Prototype of cascade level and flow control system on steam drum based on IoT

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Abstract — In the industrial field, the boiler functions to heat a fluid in the form of water. The boiler has a part, namely the steam drum, which functions to produce steam used for utility needs, and the steam turbine; in practice, the state of the water level must be maintained at the desired value or set. So that carryover does not occur, and to overcome these problems, a control system is needed. This control works by comparing the sensor value and set point, then providing an output signal to correct this to speed up the response, so it is necessary to use a cascade control configuration that adds input flow control as a slave control. In this prototype, the cascade level control functions to control the level process. So in this study, a cascade level and flow control system was designed on an IoT-based steam drum to maintain water levels so that carryover does not occur. In addition, the human-machine interface has been designed to monitor processes in real-time. In addition, this prototype is equipped with an Internet of Things system that functions for the monitoring process as long as it is always connected to the Internet. To run the control system, parameter control is needed; in this project, the PID parameter setting uses the Ziegler-Nichols method with the parameter K_p level = 20.25; K_i level = 1.51; K_p flow = 5.14; K_i flow = 2.2 because the experimental results produce a good response.

Keywords – internet of things, level, PID, steam drum, temperature

I. Introduction

A boiler or steam boiler is a vessel-shaped device closed, which is used to generate steam. The boiler system consists of a feed water system (feed water system), a steam system, and a material system fuel (fuel system). The feed water system supplies water for the boiler automatically according to steam requirements [1]. A steam Drum is an important component for this type of boiler naturally, pressure boilers, and boilers with combined circulation. The function of the steam drum boiler is to mix the water into the drum (feedwater) with water circulated in the boiler, providing water for delivery to the component of the vaporizer (evaporator) through the downcomer, Accepting mixed hot water/steam (steam) coming from the riser pipe, and separating hot water and steam [1].

Variables analyzed in the steam drum boiler are the water level and temperature of steam. Measuring the level of the water and the temperature of the steam in the Steam Drum is very important for the safety and operational efficiency of the boiler [2]. It is said that the Steam Drum is the heart of a boiler [3]. In the process of producing steam, it is important to maintain the level, because if it is above the upper limit, then water can be carried to the turbine which should only be entered by steam and will cause corrosion, if the water level is too low it can damage the heating element [4].

To speed up the response of the steam drum level parameter, a cascade control can be carried out, which of course, improves the control response rather than just using a single control loop because the flow rate measurement for other load disturbances is not measured, it is necessary to pay attention to the feed water flow to compress the error [4].

In industrial control systems, proportional-integral-derivative (PID) controllers are widely used for comparing target and calculated values due to their robustness, economy, and good efficiency. Controller parameters (KP, KI, and KD) are tuned for optimal results [5]. One of the main challenges is transforming the PID controller from conventional behaviour to intelligent behaviour by using intelligent optimization techniques to modify the PID parameters [6]. The initial values of proportional, integral, and derivative gains were adjusted using heuristics, and tracking error graphs were observed. Maximum tracking error, number of oscillations, and peak values in the initial state [7].

In process control, the most widely used systems at the industrial level are PID controller loops; these are very important alternatives that represent around 90 % of the market [8]. PID controller parameter setting is an important task [9]. One of the widely used controllers is the programmable logic controller (PLC). PLC is an electronic device that is used to control input and output signals by applying complete logic and algorithms so that the controlled process can run as desired [10]. However, the main drawback of the PID controller is the possession of proportional and descending kicks, which are judged in sudden spikes and haphazard overshoots. In the PID controller, the derived mode restores the stability of the system and increases the response speed of the controller; however, it makes the factory draw a large number of control inputs [11].

The control of the steam drum must be optimal to produce efficient control output; in addition to optimal control, a monitoring system is needed that functions to monitor the process. This monitoring system will be a bridge between the operator and the machine, namely human-machine interface (HMI); this system is designed using LabVIEW, which will display data in real time. In addition to close monitoring with LabVIEW, of course, it will have a significant impact if a process can be monitored remotely by using internet of things (IoT) as the base, and the process will be monitored through the blank application. Like previous research using LabVIEW as an HMI in the process of measuring level and temperature, in this study, the data can be monitored in real-time [12].

In the research that has been conducted by Wahyudianto and Ilyas [4], this study designed a multilevel control with three control parameters, and by using the Ziegler-Nichols method, the control parameters obtained were $K_p = 77.34$; $T_i = 0.9375$ seconds, and $T_d = 0.3821$, with these parameter values, obtained max overshoot data of 27.7 %, settling time of 19 seconds.

Based on research conducted by Yuliawati [13], steam drum control in this study is required not to interfere with existing systems or existing processes,
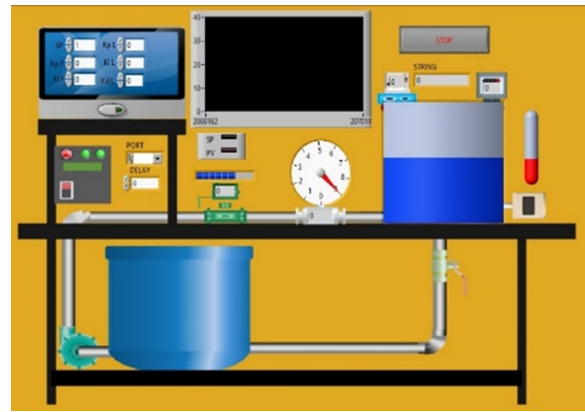

Fig. 1. Prototype design.

so the authors use the ANFIS method, which can adapt to existing processes, but in this study, it is still a simulation which indicates there is no guarantee that the simulated value will be the same as the value when it is implemented, therefore in this research a tool is built that can implement the control system in actual or real-time.

Research on DC motor control conducted by Hansza and Haryudo is an IoT - based research on the use of IoT that can provide benefits in the form of monitoring process parameters and being controlled remotely wirelessly by utilizing connectivity data. Parameters such as rotational speed, current, and voltage can be monitored remotely in real-time; this study also uses voice recognition to give orders [12].

So in this study, a cascade level and flow control system was designed on an IoT-based steam drum to maintain water levels so that carryover does not occur. In addition, the human-machine interface has been designed to monitor processes in real-time. In addition, this prototype is equipped with an Internet of Things system using Blynk that functions for the monitoring process as long as it is always connected to the Internet. To run the control system, parameter control is needed; in this project, the PID parameter setting uses the Ziegler-Nichols method with the parameter K_p level = 20.25; K_i level = 1.51; K_p flow = 5.14; K_i flow = 2.2 because the experimental results produce a good response.

II. RESEARCH METHOD AND RESULT

Broadly speaking, the implementation of this research is divided into 2 (two) stages, namely, the prototype design stage and the HMI design stage. The prototype design stage is an activity of making 3-dimensional visuals from the prototype framework to be made. This monitoring design stage is the initial stage to create a display design that will display process operation data in the actual state and present it in the form of graphs and numbers. As shown in Fig. 1. From Fig. 1, we can be used as a reference in the prototype design that will be made so that the resulting prototype can match the design.
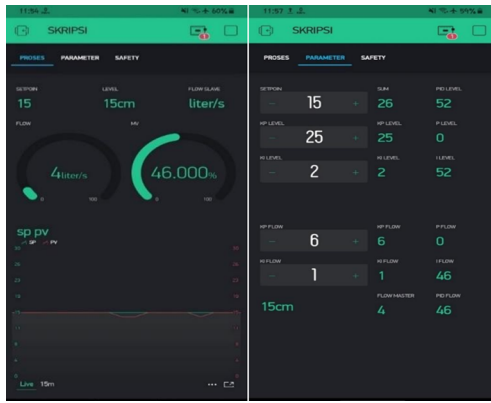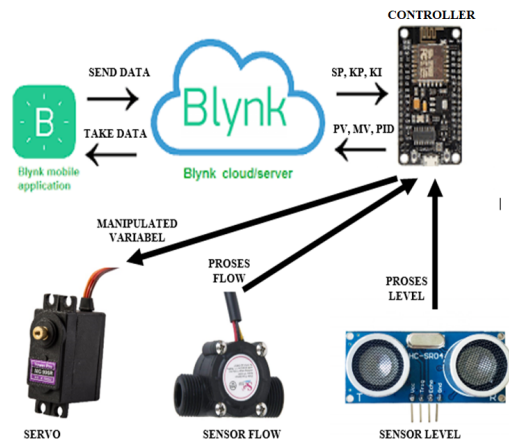
Fig. 2. Interface of Blynk.

Fig. 3. Controller communication diagram with IoT.

The process of monitoring data is important; in the Industry 4.0, the Internet of Things is becoming a trend, namely when process data can be viewed and intervened from anywhere and anytime when they have internet connectivity which, of course, has the advantage of easy access. The data from the cascade level-flow control on the steam drum can be accessed by the operator through the Blynk application as an IoT platform; the process data is sent to the cloud server from Blynk, and then the data is sent to the Blynk account that corresponds to the auth token. The interface design and the process of sending data on the Blynk application can be seen in Fig. 2 and Fig. 3.

The core materials in this study include steam drums, sensors, and actuators. A steam drum, as the name implies, is a drum-shaped vessel that is part of the boiler and functions to produce steam by boiling water, which then flows the steam to the next process. A sensor is a tool that functions to convert physical quantities to electrical quantities [14]. Sensor types can be divided into two, namely active and passive sensors. An actuator is a device that converts energy into mechanical energy [15]. In the control system, the actuator functions to actuate, meaning that the actuator will convert the correction signal from the controller into a physical change that will affect the process to be detected by the sensor to form a closed-loop system.

A. Closed Loop Control

A closed-loop control system is a system in which the output signal of the system has a direct influence on the control signal. This closed-loop control system has a feedback configuration [16]. In a closed-loop control system, the reading of the process variable value of the measuring element is fed back to be compared with the setpoint [16].

B. IoT

The development of science and technology is developing quickly. Even every second, we experience something new developments both in terms of science and technology. People need information reliable, flexible, and real-time technology fulfilled due to the rapid development of wireless technology [17]. According to research [18], the rapid development of science and technology can facilitate all our activities and human work. Because of that, a network that is accessible to everyone, everywhere, and whenever needed. One of them that met the criteria is the IoT. There is Many studies use this technology to be related to the needs of everyday life. In research [19], IoT is designed for home security systems; in addition, in research [20], IoT is designed to detect human movement. The two quests above are some examples of everyday use of IoT life. IoT is a technology that can connect devices that have low power, such as microcontrollers and sensors [21].

IoT is a technology that can connect all physical devices to the Internet and create a device capable of storing and exchanging information to fulfil a specific purpose in a certain context [22]. The concept of the Internet of Things includes three main elements, which consist of physical objects that have been integrated into sensor modules, internet connections, and data centres on servers to store data and information from applications. The use of objects connected to the Internet will collect data which is then collected into "big data" to be processed and analyzed by government agencies and related companies [23].

C. Level Process Model

Determination of parameters P, I, or D needs to be done for testing the whole tool. Testing this tool using the bump test method with Ziegler Nichols tuning. In the bump test method, the required values for the data are the process variable (PV) and manipulated variable (MV) values which are then entered into MatLab to search for the system identification tool in MatLab. The author conducted three (3) experiments; where the first experiment, the author set the servo opening from 25 % to non-servo 90 %, from 60 % servo opening to 30 % servo opening, and from 20 % to 40 % servo opening. Then the bump test results are entered in MatLab to get the transfer function value from the level process on the steam drum. In Table 1, the following are the results of the three bump test values.
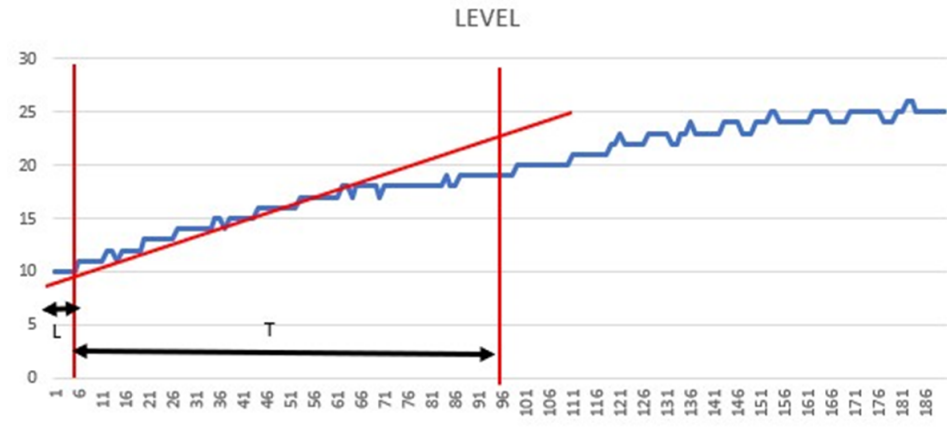
Fig. 4. Graph bump test level.

Table 1. Bump Test Level

No.	Gain Process	Fit Estimation (%)
1	$\frac{0.4739}{1+232.57\ s}$	92.26
2	$\frac{0.46003}{1+219.93\ s}$	92.3
3	$\frac{0.84087}{1+270.68\ s}$	78.07
Average		87.54

D. Flow Process Model

In addition to the level process, the same thing must be done on the pross flow, namely the bump test to determine the process gain, which functions to find the PID parameter. In the bump test method, the required values for data are the PV and MV values as input values in MATLAB to search for the system identification tool in MATLAB. Three (3) experiments were carried out in the first experiment by setting the servo opening from 50 % to non-servo 90 %, from 25 % servo opening to 90 % servo opening, and from 30 % to 80 % servo opening. Then the bump test results are entered in MatLab to get the transfer function value from the flow process on the steam drum. In Table 2, the following are the results of the three bump test values:

Table 2. Bump Test Flow

No.	Gain Process	Fit Estimation (%)
1.	$\frac{0.16668}{1+5.5866\ s}$	78.48
2.	$\frac{0.16665}{1+0.2237\ s}$	93.13
3.	$\frac{0.10015}{1+0.97519\ s}$	83.98
Average		85.19

E. Calculation of PID Parameters with Ziegler-Nichols

After doing the bump test and getting the process model, then choosing the process model with the largest fit estimation, then tuning the PID parameters with the most commonly used method, namely Ziegler-Nichols. The graph of the level process is shown in Fig. 4.

The process level in this control design orders 1, so the control configuration is PI. The following is a PID tuning using the Ziegler-Nichols method [24].

1) Determine the proportional gain using the Ziegler-Nichols method using (1) [25].

$$K_p = 0.9 \times \frac{T}{L} \qquad (1)$$

where K_p is proportional gain, T is time constant, and L is time delay. So, the proportional gain using the Ziegler-Nichols is:

$$K_p = 0.9 \times \frac{90}{4} = 20.25$$

2) Determine the time integral using the Ziegler-Nichols method using (2) [25].

$$T_i = \frac{L}{0.3} \qquad (2)$$

where T_i is time integral. So, the Time Integral using the Ziegler-Nichols is:

$$T_i = \frac{4}{0.3} = 13.33$$

3) Determine the integral gain using the Ziegler-Nichols method using (3) [25].

$$K_i = \frac{K_p}{T_i} \qquad (3)$$

where K_i is integral gain. So, the Integral gain using the Ziegler-Nichols is:

$$K_i = \frac{20.25}{13.33} = 1.519$$

Meanwhile, the graph for bump test flow is shown in Fig. 5.

Meanwhile, process flow in this control design is order 1, so the control configuration is PI. Similar to process level, the following is a PID tuning using the Ziegler-Nichols method.

- Determine the proportional gain using the Ziegler-Nichols method using (1). So, the proportional gain using the Ziegler-Nichols is:

$$K_p = 0.9 \times \frac{4}{0.7} = 5.14$$

Fig. 5. Graph bump test flow.

- Determine the time integral using the Ziegler-Nichols method using (1). So, the time integral using the Ziegler-Nichols is:

$$T_i = \frac{0.7}{0.3} = 2.33$$

- Determine the integral gain using the Ziegler-Nichols method using (1). So, the integral gain using the Ziegler-Nichols is:

$$K_i = \frac{5.14}{2.33} = 2.2$$

With the same steps as above, for three pairs of process gain obtained from the bump test, Ziegler-Nichols tuning was also carried out with the results as shown in Table 3.

III. DISCUSSION

Mechanistically, the way the cascade level-flow control works on the steam drum is to maintain the water level in the steam drum; the addition of flow parameters as slave control functions to speed up the response when there is a change in the inlet so that the controller can cope with changes more quickly.

In this design, the vessel is used as a miniature cylindrical steam drum with a diameter of 20 cm and a height of 30 cm. At the level sensor using HCSR-04 with ultrasonic wave reflection working to detect the flow inlet process, the sensor used is YFS201 with hall effect work; namely, some blades will rotate based on the flow that passes through the sensor, which will produce pulses that are proportional to straight with the flow rate. As an actuator, a servo motor is used to drive the valve, with the MG996R type, with a torque of 12 kg.

The working principle of the whole system is that the level and flow sensors will detect the process, then the level value will be compared with the setpoints given through LabVIEW and Blynk, and then the errors obtained are used as data to calculate the correction signal using the PID method whose parameters are

Fig. 6. Hardware prototype.

obtained from LabVIEW and Blynk, after the resulting correction signal from the level control, the data becomes the setpoint of flow control which will be compared with the flow sensor reading process, and with the PID method also obtained a correction signal from the flow control which will be sent to the servo to move the valve and which has an effect with the correction of the process. to the set point. The following are the results of the prototype design that has been made in Fig. 6.

To test the PID parameters of the Ziegler-Nichols tuning results, Simulink is used. The results of the block diagram as shown in Fig. 7.

Fig. 7 is the PI level and flow cascade control with the process gain obtained from the bump test and the K_p and K_i parameters obtained from the Ziegler-Nichols tuning, then inputting the unit step input and entering the three tuning parameters K_p, K_i in Table 3 to produce a graphic result specification in Table 4 below. In Table 4, it can be seen that the three specifications of the three tuning parameters, it can be concluded that the first one is with a K_p level of 20.25, a K_i level of 1.519, a K_p flow of 5.14, and a K_i flow of 2.2 which produces the good response.

IV. CONCLUSION

Design and build a PID-based Cascade Level Flow Control System with LabVIEW and IoT interfaces on

Table 3. Tuning Results

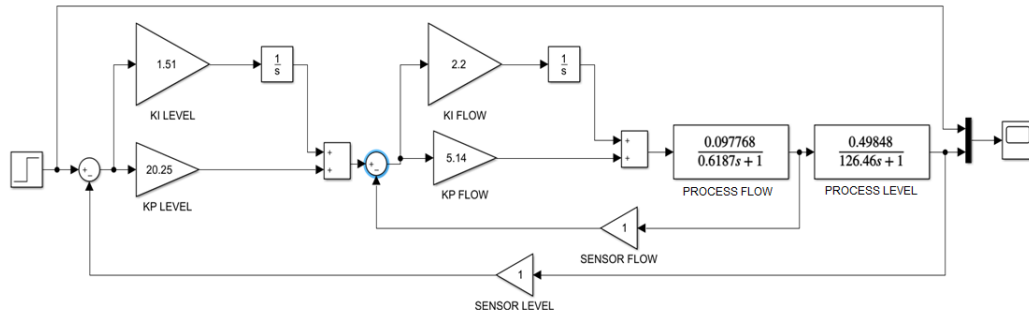| No.	Gain Process		Parameter Level		Parameter Flow	
	Level	Flow	K_p	K_i	K_p	K_i
1.	$\frac{0.4739}{1+232.57\ s}$	$\frac{0.16668}{1+5.5866\ s}$	20.25	1.519	5.14	2.2
2.	$\frac{0.46003}{1+219.93\ s}$	$\frac{0.16665}{1+0.2237\ s}$	21	2.1	2.7	0.81
3.	$\frac{0.84087}{1+270.68\ s}$	$\frac{0.10015}{1+0.97519\ s}$	14.62	1.09	1.8	1

Fig. 7. Cascade control simulink block diagram.

Table 4. Bump Test Flow

No.	Time Constant (s)	Settling Time (s)	Overshoot	Error Steady State (%)
1.	16	300	0.4	0
2.	17	900	0.65	0
3.	19	1,000	0.7	0

the Steam Drum running according to its function. This tool can be used as a learning tool to determine the response generated by the tool when testing the PID parameter value. With the Ziegler-Nichols method, the parameter K_p level = 20.25; K_i level 1.51; K_p flow = 5.14; K_i flow = 2.2, and for the response to the setpoint test. The use of LabVIEW as an interface runs according to its function; namely, it can monitor and can change the setpoint and PID parameters from LabVIEW, which, of course, makes it easier for operators to see the process in real time in the form of graphs, animations, and values in centimetres. The use of Blynk as an interface platform for IoT can run according to its function, namely, to monitor processes in real-time from anywhere as long as you have an internet connection; the Blynk interface in this design can provide setpoints, PID parameters, and set auto and manual modes of the system which is certainly very useful for operators who can monitor the process when not in the control room.

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