UV-ROBOT SUPERVISION SYSTEM DESIGN AND DEVELOPMENT

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Abstract. Introducing the supervision system architecture of an agricultural robotic system enable the improved performance overcoming the complexity that current autonomous robots face due to the dynamic and unstructured agriculture environment. This requires the design of a human-robot interface. When designing a user interface several principles must be considered aiming to improve the usability of the user interface. This paper describes the design of the GUI web application and the coverage planner suitable for controlling the UV-Robot for typical coverage style greenhouse mildew treatment operations. The cross-platform user interface allows the farmer to specify their farm including fields, roads and docking stations, as well as controlling the whole operation. The contribution of this paper is to specify the design guidelines and the development of a user interface for a human-agricultural robot, in the case of UV treatment. Along with identifying the supervision system architecture and the communication control development, connecting the farmer, the UV-Robot and the cloud server associated.

1 INTRODUCTION

Fungi are multicellular organisms which include mildew, molds, and mushrooms. As with all fungi, mildew grows on organic material in conditions of humidity and within a certain temperature range. Fungi reproduce by spreading airborne spores that can establish new colonies elsewhere. Extremes of cold and heat can kill mildew, but fungal spores can tolerate these conditions and remain dormant until the environment is ideal for growth.

Though part of the fungi family, "mildew" refers to a mold which is growing on fabric or any other covering made of organic matter. As with all fungi, mildew does not produce food by photosynthesis; it extrudes roots, or "hyphae" into the material it is growing in. The hyphae secrete enzymes which breaks down organic matter into compounds the mildew fungus can absorb for nutrition. This leads to damage to whatever the mildew colony is growing on. Optimal conditions for mildew growth are 60 percent humidity in the environment, with a temperature of between 10 to 32 degrees Celsius.

Ultraviolet or "UV" light is a wavelength of radiation. It is part of the electromagnetic spectrum, which includes microwaves, visible light, and infrared radiation. Each wavelength of radiation is composed of an electric and magnetic field, with energy moving back and forth between them. All radiation vibrates at a particular frequency and moves at the speed of light. Ultraviolet light has energy characteristics which make it effective in destroying microorganisms such as fungi. When exposed to UV light, the genetic material in cells is damaged as chemical bonds are severed within the DNA structure. Prolonged exposure to UV light inflicts more damage to the point where the DNA cannot be repaired and cells die as a result. UV light is used to control fungal growths in homes after water damage and to treat items infested with molds, such as books and museum exhibits [1].

In the North West European countries (NWE), fruit, fresh vegetable, and spice production is a prosperous and innovative component of the economy, but the intensive use of pesticides is still widespread. An important disease in many crops is downy mildew, the chemical treatment of which contaminates other crops. In the case of strawberries, the spray against powdery mildew can leave up to 6 active ingredients (40% of the residues). Several research studies have shown that Ultra Violet Type C (UV-c) is effective for the physical control of mildew and can become a sustainable alternative [2]. For strawberries, this treatment can reduce the rate of residues by up to 10%. Due to the high degree of manual labor and the risk of exposure to the radiation, the UV-c technique is not yet used in NWE horticulture [3].

The aim of the “UV-Robot" European project is to develop autonomous mobile robots able to analyze and to disinfect the mildew disease affecting widely various kind of the agricultural crops specifically strawberry, cucumber, tomato, lettuce, and basil, using the UVc rays. To well operate this disinfection mission, ensure targets and complete tasks, an intelligent supervision system along with an adapted user interface is to be designed and developed. Several technological, functional and temporal constraints must be taken into account in order to ensure effective use of these robots. The supervision of these robots represents a challenge for development. Indeed, the efficiency of these robots requires a graphical interface facilitating the programming of robots and allowing the farmer to choose the best options for treatments.

In fact, farmers are under growing pressure to increase production, a challenge that robotics has the potential to address. A possible solution is to replace large farm machinery with numerous smaller robots. However, with a large number of robots it will become increasingly time-consuming for the farmer to monitor and control them all, hence the need for an effective user interface and automatic multi-robot coordination [4].

CESI's LINEACT laboratory participates in the "UV-Robot" project for the development of an ergonomic and efficient supervision system for planning and monitoring the tasks of the processing robots. In this project, we work on the development of a supervision system usable from several types of terminals (computer, tablet, mobile phone) along with specifying the communication protocols between the different elements in the system. Two main features of the interfaces will be developed; the first one for the definition of the mission of the robot and the supervision of its execution, and the second one for the direct control of the robot (manual control).
This system allows the UV-robots to accomplish tasks autonomously. A specific and safe plan is optimized according to the field specification and disease potential. Through the user interfaces, the robot is controlled manually and automatically by the farmer and/or by the cloud management, all connected, coordinated and supervised through an intelligent network and communication control system. This constitutes a kind of Internet of Robotic Things IoRT, an innovative and emerging vision that brings together pervasive sensors and objects with robotic and autonomous systems as claimed by Simoens et al. [5].

The rest of this paper is organised as follows. Section 2 presents the innovative UV-Robot project in comparison with some existing relevant projects. In section 3 we define the middleware challenges of the mildew treatment in the agriculture greenhouses. Section 4 shows the UV-Robot graphical user interface. Finally, the supervision system architecture is targeted in Section 5.

2 UV-ROBOT, AN INNOVATIVE MIX

Robots applications have been increasing since the last few decades, from civilian search and rescue, agriculture and medicine to military missions. In agriculture, they are used to ensure the human’s safety from unhealthy and risky tasks, the high productivity and the precision agriculture. A problem that comes up when it is necessary to work with a robot or a fleet of robots in the field is having an adequate supervisory system [6]. In the following, we firstly review the existing robots and the relevant projects in the agriculture sector. Secondly, we present the innovative UV-Robot project in details.

2.1. Existing robots and relevant projects

Many robotic projects already existed in the agricultural field providing several activities and serving the cultivation process. On the other hand, the robots are well integrated into the healthcare domain, assisting the disinfection process in the hospitals and working alongside with the Clinical Lab Technicians.
The robot, called "Bonirob", has been developed to reduce the environmental impact of farming by optimizing fertilization and monitoring crop growth. It also makes farm work easier and greener by automating the weeding process without the use of controversial herbicides [7].

The project "Robot Fleet for Highly Effective Agricultural and Forestry Management" (RHEA) was implemented to integrate smart and autonomous robots to farms, in order to develop the concept of the “farm of the future". The global approach consists of conducting experiments and evaluating a new generation of automatic systems and fleets of robots for chemical and physical weed management and crop spraying. The aim of this project is to reduce the use of chemicals in agriculture and to decrease production costs while improving crop quality, health, and safety to both humans and animals [8].

In the healthcare sector, disinfecting UV-rays robots developed by “Xenex”, are portable, automatic and self-contained. Some units use low-pressure mercury lamps, non-mercury, and xenon-lamp. These robots have increased in popularity and are being trialed and implemented in hospitals to perform the disinfection of patient rooms and operating rooms.

2.2. UV-Robot in the agricultural field

The UV-robot is an innovative project mixing both the agricultural and the disinfection facilities. As part of the European project "UV-Robot" mobile robots (see Figure 1) will be developed and tested in order to make the UV-c treatment for crop protection against mildew in horticulture [9]. The goal is to develop a UV-c strategy for five crops (strawberry, tomato, cucumber, lettuce, basil). The automation of the UV-c application is essential for the implementation of this technology and will increase innovation in horticulture. This automation aims to reduce the labor cost of this treatment and to improve health and safety of the production operators.
UV-robots will be developed to move through different crop types. For each crop type, a specific version of the robot will be designed to treat mildew in a typical greenhouse cultivation system. To stabilize the UV lamps when driving through the crop an adapted suspension should be implemented to deal with soil undulation. An autonomous localization system will be integrated into the robot; this will make it possible for the robot to move through the crop along a pre-set path. Each robot needs to optimally treat the cultivation with UVc-light. A unique system will be delivered to autonomously localize the robot.

Figure 1 UV-Robot, by “Octinion”.

Existing sensors will be adapted to detect the specific strains of mildew. The E-nose will incorporate an environmental sampler, developed by “RoboScientific”, which pumps air from around the plants through an absorbent pad to concentrate the Volatile Organic Compounds VOCs to be measured by the sensors. A number of operating parameters (sampling period, sensitivity, digital VOC fingerprint) will need to be fine-tuned to optimize the performance of the system. Three sensors will detect specific species of powdery and downy mildew. First of all, the grower uses the interface to implement the cultivation area to determine the path planning for the treatments. Second, while driving through the crop the robot will monitor for mildew presence.

Visualized on an interactive map, the grower can evaluate the treatments. Finally, the grower can adapt the next treatment and avoid further infestation in certain locations in the greenhouse. The user interface allows the grower to define the working surfaces of the UV-robot on which the path planning should be based on. Using this input the robot can navigate through the crop with the autonomous localization. The output will show on an interactive map the localization and the severity of mildew in the greenhouse. An interactive map will allow the grower to adapt the next UV-c treatment. As the vehicle should work autonomously in treating crops for mildew, it should be safe in all aspects: human, crops, and environment. An elaborate risk analysis will be performed on the operation vehicle and the use of UV-c lamps to avoid human and plant damage. During field tests, the vehicle will be monitored and safety-critical situations will be evaluated by clearly describing the scene and the conditions of the robot. Accordingly, procedures will be set in order to guarantee the safe operation in greenhouse cultivation.

3 MIDDLEWARE CHALLENGES

The past decade has witnessed a huge increase in the number of proposed middleware solutions for robotic operating in unstructured environments. As a result, it has become difficult to decide which middleware is the most appropriate for a specific application or domain. This section gives an overview of the most relevant challenges to be considered when designing the middleware of the supervision system of the UV-Robot.

3.1. Global design challenges

Drenjanac and Tomic [10] proposed a classification of middleware challenges according to their specific domains of concern. These challenges are derived from a specific precision agriculture use-case based on the robotic fleet for weed control, which was elaborated within the framework the European project RHEA-robot fleets for highly effective agriculture and forestry management. When a new application is being developed, understanding the challenges of a specific application domain is the first important step towards making the decision which middleware to use. According to this analysis, several criteria and missions have to be defined, aiming to well develop the treatment strategy. After the mission is defined, it is decomposed into a set of tasks and assigned to corresponding robots. The centralized control system is responsible for both task-robot mapping and robots' coordination during the mission execution. During the mission, distributed robots report their status to the base station (user) who supervises the mission and acts as a central point in the system. The base station is a place that manages, coordinates, makes decisions, collects data, instructs, and monitors all robots in the network. The result is the classification of middleware design challenges, addressing three domains of design decisions [10]: General Fleet Realization Challenges, Environmentally Imposed Challenges, and Task Dependent Challenges.

3.2. Power supply availability, limits, and constraints

Another main challenge in our project case is the power supply. Power consumption is mainly due to: the robot’s movements, the UV lighting, sensors, the network and communication center, the towers or access points, and the user interfaces (tablets, PCs, phones). The strategy of the power supply and resources could be developed by defining the required power consumption of each component of the system after choosing the best technology and optimizing the power saving ones. Then leading the power system size can be reduced. Moreover, the installation of the docking station (refuel or rechargeable stations) is necessary to complete tasks according to an efficient optimization architecture, and considering each field specifications.

3.3. Input and output data to be exchanged

Precision agriculture is about applying the right treatment, at the right place and at the right time [11]. The key factor behind the right treatment and the overall robot scout technology is the ability to communicate with the swarm at each moment transferring and receiving data and orders through the network. Some of these data transferred to the swarm are coming from the cloud management system or the base, while some others are collected by the robots' sensors. Referring to this fact, we divide our data into two categories: input and output data. With the aim of avoiding conflicts, this categorization is classified from an operator point of view:

- Input data: This data category contains any information added to the system, which can be added manually by the farmer or automatically analyzed and visualized by the robots. Basically, the information (or the sensors’ data) in need can be listed as follow: Navigation (row detection, ground detection, mapping, turning control, ...), Localization (Global Positioning System GPS or the Global Navigation Satellite System GNSS), and Autonomy.
- Output data: These data correspond to the order received by the robots, coming from the user interface or the base station, the web user or the system itself. Several kind of orders are to be developed depending on the operating mode either manual or automatic: UV doses or treatment level, the greenhouse dimension and the architecture specifications, the path planning and the operation instructions, the operation schedule and timing, the day or night operation with the specified starting time, testing and regulation purposes. Other tools can be fitted into the system for other applications when necessary, which collect data for the accomplishment of the good treatment: measuring soil density (soil can be examined to a depth of 800mm per example), measuring air temperature and moisture, etc...

4 GRAPHICAL USER INTERFACE GUI

There are many factors to consider in Human-Robot Interaction HRI design, such as ease of use, user workload, information flow, software maintenance, and robot maintenance. Although, the GUI display is essential to supervise the whole system by allowing the visualization of internal state, it can become cluttered and inefficient, if it is not designed properly [12].

4.1. GUI functionalities and design principles

In order to well design our user interface, it is relevant to start by defining the main functionalities: the GUI design usability and acceptability [13], and the GUI awareness (location awareness, activity awareness, status awareness, surroundings awareness, overall mission awareness) [14]. Several design guidelines and principles are considered based on many studies concerning the GUI design [14]: visibility, safety, simplicity, feedback, extensibility, and cognitive load reduction.

4.2. GUI development

When developing user interfaces there are two approaches: web-based and a native application.

The web-based approach is the development of a website in languages such as HyperText Markup Language (HTML), JavaScript, Cascading Style Sheets (CSS), and Hypertext Preprocessor (PHP), and takes advantage of web browsers to provide support for multiple devices. Alternatively, native applications are developed for a specific device and can be optimized to run more efficiently in some specific cases. Typically, these applications are precompiled and installed on the target device. Each platform requires a software development kit and framework. Native applications can also employ a variety of networking techniques to communicate to any robot middleware [15].

Otherwise, taking into consideration the GUI objectives, referring to the project management strategy, it is relevant to respect the project development sequences and goals, in order to achieve the well done operation monitoring regarding all constraints and aspects. In our case, at the early stage of the system development, and in order to boost the treatment trial operations along with testing carefully the optimized system, the GUI is implemented as a web application. The UV-Robot web application has the major role in running the system properly, as a result of the trials feedback concerning the supervision coverage, the treatment itself and the optimized treatment plan efficiency, and the whole system reliability. The GUI web application gives the user a wide range of flexibility in terms of end-use devices, and offers the quick ability to develop a specific IPhone Operating System (IOs) or android phone application in advanced stages, if needed.

Starting from the greenhouse specifications and the mildew level divisions, a lightweight data-interchange format JSON (JavaScript Object Notation) or XML (Extensible Markup Language) file is generated. This file lists the main field specification. It could be generated through the web application directly, uploaded from any PC, or even accessed from the system web server by an admin user.
After choosing the desired option, the specification file is transmitted to the web server, where it can be treated with the simulator, sending back a new generated file (with the same format) containing the optimized treatment plan, along with the docking (recharging) stations number and framing grid, according to each field architecture.

In order to set up the settings and run the robot, this file is then sent through the communication control system as a light packet to the UV-Robot micro-controller. In fact, the JSON and the XML formats are frequently used between a server and a web application. In addition, it must be noticed that working with these formats facilitates the robot micro-controller python programming and enhances the processing speed. As it is well known, the JSON and the XML modules enable the simple convert and parse processes into Python Objects fluently. On the other hand, what makes the GUI application light and facilitates the communication system development is the fact that the system is not supposed to handle and transmit some heavy data such as live streaming videos or pictures.

The application gives the user the ability to supervise the whole treatment operation, showing instantly the treatment evolution and the robot position as well as the treatment estimated and remaining time (see Figure 2).
The code is well developed thanks to the Extensible HyperText Markup Language (Xhtml) web pages, the CSS formatting, the JavaScript applications using React library for building user interfaces, jQuery (JS library) and AJAX technique for accessing web servers from a web page, which stands for Asynchronous JavaScript and XML).

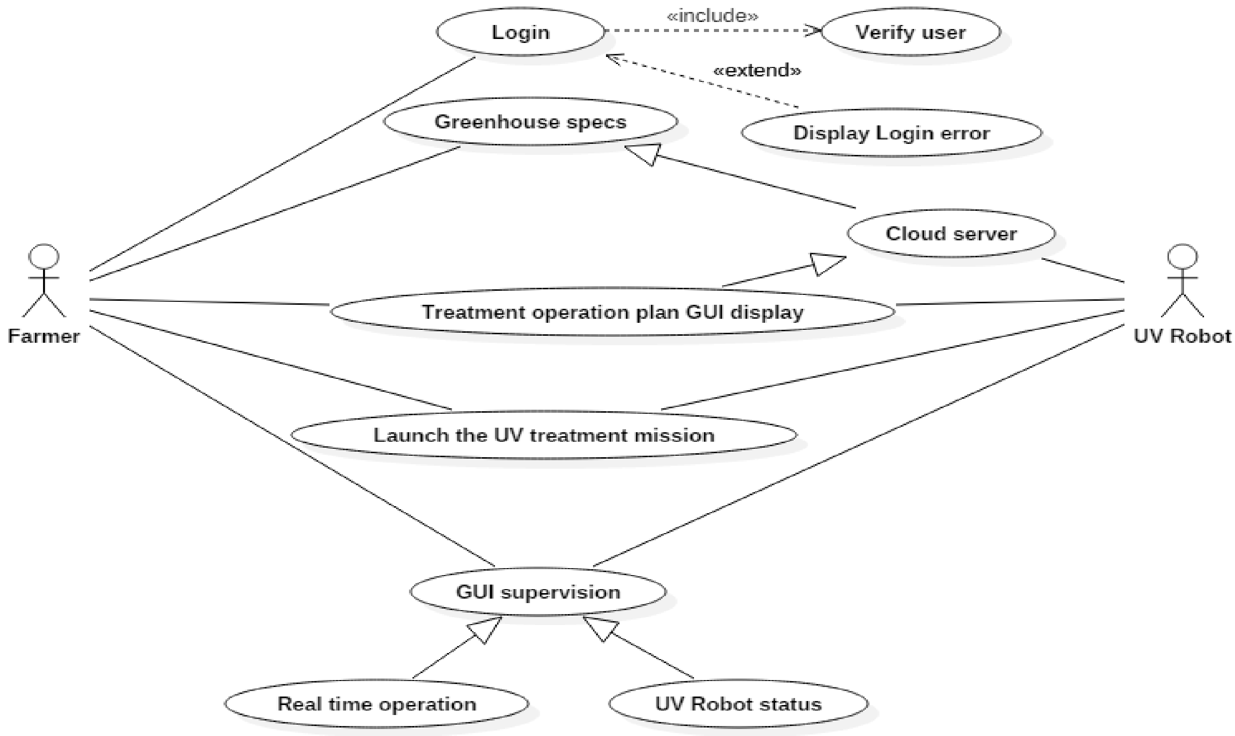

Figure 2 UV-Robot web application use case diagram

The layout of the interface consists of several windows (see Figure 3,4):
- The welcome page window.
- A window for setting the greenhouse specifications.
- A window for the mildew treatment configuration: doses, day and night treatment.
- A window for the greenhouse treatment plan configuration.
- The main window displaying the running treatment operation.

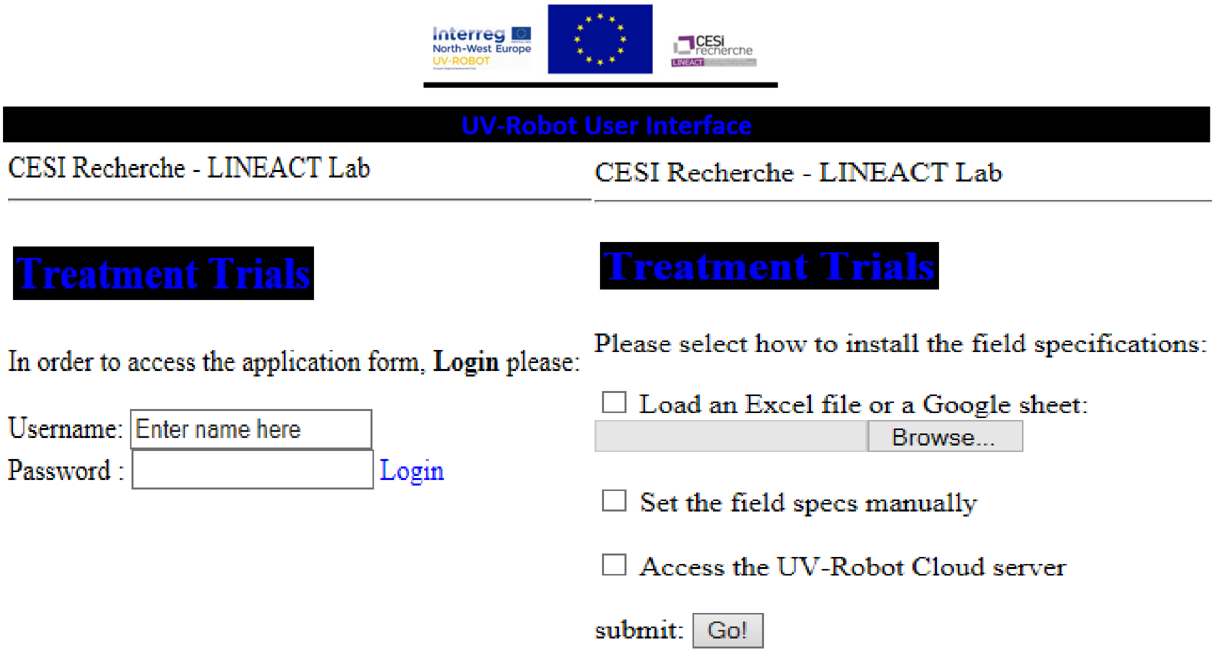

Figure 3 UV-Robot web application, sign in and settings pages.

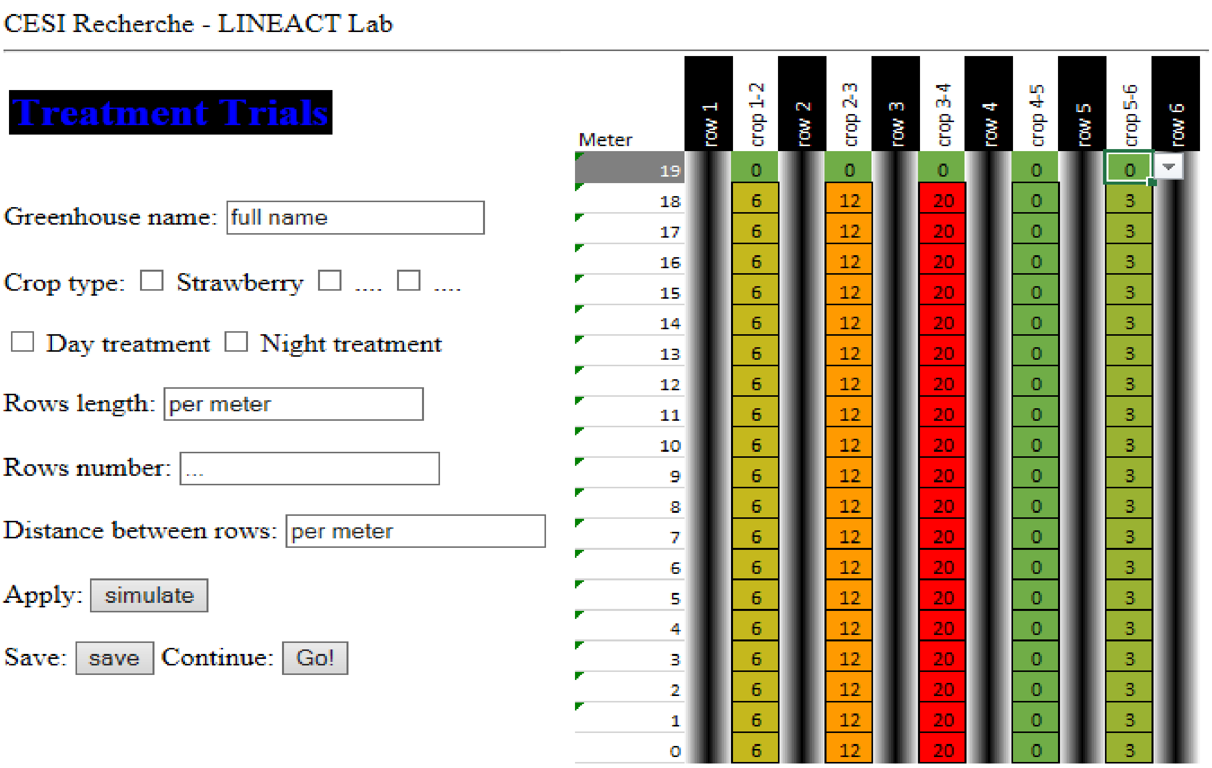

Figure 4 UV-Robot web application, specification sheet and GUI.

The robot control is the main function of the interface. This allows the operator to have access to all the functions available for interacting with the robot, which are:

- Overview Map of the Environment: This area is used to display the generated map of the environment. The map includes the location of the robot in the greenhouse.
- Robot Sensor and Actuation Display: Displaying the status indicators of the robot, currently robot velocity, level of battery, etc...
- Autonomous/Manual Mode control: Allows the operator to change the level of autonomy of the UV-robot.
- The user interface is able to run on a variety of platforms including Windows, and Linux.
- Through the GUI, the user can get an approximation of the needed time for the treatment operation execution regarding the current disease presence and the greenhouse specifications.
- Stop option: When the stop button is clicked, all processes will be terminated.

5 SUPERVISION SYSTEM ARCHITECTURE

The definition of the network system depends on the level of automation required, the level of supervision required, and the resources availability. Several network technologies can be used separately or combined depending on the data transfer awareness such as the General Packet Radio Service GPRS/3G/4G, Bluetooth, Wi-Fi or ZigBee. The challenges in using any communication protocol are the field coverage, the data transfer package, the power consumption and the cost. The aim of choosing any transmission mode and data formats is to improve the Human Machine Interface functions during the treatment operation execution.

5.1. Network and communication control

The definition of the UV-robot network and communication system components includes: the base station, the field communication towers or routers, the robot devices sub-system, the cloud-based system and the web server. In order to be a platform for different developments, the system hardware needs to be designed to support not only a specific task but also a wide range of applications. In our system, the hardware design is divided into: the communication configuration, the sensor and actuator, and the user interaction; each is to be developed with the feasibility, the flexibility and the extendibility in mind.

5.2. Transmission modes and data formats

There are two modes of transmission: either broadband landlines or alternative mobile long-range transmission technologies, e.g. 3G, Short Message Service (SMS), and Multimedia Messaging Service (MMS) [16]. The regional combination of sensors, Wi-Fi, 3G, RFID, NFC (near field communication), and Bluetooth will allow significantly improved measurement and monitoring methods of the agricultural cultivation. In addition, the sensor technology is becoming available at much lower cost and with built-in support for network connectivity and remote monitoring. In the UV-robot supervision system we will examine the following cases of data transmission: The Global System for Mobile Communications, Bluetooth, The Radio-Frequency Identification RFID, The Wireless Local Area Network (WLAN), and ZigBee (see Table 1).

Technology	WIFI 802.11	Bluetooth 802.15.1	ZigBee 802.15.4
Frequency	2.4 GHz	2.4 GHz	2.4GHz-868/915 MHz
Modulation	OFDM	FHSS/BPSK	DSSS/QPSK
MAC	CSMA/CA	TDMA/TDD	CSMA/CA
MAX. data rate	54 Mb/s	1 Mb/s	20/40/250 Kb/s
Device types	One	One	FFD/RFD
No. of channels	11-14	79	26
No. of devices	32	8	Up to 65 535
Battery life	Days	Weeks	Months
Coverage (m)	100	10	15/50
Topology	Star	Star	Star and cluster-tree

Table 1 Comparison of parameters of various wireless technologies [17].

5.3. Supervision system architecture

Our work focuses on three of the available technologies for data transfer, in mobile communication, SMS, GPRS, and Wi-Fi/ADSL (Asymmetric Digital Subscriber Line) technology, which are currently the dominant ones and which are expected to remain important in years to come as well. In our scenario, the UV-robot may have any kind of sensor devices, enabled with Bluetooth, Wi-Fi, NFC, RFID, cabling or any other kind of technology collecting information and allowing for data registration and communication with a mobile phone or a PC. The Robot's position can be determined through GPS technology, if the mobile device supports it, or alternatively through possible Wi-Fi technology in that area, or even through mobile telephony antennas, providing different levels of accuracy. Some kind of appropriate mobile or web application exchanges data with a web service, and depending on the technology used for the data transfer, two architectures arise, which are briefly described below.

- In the 1st architectural approach, the mobile application is connected to the internet through its Mobile Telecommunications Provider, using GPRS technology. After the connection is established, the application sends data directly to the robot also connected to the internet. A 3G USB (Universal Serial Bus) device with an internal mobile Subscriber Identity Module (SIM) card can be used. The USB is to be plugged into the computer inside the robot and registered to a mobile phone service provider allowing it to have access to the Internet. This simple configuration enables the robot to connect to the Internet without any restrictions in physical distance, as far as the 3G mobile signal is presented almost everywhere.
- In the 2nd architectural approach, the mobile application exploits the established ADSL internet connection and the existence of a wireless router. Data are sent to the wireless router using Wi-Fi technology and then are forwarded to the robot and vice versa. Using Wi-Fi technology, which is already included in many mobile phones provides a benefit in enabling the agricultural robot control. The connectivity aspect is to take the data from a smartphone or PC and send it to the robot.

6 CONCLUSION

The need of an effective supervision system for the robots in the agricultural field has guided the researchers and the engineers to improve and implement several user interface designs and communication control architectures. Depending on the operation configuration, the mission tasks, and the field specifications, the supervision system design and development is a big challenge to be addressed, in order to run the project properly. Based on our review concerning the development of a robotic supervisory system in the agricultural field, the guidelines of the research work and the implementation of the UV-robot GUI web application are defined. A suitable design of a user interface and coverage planner for controlling and monitoring the UV-robot for typical coverage style farm treatment operations are proposed. The cross-platform user interface allows the farmer to specify the greenhouses including disease potential, roads, docking stations and all needed specifications, well optimized to fit the field requirements. Many factors are to be addressed in order to create the ideal network architecture, mainly the coverage planner, the power consumption and the operation efficiency. In an advanced stage, an innovative task to be defined, addressing the development of the cloud management and a web server, aiming to collect data information about the treatment operations and to set the optimal management plan for a specific mission and using an autonomous fleet of UV-Robots.

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