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THE MODERN GREENHOUSE SYSTEM ARCHITECTURE CASE STUDY

ANALIZA ARHITEKTURE MODERNOG STAKLENIKA

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ABSTRACT

Embedded systems connected to the global network (IoT) are increasingly entering all areas of science. Network connectivity makes it possible to transfer information obtained in the field to the cloud in a very short time, where, thanks to processing, it is possible to draw important conclusions and determine the further course of a particular process. In the field of agronomy, environmental and process variables are improving cultivation by reducing the cost of sensors and electronic components. By analysing the characteristics of environment and nutrients, it is possible to discover their relationship with cultivation. The necessary environmental variables were found in recent papers and new ones are introduced according to project team. With proposed greenhouse architecture, we tried to achieve the most reliable and accurate measurement with the lowest possible project cost. The proposed architecture allows for scalability by changing the number of nodes or sensors. The software design controls the frequency of measurements and the unit of accuracy. The data is transferred to the cloud in a very short time and is insured against losses in case of network connectivity disruption. The paper presents preliminary results of the working system.

Keywords: *Embedded system, IOT, Sensor, Agronomy, Hydroponic*

SAŽETAK

Ugrađeni sustavi povezani s globalnom mrežom (IoT) sve više ulaze u sva područja znanosti. Mrežna povezanost omogućuje prijenos informacija dobivenih na terenu u vrlo kratkom vremenu u oblak, gdje je zahvaljujući obradi moguće donijeti važne zaključke i odrediti daljnji tijek pojedinog procesa. U području agronomije, okolišne i procesne varijable poboljšavaju uzgoj smanjenjem troškova senzora i elektroničkih komponenti. Analizom karakteristika okoliša i hranjivih tvari moguće je otkriti njihov odnos s uzgojem. Potrebne varijable okoliša pronađene su u novijim radovima, a nove su uvedene prema projektnom timu. S predloženom arhitekturom staklenika pokušali smo postići najpouzdanije i najtočnije mjerenje uz najnižu moguću cijenu projekta. Predložena arhitektura omogućuje skalabilnost promjenom broja čvorova ili senzora. Dizajn softvera kontrolira učestalost mjerenja i jedinicu točnosti. Podaci se u vrlo kratkom vremenu prenose u oblak i osigurani su od gubitaka u slučaju prekida mrežne povezanosti. U radu su prikazani preliminarni rezultati rada sustava.

Ključne riječi: *Ugrađeni sustavi, IOT, Senzori, Agronomija, Hidroponija*

1. INTRODUCTION
1. UVOD

New technologies, particularly the Internet of Things (IoT), are driving innovation in all areas of science by providing access to information through new concepts. Advances in computing technology based on embedded systems and the recent development of Smart Sense are leading to cost-effective solutions for the Internet of Things (IoT). Innovative solutions

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in the field of sensors enable the installation of a range of sensors in the production process itself [1].

By monitoring the growth process in greenhouses, we can increase the value of plant nutrients, achieve better quality of food, cosmetics and pharmaceuticals [2].

This paper presents the architecture and design of a modern system for scientific research facilities in greenhouses.

Multiple sensor nodes at different locations are proposed, interconnected by a dedicated central node. The implemented system architecture and initial results are presented.

We wrote this paper as part of the Urtica - Bio future of Croatia project of the Science Foundation [3]. The project focuses on the development of a modern greenhouse research facility as a quality base for future research at the Faculty of Agriculture, University of Zagreb, Croatia.

This paper is organised as follows. In the ”Related Work” section, existing greenhouse solutions are discussed. Then, the main aspects of system architecture and design are presented in the Greenhouse Architecture section. This section is followed by a description of the cloud application. The paper concludes with the preliminary result, where the advantages of our proposed system are discussed and demonstrated.

2. RELATED WORK
2. POZNATI RADOVI

In any greenhouse, it is desirable to collect as much data as possible through as many sensors as possible. Wei et. al. [4] presents hydroponic technologies in his paper. He proposes several elements that can be included in monitoring and control. The work summarises the techniques that serve as a starting point for the development of our greenhouse [5].

An important element of any project or cultivation is the total cost of the project. An environment with expensive and complicated sensors can be difficult to implement in a production facility. Due to the unique requirements of the greenhouse experiment, it is important to monitor as many environmental variables as possible with simple and inexpensive sensors [6].

Bersani et al. [7] describes the modern principles of precision and sustainable agriculture. The paper discusses sustainable approaches to achieve near zero energy consumption while reducing water and pesticide use to near zero.

In addition to environmental measurements, the importance of the liquid sensor is also highlighted [4]. In a nutrient solution, the sensor quality may change over time, which may affect the sensor value. Therefore, the differential values of the sensors in the time frame are more relevant than the directly measured results [8].

Data reduction can be achieved by eliminating repetitive results using sensor data sampling techniques. Similar measurements can be excluded if the difference is below the context-specific threshold, which depends on the desired data granularity. The second approach in the sampling process assumes a small hysteresis around the last measurement result. If the result remains within the standard range, it is discarded because no changes are detected [9].

Data acquisition and sampling require computing power in the form of data processing and storage. A computer board equipped with a microcontroller or a processor with an operating system is essential to establish a connection between the sensor and the cloud.

Microcontrollers provide better interface connectivity to the sensors. The most popular Arduino-compatible boards include ESP8266, ESP32, Arduino UNO, Arduino Mega. Microcontrollers provide analogue input interfaces as they are equipped with analogue-to-digital converters. They can also provide complex interfaces supported by hardware. The disadvantage of microcontrollers is their processing power. Rabadiya et al. [10] proposed a system based on multiple microcontrollers (ESP8266, Arduino UNO) as opposed to a system with a single microcontroller [6].

Microcontrollers can be replaced by processor boards with operating systems. The most commonly used operating systems are based on Linux distributions suitable for embedded systems. In such environments, multi-threading, local file system storage or even a database can be implemented. In addition, the operating system simplifies the implementation of web services via scripts. The most popular processor boards with operating system are Raspberry PI, Orange Pi, Banana Pi, Odroid. Processor boards have fewer pins than microcontroller boards. They can have complex interfaces, but usually do not have direct analogue inputs. In most cases, these boards have higher power requirements and larger dimensions.

There are hybrid solutions based on a small OS microcontroller board (e.g. RTOS, MicroPython) [8]. In a combined system, a node consists of a set of microcontrollers that provide sensor interfaces to processor boards that compress and send data to the cloud. A combined system requires a central node based on the processor board node [11]. This paper uses known knowledge from other papers about the used sensors build its own network. Primary focus was on low-cost electronics-

3. GREENHOUSE ARCHITECTURE
3. ARHITEKTURA STAKLENIKA

To achieve complete monitoring of the system, several sensors are placed in the greenhouse. The system is built on Raspberry PI 3 and ESP32 boards. The complete system architecture is presented in Figure 1. The implemented units are presented in figure 2.

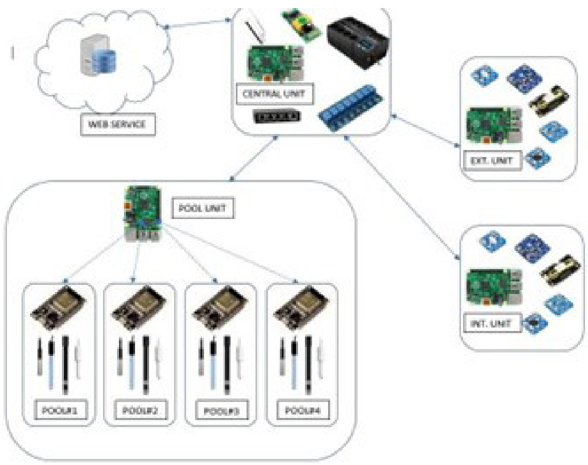

Figure 1 *System architecture*

Depending on the location, the sensors are grouped into four nodes:

- Central unit, which is mounted in the greenhouse. This unit provides uninterruptible power supply, enables temporary database and connects to the cloud database.
- External unit mounted outside the greenhouse. This unit monitors the parameters of the external greenhouse environment: temperature, humidity, pressure, CO_2, light, light with IR cut filter and UV light.
- Indoor unit, which is mounted inside the greenhouse. This unit monitors the internal parameters of the greenhouse environment: temperature, humidity, pressure, CO_2, light, light with cut filter IR and UV light.
- Pool unit, which is mounted near the hydroponic pools, with pool sensors in each pool: PH, EC, oxygen content and temperature. The temperature sensor is used to compensate the values of the pool sensors.

All units are connected with an Ethernet cable. The Pool unit has four esp32 pool nodes connected via a USB port. The central unit is supplied with mains voltage. The other units are powered via Ethernet in a non-standard PoE 12V. Each unit has a voltage regulator that supplies 5 V to the electronics and a reference voltage to the sensors. The pool nodes are supplied with power via the USB port.

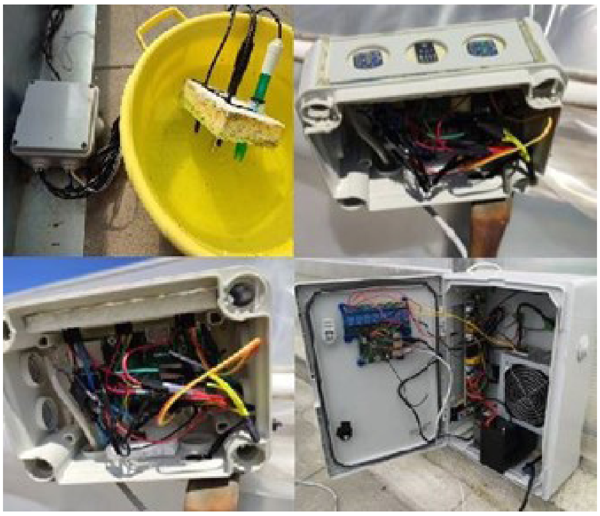

Figure 2 *Control, Indoor, External and Pool units*

A. Central unit

The central unit is based on a main power supply that is rectified and protected by a CyberPower 800VA UPS (Uninterruptible Power Supply). UPS is connected to the Raspberry Pi via a USB interface. If the voltage drops for a longer period of time, a complete shutdown process is initiated. Via the network broadcast function, other Raspberry Pi devices are notified to start a shutdown process. The central processing unit sends a notification to the cloud and shuts down any daemons that may be at risk in the event of an unexpected power failure. After receiving the power restoration information, the devices are restarted via relays and all daemons are restored to the central processing unit operating system.

The output of UPS is converted from a computer power supply to a 12V and 5V system. The regulated 5V is used to power an Ethernet switch, the Raspberry PI3 board and a relay module. The regulated 12V is used to power other devices via the Ethernet cable system. The power is supplied by a relay system, so the Raspberry PI can switch the power supply of the devices by software. In this way, each device can receive a hardware reset signal from the central unit.

The Raspberry PI with Raspbian installed provides a web server interface with database (Apache2 and Maria Database). The server-side PHP language provides a web service interface for receiving JSON data from other units. The communication is not encrypted, but is secured by an additional GET parameter, which is a hash digest formed from all provided shared keys and other parameters. This web interface further streamlines the data. Repeated data is ignored to optimise data storage.

The data resides in the Maria database and is continuously transferred to the cloud. The cloud has a fixed web service point that is used by the Raspberry Pi. Successfully sent data is deleted from the database because the amount of data in the IoT is limited.

The database has information in unit table linked to device table . The Units table contains data about the active unit. The attribute unitPin defines the relay PIN, which passes the voltage to the specified unit via PoE. The unit can be reset with PIN voltage change, i.e. by software. Each unit contains devices (sensors). Each device has a defined adjustment factor, i.e. a coefficient used to convert the floating point value of the sensor into an integer value. This adjustment factor is applied within the cloud service module. The sleep attribute defines the pause after a successful measurement in seconds. These values are displayed when the getAtribute web service is called by a sensor measurement script installed on the devices. The script running on the devices sends the data with the call sendData. When the data is accepted, it is inserted into the data table with the current date and time and the sendCloud attribute is set to zero. Each month is stored in different data table. Data table is labeled according with current year and month number with a leading zero.

The web server script creates a new table when the first entry of a new month is received. Multiple data tables are due to the lower processing power of the Raspberry Pi when you work with tables containing more than one million rows (the idle time of the sensor is about 30 seconds).

The central processing unit uses a script to send data to the cloud. This script reads rows from data tables that have the sendCloud attribute set to zero. This data is prepared in JSON format and sent to a web service instance in the cloud.

The central unit is also equipped with an energy measurement unit between the network and

UPS. The unit is connected to the serial port of the Raspberry Pi 3. It provides data on energy consumption (voltage, current and watts). This data is entered into a local database and sent to the cloud along with the collected data from the devices.

All scripts are loaded using the autoload function. This script is executed when the operating system starts and is included in the operating system scheduler to run every 30 minutes.

B. External unit

The external unit is placed outside the greenhouse. It consists of a Raspberry PI 3 connected to sensors. The sensors are used to collect information about the external environmental data. Most of the sensors are connected through an I2C interface. Due to identical device numbers for multiple sensors on the I2C bus, two additional pins on Raspberry Pi are used as an additional I2C bus. This is achieved by changing the configuration file in the boot folder of the device. The device is supplied with 12V voltage from the central processing unit via an Ethernet cable. This voltage is converted to 5V inside the device.

The external unit is equipped with five sensors:

- BME280 - I2C interface - Temperature, humidity and atmospheric pressure sensor [12].
- Analogue IR CO_2 sensor - Analogue voltage output interface - Analogue infrared (IR) CO2 sensor [13]
- VEML6075 - I2C interface - Ultra violet (UV) light sensor [3].
- VEML7700 - I2C interface - Visible light sensor [14].
- VEML7700 with IR cut filter - I2C interface - Visible light sensor with additional mounted IR cut filter. [15].

The Raspberry Pi has a separate Python script for each sensor. These Python scripts log the measured value, perform a simple conversion from floating point to integer values, and send the data to the central processing unit database via a web service.

If the central unit is not available, the measurements are collected in a log file and can be manually uploaded to the central unit database. The retention period for the log is one month.

The scripts pull the readings from the sensors according to the frequency of the measurements. The conversion multiplier and the measurement frequency are retrieved from a web service when the script is started.

To ensure that the script is running, the operating system scheduler (CRON) checks every 30 minutes to see if the scripts are started (autoload script). The autoload script is also run every time the operating system starts.

C. Indoor unit

The indoor unit is mounted inside the greenhouse. This unit is made as a replica of the external unit. For proper positioning, the indoor unit is placed in the centre of the greenhouse at plant height with no obstructions for proper sensor detection. The unit is placed out of reach of windows, doors or other vents. Proper positioning is determined by testing the unit in various positions over a period of time.

D. Pool Unit

The central part of the pool unit is a Raspberry Pi with a Python script that communicates with four pool nodes via a USB interface. Each pool node consists of an Esp32 microcontroller and sensors. The USB interface enables a virtual serial port for communication with the Esp32 microcontroller. Each node is equipped with four sensors covering a pool for deep water hydroponic culture:

- DS18B20 - I2C interface - waterproof temperature sensor [16].
- EC sensor/metre - analogue voltage output interface analogue EC metre [17].
- PH metre - analogue voltage output interface - analogue PH metre [18].
- Dissolved Oxygen metre - analogue voltage output interface - analogue dissolved oxygen metre [19].

The Esp32 microcontroller is programmed to measure all sensor data on demand. The request is issued by a Python script on the Raspberry

Pi. Similar to other devices, the multiplier and measurement frequency are retrieved from the central processing unit. Also, an autoload script is used to start the code at boot time or restart every 30 minutes in case of failures.

The virtual serial port addresses are fixed and thanks to the Raspberry Pi, the hardware nodes can be turned off with a software script. Furthermore, the Esp32 microcontroller is equipped with a watchdog that allows a reset in case of software or sensor failure.

4. THE CLOUD
4. OBLAK

Data processing and advanced visualisation are performed within the cloud-oriented web service. Therefore, we have created three main modules within the cloud service: Authentication Module, Data Processing Module and Visualisation Module.

A. Authentication Module

The authentication module is based on OAuth 2.0 protocols implemented in ASP.NET Core Framework. User authentication is based on a standard login mechanism, while the microcontroller's communication with data collection endpoints is protected by a standard token mechanism (JWT).

B. Data Processing Module

The data processing module is responsible for processing the potentially large amounts of sensor data that is ingested. Therefore, the NoSQL database MongoDB was chosen to support a high rate of writes in a timely manner. In order to be able to retrieve the aggregated data over longer periods of time, the incoming data is aggregated "on the fly" - by updating the values to support K-line visualisation, which is often used to display financial data such as stock price changes. Data is aggregated hourly, 4-hourly, 8-hourly and daily, allowing reports to be displayed with sufficient granularity over long periods of time. The data processing module is robust to changes in sensor architecture. Adding new sensors requires no additional configuration in the backend. Data is automatically processed and grouped based on the identification number sent by the sensor itself. Each sensor reports the unit of measurement and an adjustment factor.

C. Visualisation module

The visualisation module displays the aggregated data for each sensor group. Sensors with the same unit of measure and adjustment factor are grouped on the same graph. The data can be displayed as a simple line graph or as a K-line graph showing the input value, the maximum value, the minimum value, and the output value, providing the user with more detailed information as needed.

5. PRELIMINARY RESULTS
5. PRELIMINARNI REZULTATI

The system was installed in the greenhouses of the Faculty of Agricultural Sciences of the University of Zagreb on 14.05.2021. Within a month, the initial errors in the form of system failures and individual sensors were eliminated. Several faulty sensors were replaced and the supply voltage was stabilised by intervening in the supply line to the central unit.

Over the next few weeks, outage tests were conducted to verify proper operation of the sensors in the event of individual unit power failures, network outages, and Internet access failure. Finally, data was uploaded to the cloud and tested. The system began regular operation and data collection in mid-June 2021.

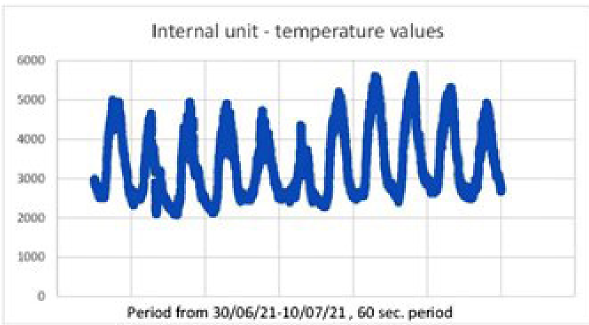

Figure 3 *Temperature sensor values in Indoor unit from 30/06/21-10/07/21 (60 sec. period) – Vrijednosti senzora temperature na unutrašnjem uređaju u periodu od 30.06.2021.-10.07.2021. (60 sekundi period mjerenja)*

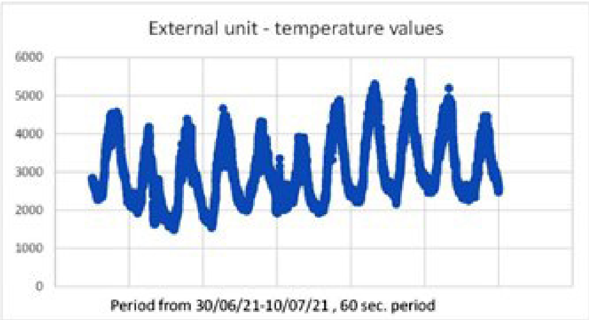

Figure 4 *Temperature sensor values in external unit from 30/06/21-10/07/21 (60 sec. period) - Vrijednosti senzora temperature na vanjskom uređaju u periodu od 30.06.2021.-10.07.2021. (60 sekundi period mjerenja)*

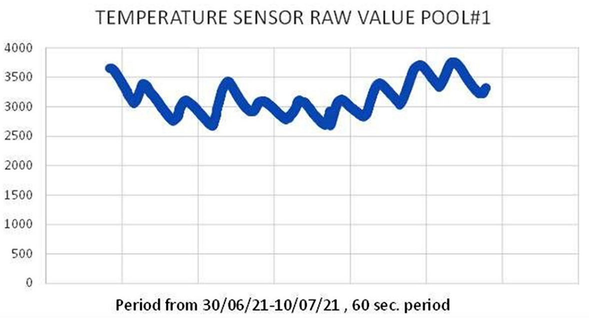

Figure 5 *Temperature raw sensor values for Pool1 from 30/06/21-10/07/21 (60 sec. period) - Neobrađene vrijednosti senzora temperature na unutrašnjem uređaju u periodu od 30. 06. 2021. - 10. 07. 2021. (60 sekundi period mjerenja)*

Figures 3, 4, and 5 show indoor, outdoor, and pool1 temperature values. The results are proportionally related, as the value of the temperature inside the greenhouse is slightly higher. As expected, the value of the pool temperature follows the trend of the air temperature, considering that the pool is not buried and insulated from below. Also, the plants are placed and cultivated in styrofoam, so the pool is insulated from above.

Anomalies in the form of values that differ significantly (by more than one scale unit) from the previous and next values, as well as repetitive values in the same time period, are excluded from the display. This algorithm is implemented in an embedded system. Further clarification of the values will be implemented later in the cloud.

In parallel, the pools were filled with nutrients and the growth cycle of the Urtica began. In mid-June, an attempt was made to calibrate the nutrient sensors (sensors that were immersed in the nutrient). During this process, we noticed several times with the nutrient sensors that it is extremely complicated to accurately calibrate the sensors in a short time due to the slow response of the water sensors (change in values) and the rapid loss of the properties of the test liquid or a test experiment in the case of oxygen saturation.

For this reason, a methodology for calibration via the cloud is proposed. The sensors only collect raw values and transmit them to the cloud. As with the other two devices, the repetition of the same value over a period of time is isolated, and values that are one scale unit larger or smaller than the previous or next (large deviations) are discarded. The data processed in this way is sent to the cloud.

Figure 8, 6, and 7 represent the raw values of the nutrient sensors that are sent to the cloud. These data are converted to real values in the cloud. The correct formula is determined by comparing the manually measured values on site with professional instruments to the raw values received from the sensors. The manual measurement is performed hourly by a laboratory employee of the Faculty of Agronomy. Temperature also plays an important role, as the values from PH and EC must be corrected for a temperature coefficient.

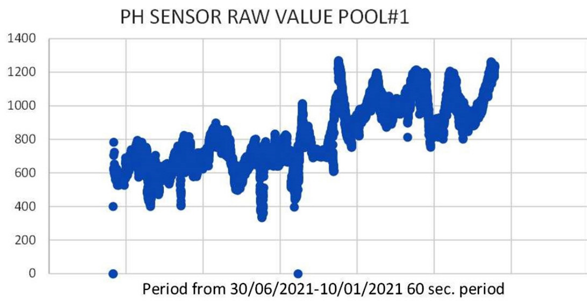

Figure 6 *PH raw sensor values for Pool1 from 30/06/21-10/07/21 (60 sec. period) - Vrijednosti senzora PH vrijednosti iz bazena 1 u periodu od 30.06.2021.-10.07.2021. (60 sekundi period mjerenja)*

6. CONCLUSION
6. ZAKLJUČAK

In today's embedded systems, we strive to connect as many sensors as possible to the network. Especially in agriculture, many sensors are needed to send frequent measurements about the production environment. By monitoring these measurements, it is possible to make decisions and act on other processes such as heating, climate or ventilation.

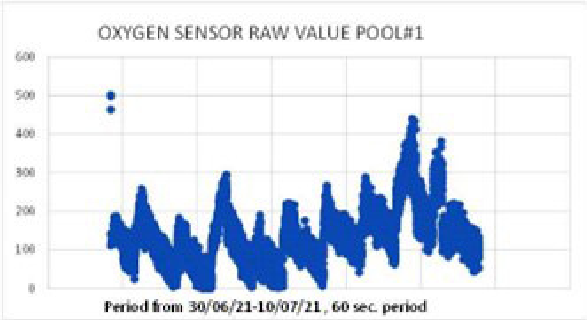

Figure 7 *Oxygen raw sensor values for Pool1 from 30/06/21-10/07/21 (60 sec. period) - Vrijednosti senzora kisika iz bazena 1 u periodu od 30.06.2021.-10.07.2021. (60 sekundi period mjerenja)*

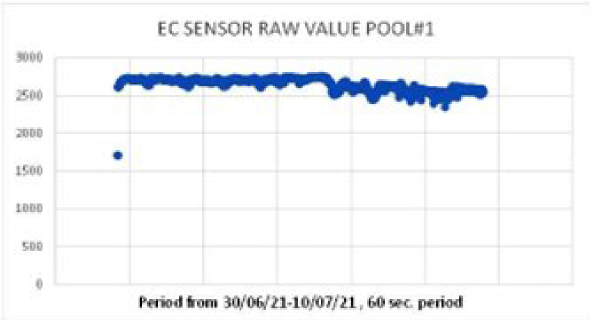

Figure 8 *EC raw sensor values for Pool1 from 30/06/21-10/07/21 (60 sec. period) - Vrijednosti senzora vodljivosti iz bazena 1 u periodu od 30.06.2021.-10.07.2021. (60 sekundi period mjerenja)*

The aim of this paper is to present a case study for a modern greenhouse with a limited budget, inspired by lowcost electronics. The case study presents a complete solution architecture that ensures the measurement of environmental and nutrient variables. The required environmental variables were determined in collaboration with the agronomic project team based on their current research activities. Nutrient sensors are particularly important as the one of the project objective in the field of agronomy is related to selecting the best combination of nutrients. Based on the selected sensors and their interfaces, a hybrid model of system design with an operating system and microcontrollers was chosen. The architecture is proposed and the details of the hardware and software design are described.

In the last chapter, the first measurements are presented and the problems with the nutrient sensors are discussed. A solution based on manual calibration of the data is proposed. A method for isolating values is proposed to be implemented in the cloud for the given data. In further work on the project, measurements will be collected with the aim of improving the cultivation of nettles in greenhouses.

In our future work on the project, we will work on the technical implementation of the ebb and flow technology and the analysis of the effects of the microclimate in the greenhouse to further improve the results obtained.

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7. REFERENCE

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