IoT-based pH Monitoring for Nutrient Absorption Efficiency in Hydroponic Plant at Pion Hidrofarm Start-Up

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Abstract. Farming land in Malang City is getting more limited because several agricultural areas have changed their function to housing or commercial areas such as cafes. Pion Hidrofarm, a startup company in Malang City, demonstrated how to use this hydroponic technique to save land by arranging it vertically and on narrow land. This research aims to make a simple prototype in the form of a tool that can monitor the pH of water nutrients. In addition, this device will also neutralize the pH of the water automatically. The method used in this research is a single case study using a design thinking approach. The author studied literature from various sources as secondary data to support the research. Four stages have been carried out, starting from learning the concept of hydroponic growing media to buying model "A" hydroponic media with 180 planting holes. The fifth stage currently being researched is monitoring the pH of the water. In addition, this tool also functions to neutralize the pH of the water automatically if there is a pH swing with a value above or below the threshold. If automatic neutralization cannot run for some time, it will notify the farmer for manual action.

1 Introduction

The agricultural sector contributes significantly to the national economy through its Gross Domestic Product (GDP), foreign exchange, provision of food and raw materials, reduction of poverty, creation of jobs (the agricultural industry can employ more than 35% of the workforce) and rises in average incomes of people [1]. The multiplier effect, exemplified by the connections between industries' inputs and outputs, consumption, and investment, benefits the farm sector in addition to direct contributions. However, as the population grows, technological advancements cause agricultural land to become smaller [2]. In Indonesia, urban areas are primarily affected by this illness.

The rising conversion of agricultural land brought on by urban growth is particularly alarming and poses a threat to agricultural industries, according to State Regulation No. 26

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of 1997 on spatial planning. Urban expansion must continue; thus, it is crucial to consider how agricultural operations may be accommodated into other parts of the urban development plan. Urban ecosystems can be improved, and urban poverty can be decreased by integrating agricultural growth with urban development [3]. By utilizing the limited land in urban areas, the government is attempting to solve these issues.

The Pandemic has altered our way of life because, when working from home (WFH) is advised, our house has become the center of our daily activities. Having a garden at home may be practical and advantageous at this time of plague, as individuals occasionally need to take a break from working, and gardening is one of the possibilities. Considering the COVID-19 epidemic, urban farming has become more popular, accelerating the tendency [4]. Urban farming has benefits for farmers who have limited land but have modern farming skills. In addition, it impacts the community to fulfil the need for healthier food alternatives for various types of Horticultural crops. One technique that is often used is Hydroponics.

Hydroponics can produce larger yields than traditional farming by utilizing the horizontal surface area and the vertical space above it, thereby increasing the number of plants per unit area and leaning toward vertical farming to meet everyday consumer needs for nutritious fresh food around densely populated places. Moreover, hydroponics enables several crops to be harvested year-round without haphazard fertilizer or pesticide environmental releases. In comparison to conventional open-field agriculture, it utilizes less land and water. Hydroponics optimizes water and chemicals to reduce potentially dangerous waste and residuals by using intelligent greenhouses outfitted with various technologies to control crucial factors for proper plant physiology [5,6]. There are various hydroponic ways for growing food, and how they are used will depend on the type of plant, the climate where it will be used, and the available resources.

Pion Hidrofarm is a startup in Malang that is already running hydroponics [7]. This startup still implements a manual system for monitoring the potential of hydrogen (pH) and parts per million (PPM) in hydroponic water nutrition, as represented in Fig. 1. The conventional method usually carried out by farmers requires repeated checks, often resulting in inaccurate measurements. This method has an impact on fertility as well as plant health. Plants can be damaged if farmers do not consider the right timing and conditions for providing nutrients. Therefore, we need a technology that can monitor pH and PPM automatically by sending notifications. Internet of Things (IoT)-based monitoring is a technology that helps to save time, energy, and costs in hydroponic systems. In working on plants, it is necessary to provide proper plant nutrition efficiently [8]. Setting the correct pH and PPM will affect the growth of healthier vegetables.

Fig. 1. Hydroponic starter kit 36 holes, 180 holes, and green lettuce harvest of Pion Hidrofarm

This research aims to make a simple prototype in the form of a device that can monitor the pH of water nutrients. In addition, this tool will also neutralize the pH of the water automatically. This tool will also send notifications if the pH conditions are in poor condition for some time. Thus, the farmer will be responsive and immediately respond by neutralizing the nutritional requirements in the water according to the standards required by the plants.

2 Method

This research continues previous research on a startup engaged in hydroponics called Pion Hidrofarm. This startup used a manual system to monitor and provide nutrition in previous research. In this study, the author created a prototype for monitoring and providing nutrition using a microcontroller automatically.

This study uses a qualitative research method with a design thinking approach. Five stages in design thinking will be carried out. The first stage is empathy, in which the author observes that in order to produce an optimal harvest, monitoring and providing nutrition are necessary. The second stage is the define phase, where the author found a problem, namely monitoring and providing nutrition manually so that farmers can stay in the hydroponic land relatively long. Therefore, we need a solution to monitor and provide nutrition automatically. In design thinking, this solution stage enters the third stage, namely the ideate.

Making a prototype to realize this solution is necessary, which is the fourth stage in design thinking. Making the prototype itself consists of three parts: low fidelity, medium fidelity, and high fidelity. In this study, the author will apply medium fidelity, namely sketch programming tested on a microcontroller simulation. The next stage is the test stage. This stage will be carried out if the medium-fidelity prototype is successful, namely by developing a high-fidelity prototype as a tool. The further details of the methodology research can be seen in Fig. 2

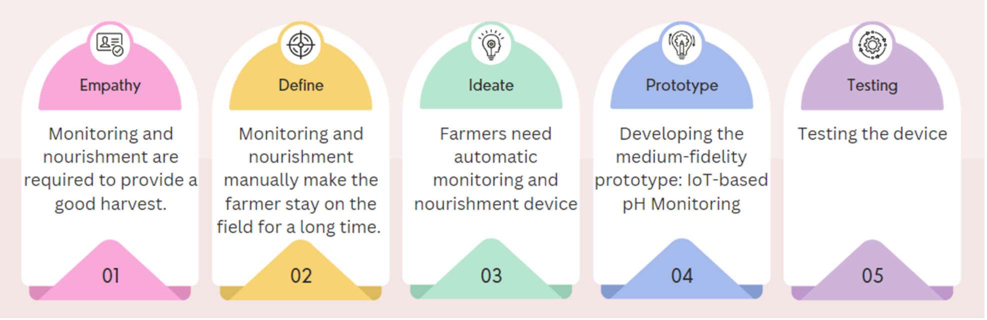

Fig. 2. Flowchart of methodology research using design thinking approach

3 Result and discussion

One of the determining factors for the success of hydroponic gardening is the accuracy of hydroponic plants' potential hydrogen (pH) value. A hydroponic plant must absorb nutrients perfectly to get good plant results. Nutrients can be absorbed perfectly if the pH of the water is at the required level. Some plants require a pH of 5.5–6.5, such as mustard greens, and some require a pH of 7.0, such as Bok Choy (*Brassica rapa*), also called Pak Choi. If the pH is below 5.5, nutritional components such as nitrogen, phosphorous, potassium, sulphur, calcium, and magnesium cannot adequately absorb. On the other hand, if the pH is above 7.0, the nutritional components such as nitrogen, calcium, magnesium, and iron cannot be adequately absorbed. If the pH is less than 5.5 or more than 7.0 occurs continuously, the crop will not get optimal results.

If the pH does not match the requirements of the plant, it means that the plant will lose its ability to absorb the nutrients needed for growth. Each hydroponic plant requires a different pH value, depending on the type of plant. However, in general, plants need a pH between 5.5-6.5. The device used to measure pH is a pH meter.

3.1 Factors affecting the pH of water in hydroponics

The pH level of the nutrient solution is changed due to the ratio of the amount of anions and cations. Anions are nutrients with a negative ion charge, while cations have a positive ion charge. In the morning and afternoon, plants carry out the process of photosynthesis and produce ions, which can increase the acidity of nutrients, causing the pH to decrease. On the other hand, in the evening and at night, plants carry out respiration processes and produce ions that can reduce acidity levels, causing the pH to increase.

In the hydroponic method, plants have a pH limit of 5.5 - 6.5 [9,10]. Plants need a range of pH values that must be maintained to ensure the availability of all nutrients to be absorbed by plants. Optimal pH conditions will impact average growth and nutrient absorption in plants [11]. At pH below 5 (very acidic), it can affect the change and spread of fungal diseases resulting in plant rot [12,13]. Then, pH conditions above 7.5 will reduce the availability of iron, manganese, copper, zinc, and boron [14].

It is crucial to increase photosynthetic activity due to a lack of available agricultural land and a growing global population. Oxygenic photosynthesis is vital since practically all life on Earth depends on it, either directly or indirectly. It is the source of our food, fiber, and many valuable compounds. To produce the organic molecules glucose ($C_6H_{12}O_6$), sugars, and starch from carbon dioxide (CO_2) and water (H_2O) and release molecule oxygen (O_2) into the atmosphere, plants utilize light energy [15].

$$CO_2 + H_20 + sunlight = CH_20 + 0_2 \tag{1}$$

$$carbon\ dioxide + water + light = carbohydrates\ (sugar) + oxygen \tag{2}$$

From the morning until noon, plants carry out the process of photosynthesis. The process of photosynthesis is the process of producing and storing food in the form of sugar and starch. Food will form growth wall cells to produce O_2 and CO_2 from the air. This process causes changes in pH from swing towards alkaline, and the temperature of the nutrient solution also increases [16].

3.2 Alkaline conditions at night

At night the plant performs the process of respiration. The method of respiration occurs when the process of photosynthesis has stopped, marked by the light of the sun has set. Plants will store food (sugar and starch) that is continued in the combustion process for growth [17]. The method of burning energy will release CO_2, which dissolves in water H_2O to produce carbonic acid (H_2C0_3). This condition will bring the pH to a more acidic level [18].

$$CH_20 + O_2 = CO_2 + H_20 + Energy \tag{3}$$

$$Carbohydrates\ (sugars) + oxygen = carbon\ dioxide + water + energy \tag{4}$$

Plants take more potassium and phosphorus from the fertilizer solution when less light is available, raising the acidity (pH will drop). Low light levels also decrease transpiration rates, reducing calcium uptake. Calcium shortage symptoms may manifest in conjunction with a low pH in the substrate [19]. When bright sunshine is abundant, plants absorb more nitrogen from the nutrition solution (on clear sunny days). The result is a reduction in acidity (pH rises).

3.3 Neutralize the pH

Significant pH fluctuations in the developing system can result from the uptake of anions' negatively charged nutrients and cations' positively charged nutrients by plants. If more cations than anions are absorbed, the pH will fall. A higher pH results from the absorption of more anions than cations. The ratio of these two forms of nitrogen in the nutrient solution can have a significant impact on both the rate and the direction of pH changes over time because nitrogen, an element needed in large quantities for healthy plant growth, can be supplied either as a cation (ammonium - NH_4^+) or as an anion (nitrate - NO_3^-). pH changes can happen unexpectedly quickly [10,20].

Reducing the pH in a hydroponic solution can add 10% nitric or phosphate acid, H_2SO_4, HNO_3, and H_3PO_4. On the other hand, to increase the pH content in an aqueous solution, it can use 10% KOH (Potassium Hydroxide). There is a fast way to raise and lower the pH, namely by adding a pH-up solution to raise the pH and adding a pH-down to lower the pH. This liquid is sold in farm shops or online marketplaces.

3.4 Developing a prototype of pH monitoring and pH neutralizing

This prototype is divided into 3 parts: sensors, microcontrollers, and actuators. The pH meter module PH-4502C represents the sensor for the microcontroller using the Arduino Nano. Arduino designed it that is based on the Microchip ATmega328P microcontroller (MCU). It is one of the slightest circuit boards in the Arduino class and an open-source breadboard-friendly microcontroller board [21]. As for the actuator, it uses 1 infusion tube filled with a pH-increasing liquid and 1 infusion tube filled with a pH-lowering liquid.

The main task of the sensor is to read whether the pH of the water is under the appropriate conditions or is it at the upper or lower threshold. The sensor will report its value to the microcontroller every 15 minutes, and this chip will process the existing data. If the data shows the appropriate value, for example, at levels 7.0, then the water is in average condition, and there is no action.

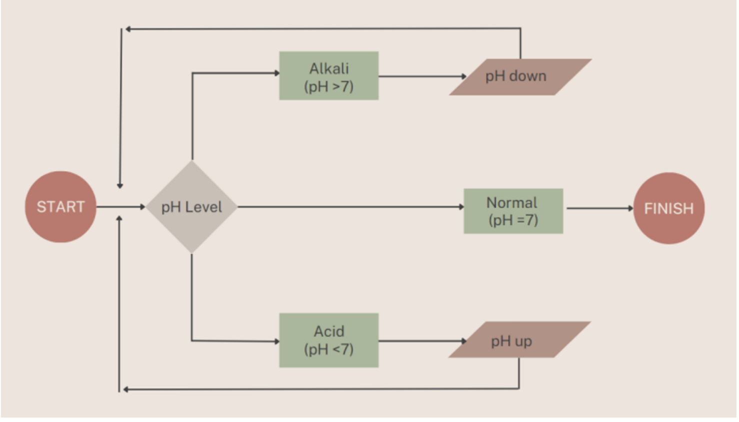

Fig. 3. Flowchart on how the device works

Each plant has a different pH standard—Bok Choy (*Brassica rapa*), which requires a water pH of 7. If the sensor reads the pH of the water far below the lower threshold, 6 or 5, for example, the microcontroller will order the pH-up liquid to drip once through the infusion tube. After the pH liquid drips, the pH will be checked for 15 minutes. This process is carried out until the water's pH reaches the standard Bok Choy requires, which is pH 7. Likewise, when the pH of the water is at the upper limit, the actuator will order the pH infusion hose down to give one drop of liquid. Details of how the device works can be seen in the flowchart, as seen in Fig. 3.

The flowchart shown in Fig. 3 starts with reading the pH of the water using the PH-4502C sensor. If the pH level is at a specified number, for example, pH = 7, then no action will occur on the actuator. If the pH meter reading shows a number below 7, the actuator will give the order to run an infusion containing pH up; likewise, if the pH level shows a number above 7. The block diagram of the microcontroller circuit connected to the sensors and actuators can be seen in Fig. 4.

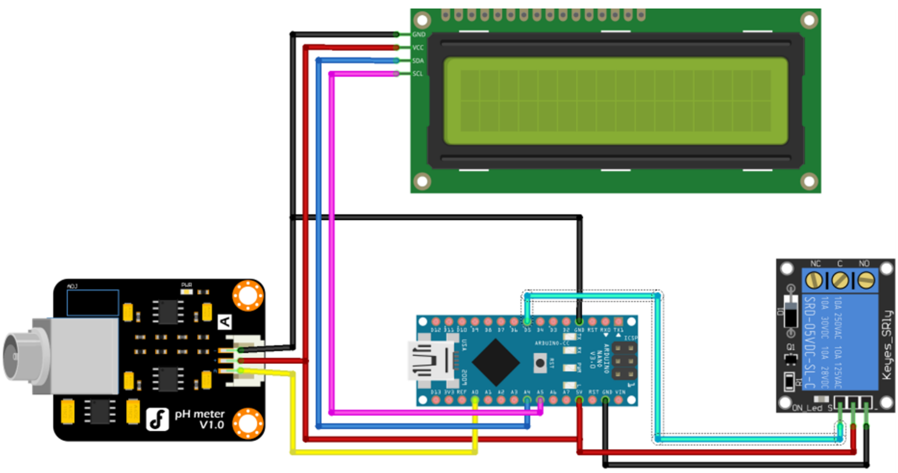

Fig. 4. Arduino nano block diagram equipped with sensors and actuators

It should consider the tolerance given in determining the threshold so that the actuator does not work continuously. For example, if the pH meter shows 6.5, this number is still considered the lower threshold of reasonableness. However, if it shows a number below 6.5, the chip can instruct the actuator to add a pH-up liquid, likewise if the number is at the limit of 7.5. The determination of the upper and lower limits is related to the pH swing that the author has explained in the previous sub-chapter, where the photosynthesis system influences the pH swing during the day and the respiration process in the evening.

Real-time water pH data is displayed on the LCD. The screen will display a number when the button is pressed. In addition, water pH data can also be viewed in real-time through the Thingspeak server using IoT technology available in a smartphone application or website. The use of this server can be seen privately or publicly by everyone in the form of a channel. Fig. 5 is an example of a public Thingspeak channel.

In this experiment, the author learns from a system worked on by Bina Nusantara @Malang researchers who apply aquaponic. The term aquaponics derives from the words aquaculture, which refers to the cultivation of fish in an enclosed environment, and hydroponics, which refers to the cultivation of plants in a typically soil-free environment [22]. In this study, farmers placed several sensors, such as Total Dissolve Solid (TDS) and pH meters, floating above the surface of the pond water containing catfish. Farmers can monitor the amount of dissolved solids or particles in the water and the pH of the water online through an application they made on their smartphones.

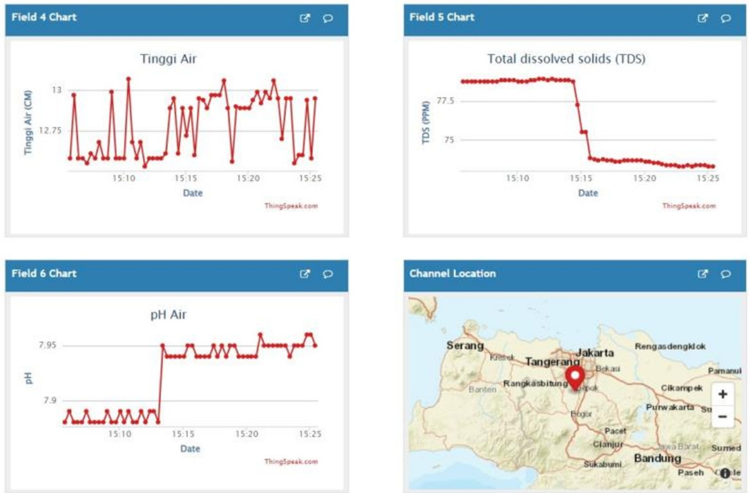

Fig. 5. Public hydroponic channel on thingspeak (https://thingspeak.com/channels/1303269)

Pond water containing catfish contains several nutrients needed by hydroponic plants. So that farmers do not need to provide AB mix nutrition as hydroponic farmers do in general. AB Mix is one of the nutritional mixtures created especially for the growth of hydroponic crops [23]. Formula A and Formula B were present in the AB mix. Water from the pond is channeled into the upper tank using a pump and fills the tank containing the filter. Furthermore, water flows from the tank to the hydronic pipe using gravity. Hydroponic pipes are arranged like the siring terrace concept so water flows to the lowest pipe. Then, the water from the hydroponic pipe returns to the pond. Details of aquaponic carried out by researchers from Bina Nusantara University @Malang can be seen in Fig. 6. Because the position of the pipe is higher than the pond, the water that falls into the pond will produce oxygen suitable for catfish growth.

Fig. 6. Some sensors implemented in an aquaponics system

4 Conclusion

In hydroponics, water's pH has a crucial role so that plants can absorb nutrients properly. The height and drop of the pH of water in hydroponics are influenced by several factors, including plant activities such as photosynthesis during the day and respiration at night—

significant fluctuations in pH need to get attention from farmers. Therefore, monitoring is carried out online using an IoT-based device that allows farmers to control the pH of the water from their smartphones. This device will also neutralize automatically for some time. If the system does not get handled automatically within a certain period, farmers must carry out manual handling. The device being worked on is still in the experimental stage as a medium-fidelity prototype, so it takes time to test the hydroponic field.

For future research can develop a prototype in a high-fidelity form so that the device can help farmers work in monitoring the water pH level in hydroponics. In addition, future research can add other sensors, such as a TDS meter, to see the density of dissolved particles in water. Applying pH sensors and TDS sensors in hydroponics will help farmers produce better quality and more quantity crops.

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