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SLiCE: Implementation of automation technology and Internet of Things in the greenhouse

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ABSTRACT

SMK Negeri 1 Sidoarjo aims to create an automated hydroponic greenhouse system with IoT technology. Limited knowledge and costs hinder their progress. However, the Audio Video Engineering Department seeks assistance to achieve the program's goals by upgrading their knowledge and skills in automation. The Service Learning in Computer Engineering (SLiCE) program focuses on introducing and implementing automation and IoT technology in greenhouses. The community service project starts with surveys and discussions involving the principal and teachers. It then proceeds to analyze the needs and develop a hydroponic and IoT automation system. Training is provided for students and teachers of SMK Negeri 1 Sidoarjo. The ESP32 microcontroller enables remote monitoring and automatic control of nutrient levels and water pH, ensuring optimal plant growth. The outcome is a real-time hydroponic automation system capable of monitoring pH, nutrient PPM, and controlling nutrient addition through a website. After training, 87.9% of students reported improved comprehension of IoT and its implementation.

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1. INTRODUCTION

SMK Negeri 1 Sidoarjo is one of the vocational high schools located in the Sidoarjo Regency and is the first vocational school in the Sidoarjo Regency. This school has a hydroponic greenhouse located beside the student workshop building. The hydroponic system used in SMK Negeri 1 Sidoarjo is the Deep Flow Technique (DFT). DFT is one of the hydroponic cultivation systems that involves pooling water in the installation and using slow-flowing water circulation. This system utilizes electricity to drive the pump, enabling easy circulation of nutrients to the plant roots. Hydroponics is a cultivation technique that doesn't use soil as a growing medium but instead utilizes water. This technique is one of the rapidly evolving agricultural technologies that can enhance future food production (Aravind & Sasipriya, 2018).

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The hydroponic planting method is useful for replacing available soil with other media. Hydroponic plants are usually developed by the community as a hobby because they have many advantages. In addition, the cultivation technique in hydroponics is also a cultivation technique that can produce pesticide-free, high-quality, healthy, uniform agricultural products and can be used continuously (Darto et al., 2021; Fathurrahman et al., 2021). Factors that affect plant growth such as caterpillar pests and plant infectious diseases can be prevented when utilizing hydroponic in a closed room such as a greenhouse (Aliac & Maravillas, 2018). Hydroponic farming also does not require a large planting area (Waluyo et al., 2021). In addition, hydroponics can provide plants with a high success rate of planting, better quality and sustainability. The quality and quantity of hydroponic plants is very dependent on the growing media and nutrients (Mustofa et al., 2021; Sudarmo, 2018). By controlling the nutrients for hydroponic plants, some of them are controlling the pH value and Electrical Conductivity (EC) of the nutrient solution (Mustofa et al., 2021; Ruengittinun et al., 2017).

The problem that occurs in hydroponic cultivation in small industries with conventional treatment methods is that it takes time and effort by always checking the levels of water nutrients (Salinity, pH, Temperature and Oxygen) in hydroponics to avoid wilting and dying plants. In addition, mold also occurs due to humidity that is not maintained, so monitoring is needed within the daily range to detect its presence and maintain moisture from the hydroponic installation (Zulhajji et al., 2022). In the era of the technological revolution 4.0, all devices are connected to the internet, commonly known as the Internet of Things (IoT) (Nahdi & Dhika, 2021). Therefore, it is highly possible to develop an automated hydroponic system using the Internet of Things (IoT). The term IoT was first coined in 1999 by Kevin Ashton to describe a system that connects physical objects to the internet network using sensors. The rapid growth of technology, along with the support of automation systems, information systems, and telecommunication systems, allows for the creation of intelligent systems that can enhance human well-being (Lukito & Lukito, 2019). The Internet of Things (IoT) is a global network connectivity infrastructure that uses data collection and communication technologies to connect physical and virtual objects (Setiadi & Muhaemin, 2018).

Automation has changed the way people work, live and produce things (Lakshmanan et al., 2020; Winarno et al., 2022). Automatic products are now often found in public facilities, companies and even people's homes. To maintain and upgrade automated products, high costs are required depending on the product and the manufacturer. Therefore, IoT is a developing technology that can be a solution to this problem (Sihombing et al., 2018). The application of IoT-based automation to hydroponic systems has advantages such as minimal manual control. Thus, enabling remote access to various environmental parameters in a hydroponic system (Zulhajji et al., 2022).

Based on the on-site evaluation conducted at the greenhouse of SMK Negeri 1 Sidoarjo, it has been observed that the hydroponic system is still being operated conventionally. The nutrient distribution in the hydroponic system is manually performed, and checking the water conditions and volume in the reservoir tanks is also done manually. This manual approach proves to be less effective and inefficient, particularly during school holidays when the water and plant conditions cannot be properly controlled. SMK Negeri 1 Sidoarjo has a program to develop a technologically advanced greenhouse equipped with automation and Internet of Things (IoT) features. However, the implementation of the program is hindered by a lack of knowledge and financial resources. The Audio-Visual Engineering department at SMK Negeri 1 Sidoarjo is currently focusing on automation and seeks assistance to realize this program. The SLiCE community engagement program aims to transform the conventional hydroponic system into an automated one by integrating IoT technology. With the addition of automation and IoT in the greenhouse at SMK Negeri 1 Sidoarjo, the hydroponic plants can grow optimally and be monitored through the system.

2. METHODS

The community engagement activity is carried out in the form of embedded system training and the implementation of IoT technology for hydroponic automation at SMK Negeri 1 Sidoarjo. The activity began with a discussion and survey of the greenhouse owned by SMK Negeri 1 Sidoarjo on 4th August, 2022. Based on the survey results and discussions with the partners, the team of community service providers created equipment assembly designs and conducted testing. On August 15, 2022, the community service team installed and provided training on the IoT-based hydroponic automation system to the students and teachers of SMK Negeri 1 Sidoarjo.

Schedules

The schedule for a series of SLiCE 2022 activities is presented in Table 1.

Table 1. Schedules

Activities	Date
Preliminary survey	Thursday, 4th August 2022
Needs analysis	Friday, 5th August 2022
Tool assembly and testing	Monday - Friday, 8-12th August 2022
Equipment training, installation and delivery	Monday,15th August 2022

Table 1 shows that the activities took place for almost 2 weeks in August 2022. Surveys, needs analysis, training, installation and handover of tools were carried out in the school environment of SMK Negeri 1 Sidoajo. Equipment assembly and testing is carried out in the real time computer system laboratory building D3 Study Program D4 PENS Computer Engineering.

Preliminary Survey and Discussion with SMK Negeri 1 Sidoarjo

The service team and SMK Negeri 1 Sidoarjo conducted a review and measurement of the greenhouse area for planning automation and IoT systems as shown in Figure 1. SMK Negeri 1 Sidoarjo has built a greenhouse with a manual system without any touch of automation technology as shown in Figure 1(b).

Figure 1. (a) Discussion with Teachers of SMK Negeri 1 Sidoarjo;
(b) Hydroponic greenhouse seen from the outside

During the discussion and survey, data was collected on the length, width, height, and the number of hydroponic pipe holes, along with photo and video documentation as shown in Figure 1(b). The hydroponic pipes consist of three levels with holes measuring 5.5 cm in diameter. These pipes belong to the Deep Flow Technique (DFT) hydroponic pipe type. The hydroponic pipes have a length of 440 cm, a width of 119 cm, and a height of 150 cm. There are three levels of pipes: the first level has 77 holes, the second level has 72 holes, and the third level has 88 holes. Each level is connected with small pipes and hoses. The hydroponic pipes are placed in a greenhouse with dimensions of 726 cm x 380 cm. Additionally, during the evaluation, water was flowed into the pipes to observe the direction of the water channels.

Needs Analysis and Manufacturing of Automation System Equipment

The preparatory stage is carried out by preparing the tools and materials used. At this stage, the design of tools which include hydroponic pipes, controllers, and web applications is carried out as shown in Figure 2.

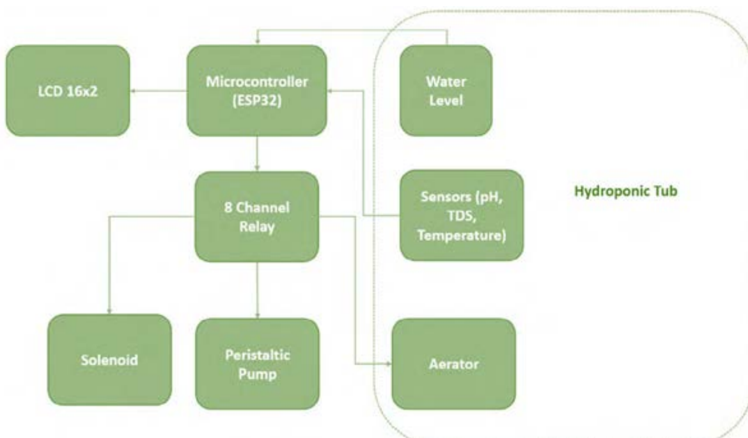


Figure 2. Block diagram system

The workflow of the designed system is as follows: The microcontroller (ESP32) sends commands to the relay to activate the pump and aerator. The water level sensor detects the water level. When the water level is low or empty, the water level sensor sends a command to the ESP32, which then forwards the command to the relay to open the solenoid valve and activate the pilot lamp buzzer as an indicator for water filling. When the water level is high, the water level sensor sends a command to the ESP32, which then instructs the relay to close the solenoid valve and turn off the pilot lamp. Once the water level is full, the ESP32 sends a command to the relay to activate the peristaltic pump. The peristaltic pump pumps the pH solution and nutrient solution into the water tank. The ESP32 then sends a command to the relay to activate the aerator, which stirs the liquid in the water tank for 1 minute. After that, the water is directed towards the hydroponic pipes.

The system also includes three sensors: pH sensor, TDS sensor, and temperature sensor. The pH and TDS sensors are used to control the content of the liquid in the water tank. When the pH and nutrient levels are not suitable, the relay activates the peristaltic pump to pump the nutrient and pH solutions. The temperature sensor serves as room temperature monitoring. The data captured by these sensors is sent to the ESP32 and displayed on the LCD screen.

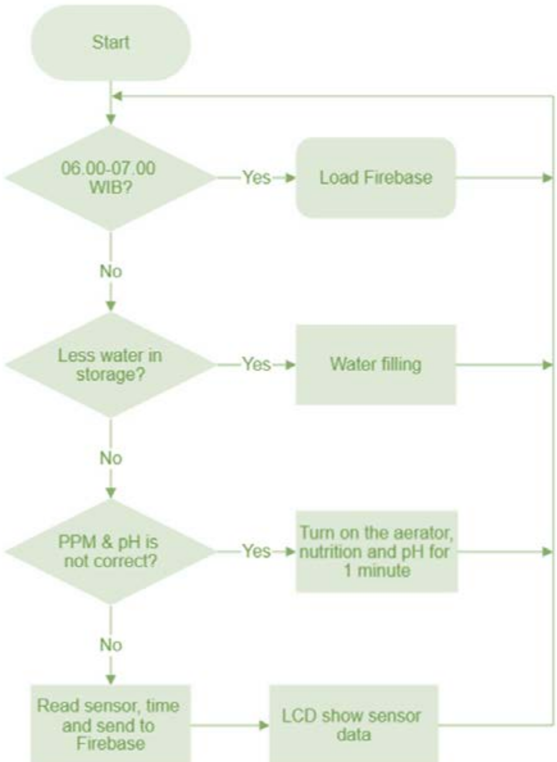


Figure 3. Hydroponic nutrition monitoring and automation system flowchart

Figure 3 The flowchart illustrates the monitoring and automation system for hydroponic nutrient management in the implemented system. The adjustment of water level and pH is done by comparing the sensor readings with the setpoint values obtained from the web interface. If the measured water level (PPM) is below the setpoint, the microcontroller will activate the peristaltic pump to flow 16 mL of the AB Mix nutrient solution. Similarly, if the measured pH value is below the setpoint, the microcontroller will activate the peristaltic pump to flow 16 mL of the pH down solution. The fluid flow continues until the water level or pH reaches the setpoint. The adjustment of water level (PPM) and pH is performed once the water volume in the tank is full. In the event that the water volume in the tank becomes empty, the microcontroller will activate the water tap pump, and the adjustment process for water level and pH will be stopped.

Simultaneously, the microcontroller sends all the read sensor data to the Firebase database. The transmitted sensor data includes Total Dissolved Solids (TDS) sensor readings for water level (PPM), pH sensor readings, temperature sensor readings, and humidity sensor readings. The transmission of sensor data is carried out once every minute. Upon receiving the data from the microcontroller, the Firebase database immediately processes the data, which is then visualized on the web interface for monitoring purposes. The website provides three types of monitoring, namely: (1) Day monitoring; (2) Sensor data value monitoring; (3) Graphical form of sensor data value. The application of an automated system still needs monitoring so that the calculation of nutrients needed in hydroponic plants and checking the duration of planting is maintained.

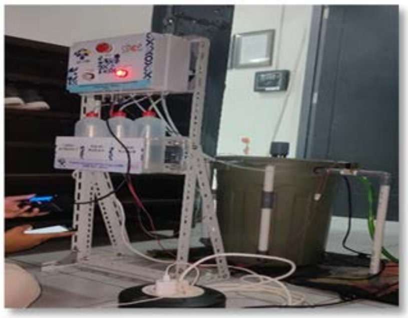


Figure 4. Hardware control box and nutrient bottle container

Figure 4 shows the hardware control box and nutrient bottle container placed on a support pole with a height of 101 cm. The support pole is made of iron which functions to place the control box hardware which contains the automation components and to place the nutritional bottles. Nutrition bottle containers can also be mounted on the wall. The nutritional bottle container uses acrylic material which is placed under the hardware control box. There are 3 bottles of nutrition, namely bottles of liquid nutrition A, nutrition B, and pH buffer. The hydroponic plants selected for observation at SMKN 1 Sidoarjo are bok choy and mustard greens. Table 2 shows the levels of nutrients needed for hydroponic bok choy plants.

Table 2. Nutritional levels of the bok choy plant

Weeks	PPM	m (A + B)/L
1	500	1,5A + 1,5B
2	700	3A + 3B
3	900	4A + 4B
4	1200	5A + 5B
5	1200	5A + 5B
6	1300	5,5A + 5,5B
7	1300	5,5A + 5,5B

For hydroponic cultivation of bok choy, the water pH used ranges from 6.5 to 7, meaning the pH falls within the neutral range and is desired for the normal growth of the plant. Hydroponic bok choy cultivation has an estimated harvest period of around 40-60 days. The nutrient level control in this system is carried out by referring to the specific nutrient requirements of bok choy: (1) The nutritional dose in the first week is 500 PPM with a mixture of 1.5 liters of nutrients A and 1.5 liters of nutrients B; (2) The nutritional dose in the second week is 700 PPM with a mixture of 3 liters of nutrient A and 3 liters of nutrient B; (3) Giving a nutritional dose in the third week of 900 PPM with a nutritional mixture of 4 liters of nutrient A and 4 liters of nutrient B; (4) Giving a nutritional dose in weeks 4-5 of 1,200 PPM with a mixture of 5 liters of nutrient A and 5 liters of nutrient B; (5) Giving nutritional doses at week 6 – 8 of 1,300 PPM with a mixture of nutrients as much as 5 liters of nutrition A and 5 liters of nutrition B.

Figure 5 shows a website application design image that is used for monitoring hydroponic automation tools with an internet network. On the website there is monitoring of PPM, pH, room temperature, and humidity from hydroponic automation tools. In addition, there is a planting day setting feature (menu button 16). Button (17) is a setpoint configuration feature to set the PPM and pH needed by plants. Users can set the setpoint from the first to the fifth day, pH and PPM as needed.

Figure 5. Link Webpage (https://pens.id/slicekomputer)

3. RESULTS AND DISCUSSION

Results

SLiCE community service activities were carried out for approximately two weeks. The highlight of the activity was the provision of training to students and teachers of SMK Negeri 1 Sidoarjo. Next is the installation of an automation and IoT system for hydroponics in the green house of SMK Negeri 1 Sidoarjo. All processes starting from designing hardware, mechanics, programming and making monitoring applications are carried out in the PENS Computer Engineering laboratory. Community service products that have been successfully built can be seen in Figure 6.

Figure 6. Tool implementation at hydroponic greenhouse

Figure 6 shows the implementation of the device in the hydroponic greenhouse of SMKN 1 Sidoarjo, which was carried out by the team of collaborators, students, and teachers of SMKN 1 Sidoarjo. When the device is initially powered on, the microcontroller activates the buzzer as an indication that it is connecting to the predetermined Wi-Fi network. Next, the microcontroller obtains the data for the Western Indonesian Time (WIB) zone, which is used for internet synchronization. Once the microcontroller has established an internet connection and obtained the time zone data, it proceeds to execute the automation process.

The microcontroller initializes the sensors, digital pins, and Firebase as the database. It retrieves the user-defined setpoints for the water level (PPM) and pH values through the web interface connected to the Firebase database. The retrieval and synchronization of these setpoints are performed every day from 06:00 to 07:00 WIB. In case the device encounters any issues such as power outage, short circuit, or other problems that cause the microcontroller to shut down, when it is powered on again, the device can immediately synchronize the setpoints at the designated time.

The application of nutrient determination function is implemented in the setpoint feature, which includes the settings for the day, PPM, and pH values in a total of 5 setpoints. The purpose of having 5 setpoints is to provide flexibility for users to adjust the day on which the nutrient levels for the plants will be changed. Each setpoint configuration will have its own effects, which will impact the plants, as each hydroponic plant has its own specific nutrient requirements that contribute to their successful growth. For example, the team of collaborators chose bok choy as the plant, which is known for its ease of cultivation in hydroponics. Bok choy has five different nutrient configurations until it is ready for harvest. This serves as a reference for determining the setpoints on the IoT website. However, these setpoints can be changed at any time according to the user's preferences.

The IoT system built on the web-based application is functioning as intended, as shown in Figure 7. The real-time data from pH and PPM sensors are displayed on the website according to the current conditions.

Figure 7. Visualization of sensor data on the website
Figure 8. Graph of PPM sensor data at 14.50 - 15.15
Figure 9. Graph of PPM sensor data at 12.20 - 12.45

The PPM sensor detects the turbidity of nutrient water as a parameter of nutrient needs in hydroponic plants as shown in Figure 8. The graph shows the PPM value measured every minute, the graph looks slightly down indicating the detected PPM is also decreasing every minute. The results of temperature measurements in the greenhouse area are shown in Figure 9. The highest temperature was measured at 36.3° C at 12.33. Moments later, the temperature reached its lowest point at 35.6° C at 12.40.

Figure 10. Graph of humidity sensor data at 12.20 - 12.45

Figure 10. shows data from the measurement results of the DHT11 humidity sensor. The sensor detects humidity in the greenhouse area every minute. The humidity value is stable at 59%.

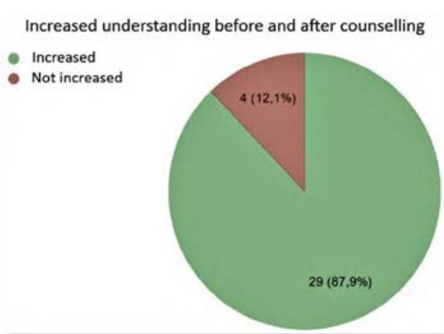
Embedded Systems and IoT Training

At this stage, it is carried out by providing training related to the implementation of Internet of Things-based automation technology in hydroponics to students and teachers at SMK Negeri 1 Sidoarjo as shown in Figure 11. This training aims to make the participants able to understand the system being built. In the end the participants were able to maintain and repair according to the correct procedure.

Figure 11. Automation technology implementation and Internet of Things training

In addition to designing the product, the SLiCE 2022 community engagement program also provides training related to the produced products. Two students and two lecturers serve as speakers to provide insights, guidance, and explanations on how the devices work. The students and teachers of SMKN 1 Sidoarjo, as participants, showed enthusiasm during the presentations. This was evident through various question and answer sessions and discussions conducted between the speakers and participants.

Students who took part in this training were students majoring in audio video engineering. Based on the existing curriculum, these students have more connections between school subjects and the training topics being delivered. Based on Figure 12, as many as 87.9% of participants experienced an increase in their understanding of IoT and its implementation. Only 12.1% did not experience an increase.



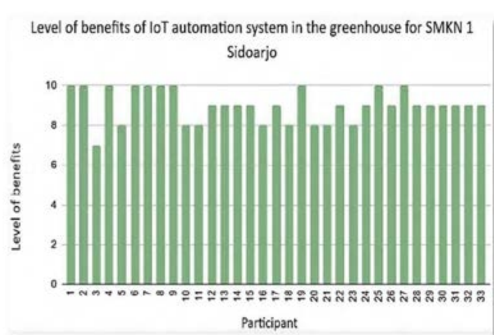


Figure 12. The results of the questionnaire about the participants' understanding before and after counseling (https://pens.id/kuisionerSLiCE2022)
Figure 13. The results of a questionnaire about the level of benefits of automation and IoT systems in green houses at SMK Negeri 1 Sidoarjo

Based on the questionnaire results shown in Figure 13, the implementation of automation technology and Internet of Things for the greenhouse at SMK Negeri 1 Sidoarjo was perceived as highly beneficial. The average score given by the respondents was 9, indicating a high level of usefulness. The questionnaire was completed by 33 participants (teachers and students) who attended the training and installation of the automated hydroponic system. The students and teachers of SMK Negeri 1 Sidoarjo gained new knowledge and experience in transforming the conventional hydroponic system into an automated hydroponic system.

4. CONCLUSION AND RECOMMENDATIONS

The SLiCE community service activity with the topic of implementing automation technology and Internet of Things for the greenhouse at SMK Negeri 1 Sidoarjo has provided an alternative solution for hydroponic plant cultivation by utilizing technology. The students and teachers of SMK Negeri 1 Sidoarjo have gained new knowledge and experience in transforming the conventional hydroponic system into an automated hydroponic system. Through the training activities as part of the SLiCE community service program, 87.9% of the participants have experienced an improvement in their understanding of IoT and its implementation.

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