POSSIBILITIES OF IOT BASED MANAGEMENT SYSTEM IN GREENHOUSES

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Abstract

The widespread use of information technologies provides new opportunities for agriculture to achieve optimal results. The IoT (Internet of Things) and Big Data, parts of the Industry 4.0 concept, provide methods to establish primary databases adjusted to the needs of the specific farm. Previously, several modular, multifunctional data acquisition systems have been developed, to measure factors at multiple spatial points. In the following, an experimental, cost-effective greenhouse management system will be presented, based on the 5th generation reference system. During the first test, the system provided multi-point environmental data to discover the characteristics of the greenhouse, to meet the decision-makers requirements and to use it as basis for controlling, thereby ensuring optimal environment during the production. To store measurement and additional data, describing the farm for management purposes, databases and a module for the web-based application was developed to ensure data integrity. The application provides functions to manage the system and to analyze as well as visualize data through ETL processes. In the paper, the initial steps of the experiment have been presented, including the opportunities, the sensor network, the management application and a test to gather real-time experience to support the development of further features.

Keywords: internet of things, sensor networks, environmental data acquisition, greenhouse, decision support

Összefoglalás

A fejlett információs technológiák elterjedése új lehetőséget biztosít a mezőgazdaság számára az optimális eredmény elérése érdekében. Az IoT (tárgyak internete) és a Big Data, az Ipar 4.0 koncepció részeként új módszereket biztosítanak primer adatbázisok létrehozására az adott farm igényeinek megfelelően. Korábban több moduláris, multifunkcionális adatgyűjtő rendszer fejlesztésével foglalkoztam a különböző faktorok több ponton történő mérése érdekében. A következőkben egy költséghatékony fóliasátor menedzsment rendszer kerül bemutatásra, mely az 5. generációs referenciarendszer alapján készült. Az első teszt alatt a rendszer több ponton biztosított környezeti adatokat a fóliasátor karakterisztikájának megismerésére, a döntéshozók igényeinek kielégítésére és vezérlési módszerek alapjaként való alkalmazására, mely biztosítja a termelés alatt az optimális környezeti feltételeket. A mérések és a gazdaságot leíró, menedzsment célú további adatok tárolása érdekében adatbázisok és a web alkalmazás új modulját alkalmaztuk az integritás érdekében. Az alkalmazás lehetőséget biztosít a rendszer menedzselésére, az adatok elemzésére és vizualizálására ETL folyamatok segítségével. A cikkben a kísérlet kezdeti lépéseit mutatjuk be, beleértve a lehetőségeket, a szenzorhálózatot, a menedzsment alkalmazást és egy tesztet a valós-idejű alkalmazással kapcsolatos tapasztalatok gyűjtése érekében, mely segíthet a további funkciók fejlesztések során.

Introduction

There are several new opportunities that arise through the development of the information technologies. The IoT (Internet of Things) concept and its technologies, defined also in the Industry 4.0 standard proves to be an effective method to provide measurable, quantifiable data in order to reveal previously unknown relationships between the measured data and other data sources, describing additional factors. Depending on the examined activity, the related data can influence the result directly or indirectly, which makes it important to collect and analyses them in order to optimize the process. Accordingly, more and more sectors try to adopt and use the technology to keep pace with the further development. This is no exception to the agricultural sector, which uses various methods described in the concept of precision agriculture in order to meet the expected doubling of crop demand from 2005 to 2050 (Tilman et al., 2011). In addition, there are other challenges of agricultural production in terms of environmental impact, food security and sustainability (Gebbers & Adamchuk, 2010). In case of precision agriculture, the first application area people think of are the machines, equipped with sensors and actuators, operating based on the measured data using a predefined algorithm. These are predominantly mobile devices however, there are activities in which the use of a local system is needed in order to achieve similar benefits. It can be a livestock farm, a processing plant, a warehouse, a transport vehicle or a greenhouse which will be discussed later. This paper is an introduction to a series of greenhouse experiments which I would intend to perform through multiple topics in the future. Several data acquisition and control systems were developed in the recent years to perform similar tests mainly for personal use in agriculture and other activities. Accordingly, it is understandable to start experimenting by integrating a similar system and optimizing it to adapt to the characteristics of the production in greenhouses in order to see some of the potentials which can be achieved using this technology.

Industry 4.0 is a data exchange and automation approach to manufacturing technologies that embraces a wide range of current concepts, including the so-called smart factory, whereby manufacturing tools are equipped with sensors and actuators, thus forming an autonomous system (Lasi et al., 2014). Some of the included concepts and technologies are IoT, Big Data, cloud computing, process control methods, augmented reality, intelligent robotics, data security and additive manufacturing (3D printing) (Luque et al., 2017). Apart from analyzing the data, using M2M (machine-to-machine communication) is also advantageous for control purposes. In addition to the PID (proportional–integral–derivative controller) based controlling mechanism, the current model-based approaches, including the Fuzzy Logic and the neural network-based methods can also be supported with data, provided by the WSN (Wireless sensor network) devices, described as the part of the IoT concept (Huang, 2013). Because this paper predominantly builds on the IoT concept, we should describe the basic understanding behind the technology. The concept consists of four pillars. The first pillar is the WSN mentioned above, while the other pillars are M2M (machine-to-machine communication), RFID (unique identification and tracking based on radio frequency), and SCADA (monitoring and data collection) (Zhou, 2013). A sensor network consists of structured or unstructured nodes that collectively monitor or track determining factors of a particular area. The low-power nodes consist of a controller, one or more sensors and actuators detect, measure and collect sensory quantifiable environmental data, which thereafter are transmitted to the user in order to support the local decision-making process (Yick et al., 2008).

In precision agriculture, data acquisition and control procedures range widely, from automatic steering to the determination of certain quality parameters via pattern recognition using machine vision and artificial intelligence (Patrício & Rieder 2018). This paper predominantly focuses on greenhouses; therefore, the later mentioned examples are also related to this. Multi-point data acquisition in greenhouses is a known topic, however, implementation is always different. Some experiment uses off the shelf component, like Arduino development board (Aiello et al., 2017) or MicaZ nodes (Akkaş & Sokullu, 2017), but some experiment utilizes custom developed systems (Park – Park, 2011) to adapt to the task. The measured parameters however are similar, including temperature and humidity sensors, soil moisture sensors (Balaji et al., 2018), illumination, CO_2 concentration, soil temperature (Lin & Liu, 2008), pH meter, as well as imaging sensors for machine vision algorithms to estimate leaf area (Liao et al., 2017), detect pest early (Boissard et al., 2008), or automate harvesting based on the classification of the visible quality parameters (Rajendra et al., 2009).

After the data acquisition, the next step is to utilize the collected data. The data can be used to control the environmental conditions or to discover new relationships by analysis in order to help the decision-making process. In terms of control methods, we have more options available to optimize the microclimate of a greenhouse, including Fuzzy Logic Control (FLC), Adaptive Neuro-Fuzzy control (ANFIS), Artificial Neural Network control (ANN) and PI control (Atia & El-madany, 2015). The quantity and structure of the data provided by the IoT conception require new methods in order to gain information. Data management can be facilitated by farm information systems which can handle the measured spatial data in addition to modules, like operation management, reporting, finance, site-specific systems, inventory, machinery management, human resource management, traceability, quality assurance, sales and best practice in order to enhance the decision-support process (Fountas et al., 2015). As far as further analytics goes, there are several models which can be implemented to use sensory data as well in order to support the decision-making process, including probabilistic and optimization models, supervised learning models, Bayesian models, time series analysis and genetic programming, based on a paper describing the AgroDSS system (Rupnik et al., 2018).

Material and methods

In this chapter, we will be discussing the devices and methods used in the data acquisition process and the environment where the test has been implemented. This is the first test using some of the modules from a new reference design of a custom developed data acquisition system. Accordingly, the test provided a sample dataset containing real data, ready to be analyzed as well as valuable experiences with the new system.

The test in question took place in a greenhouse as they have always considered as a favorable environment for test processes because of their nature of a closed system. This helps to illustrate the possibilities of the multi-point data acquisition method and it provides a basis for developing and using various environmental control methods in the future. The environment, where the test was implemented has a relatively small scale with a height of 2.64 m, maximum width of 4 m, length of 6.5 m and accordingly, volume of roughly 62 m^3. The main difference of this greenhouse (Figure 1.) that it is located 1 meter under the ground which may show distinct characteristics compared to conventional greenhouses because of the insulating effect of the soil. The main parameters, describing the shape of the greenhouse are stored in the database of the reference system in order to utilize the 3D data processing and visualization.

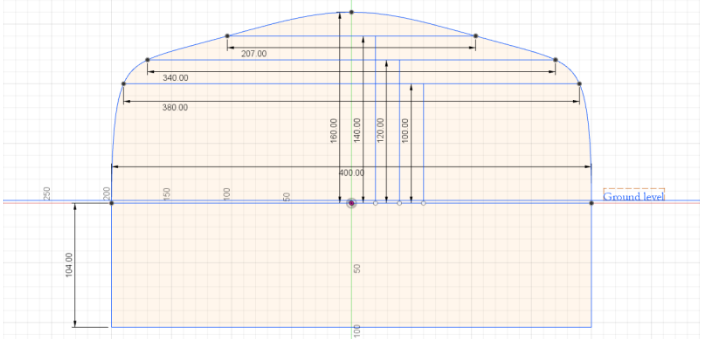


Figure 1.: Sketch about the greenhouse from a front view (values in centimetre)

Source: own figure

Before the test, multiple hardware and software development was needed in order to adapt to the circumstances. The following figure (Figure 2.) shows the logical structure of the system, including the modules from the reference system (blue), the modified modules, based on the reference system (red) and the modules developed specifically for this test (green).

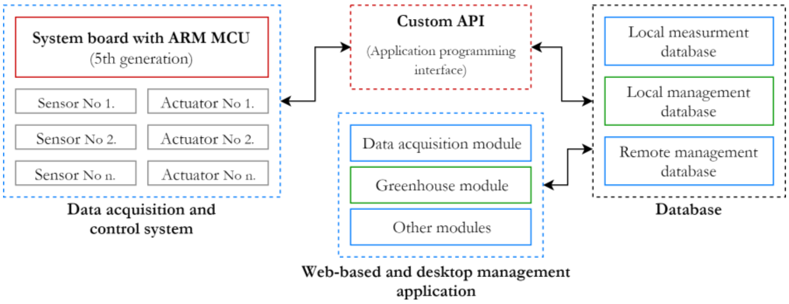


Figure 2.: Logical structure of the system

Source: own figure

Based on the figure we can distinguish between the data acquisition system (including hardware and its software) and the server-side supporting subsystems, including the API, databases, and management applications. The data acquisition system used in this test is based on the 5th generation, MCU independent (can be used with MCUs using ARM and AVR architecture as well) reference system which is still under development right now. It is developed considering the previous experiences and needs to be the successor of the 3rd and

4th generation reference system, used in various tests before in the field of multi-point data acquisition. The controller board includes all the basic components, necessary for the designed operation, like MCU socket, RTC (real-time clock), EEPROM, wireless network controller, LED driver, SD card socket, LED indicators (green for normal operation, yellow for measurement and red for error), expansion socket (for LCD, GSM and Ethernet controller) and the sensor connectors, supporting multiple communication protocols. The main purpose of the controller board is to provide a uniform interface for the devices providing the same connector and protocol for every sensor and additional component in order to optimize the installing procedure. Overall 16 sensors were used during the test which can provide 10 different data types, describing the environment where they reside. The data types include interior parameters such as temperature and humidity in 8 different positions, luminous intensity and UV radiation in 2 positions, soil moisture in multiple positions, as well as exterior parameters, like barometric pressure, rain, wind direction and speed in addition.

Results

The main goal was to perform the first test using modules from the new reference system in order to examine its functionality and usability on the long run as well as to produce a sample database which can be processed and analyzed further to discover relationships between the measurement points and data types. In order to store additional data in the existing database system other than the measurement data, a new rudimentary module was developed to extend the database system and the web-based management application.

Test measurements

Several preparations were needed before starting the test. This includes preparing a temporary IT infrastructure and determining the optimal locations of the sensors. The reference system normally uses TCP/IP protocol to transfer data (measurements, events, time and date, identifier) to the API, but for test purposes, it is not cost-effective to use a local server. To solve this issue, the main software on the Atmel SAM3X8E MCU was modified in order to use serial (SPI) connection with an external SD card to save the same messages in the same structure as it would be in case of an active network connection. After powering on the controller board, an initialization process begins, which configures the MCU and its peripherals, including the communication controllers, external network controller, LED driver and real-time clock. The software of the reference system was written with the presence of the API and local server in mind. Accordingly, after the initialization process the MCU tries to communicate with the API in order to query the time and date as well as the identifiers of the connected sensors. In order to make the least modification in the software, a tablet was used as a server during the boot process. In order to use the SD card as storage instead of sending the messages to the network controller, a flag, stored in the EEPROM ensures that the relevant program functions are used, developed for the test. Finally, the MCU initializes the connected sensors according to their protocol. In case of an error (timeout or error response) the MCU sends a message in a defined structure, including the identifier of the sensor and the error. Thereafter, the measuring cycle begins which consists of reading the sensors, check their status, concatenating the measurement data according to the message protocol and writing it to the SD card or in in general case, transmitting it to the API via the network controller. The message, based on modified JSON format, contains sensor identifiers, associated values, errors, the device identifier, and a timestamp. Subsequently, the device enters a low-power mode that is interrupted by a timer after 3 minutes, repeating the measurement cycle. After the measurement session, a new module of the API, written in C++, developed for this test was responsible to process the saved messages line by line as in the case of a real-time connection and add them to the table of a database, identified by the additional parameters in the message. This includes the measurement data as well as other events. The database tables used for storing the measurement data have a transaction-oriented structure. To support the visualization methods, an ETL (Extraction, Transformation, and Loading) algorithm was developed to merge the various data types according to the time and date, creating a single record for every sampling cycle with the spatial coordinates of the devices. The ETL process reads structured or unstructured data from multiple sources and includes data only in case of meeting the established criteria (Geng, 2017).

Because of the temporary nature of the system, some components were mounted just like as is was on a production system (custom PCB-s and 3D printed enclosures for the sensors) but some sensors were operated using breadboard connections. A home-made PCB for the DHT22 temperature and humidity sensor was developed, driven by a separate MCU with AVR architecture in order to work optimally with the existing, custom developed reference controller board using the same connector and communication protocols. The unified RJ45 connector includes a one-wire, I^2C, analog, output and status LED channels as well as the power lines. The PCB of the sensor also provides direct connection to the sensor with a jumper setting. In case of direct connection, the controller board is able to handle 16 sensors (considering the one-wire protocol). When using the MCU on the PCB of the sensors, this number increases according to the characteristics of the I^2C bus. The concept of the homogeneous sensor network was followed which means that the sensors were located along an equal-sized grid. In general, this method requires a high number of sensors in case of the need of high resolution, but because of the good experience from a previous test (Tóth et al., 2018), the temperature and humidity sensors were placed along the grid in crossing positions near to the sides. There are three additional sensors of the same type, two of which are located in the middle of the greenhouse in a row and one is located outside of the greenhouse as a reference. Two luminous intensity and UV intensity sensors are located at either side of the greenhouse. The other sensors, measuring datatypes less influenced on the location are located near to the controller board from the reference system using breadboard connection. Later, similar PCBs will also be available for these sensors as well to create a unified system.

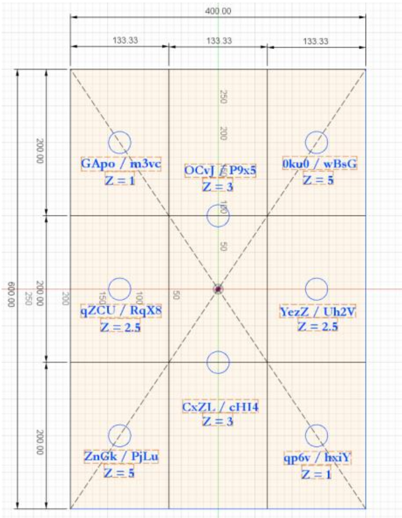


Figure 3.: The placement of the temperature and humidity sensors from top view

Source: own figure

The greenhouse was divided into multiple zones to utilize the location-specific data. The devices are placed along the X, Y and Z axis. The origin is located near to the entrance, at the lower left corner. Accordingly, there are 3 zones along the X-axis (width), 3 zones along the Y-axis (length) and finally 5 zones along the Z axis (height). The dividers are defining roughly equal sized zones. The sensors are located in the centre of the specified zone, defined by the intersection of the coordinates (Figure 3.). The main points are recorded to the database of the reference system to provide data for the 3D visualization. Some sensors are able to measure more than one data type. In order to distinguish them, the database routine used by the reference system creates unique identifiers. Some of the identifiers of the main sensors used during the test can be interpreted using the following table (Table 1.).

Table 1.: Sensor identifiers

Identifier	Sensor (X Y Z zone)	Identifier	Sensor (X Y Z zone)	Identifier	Sensor (X Y Z zone)
GApo	Temperature (1 3 1)	m3vc	Humidity (1 3 1)	0ku0	Temperature (3 3 5)
wBsG	Humidity (3 3 5)	qp6v	Temperature (3 1 1)	hxiY	Humidity (3 1 1)
OCvJ	Temperature (2 2.5 3)	P9x5	Humidity (2 2.5 3)	CxZL	Temperature (2 1.5 3)
cHI4	Humidity (2 1.5 3)	qZCU	Temperature (1 2 2.5)	RqX8	Humidity (1 2 2.5)
YezZ	Temperature (3 2 2.5)	Uh2V	Humidity (3 2 2.5)	ZnGk	Temperature (1 1 5)
PjLu	Humidity (1 1 5)	xU4U	Luminous int. (2 3 3)	6OfU	Luminous int. (2 1 3)
gYgi	CO_2 conc. (-)	iA2K	UV (2 3 3)	a3z8	UV (2 1 3)
rWjd	Soil moisture (-)	HY3y	Bar. pressure (-)	L93D	Ext. temp. (-)

Source: own data

In order to demonstrate some sample of the measurement data, including temperature, humidity, atmospheric pressure, luminous and UV intensity, a dataset, containing measurement data describing a randomly chosen time period is visualized using the 4th and 5th figure below.

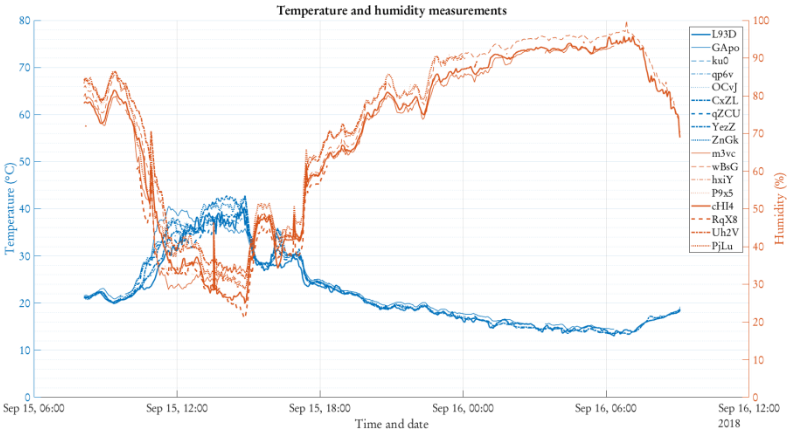


Figure 4.: Temperature and humidity data, measured by multiple sensors

Source: own figure

As we can see, the measured temperature and humidity data converge with the same datatype, measured in different locations, but we can experience a visible increase in standard deviation comparing the measurement points during a cloudy time period with a rainfall (in the early afternoon), which was also predicted before using atmospheric pressure measurements. The largest difference experienced in temperature was 12.9 °C whereas in humidity it was 12.5% examining the same timestamp. This difference would not have been detected using a single sensor, which is typical for many systems in use for data acquisition and controlling purpose. Unfortunately, in the evening the high humidity caused connection error at some sensor nodes, which resulted in data loss. The multi-sensor design, in addition to the location-specific data may help in similar cases with redundancy. In this test, the data loss was not a critical factor due to this property.

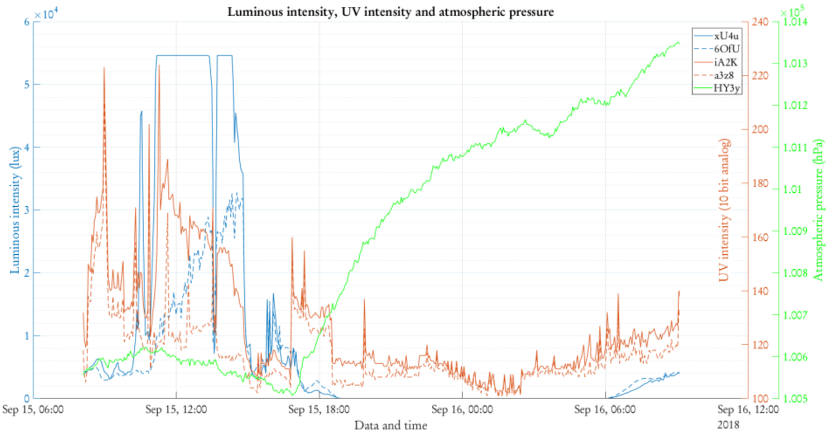


Figure 5.: Luminous intensity, UV intensity and atmospheric pressure

Source: own figure

The luminous intensity, as well as the UV intensity drops at the time period mentioned above. The luminous intensity sensor has a measurement range of 1 lx to 65535 lx which led to overflow at direct sunlight, can be seen at the chart as well observing the data, measured by the sensor with “xU4u” identifier. The UV intensity measurements were executed using a sensor with analogue output. As we can see, the luminous intensity data shows correlation with the UV intensity data, but the latter tends to show noise because of the ADC (analogue to digital conversion) process. This characteristic can be solved using post-processing or hardware modification.

In order to visualize the spatial distribution using a single record from a specific time, interpolation was needed. The arrangement of the temperature and humidity sensors ensures that the smallest number of sensors represent the reality relatively precisely. The interpolation was done with a custom application developed for the test, written in C++ based on the INPAINTN iterative algorithm (Garcia, 2010). A three-dimensional data visualization may help the management in the optimal production site for the specific plant and may help in tool placement as well. In addition, it provides a basis for process control methods which can work more accurately using multiple sensors if conditions are given, including multiple, controllable actuators and an algorithm, which is able to take advantage of the multi-point data acquisition.

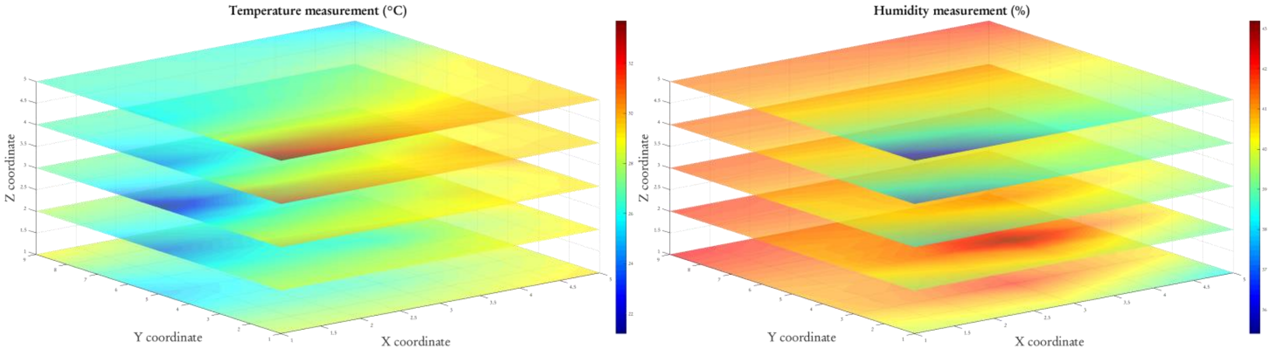


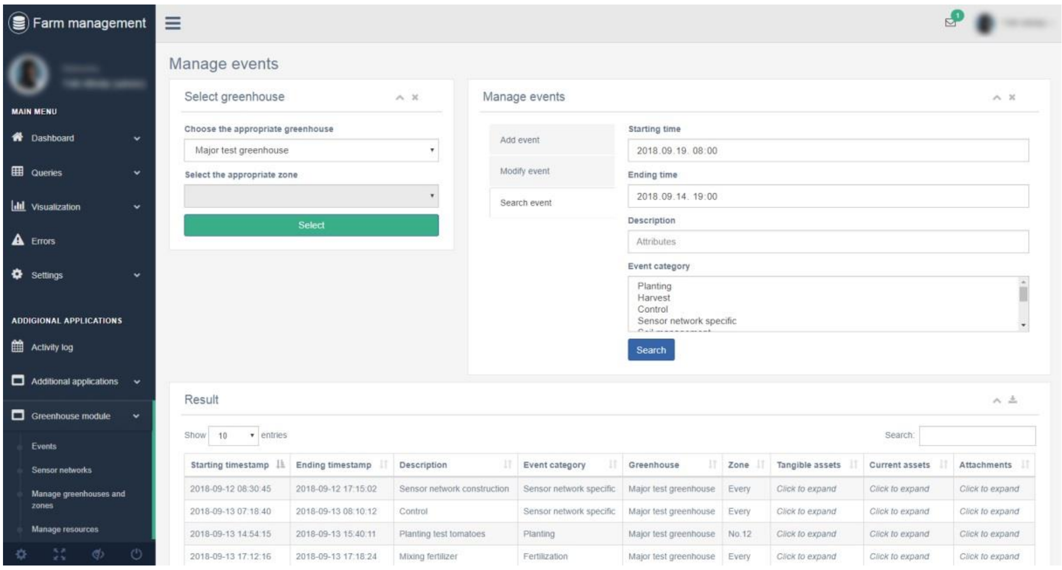
Figure 6.: 3D data visualization of temperature and humidity

Source: own figure

The temperature and humidity difference can be seen in the 3D data visualization as well at the mentioned time (Figure 6.). If we create a figure representing each measurement cycle, used them as an animation, we can discover the characteristics of the greenhouse at a changing period. Considering the environmental parameters measured outside, it can provide us with a sample dataset to use them in a simulation thus providing additional benefits in decision support and control methods.

Database and web application extension

The measurements are describing the primary production environment which may influence the result whether it is quantity or quality. We can relate them as production variables. But in order to cover the process in more detail, there is a need for further data describing the activity. This was implemented through the web application developed originally for the reference system. Because of the modules from the reference system were used during the test, it provides compatibility with the existing software. Of course, it had to be modified as well to gain an advantage from the new data structure. The web application ensures platform independent operation, optimized for desktop and mobile devices as well via its responsive design. The interface is based on the Bootstrap 4 framework, while the logic is determined by custom PHP and JavaScript code. The management application for the reference system implements custom user right management, which ensures the accessibility of the module for the users.



Choose the appropriate greenhouse: Major test greenhouse

Select the appropriate zone:

Starting time: 2018.09.19. 08:00

Ending time: 2018.09.14. 19:00

Description: Attributes

Event category:
Planting
Harvest
Control
Sensor network specific

Show 10 entries

Starting timestamp	Ending timestamp	Description	Event category	Greenhouse	Zone	Tangible assets	Current assets	Attachments
2018-09-12 08:30:45	2018-09-12 17:15:02	Sensor network construction	Sensor network specific	Major test greenhouse	Every	*Click to expand*	*Click to expand*	*Click to expand*
2018-09-13 07:18:40	2018-09-13 08:10:12	Control	Sensor network specific	Major test greenhouse	Every	*Click to expand*	*Click to expand*	*Click to expand*
2018-09-13 14:54:15	2018-09-13 15:40:11	Planting test tomatoes	Planting	Major test greenhouse	No.12	*Click to expand*	*Click to expand*	*Click to expand*
2018-09-13 17:12:16	2018-09-13 17:18:24	Mixing fertilizer	Fertilization	Major test greenhouse	Every	*Click to expand*	*Click to expand*	*Click to expand*

Figure 7.: The greenhouse module of the management application

Source: own figure

The greenhouse module utilizes an event-driven method which means, that every operation creates a new record (event) in a database table with parameters, like the timestamp of the beginning and ending of the event, the name and category, the location which is affected by the event as well as the zone inside of it, the transaction of tangible and current assets and other attachment, varying from scanned documents to individual datasets describing the event (Figure 7.). The event-driven method is an effective way (Paraforosa et al., 2017) to develop Farm Management Information Systems (FMIS) in order to store and process data for the farm management (Fountas et al., 2015). The structure of the database ensures the scalability and that it can be analyzed in conjunction with the measurement data, which tells us the environmental parameters which were typical at the time of the event as well as the environmental parameters typical for the period between the events.

Discussion

In this paper the data acquisition and the management interface are distinguished. The data acquisition test provided valuable experiences which can be used as a starting point for future developments. However, to fully utilize the potential behind the technology, various developments of the tools and the methods are needed.

This data acquisition and control system was tested for the first time in a greenhouse, which raised several issues in weather resistance (temperature and humidity) and measurement resolution (sampling time and spatial resolution). The weather resistance can be solved by redesigning the 3D printed enclosure and using proper cooling solutions along with sealing, but the optimal measurement resolution, which is unique for every greenhouse, can only be determined via a long-term test and statistical analysis of the channels. As a first test, the homogenous grid was an appropriate decision, but in case of a large dataset, we may be able to find critical zones which require higher resolution, as well as zones, which tend to have homogenous parameters, accordingly, lower resolution is also sufficient. The resolution is an important factor not just because of the cost-reduction, but also because of the data quantity which highly influences the manageability. The management application, used by the reference system was extended with a rudimentary greenhouse module, providing application-specific functions, in addition to the former data acquisition module. The functions were developed without determining the demands of the potential users. As a person, with a profile of arable crop production, I have no proper view of the needs of a greenhouse management. In order to make the application useful in practice, there is a need for additional research among professionals in this field. Definition of the functions could be supported by questionnaire research.

In order to use the data acquisition and farm management in conjunction effectively, we must find a connection between the environment variables and the management data whether it's a greenhouse or other closed system to utilize their usefulness in decision support. To realize these connections, there is a need for statistical analysis which will be the next step in the experiments when the testing period succeeds.

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