Development of an Integrated IoT-based Greenhouse Control Cablebot System

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Abstract. The control of large greenhouse installations, especially of those with hydroponics crops, is based on analysis and utilization of data recorded by sensor grids. In open air plots unmanned aerial vehicles (drones) equipped with spectral sensors scan and map large areas fast and efficiently. However, spectral imaging is not easily performed inside greenhouses since drones do not fly freely indoors. The proposed solution is a prototype solar-powered cablebot, a robotic device that is hung from an overhead cable system that roams freely inside greenhouses. This 3D printed device is equipped with an array of ag-sensors including a spectral sensor. A web-based user interface & control app has also been developed. This robotic system has been primarily tested and now is in installation stage and will operate in a pilot production greenhouse of the Department of Agriculture of the University of Patras.

Keywords: Precision Farming; greenhouses; cablebot; interface app; smart irrigation; sensor box.

1 Introduction

A worldwide concern on food security and environmental conservation is evident nowadays. Recent technological advancements in IoT, GPS guided aerial and ground vehicles, molecular biology and AI neural networks have spurred a global investment trend towards ag-tech & food-tech, so as to remedy for threats that may lie ahead.

Precision agriculture (Dwivedi, 2017) has literally taken off with the development of autonomous UAVs (Unmanned Aerial Vehicles) also known as drones, that help farmers map large areas in a fast and economical way (Vasudevan, et al., 2016; Gonzalez et al., 2019). The UAVs provide farmers with data sets, from RGB, spectral, thermal & Lidar sensors that they carry. Additionally, data captured by UAVs need to be complemented by other variables like local climate and soil conditions.

A variety of fixed ground stations are cropping up in fields and greenhouses all around the world, collecting soil data and local climate information. All this information is then fed back to an AI engine in order to produce an actionable prescription map of fertilizer, irrigation or crop protection needs. However, a sensor

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placed at a fixed point in a field or a greenhouse, does not necessarily record the critical conditions of temporal & spatial variability necessary to make informed decisions, thus expensive sensor grids are being utilized. Furthermore, greenhouse installations lack the benefits of stress maps and prescription maps that can be produced through UAV scouting, as is the case with open fields.

The aim of this study is to introduce IoT technologies into greenhouse cultivations (Comba et al., 2010) turning them in effect into smart installations. It also challenges the authority of drones in precision agriculture scouting, since the cablebot- hereinafter referred as *KYTION Aeir* - is also suitable for open-air use, albeit geared towards micro-farm use.

The idea was to develop a cost-effective and autonomous moving sensor box equipped with a necessary array of sensors for indoor and outdoor use. This aerial moving platform (cablebot) would capture data inside a greenhouse much like a drone would do outside and would also provide microclimate data and soil sensitive information. With greenhouses and small to medium sized plots in mind, a cablebot presents an ideal cost/benefit ratio compared to UAVs.

Furthermore, an OEM flow control valve and a user interface app were also developed and are still evolving. The flow valve acts as the main controller of the system and also controls the irrigation of the installation. The web-based application acts as the portal from which growers could receive digested feedback from their smart agriculture system onto their PC, tablet or mobile device (Donovan, 2017).

The development of *KYTION Aeir* aims to increase the quantity and quality of agricultural produce, reduce the carbon footprint of the growing process and provide producers with a broad set of usable data, giving them access to the complete picture of their crop at all times. The system acts as an early warning & smart irrigation (Smith et al., 2010; El-Naggar et al., 2019) solution for farmers and comprises of a set of technologies that could be applied either as standalone autonomous solutions or as an integrated system of all the above technologies, complete with a man-machine software interface for overall control and final decision making.

The final product will integrate data collected from the *KYTION Aeir*, with data collected from weather data via satellites to produce an autonomous smart irrigation schedule for any plot in question. The benefits of using the system can be identified at various levels. The farmer receives though the device an overview of his crop and of the potential dangers that may exist or arise. *KYTION Aeir* is expected to also anticipate and to properly handle phenomena that could damage a crop. As *KYTION Aeir* also automates irrigation and contributes positively to irrigation water savings, the overall physical presence of the grower in the field is greatly reduced too.

The high-level system architecture is illustrated below:

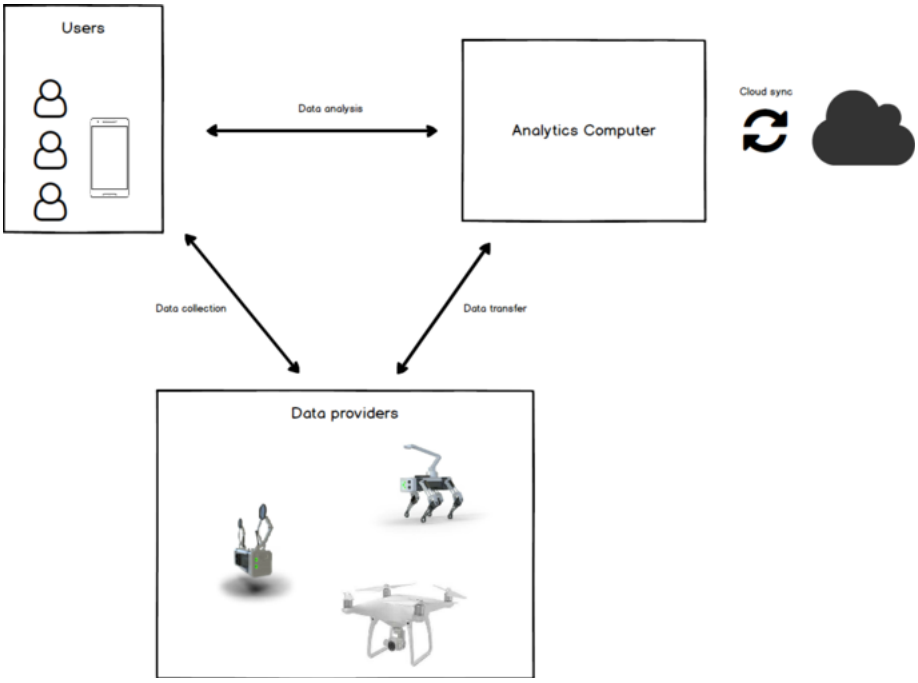

Fig. 1. Cyber-physical system and the interaction among the system parts.

Its core competitiveness lies in systems' ability to integrate data from a variety of data providers (see in fig.1) into a single straight forward application that will assist farmers with their day to day operations (Dhillon et al., 2017). A secondary objective is to introduce cost-effective sensing and spectral imaging inside greenhouses and to reduce the initial cost of PA deployment inside greenhouses. To this respect, extra care has been taken so that the system cost remains low so that it can be fitted to even small greenhouse installations.

The following sections depict the detailed methodology of the cablebot development process and the whole robotic system implementation and demonstration.

2 Development Methodology

The Device development methodology has followed the next steps:

i. Development of functional 3D design for the *KYTION Aeir* printing
ii. Design of its functional circuits with all the necessary hardware
iii. Software programming of all the individual components of the system. (Xbee for communication, Raspberry for control)
iv. Overall check of the proper operation of the device and its components

In addition, a prototype electric flow valve (co-ordinator) was also developed, following the steps described below:

i. Development of a functional 3D design for the solenoid printing
ii. Design of its functional circuit with all the necessary hardware
iii. Software programming the individual components of the system (XBee for communication, Linux SBC for data checking received from the Cablebot and uploading them to our server)
iv. Overall check of the proper operation of the device and its components

Finally, a support/control App was also developed, following the next steps:

i. Development of a prototype user interface app that feeds the end user with digested information and data from the coordinator valve.
ii. Check and double check for user-friendliness (easy to follow & understand)
iii. Improved graphical design
iv. Add-on functions such as manual override etc.

3 Operational Method

The operation of the Cablebot (*KYTION Aeir*) is to be controlled by an Arduino Pro Mini which controls the time intervals between data collection and the overall device movement. The whole process will be controlled by an automatic relay in order to avoid unnecessary waste of energy. A 12V operation is to be achieved through a buck converter.

The cablebot collects data and sends it to the coordinator/flow valve. The flow valve is attached to the zonal irrigation system of a given greenhouse installation or plot. Data will also be automatically uploaded to our server as back up. Various other capabilities are to be addressed at a second stage.

The definitive overall configuration and technical characteristics of the system will be finalized after the completion of a series of test runs in real conditions, in the forthcoming greenhouse installation at the Amaliada Campus of the Agriculture Department of University of Patras. The tests will include the cultivation of high-yield floricultural and horticultural plants, which require strict control of the greenhouse environment, such as for cut flower, vertical strawberry cultivation, continuous tomato cultivation, hydroponics cultivations, etc.

4 Implementation

The moment the Arduino Nano receives measurements successfully (through a pin TX/RX), it sends a signal to the Arduino Pro Mini so that the latter puts the device into stand-by mode. Communication between *KYTION Aeir* and the electric valve begins through XBee technology, which sends encrypted data packets to the coordinator/flow valve. Once the data is successfully transmitted it is decoded by a NodeMcu chip it is uploaded to our database.

The ESP of the coordinator will be replaced with a NodeMcu so that the voltage can be converted easily through the Vin pin. The coordinator will also boast an LCD screen for debugging.

Decisions for irrigation/fertilization will be made through our proprietary AI (based on neural network technology) models (Helong et al., 2010) after all collected data has been analyzed and combined with data from external sources such as satellite weather data etc. All data processing is to be handled locally so that the system will not depend on 3G/4G network availability on-site.

The control app/user-interface tool is developed using Node-RED. The control app has a back-end and a front-end architecture. The back-end serves as a programming interface and the front-end serves as the user interface. Should a potential danger or a critical situation is identified; the end-user will receive an alert through the app.

Tools that will be utilized to develop *KYTION Aeir*:

- *Solidworks* to design the hardware.
- *Ultimaker Cura* to convert SLT to G-CODE.
- A *Creality Ender-3* 3D printer to print the prototype *KYTION Aeir* and the electric valve. Printing occurred with 20% infill and 0.2 layer height extra supports were needed. Print material was *eSun PLA+*
- *Arduino IDE* to program the Arduino boards.
- *XCTU* to program the XBee's.
- *Raspberry Pi SBC* to run the neural networks and PuTTY to gain remote access.
- *LabVIEW-NI* to test the overall performance of the system.
- *OpenCV* and *TensorFlow* for image recognition
- *Fritzing* to design the PCB's.
- *Firebase* database for measurements.
- *Node-RED* to develop the control app.

The *KYTION Aeir* embedded sensors are:

- Relative humidity sensor
- Air composition sensor
- Temperature sensor
- RGB & Spectral sensor (Ujjwal Mahajan and Bharat Raj Bundel, 2016)
- Sunshine sensor
- Rain sensor (for outside use)

The systems' reproducibility is ensured by the use of the above list of easily sourced hardware and software tools.

5 Demonstration

The resulting device can be seen in action in the following video:

https://www.youtube.com/watch?v=Fkrah_vgTnE

Moreover, a series of photos are given.

Fig. 2. The prototype KYTION Aeir device being tested.

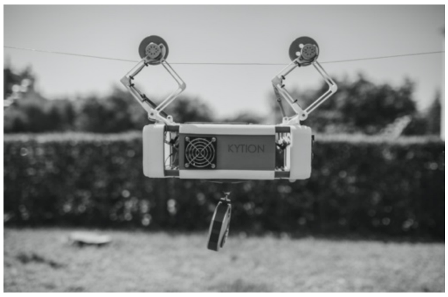

Fig. 3. The prototype KYTION Aeir device (side view).

6 Conclusions

An integrated IoT-based robotic greenhouse control system, a cablebot device, was developed together with a prototype electric valve (coordinator) and the necessary interface app. The operation of the whole system has been initially tested and is now being installed in a greenhouse installation, belonging to the Agriculture Department of the University of Patras

The system is capable of collecting a series of crop sensitive data and performs autonomously a number of tasks such as automated smart irrigation. On site testing with real measurements, data collection and mapping will be the subject of further study.

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