Integration of PID Controllers in Automated Water Irrigation Systems

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***Abstract* — Agriculture remains to be one of the most important sectors in the Philippine economy. However, this sector face many problems as natural calamities and poverty remain to be main factors that affects low productivity. Realizing the need for rehabilitation of current National Irrigation Systems (NIS) in the Philippines, this paper proposes an improvement of Proportional-Integral-Derivative-Controlled automated irrigation systems that helps optimize existing irrigation systems. The project utilizes matrix laboratory (MATLAB) approach to PID tuning in a hybridized manner. The system is intended to efficiently achieve minimal initial error and in turn, minimize use of natural resources.**

***Index Terms* — agricultural production, irrigation, low productivity, MATLAB, PID controller**

I. Introduction

AGRICULTURAL production remains one of the most critical sectors in the Philippine economy as it covers 39.8% of the total labor force and contributes an estimated 20% of the gross domestic product (GDP) of the country [1]. Crop cultivation continues to be a significant aspect of the nation's agricultural industry, constituting 53.7% of the overall agricultural output [2]. Crop production is vital to our agriculture, primarily serving as food for domestic consumption. Rice, known as "palay," stands out as the most abundant crop, with a production of 18.81 million metric tons in 2020 [2].

Irrigation systems have played a significant role in water management as it allows more intensive cropping over the same plot of land [3]. Irrigation systems capture, store, convey, distribute, and apply water for crop farming. Irrigation allows farmers to plant rice during the dry season, boosting cropping intensity and yield, highlighting the benefits for rice crops.

\A. Statement of the Problem

The Philippines remains to face many problems in the agricultural sector such as low productivity. Factors that lead to this include the numerous natural calamities that the country faces with typhoons being the primary example [1]. Considering how time-consuming it is to maintain and grow these fields, a single typhoon can destroy thousands of hectares of crops. Typhoon Ulysses caused damage to the agricultural sector worth 4.2 billion, affecting 102,500 farmers and 99,660 hectares of agricultural land [4]. The Department of Agriculture has estimated that such disasters caused a production loss of 167,385 metric tons in commodities including rice, corn, high value crops, fisheries, livestock and poultry, irrigation facilities, and agricultural infrastructures.

In the Philippines, irrigation development is largely determined only by public sector investment, whose budget, has decreased over the decades [3]. Additionally, operation and maintenance of irrigation systems are done by farmers who amortize cost recovery arrangements for a period not exceeding 50 years at 0 percent interest. Giving an emphasis on water charges itself, farmers themselves would have to pay irrigation service fees per hectare, season and crop for National Irrigation Systems (NIS) and pay amortization for communal irrigation systems in the Philippines [6]. This does not consider the fact that the farmers who maintain these agricultural fields are also impoverished, lacking financial support from the local government whenever these disasters destroy their livelihood. Philippine Statistics Authority reports on the poverty incidence of farmers rated at 30% among the two populations that has the highest poverty incidence in 2015 and 2018 [5].

B. Purpose of the Study

In this plight, it is then necessary to develop a system that will improve the cost-management and efficiency of the overall production and post-harvest process of these crops. Manual irrigation systems hinder water conservation, leading to either excess or insufficient moisture in the soil. Proportional-Integral-Derivative (PID) Controllers that monitor and regulate a desired water level or soil moisture content help in making farming crops more cost-efficient and less labor-intensive [7]. Automated Irrigation Systems also help speed up the process of production, especially considering that rice is the most abundant crop relevant to the country's food sufficiency. Palay relies mainly on irrigation systems with 75.5 percent coming from irrigated areas and the remaining 24.5 percent coming from rainfed areas [2]. Considering all these points, this study aims to improves the implementation of PID tuning in the context of farming optimization which is essential in the improvement and development of a PID Controlled Automated Irrigation System.

II. Related Literature

With similar automated watering systems in the past, this section then discusses and emphasizes similar studies and projects that are relevant to the development of this study's proposed software program.

A. Irrigation Systems in the Philippines

National Irrigation Systems (NIS) are irrigation systems in the Philippines managed by the National Irrigation Administration (NIA) [3]. NIS are irrigated systems that exceed 1,000 hectares and are designed as "run-of-the-river" type systems, meaning they utilize the natural flow of water without the need for storage reservoirs. These NIS account for the majority of the capital of the Philippines however, these systems are still reported to have poor performance. This poor performance stems from overly optimistic technical and economic design assumptions, coupled with inadequate water source supply. Additionally, inappropriate irrigation system design and maintenance difficulties further contribute to the inefficiency of the system. As a result, rehabilitation of NIS through the utilization of new technologies such as Geographic Information System analysis, mathematical modeling, and simulations will allow the system to be more rigorous for analysis and design. Considering this, it is still important to consider that the proposed strategies for rehabilitation and improvement of the system still requires participatory governance of the irrigation sector and the involvement of farmers.

B. Automated Irrigation Systems

Automated irrigation involves using a device to control irrigation structures, allowing for the flow of water to be adjusted without the need for manual intervention by an irrigator [8]. There are three main purposes of an automatic irrigation system namely, (1) start and stop irrigation through supply channel outlets, (2) start and stop pumps, and to cut off the flow of water from one irrigation area. Automatic irrigation systems will provide benefits such as reduced labor, implement timely irrigation, reduced runoff of water, and reduced costs for vehicles that check and maintain irrigation processes. Alternatively, they also outlined the drawbacks of this system.

C. Automated Plant Watering System using Arduino Uno and Moisture Sensors

The automated system utilizes soil moisture sensors connected to an Arduino microcontroller board programmed using the integrated development environment (IDE) software to sense the humidity of the soil. The humidity of the soil indicates whether the plant needs watering, so that the level of humidity of the soil is then sent to the Arduino. After the Arduino microcontroller receives the signal, the user is then notified with a buzzer [9].

D. Automatic Watering System for Plants with Internet of Things Monitoring and Notification

The watering system consists of three main parts for the Automatic Watering System to function. These parts are the watering system, monitoring system, and notification system. The first component is the watering system, which includes a soil moisture sensor connected to a Wemos DI microcontroller. The moisture of the soil will be detected by the sensor send an analog input signal to the microcontroller. The microcontroller then sends an output signal to the relay acts as a switch for the valve that controls the water flow. The next part of the system is the monitoring system, which consists of a Wemos ID microcontroller equipped with a WiFi module to utilize ThingSpeak.com's cloud function. The user can then monitor the soil moisture of the plant in graphical form through the website. The last part of the system is the notification system, which functions similarly to the monitoring system but utilizes the Blynk app instead [10].

E. Proportional Integral Derivative (PID) Control

A PID controller is one of the most common control algorithms used in industries [11]. The PID controller is popular due to its simplistic functionality and operation conditions, making it easier for engineers to use. PID controllers are widely used for controlling variables such as pressure, temperature, speed, and flow [12]. To process the variables, it works as loop control feedback to provide precise results. The study used the PID controller to maintain the pump flow rate at a specified and desired value [13]. Real-time automatic irrigation relies on the DC motor as the output and soil moisture content as the input.

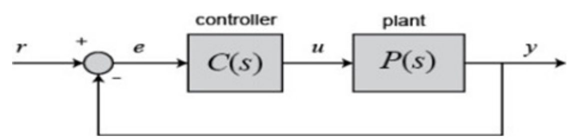

Fig. 1. Structure of a PID controller for the pump flow rate

An equation was formulated to interpret the structure of a PID controlled with the following variables $u(t) = Kpe(t) + Ki\int e(t)dt + Kd\frac{de}{dt}$, where e is the tracking error, u is the control signal, K_p is the proportional gain, K_i is the integral gain, K_d is the derivative gain.

F. Application of MATLAB in Irrigation Systems

MATLAB has a multitude of uses in the field of engineering, and is used by scientists and engineers to analyze systems that are seen in our world. It is an efficient tool for analyzing and simulating irrigation systems, capable of designing high-efficiency and center pivot irrigation systems [14]. The study proved the efficiency of MATLAB by using it as the main programming language for the research, and it was used to simulate their dynamic modeling of a solar power irrigation system [15].

G. PID Tuning

PID Tuning refers to the process of finding the values of the proportional gain, integral gain, and derivative gain of the PID controller to meet the expected results or the desired performance of the system [16]. It also allows for optimization and minimization of the error that can occur between the variables [17]. Some of the known PID tuning methods are the Ziegler-Nichols tuning method and the Tyreus-Luyben tuning method. The Zeigler-Nichols method, developed in 1942, is the most common method used for tuning controllers [18]. The Zeigler-Nichols method has a set of rules in tuning that includes: 1) Removal of integral actions from the controller by setting it to either 0 if it is in units of reset., 2) Set the controller derivative time to 0. 3) Increase the gain of the controller until the loop is continuously cycling in the shape of a sine wave [19]. However, these rules oftentimes have an overshoot of 25%. On the other hand, the Tyreus - Luyben tuning method, introduced in 1997, is similar to the Zeigler-Nichols method. Although it is based on the ultimate gain and ultimate period, the final controller settings are different; that is their settings are for PI and PID controllers only [20]. The modifications made to the formula of the controllers offer better stability in the control loop compared with the Ziegler-Nichols method [21]. But like other Z-N methods, the Tyreus-Lyben method is time-consuming and forces the system to a margin of instability.

III. Methodology

Harini produced models and transfer functions using humidity and temperature sensors which were used in the preparation of codes for this study [22]. Using the Ziegler-Nichols tuning (Z-N) method was a way of accumulating the optimal values for the PID controller. The Tyreus-Luyben tuning method was utilized to further optimize the parameters and overcome the aggressive gain performed by the Z-N method, which often leads to overshoot [20].

The MATLAB code will print a resulting average steady-state error for the reference PID tuning methods utilized in the code.

```
% Modeling of Soil Temperature and
Humidity Transfer, and Motor Functions
temp = tf(20, [1 1]);
humidity = tf(1, [1 2]);
Soiltf = tf([20 0], [3.8905 16.6715
24.3848 14.8114 3.2078]);
Motor = tf([0.01 0], [0.005 0.06
0.1001]);
% Using Ziegler-Nichols Values as

 Kd_ZN = 3.890;
 % PID Modeling of Z-N Method
 PID_ZN = pid(Kp_ZN, Ki_ZN, Kd_ZN);
Kd_ZN = 3.890;
% PID Modeling of Z-N Method
PID_ZN = pid(Kp_ZN, Ki_ZN, Kd_ZN);
% Z-N Method in Serial
Soil_ZN = minreal(series(PID_ZN,
Soiltf));
Soil_ZN = feedback(Soil_ZN, 1, -1);
Motor = feedback(Motor, 1, -1);
% Tyreus-Luyben Tuning Coefficients
(Adjusted Based on SSE Outcome)
Kp_TL = 0.001;
Ki_TL = 0.5;
Kd_TL = 0.2;
Kp_TL_adjusted = Kp_ZN * Kp_TL;
Ki_TL_adjusted = Ki_ZN * Ki_TL;
Kd_TL_adjusted = Kd_ZN * Kd_TL;
% PID Modeling of T-L Method
PID_TL = pid(Kp_TL_adjusted,
Ki_TL_adjusted, Kd_TL_adjusted);
% In Series with T-L Method
Soil_TL = minreal(series(PID_TL,
Soiltf));
Soil_TL = feedback(Soil_TL, 1, -1);
tt = 0:0.01:60;
% Static Value for PID Equation
Demonstration
u = sin(tt);
% Simulate outputs
[y_ZN, ~] = lsim(Soil_ZN, u, tt);
[y_TL, ~] = lsim(Soil_TL, u, tt)
% SSE Calculations
sse_ZN = sum((u - y_ZN).^2);
sse_TL = sum((u - y_TL).^2);
avg_ZN = mean(sse_ZN);
avg_TL = mean(sse_TL);
disp(['Average SSE for Ziegler-Nichols
Tuned PID: ' num2str(avg_ZN)]);
disp(['Average SSE for Tyreus-Luyben
Tuned PID: ' num2str(avg_TL)]);
```

A. *Program Output*

```
Average SSE for Ziegler-Nichols Tuned PID: 5626.0507
Average SSE for Tyreus-Luyben Tuned PID: 3099.6496
```

Fig. 2. MATLAB Console Outpu

IV. Experiment And Results

The program presented a significant decrease to the steady-state error using the Tyreus-Luyben Tuning method. This indicates that the optimization carried out by the Z-N tuning initially significantly reduces the error, which is then further refined during the T-L simulation.

A. *Simulation Results*

TABLE I
Summary of Results

PID Tuning Method	Parameter Values Acquisition	Average Steady-State Error
Ziegler-Nichols	Zero-Integral and Differential Gains with Gradual Proportional Gain	5626.0507
Tyreus-Luyben	T-L Coefficient Trial & Error	3099.6496

B. *Discussions*

The input signal is maintained at a constant value to allow comparative analysis of both results in a single framework. The combined method of utilizing Ziegler–Nichols optimized values as the initial values for a Tyreus-Luyben tuning method produces a system that is less prone to error. Further exploration of whether this system will achieve convergence at a faster rate than the incorporated tuning methods in an independent setting should be explored in future research.

V. CONCLUSION

Realizing the need to improve the current irrigation system in the Philippines, implementation of AIS remains as one of the key methods for enhancement and optimization of agricultural processes in the country. This paper presents a secondary PID tuning method designed to produce an improved PID tuning method that produces less average steady-state error. This tuning method implies an accelerated convergence that theoretically facilitates a progressively stabilized system.

The study also recommends future research to explore the development of a hybrid model of multiple tuning methods. Furthermore, the study believes that this approach will unlock enhanced efficiency ratios that will be an essential avenue in the refinement and optimization of PID-Controlled Automated Irrigation Systems.

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