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Optimization of Proportional-Integral-Derivative Controller Variations for an Enclosure Humidity Regulation System to Avoid Excessive Bacterial Growth

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***Abstract* —When it comes to bacterial growth, factors such as temperature and humidity play a big role. By introducing a humidity regulation system to counter bacterial growth, this problem will be mitigated. Prior to the introduction of PID controllers or Proportional-Integral-Derivative controllers, the traditional approach to systems is to manually check for each parameter in a loop before a system can proceed to its next step. Repeatedly inspecting each parameter in the loop for errors becomes tedious, expensive, and time-consuming. This is where PID controllers become an important tool as it is a type of controller in a system that checks for the difference between the measured process and the desired setpoint. By doing so, corrective measures can be taken by the controller to allow the system consistently to produce the desired output and avoid errors. Other research done in the field focuses on controlling temperature and humidity using PID controllers and applying them in different enclosure systems. The researchers designed a simpler method of optimizing said PID controller for the purpose of adjusting the parameters such as temperature or humidity. The code created takes a transfer function coefficient input from a user, a PID controller coefficient input, an input of desired output, and use all these to be able to optimize a system. To do this, a MATLAB Simulink program is created to take inputs and produce desired results. The optimal parameters for maintaining consistent humidity levels were determined. Additionally, the simulations aided in providing observations on the system's behavior in different conditions.**

Index Terms—PID controller, transfer function, control system, error correction, humidity, regulation

I. Introduction

IN an enclosed space, factors that should be taken into account include humidity, temperature, and airflow [15]. These parameters should be considered as they can affect bacterial growth. Humidity, along with air flow, affects the growth rate of bacteria at different temperatures. It is stated that bacteria is nourished more in environments that are airtight and has high humidity, such as clothing and storage cabinets [15]. Researchers used fresh pork as a test subject for bacterial growth, placed it in a storage cabinet under different temperatures, humidity levels, and different airflow conditions. Their results show that with the increase of airflow and reduction of humidity levels, bacterial growth was significantly decreased. Higher temperatures also affected the experiment such that higher temperatures resulted in the increase of bacterial growth [15]. Fortunately, these parameters can be monitored and controlled using PID controllers.

It is important to regulate humidity in an enclosed space and, similar to temperature, too low of a humidity level can cause dryness to the skin while too much humidity accelerates the growth of bacteria. It is ideal that humidity is kept in the range between 40% to 60% so as to maintain comfort while reducing the risks of growth of unwanted biological organisms. This range is said to be ideal as bacterial growth increases below 30% as well as over 60% [17]. In the context of humans, reducing humidity below 40% allows respiratory infections to occur more frequently [17]. Moreover, proper levels of humidity can prevent mold and bacteria from growing on certain surfaces as humidity is responsible for removing dust and other harmful agents in the air [18]. Ideal humidity levels also depend on seasons. During the hotter months, humidity levels should typically be around 30-45%, while colder months may require less than 40% relative humidity. [19].

A proportional, integral, and differential controller is composed of different process controls. Its purpose is to keep the output of a system as close to the desired output of the user. The controller is capable of adjusting the system based on its three main parameters: proportional, integral, and derivative, which can all be measured and tuned [3]. From the controller, there are four main variations of the PID controller namely the P, PI, PD, and PID controller [11]. The PD is used to adjust for large errors in the system while the PI is used to adjust small errors to keep the steady state value consistent. Together, the PID provides a great way to manage and tune the output of the system [16]. In line with this, PID controllers has an important role in the design of safe and efficient plants. They are often applied in automation industries due to their precise adjustment of several parameters such as speed, flow, temperature, and pressure [5]. PID controllers can be distinguished and categorized by the method in which it analyzes the data. These methods include the non-optimal restrictive method, restricted structure control, and control signal matching. In thus study, the use of restricted structure control will be used as the structure is a multivariable self-tuning PID controller which is a more optimal for the application [14]. In addition to this, the restricted structure control will be used since the other methods have difficulty in dealing with non-linear, higher order, and complex systems [10]. Another important component that is used in conjunction with PID controllers are transfer functions. Transfer functions represent the ratio of the Laplace transform of a system's output to its input, assuming no initial conditions. It is very handy as they allow engineers to simplify complex integro-differential equations, which are often seen in PID controllers [13]. Prior to the introduction of PID controllers, the traditional approach to systems is to manually check for each parameter in a loop before a system can proceed to its One interesting application of MATLAB involves creating a functional guitar tuner, achieved by designing effective logic capable of identifying the frequency of a guitar string from its frequency spectrum [4]. This becomes tedious, expensive, and time consuming the more the loop is repeated and each parameter for every step in the loop is inspected by an engineer for errors. This is in addition to the assumption that human error is non-existent. If human error is accounted for, the consumption of time and money increases further. This is where PID controllers become an important tool as it allows systems to automate every step by allowing it to verify whether each parameter in each process is good to go. Rather than make engineers spend hours on verifying parameters in a system, it becomes more efficient to simply fine tune a PID controller to automate the same tasks that engineers do manually [9]. This is done with the use of fuzzy control and the parameters are adjusted according to error and change-in-error [21].

The programming language that will be utilized in this study, MATLAB, is a very powerful tool that is used in many different applications. MATLAB comes with different software packages, some of which are able to aid in the design of real-time computer control experiments [6]. Another use for MATLAB is to make simulations. In this regard, MATLAB can also be used to simulate model reference adaptive system-based techniques which are one of the best when it comes to estimating rotor speed [2].

The use of PID Controllers in temperature or humidity regulation has already been researched in the past. Fractional-Order-PID controllers, a more advanced PID controller, is one of the more advanced PID controllers that have been researched in the past. However, with the tools currently available, tuning a PID controller can pose significant challenges. In this research, the optimization of a humidity regulation system will be done with the use of PID controller variations by using MATLAB codes. This code would ideally simplify the tuning process of PID controller parameters. PID controllers would likely be more commonly used in applications such as humidity regulation if its tuning process is made much simpler and efficient.

II. Related Literature

Humidity control or regulation systems are used in many different applications. One study applied a PID controller for the purpose of controlling temperature and humidity in bioprinter atmospheric enclosure systems [12]. The research states that bioprinting is a complex process that requires control of environmental parameters such as temperature, humidity, and CO2 concentration to ensure proper cellular viability and accurate geometry [12]. The research fine-tuned the PID controller via MATLAB and used the calculations obtained from MATLAB on Simulink.

Another study focuses on controlling temperature with the use of FOPID controllers or Fractional-Order PID Controllers. FOPID controllers are becoming more popular due to their capability to achieve better performance, robustness, stability and flexibility in systems such as heating and temperature control [8]. FOPID controllers, while more complex and costly than standard PID controllers, offer greater control over parameters, resulting in enhanced reliability and efficiency [8]. Despite this, industries question whether the newer FOPID controllers are worth their higher complexity in implementation and cost compared to standard PID controllers.

In this study, the researchers used the Ziegler-Nichols step response method and its modified version, the Chien-Hrones-Reswick method, in order to tune a PID controller. For this to work, MATLAB was utilized in order to calculate the Proportional (P), Proportional-Integral (PI), and PID controller parameters which will be used for the DC motor transfer function [1].

An experiment was done by using a PID controller to adjust DC motor speed and position control in real time using the TMS320C31 DSKCi [20]. This means that the system's PID controller was capable of being adjusted while it was kept running. The methods used to conduct the experiment were straightforward in the sense that the researcher used MATLAB to do the computations required for their system. They used functions such as "c2dm", "series", "feedback", and "dstep", which are all built-in in MATLAB [20].

III. Methodology

A. Using MATLAB and Simulink to Create the Program

With the different types of Integrated Development Environment (IDE) that can be used to better understand the use of PID controllers, and the different responses given by these control systems, the researchers have opted to use MATLAB as a means to program this application. The use of MATLAB was selected as it is a familiar IDE to be used, especially with these types of implementations. The authors find that MATLAB's commands offer just the right level of functionality for their project. MATLAB primarily emphasizes the implementation of mathematical equations through its modules and commands, aligning well with the project's needs. The use of Simulink can also be helpful due to the visual and graphical aspect of the whole control system. This allows for a more customizable and easier construction of the whole control system with the use of blocks for the transfer functions that will be used and the use of various connections for these blocks to create a single input and single output (SISO) control system that would help with the regulation for the humidity of the enclosure.

A. Creating the Code for the Control System

For the creation of the code, it is necessary to have the three main components of a working code, namely the input, process, and output. The input of the code begins with gathering the necessary information needed to create the transform functions and PID inputs. The transfer functions require two inputs, one input is the coefficients of the numerators of the transfer function in an array format, while the other input is the denominator coefficients of the transfer function. For the PID controller, there will be, initially, 3 inputs (i.e. Proportional Gain, Integral Gain, and Derivative Gain). Though these inputs are what is given initially, the user will have the option to add two more PID inputs including the derivative filter time constant and the sample time. When all those inputs are added to the program, another prompt will display output is desired by the user. The outputs are categorized as such: parabolic, step, ramp, impulse, and pzmap.

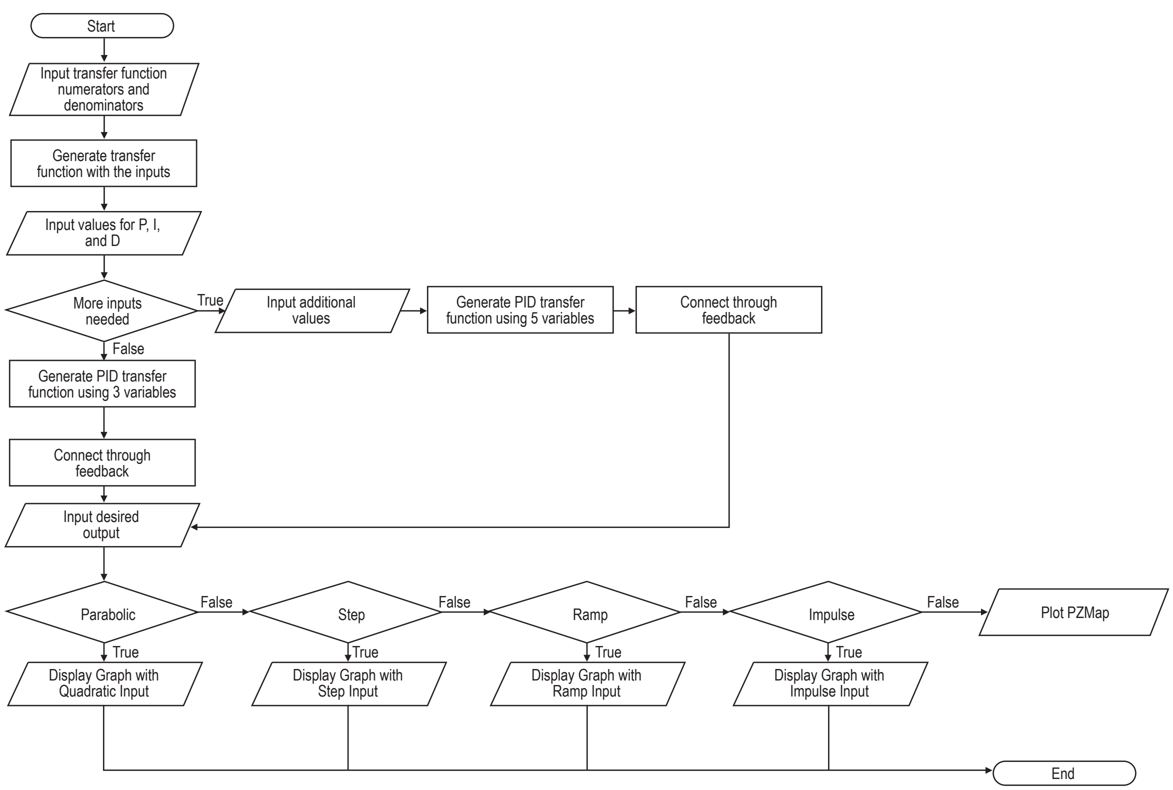

Fig. 1. Program Flowchart

Now that we have the codes for the inputs, the processes and outputs are what will be implemented. First and foremost, the transfer function inputs was processed and combined to create a whole transfer function. Similarly, the PID inputs will also be processed and converted into their corresponding transfer function and feedbacked with itself. For a parabolic graph output, the linear simulation or lsim command was used for both transfer functions with an input of '0.5*t^2' and graphed accordingly. The step graph output is done through the step function with the commands hold on and off to overlap the two graphs of the transfer function. Similarly, the ramp function also uses the step command with the input divided by is instead of just a normal transfer function input to create a linear ramped graph. Similarly, the impulse graph output is obtained through the same method as the step input however, using the impulse command instead of the step command. Lastly, the pzmap is also done with the same technique as the others however with the pzmap command. All these functions are interconnected through a hierarchical if-else statement, where integers are used as inputs to determine the desired output.

Integrating that into a Simulink diagram, the diagram would start with the input system of the desired humidity system. This humidity system input ideally would be an integer for the system to maintain. After the input target block has been placed, it will now be connected to a PID controller, this controller has the same functionality with its coefficients being tuned and calibrated for an efficient PID compensation system. Once this PID controller has been connected, tuned, and set through the simulation, the next step would be to connect the transfer function of the rate of change of humidity inside the whole enclosure that is being measured. This transfer function has been calculated and defined based on the dimensions and specifications of the room. Once all of this has been connected, the system will have a unity feedback loop from the output of the transfer function to a node before the PID controller. This allows the controller to analyze the past, present, and future state of the system to accurately determine a way to decrease the steady state error of the system. The code used can be found here: https://github.com/karlsus/PID-Controllers.git.

IV. Results and Discussion

Using MATLAB and Simulink, a simulation of a system and display its step response was achieved. By doing so, analysis on the system determined which aspects of the system can be improved.

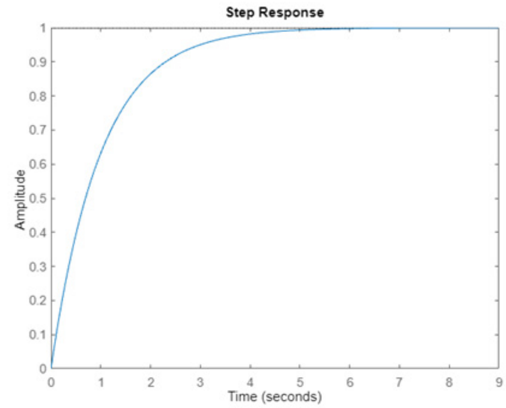

Fig. 2. Amplitude Over Time of the Step Response Simulation Produced in MATLAB.

Given a transfer function G(s)=1s+1, the step response is shown in Figure 2. This shows that as time goes on, the amplitude starts to stagnate at 1.

The group then designed a system with the same transfer function but with an added PID controller using Simulink. By using this, we can fine tune the system and obtain optimal P and I values for the PID controller. Figure 3 provides a simple input and output of the system where the input is the desired humidity level. The process goes through the PID controller as it adjusts and predicts the expected humidity levels to act accordingly and send signals to prevent the enclosure from being too humid or too dry. The output is a well-regulated enclosure that has the right environment for the desired application.

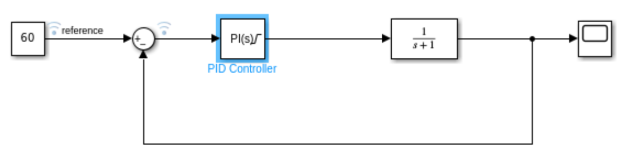

Fig. 3. Simulink Diagram of the Step Response

By adjusting the response time and the transient behavior, it was able to significantly decrease the time it takes to reach the desired value while having no overshoots compared to the original response (Fig. 4). The group was then able to obtain a fine-tuned P value of 17.84 and I value of 5.559.

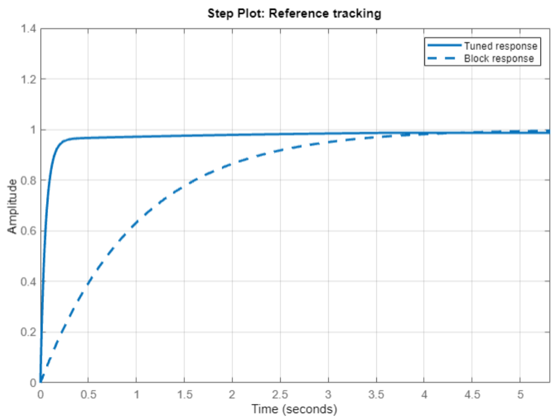

Fig. 4. Improved Response of Input Produced in MATLAB

```
>> finalproject
Enter the numerator of the TF function:
1
Enter the denominator of the TF function:
[1 2]

sys =

    1
  -----
  s + 2

Continuous-time transfer function.

Enter PID controller input p:
17.8354
Enter PID controller input i:
5.5594
Enter PID controller input d:
0
Add more PID inputs?
[1] Yes
[2] No
2

C =

  17.84 s + 3.208
  ---------------
  18.84 s + 3.208

Continuous-time transfer function.

Select your desired output by inputting the ff.
1: parabolic ((1/2)*t^2)
2: step (u(t))
3: ramp (t)
4: impulse (ds/dt)
5: pzmap
Enter your desired output:
2
>>
```

Fig. 5. Sample Screenshot of MATLAB Code of PID Controller

The group then tried to implement the same PID controller by writing a code in MATLAB. It takes in the input of the transfer function, the coefficients for the PID controller, and then asks for a desired output. The group inputted the same transfer function and the fine-tuned values for the P and I controllers (Fig. 5).

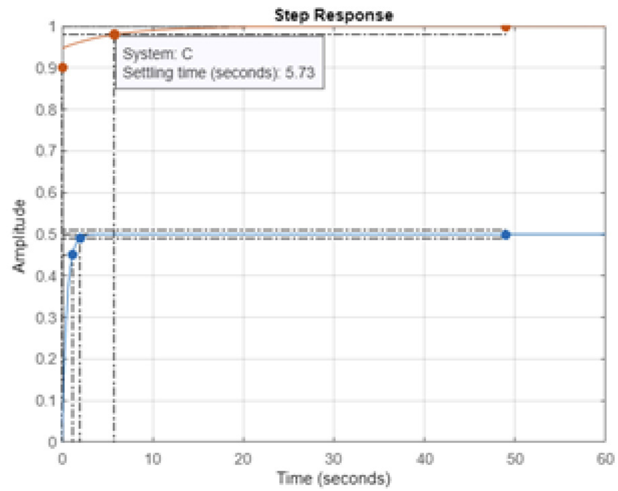

Fig. 6. Step Response of Control System Obtained from MATLAB.

The settling time between the control and the optimized system were significantly different. The optimized system was able to display a lower settling time and no overshoots. This, in turn, describes the efficiency that the optimized system provides as it calculates and predicts the humidity states of the environment and acts accordingly to prevent overshoots.

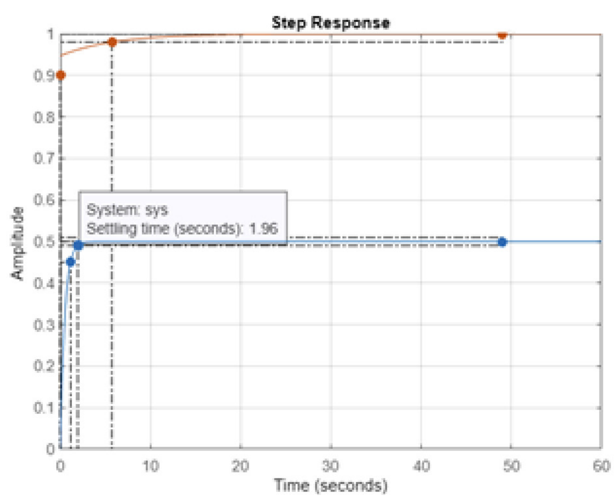

Fig. 7. Step Response of Optimized System Obtained from MATLAB.

TABLE I
Control System Descriptions and their Main Applications```````````

Control System Description	Main Application	Reference
Modeled a Mathematical equation, obtained the transfer function via MATLAB, used the Ziegler–Nichols closed-loop method to finetune the PID controller.	Used in Bioprinter Atmospheric Enclosure System	[12]
Uses the Rimann-Liouville equation for the fractional differointegral. The FOPID controller was optimized using the Dragonfly optimization.	Used to manage temperature in ambulances, and to protect paramedic equipment from damage.	[8]
Uses Ziegler-Nichols methods and Chien-Hrones-Reswick tuning method. Uses MATLAB to input the parameters obtained to the PID Controller.	Used in DC Motor Speed Control	[1]
Uses TMS320C31 DSK and MATLAB to control a PID controller	Used in Real-Time DC Motor and Position Control	[20]
This study creates a MATLAB code to simplify the adjustment of PID controller parameters by creating a question and answer type environment and returns the result of the calculations to the user.	Used in the adjustment of PID controllers	This study

V. CONCLUSION

The analysis, optimization, and simulation of PID controller variations for an enclosure humidity regulation system using MATLAB proved to be a valuable and efficient approach for improving the performance of the control system. By implementing the codes and analyzing the steady state error of different PID controller configurations and comparing them with each other, the researchers were able to identify the optimal parameters for maintaining a consistent and desirable humidity level within the enclosure while minimizing and optimizing the steady state error. The optimization process allowed us to fine-tune the controller parameters to achieve the best performance possible, while the simulation results provided valuable insights into the behavior of the system under different operating conditions. Based on the results of this study, there are several recommendations for future work. One possible avenue for improvement is to consider the use of other control techniques, such as model predictive control, to see if they can provide even better performance in regulating the humidity within the enclosure. Another option is to incorporate additional sensors or environmental factors into the control system, such as temperature or airflow, to provide a more comprehensive and accurate representation of the system. Finally, it would be valuable to test the optimized PID controller in a real-world implementation to verify its performance in a practical setting. Overall, this work demonstrates the effectiveness of using PID control and MATLAB in the design and optimization of an enclosure humidity regulation system and suggests potential directions for future improvement.

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