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ORIGINAL ARTICLE

Field Study of PID Parameter Tuning Investigation in Peristaltic Dosing Pump Control for Use in Automated Fertilizer Mixing System

Yong Wai Xhuen[1], Ahmad Najmuddin Ibrahim[1*]

[1]Faculty of Manufacturing and Mechatronics Engineering Technology, Universiti Malaysia Pahang, 26600 Pahang, Malaysia.

ABSTRACT – Proportional–integral–derivative (PID) controller is one of the linear control methods of closed-loop irrigation control. Today, it is mostly used in the industry to regulate industrial process variables such as pressure, flow rate, temperature, heat, and others. In precision farming, the use of technologies such as sensors and PID controllers is popular nowadays. The technologies help the farmer fasten the fertilizer's mixing process before using it directly to the crop. However, not all farms afford to use high technology, and using low-cost mixing systems is one way to reduce their cost. Therefore, this research investigates the accuracy of fertilizer mixture using low-cost methods, compares the results, and proposes improvements to ensure a better fertilizer distribution for precision farming. Different parameter tuning will affect the mixing process of the fertilizer. A series of experiments will be conducted based on the PID control parameter, the concentration of the salt solution, and the initial amount of nutrients in the mixing tank. The salt solution will be used as an alternative for the fertilizer because it contains some similar composition ingredients that the EC sensor can detect. The experiment starts with a preliminary test to determine the temperature effect on reading where room temperature will be the best for the next experiment. The best PID parameter that is used is K_P= 130 and K_I= 60 to prevent the phenomenon of overshoot occur during the mixing process. Using the same PID parameter for the next experiment had also found out that the higher the concentration of the salt solution, the higher the chance occur the phenomenon of overshoot. The initial amount of nutrients inside the mixing tank does not affect much for the mixing process because the best parameter for the experiment we had found from the previous experiment is used. The results extracted from the experiment that shows the mixing process from a low-cost automated fertilizer mixing system.

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INTRODUCTION

The Drip Fertigation System (DFS) is a resource conservation technology for applying fertilizer through a drip irrigation system, which has been proved as a good practice of fertilization in agricultural production. Hydroponics in this type of set-up will have less evaporation compared to the soil. So, this system that is used in hydroponics will be more confined and controlled. The use of liquid type fertilizer for the fertigation system is the only way the dispenser unit can handle it.

The use of fertilizer is considered a high cost, and the fertilizer mixture's total amount of nutrients is crucial to ensure the crops get the correct portion of nutrients. Less fertilizer may not improve productivity to the maximum, and too many nutrients might kill the crops. Hence, we must build a low-cost mixing mechanism system to mix the fertilizer according to the ratio to help the farm reduce the workforce, cost and increase the productivity of the farm.

The Proportional–integral–derivative (PID) controller is used for the automatic fertilizer mixing system. We must find out the best variables of these values through research and analyze the data we will get through some experiments. The nutrient solution control system has a noticeable time lag, and the crop is more sensitive to the nutrient solution Electrical Conductivity (EC) value. To avoid the impact of EC value overshoot on crop production, the system control strategy reduces the derivative (D) link in the PID and only uses Proportional–integral (PI) control. During the experiment, we will also fix the total volume of water inside the tanks and the water's temperature to achieve the best and fair result for our experiment.

The same fertilizer produced by the different manufacturers might have different solubility and amount of nutrient content because of the addictive added in the process. Since the salt has the same chemical composition, potassium chloride (KCl), we use the salt as an alternative and experiment with different concentrations to see the result. We will experiment with the mixing process with a different initial amount of nutrients because the actual situation in the farm will not always mix the fertilizer from an empty mixing tank.

*CORRESPONDING AUTHOR | A. N. Ibrahim | anajmuddin@ump.edu.my

Related Work

According to [1], Drip Fertigation System can save 50% to 70% of fertilizer and more than 50% of water than conventional agriculture use. It can also reduce the fertilization rate by 1/3 without reducing the plant's productivity and reducing greenhouse effects. They believe that the adoption of DFS is an incentive for the sustainable development of the cherry tomato industry in Southern China. Adopting the DFS can improve the technical efficiency of their product and save the chemical fertilizer and the cost of a farm.

Rusydi [2] stated that Electrical Conductivity sensor and Total Dissolved Solid sensor indicate salinity level with different water quality parameters. The measurement of EC value can be got easier than the one of TDS. EC sensor is more often used because the measuring methods are more advantageous and have a faster gravimetric measurement than TDS. The reading for the TDS sensor is a conversion from the EC sensor. For examples of conversion from EC (μS/cm) to TDS (mg/ℓ), it is recommended to use 0.7 for sulphate-dominated water and 0.6 for chloride-dominated water.

A study shows the development of the auto-mixing system monitors irrigation system for drip fertigation [3]. The auto pumping unit ensures water storage in a tank for the supply of irrigation water to the drip system. Throughout the test result, we had found out that the lower the volume of the water is added, the higher the EC value. Hence, the pump's flow rate to add the water and fertilizer into the mixing tank should be paid attention to to control the total volume of water added.

The use of PID controller, one of the techniques under closed-loop system linear control, can help us improve the mixing process of the water and fertilizer. According to a study [4], PID has the characteristics of fast response, stable adjustment, and easy implementation, which is consistent with system requirements. Since the nutrient solution control system has a noticeable time lag and the crop is more sensitive to the nutrient solution EC value, to avoid the impact of EC value overshoot on crop production, the system control strategy reduces the derivative D link PID and only uses PI control. Although reducing the derivative link will slow down the system response speed, it also avoids system overshoot and improves its safety in practical applications.

A review article mentioned that the monitoring and control strategies for precision irrigation systems help achieve water saving in agriculture [5]. The developing advanced control can improve crop yield, ensure water saving and optimize the energy needed for irrigation. The monitoring and advance control approaches can be enhanced to achieve water saving and reduce the cost of precision irrigation.

Methodology

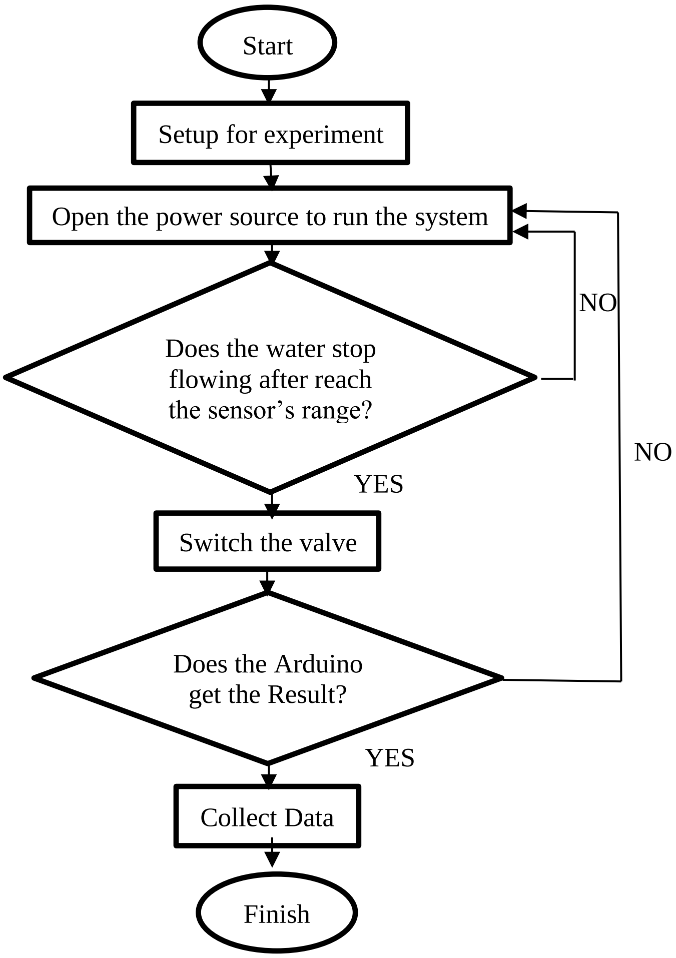

Figure 1. Experimental process flowchart

Automatic Fertilizer Mixing System

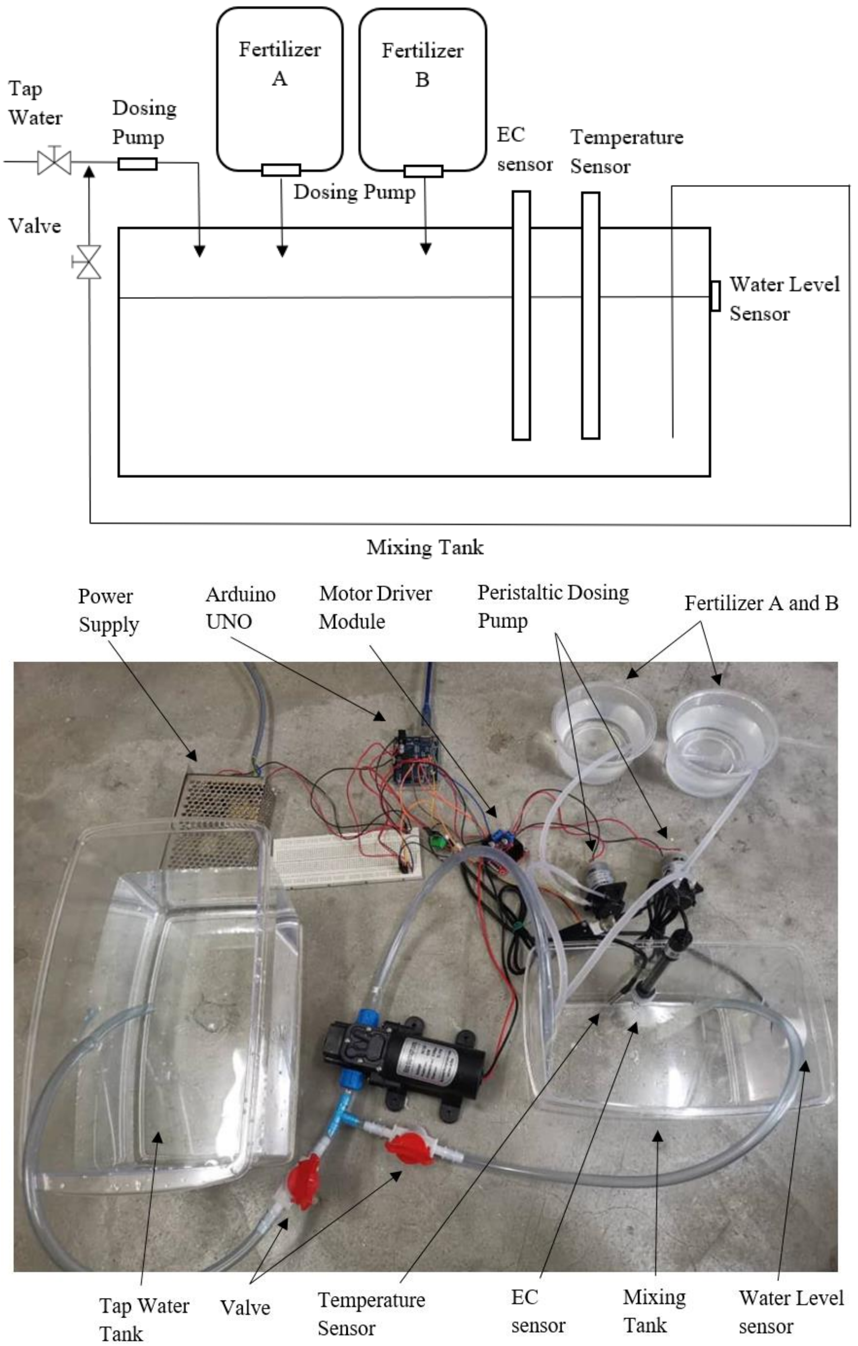

Figure 2. The architecture of the mixing system

Figure 1 illustrates the methodology of collecting data from the mixing system. Figure 2 illustrates the architecture of the mixing system for the fertilizer. The fertilizers A and B are separated into two different tanks. The amount of fertilizer and water is controlled by the dosing pump and pumped into the mixing tank. The tap water will be released and pump into the mixing tank first. When the water level is reached and detected by the water level sensor, the water will be stop pumped for 2 seconds. Then, we switched both valves from the tap water and the valve from the mixing tank. The dosing pump will be running continuously let the water cycle inside to mix the fertilizer and the water well for the sensor for detection.

After the valve is switched, the dosing pump of the fertilizer starts to run. The fertilizer is pumped into the mixing tank according to the PID controller program coding calculation. The EC sensor and temperature sensor are used to monitoring our system to automatically add in water and mix with the fertilizer according to the parameter we set in the programming. It continuously updates the data for every 2 seconds that has been detected by the EC sensor inside the mixing tank. Hence, we can get the data and form a graph to see the mixing process that had been occur easily.

When the value mixing of the fertilizer had achieved the setpoint, the whole system will stop running, and it is ready to be used for the crops on the farm. The programming continues to run repeatedly once the water level is under the detection of the water level sensor. The adding of water will dilute the amount of nutrients inside the mixing tank, and the dosing pump will run to add up the fertilizer until it reached the setpoint.

Calibration of the EC sensor

Calibration of the sensor is one of the most important steps before applying it in the system or taking specified values given by the sensor in any experiment. Calibration is done to minimize the measurement uncertainty and increase the accuracy of the test equipment. Hence, before we begin to use the EC sensor in this project, calibration of the EC sensor had been done.

The calibration of the EC sensor is recommended to be done once a month to ensure the accuracy of the sensor's reading. Hence, we should use the EC sensor calibration solution such as 1413uS/cm and 12.88mS/cm conductivity solution is commonly used. Before we start calibrating the EC sensor, we need to upload the code to the Arduino board first. We should first wash the probe with the distilled water before we dip the probe into the first conductivity solution that we want to calibrate first, which is 1413uS/cm conductivity solution.

The step for the calibration of the EC sensor will be as below:

1. Input the code 'enterec' command in the serial monitor to enter the calibration mode.
2. Dip the EC sensor into the 1413uS/cm conductivity solution.
3. Input 'calec' commands to start the calibration. The program will automatically identify the standard conductivity solution that was used.
4. Input 'exitec' command to save the relevant parameters and exit the calibration mode.

After we did the calibration, we continued the same step to calibrate the 12.88mS/cm conductivity solution.

RESULTS AND DISCUSSION

We will do three main experiments for this study: to understand the PID parameter effect in peristaltic dosing pump control, investigate the different concentration and initial EC values affect the result of reading. The controlled parameter will be shown in the table below.

Table 1. Controlled parameter

Controlled Parameter			
PID (K_P)	PID (K_I)	Concentration of Salt Solution	Initial EC Value in the Mixing Tank
110	50	• 10 mS/cm	• 0 mS/cm
120	60	• 15 mS/cm	• 0.5 mS/cm
130	70	• 20 mS/cm	• 1 mS/cm
140			
150			

Different value of K_P

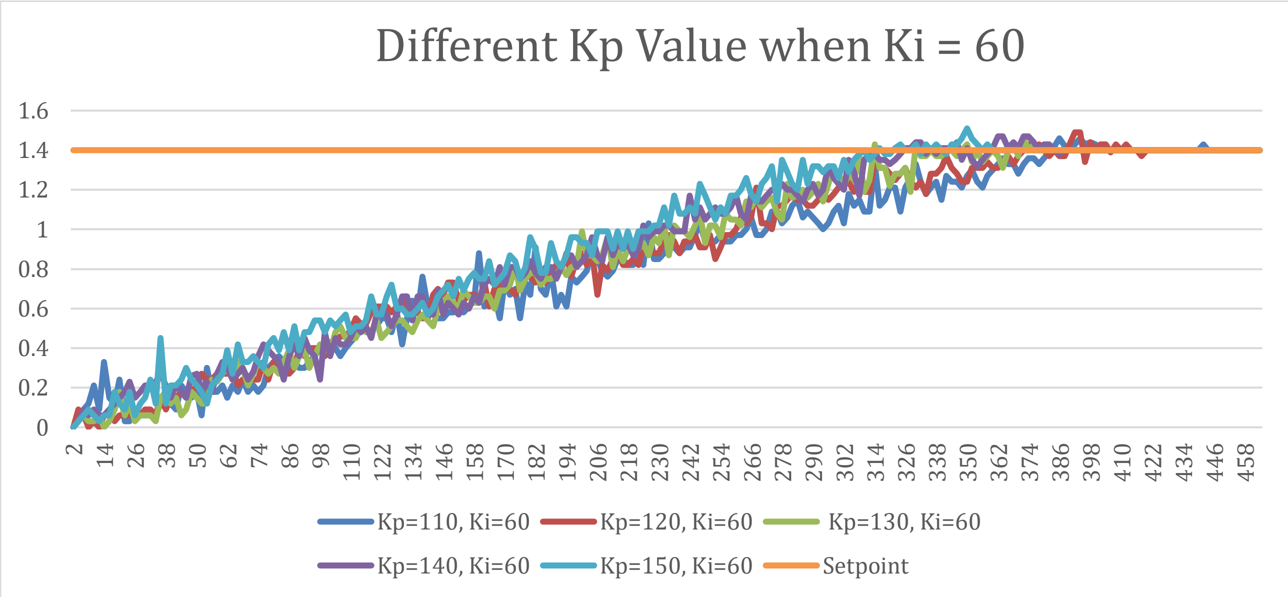

Figure 3. Raw Data Graph of Different K_P Value when K_I = 60

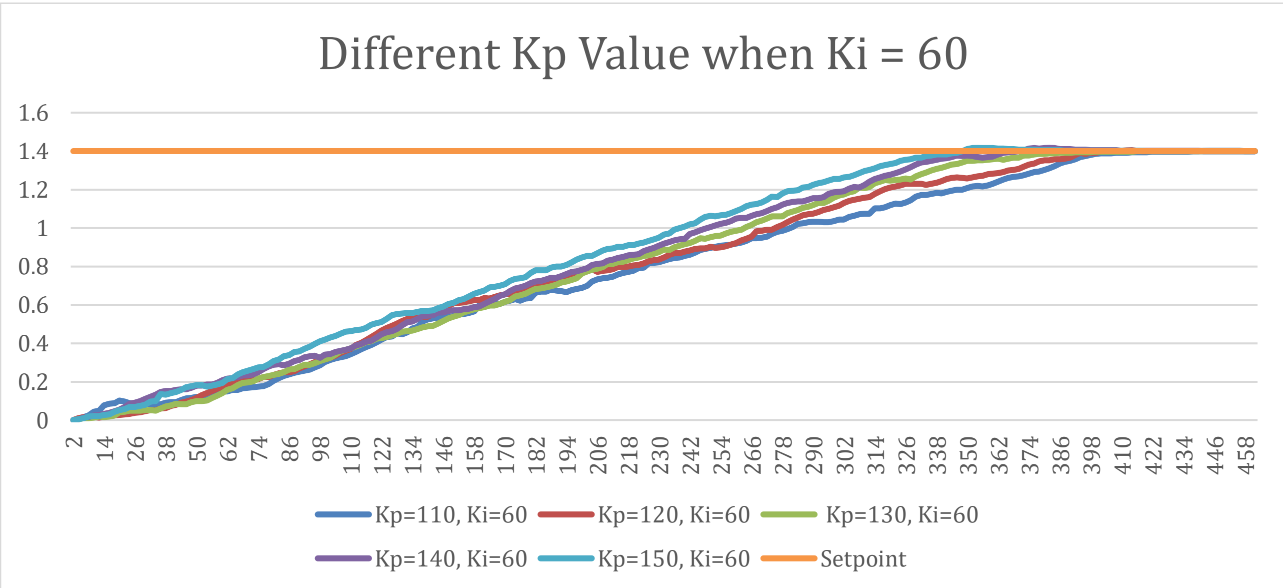

Figure 4. Exponential Smoothing Data Graph of Different K_P Value when K_I = 60

Figure 3 and 4 illustrates the raw data graph and the exponential smoothing data graph respectively. It was acquired from a series of raw data graph from the sensor. Raw data is data that shows a lot of fluctuations across time. The graph was smoothened to see the underline trend and interpret the result well. Hence, for every raw data from the experiment, the exponential smoothing function that was provided in Microsoft Excel was used.

Figures 3 and 4 show the different K_P Value when K_I = 60. The experiment suggests that when K_P = 130, the line rises steadily and reach the setpoint without occur the phenomenon of overshooting. From Figure 3, there were overshooting occur much when K_P = 140 and 150. We can also saw that the higher the value of K_P, the fastest the time is taken to reach setpoint, the higher the possibility to occur the phenomenon of overshooting. The value of K_P = 110 and 120 have less overshooting occur in their timeline. However, it also show the slowest to reach the setpoint of 1.4 mS/cm. Hence, the value of K_P = 130 is the most balance to be used for the next experiment.

Different value of K_I

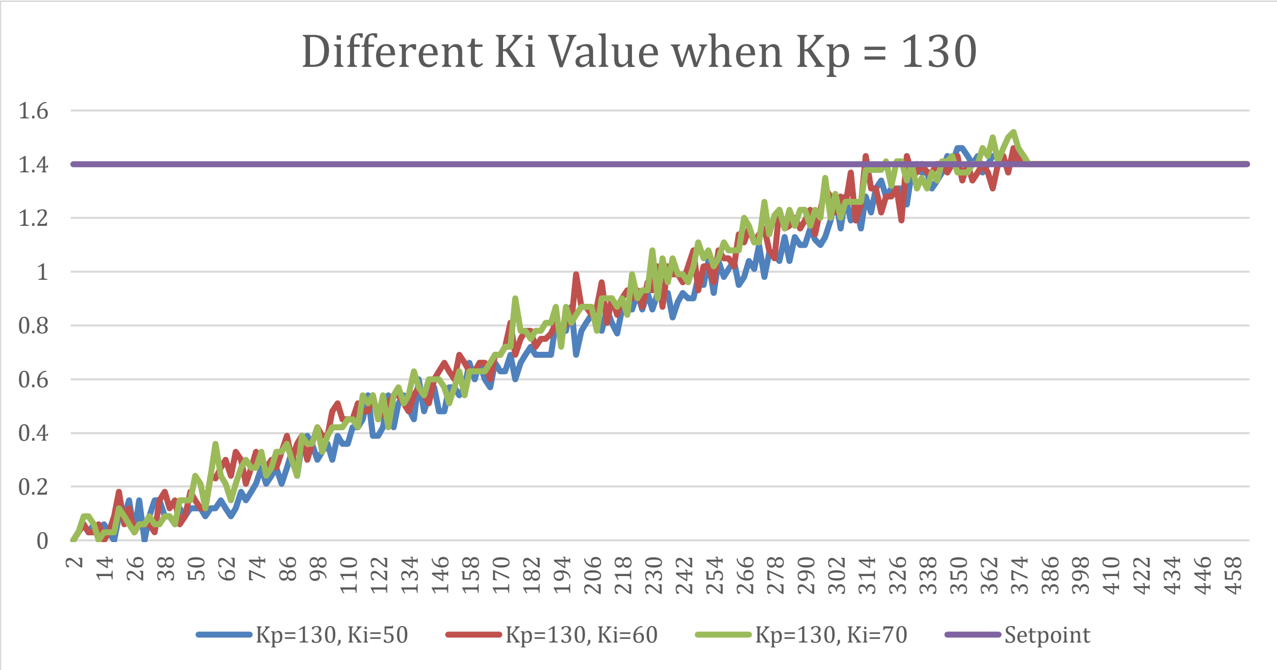

Figure 5. Raw Data Graph of Different K_I Value when K_P = 130

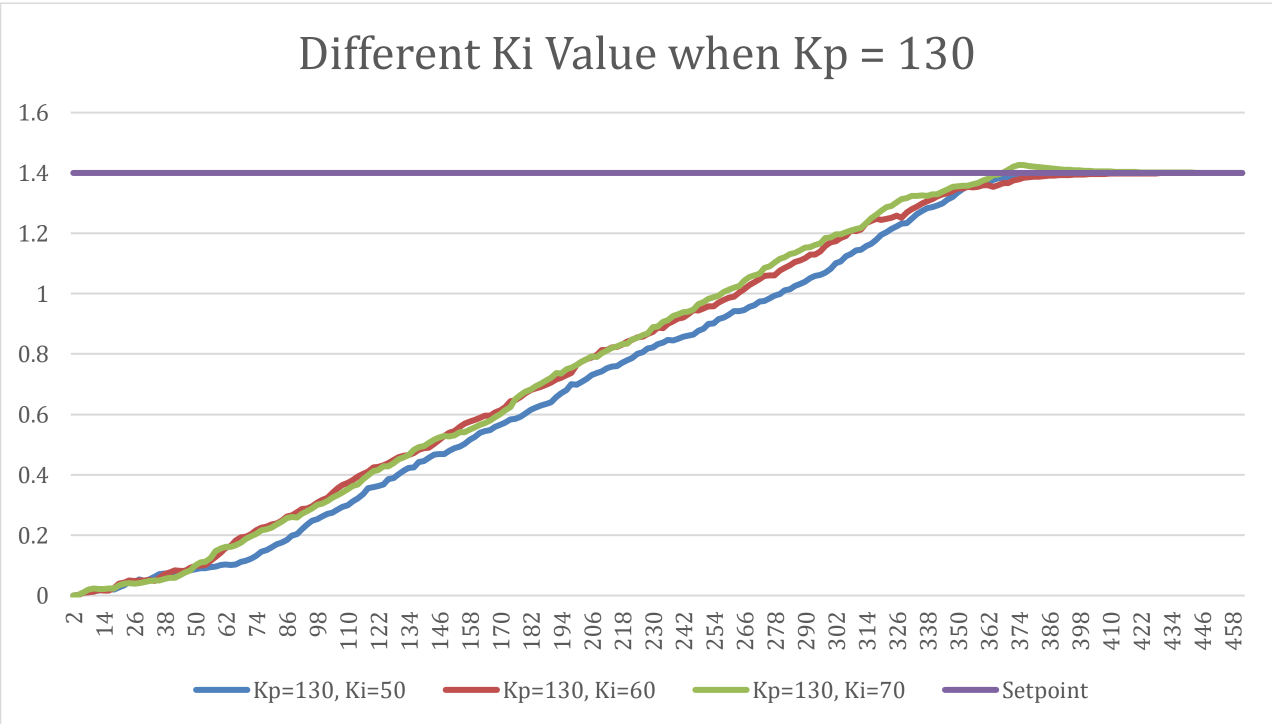

Figure 6. Exponential Smoothing Data Graph of Different K_I Value when K_P = 130

Figure 5 and 6 shows the different K_I Value when K_P = 130. From the experiment, we can see that all the values of K_I does not show apparent changes. However, we still can understand from the exponential smoothing data in Figure 6 still manage to show that there is a slight difference between them where the higher the value of K_I, the faster the time taken to achieve setpoint, the higher chance to occur overshooting. Hence, we take the value of K_I = 60 for the next experiment as the value shows us the balance of time taken and overshooting phenomenon.

Concentration of salt solution

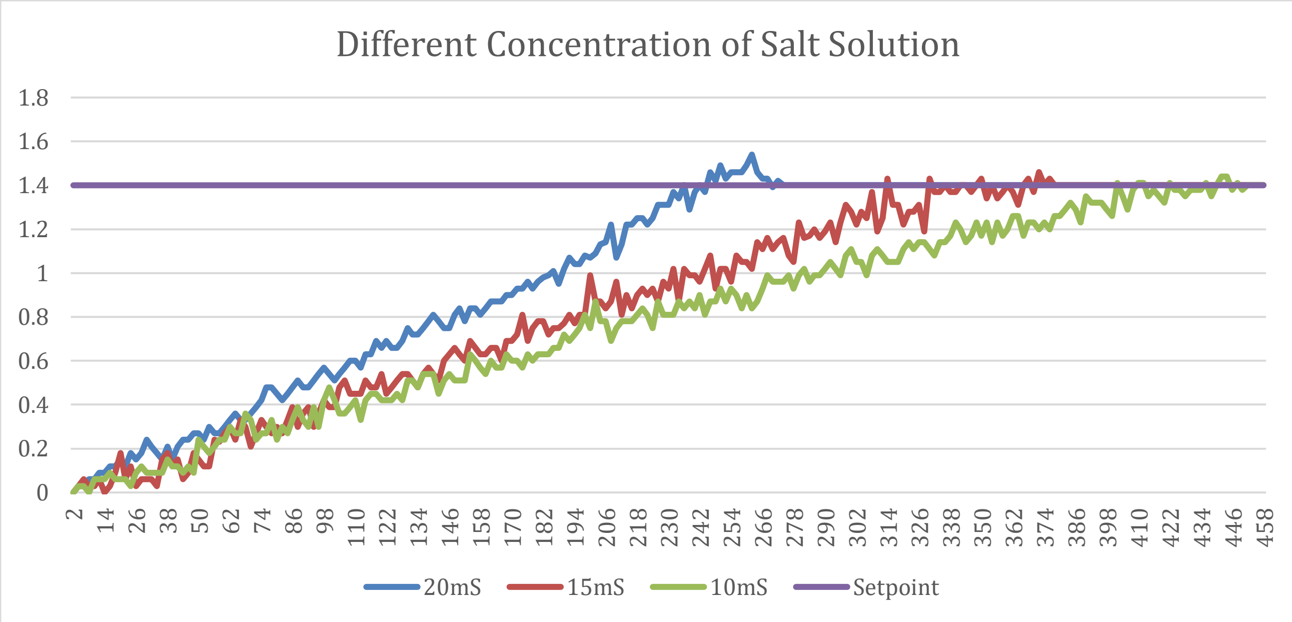

Figure 7. Raw Data Graph of Different Concentration of Salt Solution

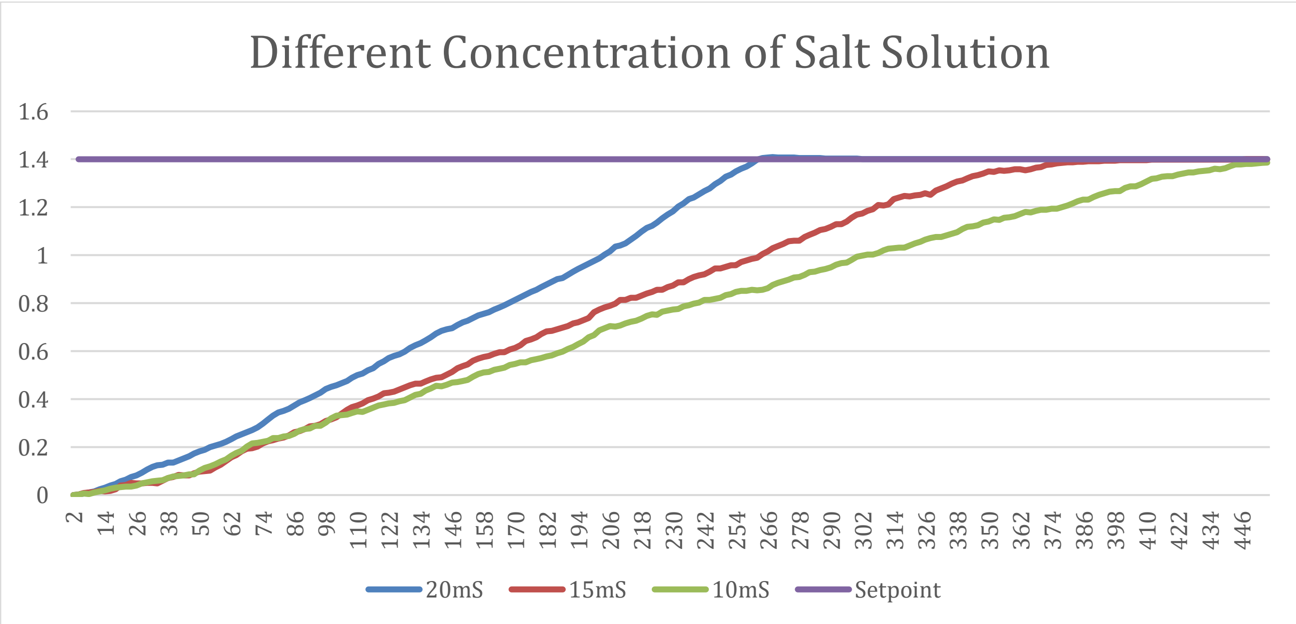

Figure 8. Exponential Smoothing Data Graph of Different Concentration of Salt Solution

Figures 7 and 8 show that the higher the concentration of the salt solution, the faster the time to reach the setpoint. The concentration of the salt solution of 20mS/cm is the fastest, where it reached the setpoint at 264 seconds, while the concentration of the salt solution of 10mS/cm is the slowest, where it reached the setpoint at 456 seconds. However, we can see that the higher the concentration, the more the chance to overshoot the setpoint. In Figure 7, we can see that the 20mS/cm of the salt solution have an obvious overshooting graph at 246 seconds. The concentration of the salt solution of 10mS/cm and 15mS/cm does not show an obvious overshoot graph. They reach the setpoint at 452 seconds and 378 seconds, respectively. Hence, we will use 15mS/cm of the concentration of salt solution for the next experiment because it does not show prominent overshoot characteristics and has faster time taken to reach the setpoint.

Initial EC value inside the mixing tank

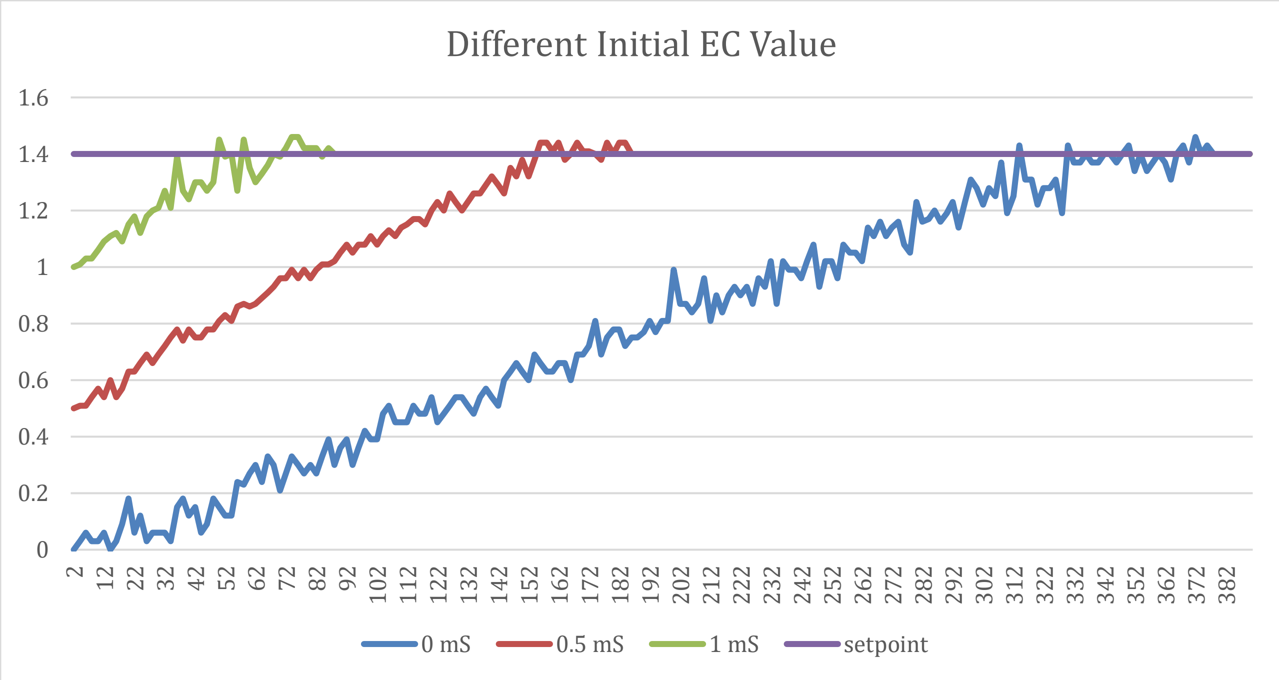

Figure 9. Raw Data Graph of Different Initial EC Value Inside the Mixing Tank

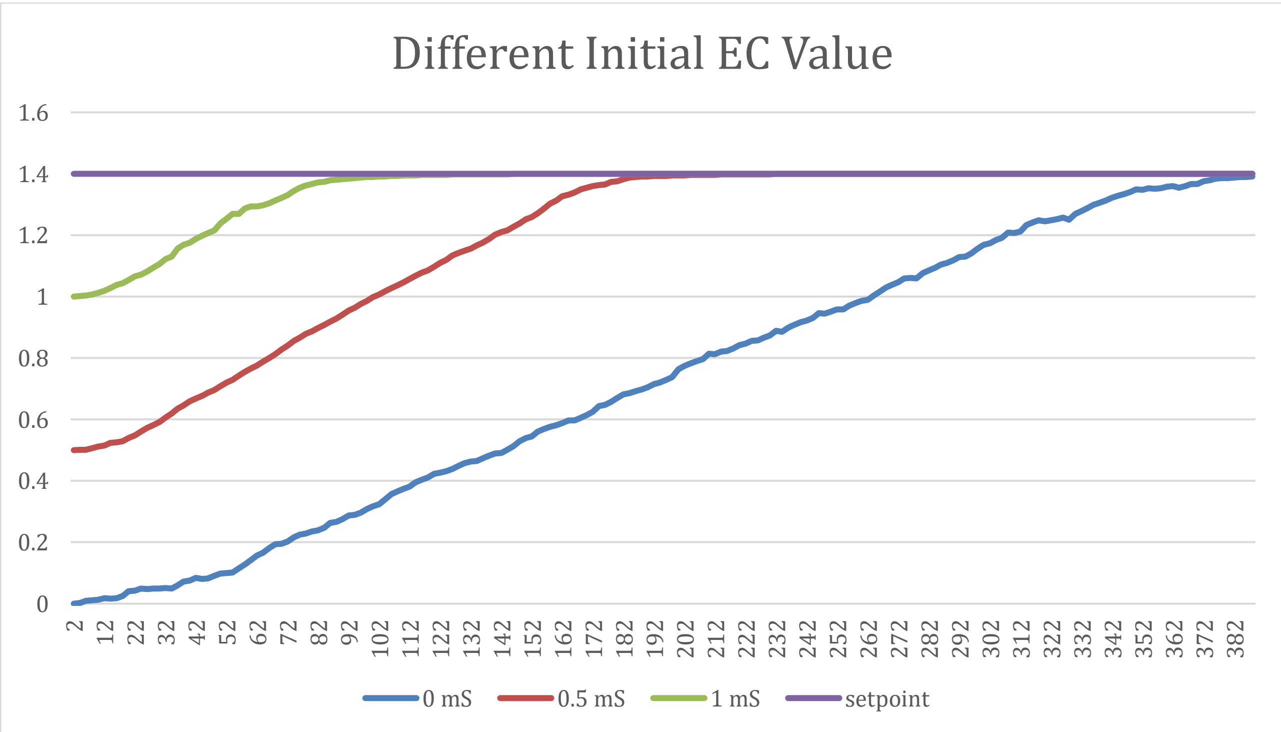

Figure 10. Exponential Smoothing Data Graph of Different Initial EC Value Inside the Mixing Tank

From the graph above, we can see that three lines rise steadily to reach the setpoint. Three lines show the near similar gradient of the upward trend graph. However, the initial EC value of 1mS/cm inside the mixing tank shows a more oblique graph compare to the other two lines. This is because the calculation of the PID controller from 1mS/cm to 1.4mS/cm has a shorter interval that giving less time for the program to react faster according to the same PID controller variable that we use for the other experiment.

The sequence of the experiment to reach the setpoint is an initial EC value of 1.0mS/cm inside the mixing tank, then 0.5mS/cm and 0mS/cm. The mixing tank that already has nutrients inside needs some more only to add up to reach the amount required compared to the empty. Hence, the PID controller does not show any obvious overshoot reading since the PID control of variable, and the concentration of the salt solution that we use is the balance variable that we experimented with before.

Discussion on effect of PID parameter

From the experiment above, we can say that the most important variable that will affect our result is the PID controller. There will be three constants for us to do for the setting, which is K_P (Proportional), K_I (Integral) and K_D (Derivative). Since the nutrient solution control system has a noticeable time lag and the crop is more sensitive to the nutrient solution EC value, to avoid the impact of EC value overshoot on crop production, the system control strategy reduces the derivative D link in the PID and only uses PI control [4].

The value of K_P affect the result more compared to the constant of K_I. This is because the variable K_P act as the present values of the error to control the speed of the pump while the constant of K_I act as the past values of the error that reacts to the load changes. Hence, the higher the value of K_P, it will affect the time for the system to reach the target setpoint faster by increase the power of the dosing pump. However, the change of K_I is to speed up the calculation of the system to react. So, the higher the value of K_I the faster the system takes action to power up the dosing pump and the faster it reaches the setpoint.

From Figure 3 to 6, we can see that the higher the value of K_P, the faster the mixing process reaches the setpoint. The phenomenon same goes for the factor of K_I where the higher the value of K_I, the faster the mixing process reaches the setpoint. However, this phenomenon does not show that obvious in the factor K_I. We can also see that the higher the factor of K_P and K_IBoth have a higher possibility of showing overshooting with the prove from the graph of Figures 3 to 6.

Discussion on effect concentration of the salt solution

The second experiment we did was about the effect of salt concentration on the mixing process. The concentration of the nutrients should be one of the factors to pay attention to because different manufacturers may provide slightly different fertilizer compositions and solubility due to the different additives added into the fertilizer. However, it is the same fertilizer [6]. So, we must do some research and testing the amount of nutrients in the fertilizer that we are going to use for the crops.

From Figures 7 and 8, we can see that the higher the concentration of the salt solution the faster the mixing process reaches the setpoint of 1.4mS/cm. However, the higher concentration of salt solution also shows that the higher chance of overshooting occurs during the mixing process.

Discussion on initial EC value inside the mixing tank

Lastly, we experiment on the effect of initial EC values inside the mixing tank because the farmer will not mix fertilizer from the empty tank every time. We do this experiment to understand whether the initial EC value inside the tank will affect the mixing process.

However, we found out that the initial EC amount inside the mixing tank is the least affected factor for the mixing process because the variable of the PID controller help us to do the calculation to do for the mixing process. We can see that from Figures 9 and 10 that all three lines rise proportional due to the same value of K_P, K_I and the concentration of the salt solution that we use for this experiment. However, a slightly more oblique line is the initial EC value of 1mS/cm inside the mixing tank. This is because the calculation of the PID controller from 1mS/cm to 1.4mS/cm has a shorter interval that giving less time for the program to react faster according to the same PID controller variable that we use for the other experiment. The higher the concentration initially inside the mixing tank, the faster the mixing process reaches the setpoint of 1.4mS/cm.

CONCLUSION

This research studies PID parameter tuning investigation in peristaltic dosing pump control for use in an automated fertilizer mixing system. We understood that the PID controller is a control loop mechanism employing feedback widely used in industrial control systems. This type of controller helped to do the fertilizer mixing for use in the farm for crops. We had done a low-cost automated fertilizer mixing mechanism for this project for further experiments, referring to Figure 2. A low-cost system was built to ensure that even a low-cost system functions properly for the mixing when applied to the actual farm. Several sensors were employed in the system: the non-contact water level sensor, temperature sensor, and EC sensor to run the whole system properly as a closed-loop system.

The investigation of the PID parameter effect in the peristaltic dosing pump is the second objective we achieved for our project. We had fully understood that how the factor of K_P and K_I affected the fertilizer mixing process. The factor of K_P is more to be concerned compared to the factor of K_I as we refer to Figures 3 to 6. The higher the value of both K_P and K_I, the faster the mixing process reaches the setpoint. However, it will also have the possibility of occurring the phenomenon of overshooting. We also understand how the concentration of the salt solution and the initial EC value inside the mixing tank affect the result of reading through this project. From Figures 7 and 8, the higher the concentration of the salt solution, the faster the mixing process reaches the setpoint and the higher chance to occur the phenomenon of overshooting. Since not every time the farmer does the fertilizer mixing process from the mixing tank, we can also know that the higher the initial EC value inside the mixing tank, the faster we get the mixing process to the setpoint with the fix K_P, K_I and salt solution for the mixing process that had been proved by Figures 9 and 10.

RECOMMENDATION

This project found out that the peristaltic dosing pump is not that perfect to use with the PID controller together. When the Arduino was giving lesser pulses to the peristaltic dosing pump to decrease the flow rate of the solution to the mixing tank, the pump is not functioning under a certain number of voltages provided. This is because the structure of the peristaltic dosing pump where the roller to form the circular muscle contraction of the pipe needs a certain number of rotational forces to overcome the frictional force between the roller and the pipe. Once the rotational force is less than the frictional force, the dosing pump does not run properly. Hence, we recommend using other types of dosing pumps, such as the diaphragm pumps.

We also think that using a larger tank and larger dosing pump for the project will be better because we can see more precise data. This is because once we increase the size of the tank and the pump, we can see that the minor changes in the experiment. When the container and the pump are small, the data collected and compared is less obvious than the big equipment use. Besides, the same size of tank and pump as the one used in the farm and experimenting can let us more understand the actual situation of the mixing process of the fertilizer that had been done in the farm.

ACKNOWLEDGEMENT

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REFERENCES

[1] Yang, Q., Zhu, Y., & Wang, J. (2020). Adoption of drip fertigation system and technical efficiency of cherry tomato farmers in Southern China. *Journal of Cleaner Production*, *275*, 123980. https://doi.org/10.1016\/j.jclepro.2020.123980

[2] Rusydi, A. F. (2018). Correlation between conductivity and total dissolved solid in various type of water: A review. *IOP Conference Series: Earth and Environmental Science*, *118*, 012019. https://doi :10.1088/1755-1315/118/1/012019

[3] Samsuri, S. F. M., Ahmad, R., & Hussein, M. (2010). Development of Nutrient Solution Mixing Process on Time-Based Drip Fertigation System. *2010 Fourth Asia International Conference on Mathematical/Analytical Modelling and Computer Simulation*.https://doi.org/10.1109/ams.2010.124.

[4] Li, L., Wang, J., Meng, F., Mu, Y., Yuan, H., Wang, H., & N, S. (2016). Model and PID algorithm realization of nutrient solution control based on two-step fertilizer mixing system. *Transactions of the Chinese Society of Agricultural Engineering*http://doi:10.11975/j.issn.1002-6819.2016.22.014.

[5] Abioye, E. A., Abidin, M. S. Z., Mahmud, M. S. A., Buyamin, S., Ishak, M. H. I., Rahman, M. K. I. A., … Ramli, M. S. A. (2020). A review on monitoring and advanced control strategies for precision irrigation. *Computers and Electronics in Agriculture*, *173*, 105441.https://doi.org/10.1016/j.compag.2020.105441.

[6] Parewa, H.P.;Singh, K. K.;Kumar, Dileep;Beura, K.;Rakshit, Amitava. (2014). Knowledge of Fertilizer Mixing is Key for Improving Nutrient Use Efficiency. *International Journal of Agriculture, Environment and Biotechnology*, *3*(4), 381–383. Retrieved from http://www.indianjournals.com/ijor.aspx?target=ijor:ijaeb&volume=3&issue=4&article=008