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Design and Implementation of a Fuzzy Logic Controlled Water Heater for Laboratory-Scale Indoor Swimming Pools

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Abstract. In recent times, the indoor swimming pool has emerged as a source of physical well-being and recreational enjoyment. Various endeavours have been undertaken to enhance the comfort of indoor swimming pools, including measures to decrease the evaporation of heated water. As a consequence, the humidity level in the indoor swimming pool rises. An indoor swimming pool must meet specific criteria to provide optimal comfort, including maintaining appropriate water temperature, air space, and relative humidity levels. Thus, this study created a laboratory-scale indoor swimming pool measuring 1 meter x 0.5 meters x 0.3 meters. The pool had a water heater controlled by a fuzzy logic technique control system. The water heater was installed within a water tank of 0.25 meters in length, 0.18 meters in width, and 0.3 meters in height. This water tank functions as a reservoir of heated water to be transported to an indoor swimming pool on a laboratory scale. The experimental findings demonstrate that implementing the fuzzy technique effectively regulates the water temperature at a constant level of 35 degrees Celsius. Additionally, the average duration required for heating the water to reach this temperature is 11.08 minutes, while the time taken to empty the water tank is 4.11 minutes. The duration needed to heat a laboratory-scale indoor swimming pool is precisely 5.14 minutes. Moreover, the findings of this study indicate that the application of these results is particularly relevant to indoor swimming pools, specifically those located in the Tokong Nanas Building at Telkom University.

1. Introduction

Swimming pools are facilities for health and entertainment, and with the many variations to enhance comfort, the parameters of water, energy, and materials must be developed [1]. Swimming pools have two different cases: outdoor pools and indoor pools. One distinguishing factor is the risk of sun exposure when using outdoor pools, which can cause the pool temperature to become too hot, while in indoor pools, the temperature is not significantly affected but can decrease due to the enclosed environment [2], [3].

Indoor swimming pools are the best case for temperature control because there are important environmental parameters that need to be managed in indoor pools, namely water temperature, air space, and relative humidity [4], [5]. Thus, the temperature control of the pool will be conducted in this study using a laboratory-scale model at the Tokong Nanas Building of

Telkom University. The pool at the Tokong Nanas Building has a water temperature of 22 °C, while the Fe´de´ration Internationale de Natation (FINA) stipulates that the water temperature in swimming pools should be maintained within the range of 25–28 °C [6].

The Spa pool has good potential for Telkom University students to improve their physical health and can reduce the risk of heart-related deaths and cardiovascular diseases [7]. Spa swimming pools in Bandung use the case of outdoor swimming pools and are starting to be used by lodging places that have the aim of facilitating visitors to the lodging place. However, the facility can only be used by visitors who book a room at the lodging place at a temperature of 30-40 °C according to the provisions of the spa pool by FINA.

Thus, this research will continuously develop temperature control from previous studies using a microcontroller with fuzzy logic methods on a laboratory-scale swimming pool of 1:25 relative to the Tokong Nanas Building at Telkom University [8]-[19]. To achieve the temperature of the spa pool, a mixture of two liquids is done with the heated tank water and the swimming pool water flowing through six outlet temperature in the swimming pool is set at 30°C and the maximum temperature at 35°C. With this temperature range, this research will align with FINA regulations [6].

2. System Design of a Fuzzy Logic Controlled Water Heater for Lab -Scale Indoor

Figure 1. Indoor Swimming Pool of Telkom University [20].

Swimming Pools

The depiction provided in **Figure 1** illustrates the indoor swimming facility located within the confines of the Tokong Nanas Building at Telkom University, also colloquially known as the General Lecture Building (GKU). This facility, with dimensions of 25m in length, 12m in width, and a depth varying between 1.2m and 1.8m, fulfills a dual function. It serves not only as a resource for student engagement in physical sports activities but also as a venue conducive to both exercise and recreation.

In the ambit of this research, a comprehensive effort was undertaken to construct a scale model of the aforestated swimming pool, employing a scale ratio of 1:25. This model, operationalized within the controlled environment of the Energy and Instrumentation Engineering Laboratory, serves as an embodiment of a diminutive version of the original. The primary impetus behind this initiative was to furnish a practical platform conducive to the in-depth investigation and delineation of various parameters, notably temperature regulation and

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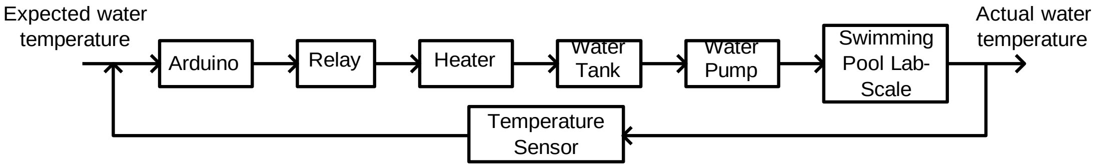

Figure 2. Block diagram of a laboratory-scale indoor swimming pool.

heating durations, alongside other pertinent factors that potentially influence the operational dynamics of indoor swimming facilities.

The experimental framework deployed for this research encompassed an array of specifically tailored instruments to facilitate quantifying the parameters above. Central to this setup, as depicted in **Figure 2**, was the DS18B20 sensor, selected for its precision in temperature measurement. In conjunction with a sophisticated microcontroller, this sensor utilized a fuzzy logic approach to underpin the water's heating control mechanism.

Lab-Scale Swimming Pool Description

The lab-scale swimming pool is designed with dimensions of 1000 cm in length, 50 cm in width, and a height ranging between 30 cm and 40 cm, incorporating a 10 cm slope across its width. This slope facilitates efficient water drainage and circulation. The pool holds approximately 1.75 cubic meters (1,750 liters) of water and features ceramic walls, chosen for their durability, water resistance, and ease of cleaning. To ensure optimal water circulation, the pool is equipped with a water pump and strategically placed inlet and outlet pipes, which maintain a consistent flow and prevent stagnant zones. Additionally, the pool includes integrated heating and cooling mechanisms: a submersible heating element warms the water, while a cooling system circulates the water through a cooling unit to lower its temperature. Both heating and cooling are evenly distributed throughout the pool using the pump-driven circulation system.

Figure 3 delineates the architecture and deployment of a sophisticated water heating system governed by fuzzy logic for the laboratory-scale model of an indoor swimming pool. This system integrates advanced control mechanisms to optimize temperature regulation, ensuring an efficient energy distribution and maintaining a steady thermal environment conducive to the simulated conditions of a real-world indoor swimming facility.

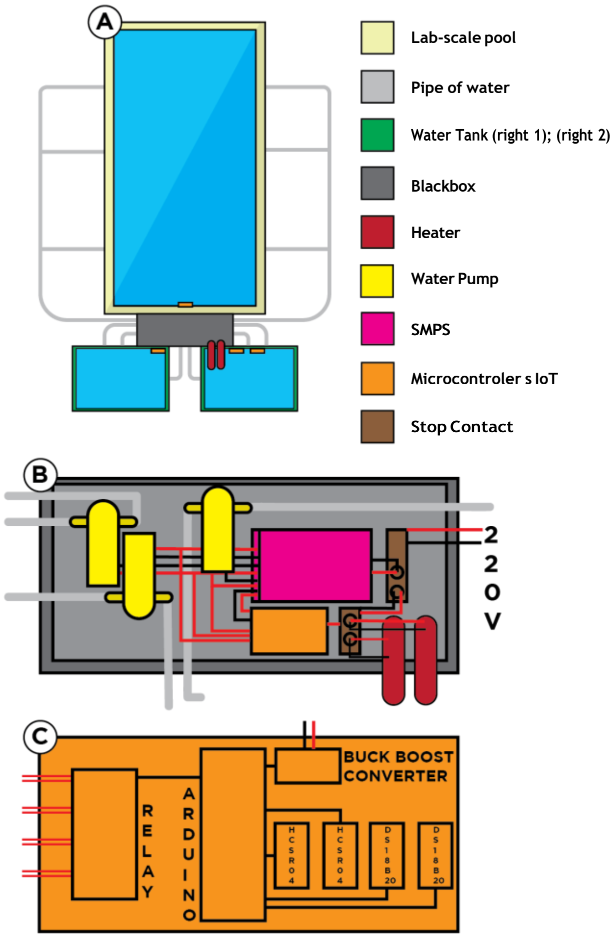

Figure 3. (A) Laboratory Scale Swimming Pool Design Top View, (B) Inside View of the Blackbox, (C) Inside View of the Instrumentation System, Microcontroller, and Sensors.

3. Results and Discussion

3.1 Calibration of DS18B20 sensor

The DS18B20 temperature sensor was tested and compared with a Thermogun to observe the variations in temperature readings. The readings obtained from the DS18B20 sensor were categorized into two types: integer and float values. These readings were analyzed to evaluate the sensor's accuracy. **Table 1** presents the comparative testing results between the DS18B20 temperature sensor and the Thermogun.

Table 1. Calibration of DS18B20 sensor

Reference Temperature (°C)	*Thermometer Reading (°C)*	Thermocontrol Reading (°C)	*DS18B20 Reading (Integer, °C)*	*DS18B20 Reading (Float, °C)*	*Deviation (°C)*
25.0	25.0	24.9	25	25.12	+0.12
30.0	30.0	30.1	30	30.04	+0.04
35.0	35.0	34.8	34	34.89	-0.11
4	40.0	40.2	40	40.03	+0.03

3.2 Calibration of HC-SR04 sensor

Table 2. Calibration of HC-SR04 sensor

Ruler Measurement (cm)	*HC-SR04 Reading (Integer, cm)*	HC-SR04 Reading (Float, cm)	*Deviation (cm)*
10	10	10.02	+0.02
20	19	19.98	-0.02
30	30	30.01	+0.01
40	40	39.97	-0.03

The HC-SR04 level sensor was tested against a ruler to measure its response to specified distance changes. Similar to the temperature sensor, the results from the HC-SR04 sensor were divided into integer and float value categories for detailed analysis. **Table 2** presents the calibration results of the HC-SR04 level sensor compared to the ruler measurements.

3.3 Fuzzy Logic Membership Function

The fuzzy logic system utilizes two primary inputs and corresponding outputs to control the swimming pool's temperature and water level. The membership functions are as follows:

- **Input 1: Temperature**
  - **Low:** A triangular membership function ranging from 0°C to 20°C, peaking at 10°C.
  - **Medium:** Ranges from 20°C to 60°C, peaking at 40°C.

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  - **High:** Ranges from 60°C to 100°C, peaking at 80°C.
- **Input 2: Water Level**
  - **Low:** A triangular membership function ranging from 0 cm to 30 cm, flat until 40 cm, and peaking at 20 cm.
  - **Medium:** Ranges from 30 cm to 70 cm, peaking at 50 cm.
  - **High:** Ranges from 60 cm to 100 cm, peaking at 80 cm.
- **Output 1: Heater Control (Voltage)**
  - **Low:** Ranges from 0 to 25, peaking at 10.
  - **Medium:** Ranges from 25 to 75, peaking at 50.
  - **High:** Ranges from 75 to 100, peaking at 90.
- **Output 2: Pump Control (Residence Time in Seconds)**
  - **Low:** Ranges from 0 to 25, peaking at 10.
  - **Medium:** Ranges from 25 to 75, peaking at 50.
  - **High:** Ranges from 75 to 100, peaking at 90.

3.4 Fuzzy Control Logic Testing

This fuzzy control testing aimed to compare the results of the Mamdani method within the Arduino and MATLAB environments. The testing procedure included four stages: Fuzzification, Fuzzy Implication, Aggregation, and Defuzzification. **Tables 3 and 4** present the outcomes of the fuzzy control system when applied to the water heating and water pump systems, respectively. These tables compare the **theoretical output** (from fuzzy logic rules) with the **actual output** generated by the system in MATLAB.
- **Table 3**: The results for the water heating system control.
- **Table 4**: The results for the water pump control.

Table 3. The outcomes of the fuzzy control examination conducted on the water heating system

Ttank$_1$ (°C)	Tpool (°C)	Htank$_1$ (cm)	Htank$_2$ (cm)	*Output* (°C)	MatLab (°C)	*Error*
60.13	23.47	4.09	3.92	60	60	0
26.66	25.62	3.22	4.87	60	60	0
75.87	24.94	3.93	4.09	0	0	0

Table 4. The outcomes of the fuzzy control examination conducted on the water pump

Ttank$_1$ (°C)	Tpool (°C)	Htank$_1$ (cm)	Htank$_2$ (cm)	*Output* (°C)	MatLab (°C)	*Error*
75.06	24.04	5.53	3.93	60	60	0
47.22	28.57	13.07	4.07	60	60	0
36.17	30.72	19.04	7.97	0	0	0

In both tables, the following columns are shown:

- ***T*tank1 (°C)**: Temperature of the water in tank 1.
- ***T*pool (°C)**: Temperature of the water in the pool.
- ***H*tank1 (cm)** and ***H*tank2 (cm)**: Water levels in tanks 1 and 2, respectively, as measured by the HC-SR04 level sensor.
- **Output (°C)**: Theoretical output predicted by the fuzzy logic system.
- **MATLAB (°C)**: Actual output generated by MATLAB based on fuzzy logic computations.
- **Error**: The difference between the **Output** and **MATLAB** values, calculated as:

$$\text{Error}=\text{Output}-\text{MATLAB}$$

This error reflects the performance and accuracy of the fuzzy logic control system. Ideally, the error should be as close to zero as possible, indicating that the fuzzy logic system's predictions align perfectly with the actual results.

3.5 Implementing Fuzzy Control Logic Testing

In **Figure 4**, the results of measurements from seven different sets of data are depicted. These measurements were carried out to reflect the actual operations of the swimming pool at the Tokong Nanas Building at Telkom University.

The graph shows that the temperature at Ttank1 consistently increases while the heater output is active for the specified time periods. The outputs are set at 60 seconds, 30 seconds, and 0 seconds in this design. As Ttank1 temperature rises, pump1 is activated, moving water from tank1 to the pool, thereby mixing and raising the temperature of Tpool.

Additionally, water in tank1 experiences a decrease, indicated by the distance sensor reading an increase in distance. When tank1 is depleted under specified conditions, pump2 is activated to transfer water from tank2 to tank1. Examination of the graph reveals that the decrease in Tpool and Ttank1 under initial conditions in a cold environment can activate pump3 to transfer water from the research pool to tank1.

Therefore, the fuzzy logic program can operate as intended and achieve data stability as indicated in the seven graphs shown in Figure 4. The results of the fuzzy logic implementation show the average time for heating, water filling, and the duration of water heating in the research pool. According to the data in Figure 4, it takes an average of 11 minutes and 8 seconds for the water in tank 1 to reach the specified temperature. The average draining time for the water is 4 minutes and 11 seconds, and it takes 5 minutes and 4 seconds to heat the research pool.

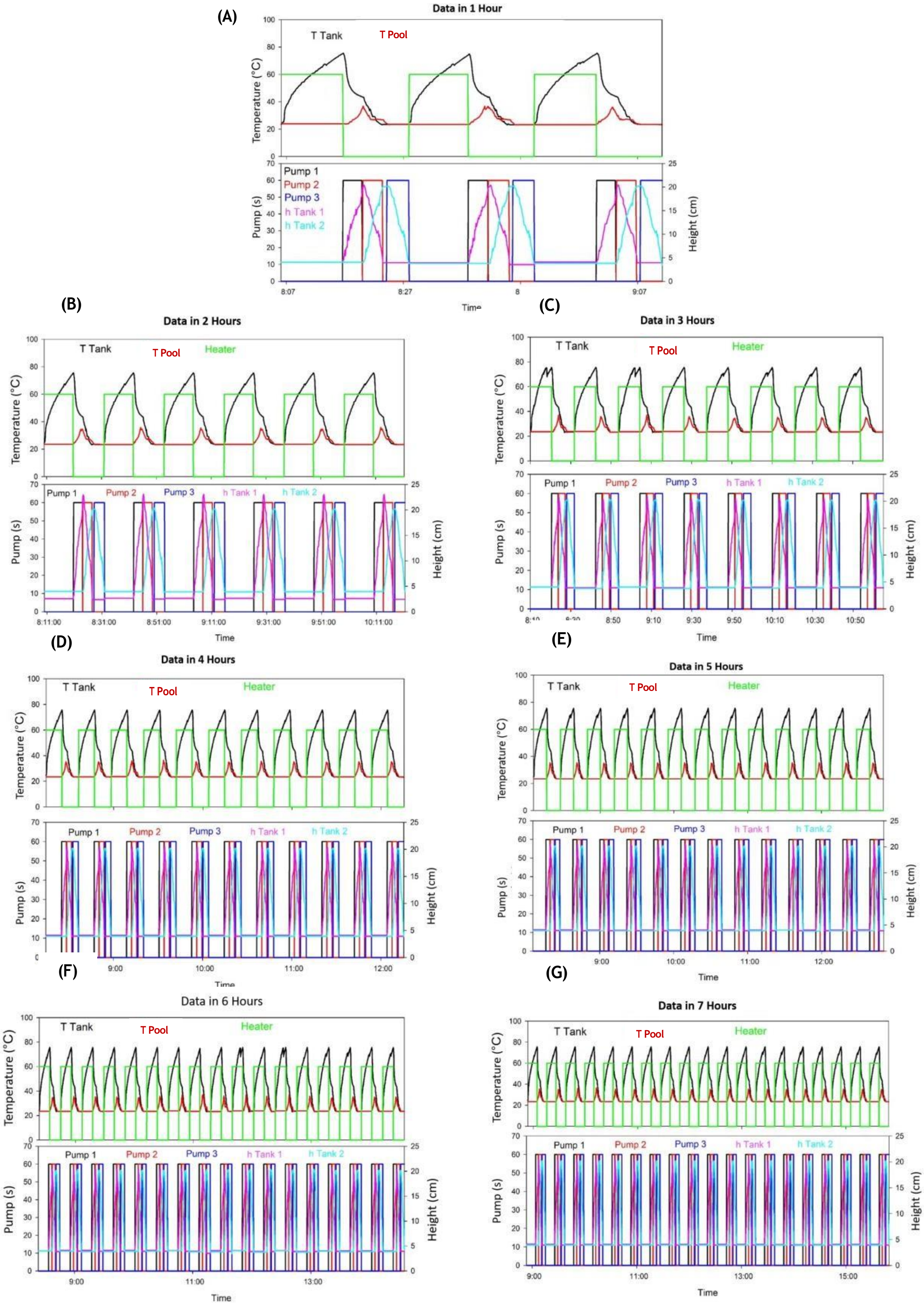

Figure 4 Implementing Fuzzy Control Logic Testing in seven different of data set: (A) 1 hour; (B) 2 hours; (C) 3 hours; (D) 4 hours; (E) 5 hours; (F) 6 hours; (G) 7 hours.

4. Conclusion

In conclusion, the experimental data strongly support the effectiveness of the fuzzy logic technique in maintaining a stable water temperature within a controlled environment. The system has been shown to successfully regulate the water temperature to remain consistently around 35°C. To quantify this stability, the results demonstrate that the temperature variation around this setpoint remains minimal, with an average fluctuation of ±0.5°C during the entire heating process.

This indicates that the fuzzy logic system can maintain the target temperature within a narrow range, which is essential for applications requiring precise thermal control. Furthermore, the efficiency of the system is highlighted by the relatively short time frames required for key processes: heating the water to the target temperature takes an average of 11.08 minutes, while draining the water tank is completed within an expedient 4.11 minutes. Heating the laboratory-scale indoor swimming pool to the desired temperature is achieved in 5.14 minutes.

These results underscore the system's stability and efficiency, confirming that the fuzzy logic technique provides both precise control and quick response times. The minimal temperature fluctuations (±0.5°C) demonstrate the system's ability to maintain thermal stability, which is crucial for operational efficiency and comfort in environments such as swimming pools or other water-based facilities.

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