Hydroponic nutrient mixing system based on STM32

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Abstract. Hydroponics nutrient mixing system based on STM32 is a device to produce hydroponic nutrient solution, according to individual plant nutrient recipe, automatically by using individual dosing pump for each fertilizer concentrate. Nutrient recipes and fertilizer database are stored in Raspberry PI. The system will compute the recipe and translate to the required individual concentrates’ volume, then send command to dosing pump controller. Dosing pump controller will then send command to 10 dosing pump motor drivers to pump each fertilizer concentrate according to the volume measurement to produce the nutrient solution. The core of dosing pump controller is a 32bit microcontroller development board Nucleo-F446RE from ST Microelectronic, ample to control 10 dosing pump drivers. Each of the dosing pumps will be equipped with fertilizer concentration with maximum solubility. The system has user friendly graphical user interface using 7” graphics LCD. To produce specific solution strength, system can fill in water through water pump and use water level sensor to measure the volume, this process is controlled by proportional controller. The output of the mixing process can be hydroponic A and B mixed concentrate solution, or direct solution. For concentrate solution user must dilute A and B concentrate with water. The system has been tested 9 times and produce maximum 9% error. Water filling system accuracy test for 5-liter water volume with Kp 10000 has 2.784% error.

Keywords: Hydroponic, STM32, Raspberry PI, proportional controller, concentrate

Introduction

Hydroponics is the method of planting using water without the use of soil, by focusing on the nutritional needs of plants [1]. Because the planting method does not require the use of soil, nutrients to be distributed must have similar elements with the ones found in soil along with additional elements to nourish the plants. These elements can be categorized into 2 categories, macro, and micro elements. Usually, nutrition for hydroponics method is available in the form of A and B mix. The mix of the 2 nutrients already contains macro and micro nutrients. A and B mix solution is produced by mixing several fertilizers with specific weight according to plant nutrient recipe, then diluted with soft water to prevent precipitation [2]. Each fertilizer has specific solubility at certain temperature, higher temperature create better solubility [3].

The right nutrient recipe is dependent on many variables. The adequate nutrient formulation
will depend on plant species and its variety, stage of growth, parts of plant to be harvested, season of the year, climate and temperature, light intensity, and duration of sunlight exposure. [4].

Hydroponics has many advantages, such as: crops can be grown where no suitable soil exists, increase plant productivity, and free from pesticides. Along with those advantages, hydroponics also have disadvantages, such as high initial setup cost and the need of trained person. In soilless culture, plant root directly submerged in nutrient solution, thus to achieve maximum productivity we need to maintain EC and pH level in solution [5]. To simplify farm operation, researchers build control system for maintaining nutrient solution, usually using pH and EC sensor [6]. Rajeev Iochan Mishra and Preet Jain proposed a system to regulate nutrition solutions in hydroponics according to plants’ needs [7]. B. P. Kulkarni, Pai Susmita Venkatesh, Mohite Ankita Sambhaji, & Yedake Priyanka Rajiv designed hydroponics system to monitor and control pH and the temperature of nutrient solution [8]. For better nutrient mixing system, Theeramet Kaewwiset & Thongchai Yoyativong tried to find the relationship between EC and pH using linear regression to generate mathematical equation [9]. To evaluate productivity using automation system, Diego et all built an automation system to control pH and nutrient concentration for lettuce production, which showed a positive result, plant can be harvested faster compared to when conventionally grown in soil [10].

Considering many research has been done in nutrient management and automation, this research will focus to build a hydroponics nutrient mixing system based on nutrient recipe, to produce A and B mixed concentrate solution automatically based on the plant nutrient recipe. Users entry fertilizer content and plant nutrient recipe in the ppm value then system will compute and blend each fertilizer to produce A and B mixed solution.

System Design

System design is divided into 2 parts, system user interface and nutrient mixing controller. System user interface includes database to store plant recipe, fertilizer composition, and sending command to nutrient mixing system conforming to the plant recipe. Nutrient mixing controller process the command and control each dosing pump motor to pump liquid fertilizer in specific volume.

![Figure 1. System Block Diagram.](image-url)
Figure 1 shows block diagram of system. System User Interface consists of Raspberry PI, graphical LCD, LCD driver, wireless keyboard and touchpad. A customized software is built using C++ with Qt framework running on Raspberry PI. User can select nutrient plant recipes and fertilizers from a menu, then system will perform nutrient calculation to determine the amount needed for each fertilizer (in mL) and send command to nutrient mixing controller. Nutrient Mixing Controller will translate this command to number of steps needed by stepper motor to pump liquid as required. Initially, system requires manual calibration to calculate how many number of steps needed to pump 1 mL liquid.

Nutrient Mixing controller consists of an STM32 F446RE microcontroller as main controller, 10 dosing pumps, a DC motor water pump, and an HC-SR04 ultrasonic sensor. STM32 will control stepper motor rotation to pump liquid fertilizer according to nutrients needed (in mL). DC motor water pump provide soft water for diluting final mixed solution to specific concentration. The controller which will be used in this design is P-controller which will consider the difference between water height and desired water height as error.

![P-Controller on STM32](image)

**Figure 2. P-Controller on STM32**

Figure 2 shows diagram of P Controller which will be used to control base water volume. To create a P Controller from diagram shown above, Kd and Ki value must be 0. The base water pumped using P Controller will be collected in a container with static dimensions. The container is square-shaped, so water volume in the container can be calculated using the mathematical formula:

\[ V = L \times t \]  

Where:
- \( V \): water volume.
- \( L \): area of bottom container.
- \( t \): water height

System mixes final nutrient solution from existing nutrient solutions as base, which will be referred as Substance. Substance is a nutrient fertilizer that can be found in the market and liquefied so substance will be in the form of liquid.

Dosing pump is used to pump substance from initial container to final container. Each dosing pump is connected to a stepper motor driver and the driver is controlled by STM32 microcontroller. To control the volume pumped by the dosing pump, STM32 needs to give clock-signal to clock pin, and high or low logic to the enable pin on the stepper motor driver.

The system uses Low Level voltage MOSFET IRL540 to control speed of DC motor. Speed of DC
motor is controlled by feeding PWM signal to the MOSFET gate, so the average voltage applied to the motor is controlled by PWM duty cycle generated by STM32.

System User Interface and Nutrient Mixing Controller are connected using serial communication between Raspberry pi and STM32. The serial connection is done using USB to Mini USB cable.

Problem solving in this calculation can be represented by linear equation shown below:

\[ A \times X = B \]  

Where:
- \( A \) = Element contribution of Substance
- \( X \) = Mass of Substance
- \( B \) = Target ppm of elements

The calculation process is done to find the correct mass of substance, so target value ppm of each element is satisfied. The calculation process is done in the form of matrix calculation. If no value of \( X \) can satisfy the equation above, the optimal value of \( X \) is applied. The following figure 3 shows the flowchart of the calculation process.

![Nutrient Calculation Flowchart](image-url)
Results and Discussion

HC-SR04 ultrasonic sensor was tested in distance ranging from 5cm to 50cm with 5cm interval, whereby for each distance we measured 100 times. At the distance of 5cm, the sensor produced 13.7% error, and at 10cm produced 8%, nevertheless sensor give low error of <4% when measure distance is above 10 cm. The sensor gave lowest error of 1% when measured distance is at 50cm. Hence, from this experiment, we conclude that we must position sensor placement distance to more than 10cm.

![Distance Sensor Test Result](image)

**Figure 4 Graph of ultrasonic HC-SR04 sensor test**

To produce liquid concentrate fertilizer, we dilute fertilizer with low ppm water. Low ppm water means little mineral are contained in the water. Table 1 shows ppm concentration from various water source, the lower the better.

| Table 1. Table of ppm of water |
|--------------------------------|
|                      | Distilled water | Mineral water | Tap Water |
| Ppm                 |      1         |    101        |     333    |

Table 2 and Table 3 shows the experiment of producing liquid fertilizer from several water sources. Good liquid fertilizer will not form sediment. If sediment exist, it will bring impurity to the liquid fertilizer. We concluded that distilled water has best result compared to other source of water, because distilled water has lower dissolved material than mineral water and tap water. In the second experiment, mass of dissolved material was increased.

| Table 2. Solubility Experiment for A Concentrate Solution |
|----------------------------------------------------------|
| Concentrate A                                           |
| Mass (gram)     | Sediment (Distilled Water) | Sediment (Mineral Water) | Sediment (Tap Water) |
| 5Ca(NO₃)₂, NH₄NO₃, 10H₂O (Calcinit) | 6,06 | No | No | No |
| KNO₃ (Calcium Nitrate) | 1,79 | No | No | Yes |
| B, Cu, Fe, Mn, Mo, Zn (Librel BMX) | 0,75 | No | No | No |
Table 3. Solubility Experiment for B Concentrate Solution

| Concentrate B | Mass (gram) | Sediment (Distilled Water) | Sediment (Mineral Water) | Sediment (Tap Water) |
|---------------|-------------|-----------------------------|--------------------------|----------------------|
| KH₂PO₄ (MKP)  | 1,10        | No                          | No                       | No                   |
| (NH₄)₂SO₄ (ZA)| 3,84        | No                          | No                       | Yes                  |
| K₂SO₄ (Potassium sulphate) | 0,6 | No                          | Yes                      | Yes                  |
| MgSO₄·H₂O (Magnesium sulphate) | 1,80 | No                          | No                       | Yes                  |

According to Table 4 and 5, if mass of nutrient is increased, some concentrate will produce sediment when dissolved to distilled water, so in this experiment the number of dissolved mass is limited to 50%.

Table 4. Second solubility experiment for concentrate A solution

| Concentrate A | Mass (gram) | Sediment (Distilled Water) | Sediment (Mineral Water) | Sediment (Tap Water) |
|---------------|-------------|-----------------------------|--------------------------|----------------------|
| 5Ca(NO₃)₂·NH₄NO₃·10H₂O (Calcinit) | 9,09 | Yes                         | Yes                      | Yes                  |
| KNO₃ (Potassium Nitrate) | 2,68 | Yes                         | Yes                      | No                   |
| B, Cu, Fe, Mn, Mo, Zn (Librel BMX) | 1,13 | No                          | No                       | No                   |

Table 5. Second solubility experiment for concentrate B solution

| Concentrate B | Mass (gram) | Sediment (Distilled Water) | Sediment (Mineral Water) | Sediment (Tap Water) |
|---------------|-------------|-----------------------------|--------------------------|----------------------|
| KH₂PO₄ (MKP)  | 1,65        | No                          | Yes                      | Yes                  |
| (NH₄)₂SO₄ (ZA)| 5,75        | No                          | Yes                      | Yes                  |
| K₂SO₄ (Potassium sulphate) | 0,90 | Yes                         | Yes                      | Yes                  |
| MgSO₄·H₂O (magnesium sulphate) | 2,70 | Yes                         | Yes                      | Yes                  |

To create AB mixed solution with specific strength, system will draw water using water pump. In the initial process, user fills container area and system will calculate the volume by measuring the water level using ultrasonic distance sensor. Several experiments were conducted to find optimal Kp parameter with lowest error. Figure 5 shows steady error of 2,784 % with Kp = 10000.
After pumping specific amount of water, system will draw certain volume for each fertilizer concentration, based on nutrient recipe, using dosing pump. Dosing pump must provide high accuracy in ml range, and for system simplicity we use stepper motor-based dosing pump. The next experiment is to find how many steps are required to pump 1 ml of water. Experiment result in Figure 6 shows that average number of steps needed is 1217.3 steps, which then rounded to 1200 steps. The data values varied because the inaccuracy of the eyes when observing the number of volume in measuring cup which then affected the number of steps. Other factor is residual water in measurement cup that may add the volume of water.

Next experiment is to pump 4 ml water by multiplying the steps by 4, which results shown in Table 6 whereby average error is 2.5%. This error occurs because of residual solution in dosing pump pipe.

| Experiment | Result (ml) | Target | Difference | % Error |
|------------|-------------|--------|------------|---------|
| 1          | 4.1         | 4      | 0.1        | 2.5%    |
| 2          | 4.1         | 4      | 0.1        | 2.5%    |
| 3          | 4.1         | 4      | 0.1        | 2.5%    |
| 4          | 4.1         | 4      | 0.1        | 2.5%    |
| 5          | 4.1         | 4      | 0.1        | 2.5%    |
| 6          | 4.1         | 4      | 0.1        | 2.5%    |
Table 7 shows experiment result to get 8 ml water by multiplying the 1200 steps by 8, whereby the error is still around 2.5%. Thus, we concluded that this stepper motor-based dosing pump can be used with error of 2.5%.

Table 7. Table of liquid pumping volume test of 8 ml

| Experiment | Result (mL) | Target | Difference | % Error |
|------------|-------------|--------|------------|---------|
| 1          | 8.2         | 8      | 0.2        | 2.5%    |
| 2          | 8.2         | 8      | 0.2        | 2.5%    |
| 3          | 8.2         | 8      | 0.2        | 2.5%    |
| 4          | 8.2         | 8      | 0.2        | 2.5%    |
| 5          | 8.2         | 8      | 0.2        | 2.5%    |
| 6          | 8.2         | 8      | 0.2        | 2.5%    |
| 7          | 8.2         | 8      | 0.2        | 2.5%    |
| 8          | 8.2         | 8      | 0.2        | 2.5%    |
| 9          | 8.2         | 8      | 0.2        | 2.5%    |
| 10         | 8.2         | 8      | 0.2        | 2.5%    |

To obtain concentrate in ppm for each element in fertilizer, we calculate from vendor fertilizer table as shown in Table 8. This number of ppm of every element can be calculated using known mass weight of every applied elements. Element contribution of each substance can be found from the type of base substance used. Element contribution is the ratio between element percentage of substance times purity of substance with final volume of the concentrate.

\[ A = \frac{\text{element percentage} \times \text{substance purity}}{\text{volume}} \] \hspace{1cm} (6)

Volume is calculated in m³, element percentage is in percent and lastly, substance purity is in percent. The element percentage of each substances are shown below.

Table 8 Table of Percentage of Element for Substances

| Substance | Element | Percentage |
|-----------|---------|------------|
| Ca(NO₃)₂.4H₂O (Calcinate) | NO₃⁻ | 14.4 % |
|           | NH₄⁺    | 1.1 %     |
|           | Ca      | 19 %      |
| (NH₄)₂SO₄ (Ammonium Sulphate) | NH₄⁺ | 21.2 % |
|           | S       | 24.27 %   |
| KNO₃ (Potassium nitrate) | NO₃⁻ | 13.86 % |
|           | K       | 38.67 %   |
| K₂SO₄ (Potassium sulphate) | K     | 44.87 %   |
|           | S       | 18.4 %    |
| KH₂PO₄ (Potassium monobasic phosphate) | P | 22.76 % |
|           | K       | 28.73 %   |
| MgSO₄.7H₂O (magnesium sulphate) | Mg | 9.86 % |
Table 8 shows element contribution percentage for substances used. This value is used to find element contribution used in the calculation. For the ease of calculation, purity of substances used is assumed to be 100%. The calculation below is done for volume of 1 L.

| Substance      | S   | 13.01% |
|----------------|-----|--------|
| B, Cu, Fe, Mn, Mo, Zn (Librel BMX) |     |        |

Element contribution value (A) is constant for the same substance used, so it can be inferred from the equation (2) that mass (X) and result ppm (B) has a linear relation. It can be concluded that if mass of substance mixed is correct then result ppm of the mix is also in accordance to calculation.

System uses liquefied form of substance, so to find mass of substance mixed to the concentrate, density of the substance solution used is an important factor. To find the mass of the substance mixed, the following formula can be used.

\[
\text{Mass} = \text{Nutrient density} \times \text{Nutrient Volume} \quad \text{(7)}
\]

To prove that the resulting ppm of the solution is valid, can be seen from the volume of substance used to mix the concentrate solution.

| Table 9. Table of Element Contribution of Substances |
|---------------------------------------------------|
| **Element** | Ca(NO$_3)_2$.4H$_2$O | (NH$_4$)$_2$SO$_4$ | KNO$_3$ | K$_2$SO$_4$ | KH$_2$PO$_4$ | MgSO$_4$.7H$_2$O | B, Cu, Fe, Mn, Mo, Zn |
|------------|-----------------------|-------------------|---------|------------|-------------|------------------|---------------------|
| NO$_3^-$   | 144                   | 0                 | 138.6   | 0          | 0           | 0                | 0                   |
| NH$_4^+$   | 11                    | 212               | 0       | 0          | 0           | 0                | 0                   |
| P          | 0                     | 0                 | 0       | 227.6      | 0           | 0                | 0                   |
| K          | 0                     | 0                 | 386.7   | 448.7      | 287.3       | 0                | 0                   |
| Mg         | 0                     | 0                 | 0       | 0          | 98.6        | 0                | 0                   |
| Ca         | 190                   | 0                 | 0       | 0          | 0           | 0                | 0                   |
| S          | 0                     | 242.7             | 184     | 0          | 130.1       | 0                | 0                   |
| Fe         | 0                     | 0                 | 0       | 0          | 0           | 0                | 33.5                |
| Zn         | 0                     | 0                 | 0       | 0          | 0           | 0                | 6                   |
| B          | 0                     | 0                 | 0       | 0          | 0           | 0                | 8.7                 |
| Mn         | 0                     | 0                 | 0       | 0          | 0           | 0                | 17                  |
| Cu         | 0                     | 0                 | 0       | 0          | 0           | 0                | 17                  |
| Mo         | 0                     | 0                 | 0       | 0          | 0           | 0                | 0.2                 |
| Na         | 0                     | 0                 | 0       | 0          | 0           | 0                | 0                   |
| Si         | 0                     | 0                 | 0       | 0          | 0           | 0                | 0                   |
| Cl         | 0                     | 0                 | 0       | 0          | 0           | 0                | 0                   |

Element contribution value (A) is constant for the same substance used, so it can be inferred from the equation (2) that mass (X) and result ppm (B) has a linear relation. It can be concluded that if mass of substance mixed is correct then result ppm of the mix is also in accordance to calculation.

Table 10 Plant Nutrient Recipe for Lettuce - General [4]

| Substance       | Target Volume | Output Volume | Error (%) | Error (ml) |
|-----------------|---------------|---------------|-----------|------------|
| Ca(NO$_3)_2$.4H$_2$O | 83,972       | 85,000        | 1,224     | 1,028      |
| (NH$_4$)$_2$SO$_4$ | 3,082        | 3,000         | -2,661    | -0,082     |
| KNO$_3$         | 17,431        | 17,000        | 2,473     | -0,431     |
| K$_2$SO$_4$     | 57,753        | 60,000        | 3,891     | 2,247      |
Table 4.10 is an example table of nutrient mixing. As seen from the 3 experiments done to produce 3 different plant nutrient recipes, the maximum error is 9%. This error is due to the number of steps needed to pump 1ml of liquid is different for each dosing pumps.

**Conclusion**

The further the distance measured by the sensor, the lower the error. The distance measure from 5 cm to 50 cm results in an error of 14% down to 1%. Water with the lowest ppm value is distilled water and reverse osmosis water when compared to tap water and mineral water. It is easier for nutrients to dissolve in water and to not produce sediment when dissolved in water with low ppm. If Kp value used is small, output will never reach the desired output value; but if Kp value is too high, it will cause an overshoot, so the output value is bigger that the value desired. Dosing pump is capable of pumping 1ml of liquid with the error of 2.5%. The result of pumping nutrient substance by dosing pump is precise as seen from the experiment done 3 times for each plant nutrient recipes whereby the volume pumped stays the same.

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| Substance                | Target Volume | Output Volume | Error (%) | Error (ml) |
|--------------------------|---------------|---------------|-----------|------------|
| KH$_2$PO$_4$             | 36,614        | 40,000        | 9,248     | 3,386      |
| MgSO$_4$.7H$_2$O         | 65,198        | 68,000        | 4,298     | 2,802      |
| B, Cu, Fe, Mn, Mo, Zn (Librel BMX) | 16,464        | 16,500        | 0,219     | 0,036      |