°C
- Relative Humidity with accuracy ±10%
- Measurement and identification of CO_2 gas
- Measurement of pH with accuracy ±10%
- Development of a Light Intensity Sensor
- Development of a custom made Soil Moisture sensor with accuracy ±10%

4.2 Image Processing

- Development of image processing capability for small UAV applications (compact, lightweight and low power).
- Achieve state of the art or higher FPS with an accuracy higher than 80%.
- Reduce power consumption on the single board computer
- Dataset for insects in Cyprus
- Detection at distance of maximum 6 meters

4.3 UAV Flight and Multispectral Data Collection

- Flight stability and immunity from vibrations
- Multispectral Data Collection

4.4 Multispectral Image Processing

- Successful multispectral data analysis for various indices using software DJI Terra and open source QGIS

4.5 Indoor Positioning

Using AI Cameras or mmWave Radar sensors

- Sub-meter accuracy

4.6 Indoor Positioning by GPS Conversion and Retransmission

- Sub-meter accuracy

5 Evaluation of Achieved Performance

The set KPIs of section 4 are evaluated and discussed in this section.

- Greenhouse Monitoring System
    - The temperature calibration data for sensor DHT-11 shows the highest percentage error being 7.4% which equates to an accuracy of +2°C. **Hence, the temperature accuracy of +2°C is within the range of indicated KPIs.**
    - The humidity calibration data for sensor DHT-11 shows the highest percentage error being 7.46% which equates to an accuracy of +5%. **Hence, the humidity accuracy of +5% is within the range of indicated KPIs**.
    - The pH Sensor SEN0161-V2 calibration data show an accuracy of +5%. **Hence, the pH accuracy of +5% is within the range of indicated KPIs**.
    - Even though, we did not have any means of verifying the measured CO_2 value. **The Air Quality sensor integration with the existing microcontroller and the indication of CO_2 has successfully met the requirements as indicated in the KPIs.**
    - **The successfully development and integration of Light Intensity Sensor satisfies the set KPI requirement.**
    - **The successfully development and integration of soil humidity with accuracy of 90% meets the requirements as indicated in the KPIs.**
- Image Processing for Small Unmanned System Applications
    - **Achievements which satisfy the set KPIs.**
        - The **optimized YOLOv5** produced the highest **mAP of 92.5%** compared to the ordinary YOLOv5s model and could detect at **7-9 FPS on the RPi-4B**.
        - The optimized model uses **35% less CPU** usage than the original YOLOv5.
        - The reduced CPU usage is also translated to **25% reduction in CPU temperature**.
        - The deployment approach in this study **reduces the difficulty** of deploying the **deep-learning fire detection** and **insect detection models** on **single board devices**.
        - **Sensitivity analysis shows** that the maximum distance the **system can detect** the frame when the light is off is **9.0 m** whereas when light is on the maximum **distance is 8.0 m**.
        - The **training of YOLO algorithm** and the **Detection of Insects** has been **successful** and meets the set KPI requirements.
- UAV Flight and Multispectral Data Collection

- The flight was successful and the DJI Mavic 3M proved its airworthiness. Furthermore, the DJI proved that the gimbal system provides stability and immunity from vibrations due to wind and UAV motors. **Successful flight, stability and immunity from vibrations were conditions set by KPIs**.
- The **UAV flight and collection of data** using a multispectral camera, along with the data analysis using the software DJI Terra and open source QGIS **has been successful and meets the set KPI requirement**.

- Multispectral Image Processing
  - The **multispectral data analysis** using the **software DJI Terra** and **open source QGIS has been successful and meets the set KPI requirement**.
- Indoor 3D Positioning
  - Using Cameras
    - For indoor greenhouse application an average 3D error of 22 cm can be considered acceptable. **Also even the maximum error of 35 cm satisfied the set KPI which was aiming at a sub-meter accuracy. Hence, the KPI requirements have been successfully met.**
  - Using mmWaver Radar Sensors
    - For indoor greenhouse applications both mmWave and camera technologies are acceptable solutions. **Even the maximum error of 35 cm satisfied the set KPI which was aiming at a sub-meter accuracy. Hence, the KPI requirements have been successfully met.**
- Indoor Positioning by GPS Conversion and Retransmission
  - As shown on the analysis of the experimental results, the accuracy is in the range of 0.15 m which is in the sub-meter range required by the set KPI. **Both the feasibility and accuracy successfully meet the KPI requirements.**

6 Conclusions

DEMETRA project had several challenges to overcome and set of KPIs to achieve. The set KPIs were the result of extensive literature review performed and documented on Deliverable 3.1. The detail analysis provided on Deliverable 4.1, identified all individual challenges and their dependencies and possible and feasible solutions were proposed. However, the feasibility of some proposed solutions were uncertain and validation had to be confirmed experimentally. Based on the detailed analysis of all the experimental work as described and documented on Deliverable 3.2, this report concludes that **DEMETRA project is SUCCESSFUL because ALL SET KPIs HAVE BEEN SUCCESSFULLY ACHIEVED**. Worth noting that in several cases the achieved results were beyond the reported state of the art.