INTERNATIONAL JOURNAL OF AUTOMOTIVE AND MECHANICAL ENGINEERING (IJAME)
ISSN: 2229-8649 e-ISSN: 2180-1606
VOL. 18, ISSUE 2, 8825 – 8832
DOI: https://doi.org/10.15282/ijame.18.2.2021.20.0676

Universiti Malaysia PAHANG

ORIGINAL ARTICLE

# Implementation of Fuzzy Logic Controller for Pressure Sensor Calibration Chamber

M. Ridwan[1,2*] and T. Taryo[3,4]

[1]Department of Electrical Engineering, Faculty of Engineering, Institut Sains dan Teknologi Nasional, Jakarta Selatan 12640, Indonesia
[2]Center for Instrumentation, Calibration, and Engineering, Meteorological, Climatological, and Geophysical Agency (BMKG), Jl. Angkasa I No.2 Kemayoran Jakarta Pusat, DKI Jakarta 10610, Indonesia
Phone: +6281381115570
[3]Center for Nuclear Reactor Technology and Safety (PTKRN) – BATAN, Serpong 15310, Indonesia
[4]Program of Magister for Informatics Engineering, University of Pamulang-UNPAM, Jalan Puspitek Raya No 10, Serpong, Tangerang Selatan 15310, Indonesia

**ABSTRACT** – Atmospheric pressure is a weather element that must be observed in the field of meteorology. Electronic barometers, aneroid barometers, mercury barometers are generally instruments for atmospheric pressure measurement. The barometer must be calibrated periodically to ensure the performance of the instrument. To achieve the best target uncertainty during calibration, besides using an accurate primary standard barometer, a stable pressure controller is also needed. Pressure calibration media using a pressurised test chamber is more beneficial due to its capability to accommodate all types of pressure sensors. However, pressurise test chamber still requires an operator to control and stabilise pressure inside the test chamber. In this study, fuzzy logic has been programmed into a microcontroller to control the solenoid valve and vacuum pump for regulating air pressure inside a pressurised test chamber automatically. Fuzzy logic changes the solenoid valve states periodically by varying the opening and closing times. The final result of this study is a comparison between the calibration results using pressure controller with fuzzy logic and without fuzzy logic with the same primary standard and unit under test. The result of expanded uncertainty without a fuzzy logic controller is 13.06 hectopascal. Meanwhile, the pressure calibration process using fuzzy logic to control pressure in pressurised test chamber achieve 0.09 hectopascal of expanded uncertainty in 1000 hectopascal pressure value with coverage factor, k=2, and confidence level of no less than 95 %.

**ARTICLE HISTORY**
Received: 17th Aug 2020
Revised: 20th June 2021
Accepted: 22nd July 2021

**KEYWORDS**
*Meteorology;*
*Atmospheric pressure;*
*Fuzzy logic;*
*Calibration*

## INTRODUCTION

The atmospheric pressure is the weight of the atmosphere above the earth surface per unit area. In the field of meteorology, atmospheric pressure is one of the weather elements that must be observed. Accurate atmospheric pressure measurement is important for aviation because it can affect aircraft performance [1]. According to United States National Transportation Safety Board's (NTSB's), temperature, humidity, and pressure-related factors were listed as causes or contributing factors for fewer than 20% of weather-related accidents and fatalities during 1982-2013 [2].

Electronic barometers, aneroid barometers, mercury barometers are generally instruments for atmospheric pressure measurement. Atmospheric pressure measurement instruments must be calibrated regularly, and according to World Meteorological Organization (WMO) guide [3], it requires uncertainty for a barometer in operational use at service around +/- 0,1 hPa. To achieve that target of uncertainty, besides having to use an accurate primary standard, use a stable pressure controller during calibration is needed. There are many methods to control pressure [4] and equipment to perform pressure calibration [5], [6], [7]. Automatic pressure calibration with PI method controller [8] and modular pressure controller [9] has been used to calibrate the pressure sensor. Pressure calibration media using a pressurised test chamber is more beneficial due to its capability for accommodating all types of sensors, such as an aneroid barometer and mercury barometer. The air inside the pressurised chamber is supplied by a pump, and the amount of air pressure regulated by the solenoid valve and both pump and solenoid valve are controlled by a microcontroller.

A proportional pressure regulator is more expensive and heavier than a solenoid valve. There are many methods to manipulate a solenoid valve so that it has nearly the same capabilities as a proportional pressure regulator [10], [11]. In this study, fuzzy logic has been programmed into a microcontroller and is used to control a solenoid valve for regulating air pressure inside a pressurised test chamber. Fuzzy logic is widely used for many purposes, such as pumping equipment control [12] and temperature control [13], [14]. The solenoid valve has two states, which are open and close. Fuzzy logic changes the solenoid valve, which states periodically by varying the opening and closing times [15], [16]. All research activity was done for calibration service in BMKG (Meteorological, Climatological, and Geophysical Agency), Jakarta, Indonesia. The results showed that pressurised test chamber controllers with fuzzy logic are more stable than those without fuzzy logic. Excessive data fluctuation do not occur during calibration, and hence this causes a smaller deviation between

***CORRESPONDING AUTHOR** | Muhammad Ridwan | ✉ ridwanandro@gmail.com

data points. The final result of the uncertainty is 0.09 or 10 % from the WMO requirement. Indeed, the calibration of the pressure controller can be principally used for daily purposes.

## METHOD AND EXPERIMENT

The available calibration service in BMKG Jakarta, Indonesia, currently performs manually and needs a technician to operate it, and he/she needs to control the pressure fluctuation in pressurise test chamber before the calibration. The first object developed is an automatic pressure chamber regulating and stabilising the air pressure in the test chamber. Fuzzy logic was programmed into a microcontroller to control the solenoid valve and vacuum pump for regulating the air pressure in the pressurised chamber automatically. The final result is of a direct approach to the calibration results of the chamber controller using fuzzy logic.

The method used in the preparation and analysis of this study is shown in Figure 1. While literature studies are related to design and developments, the design of hardware and software, before developing new hardware and software, was done firstly to determine the needs of the components used. The development of hardware includes an ATmega 2560 microcontroller, solenoid valve drivers, solenoid valves, communication modules, relays, LCD display, keypads, and voltage regulators. The software development contains a listing program for reading sensors, regulating pumps and solenoid valves, sending data and displaying data. For all development, the software uses C language uploaded to the microcontroller via Arduino sketch software.

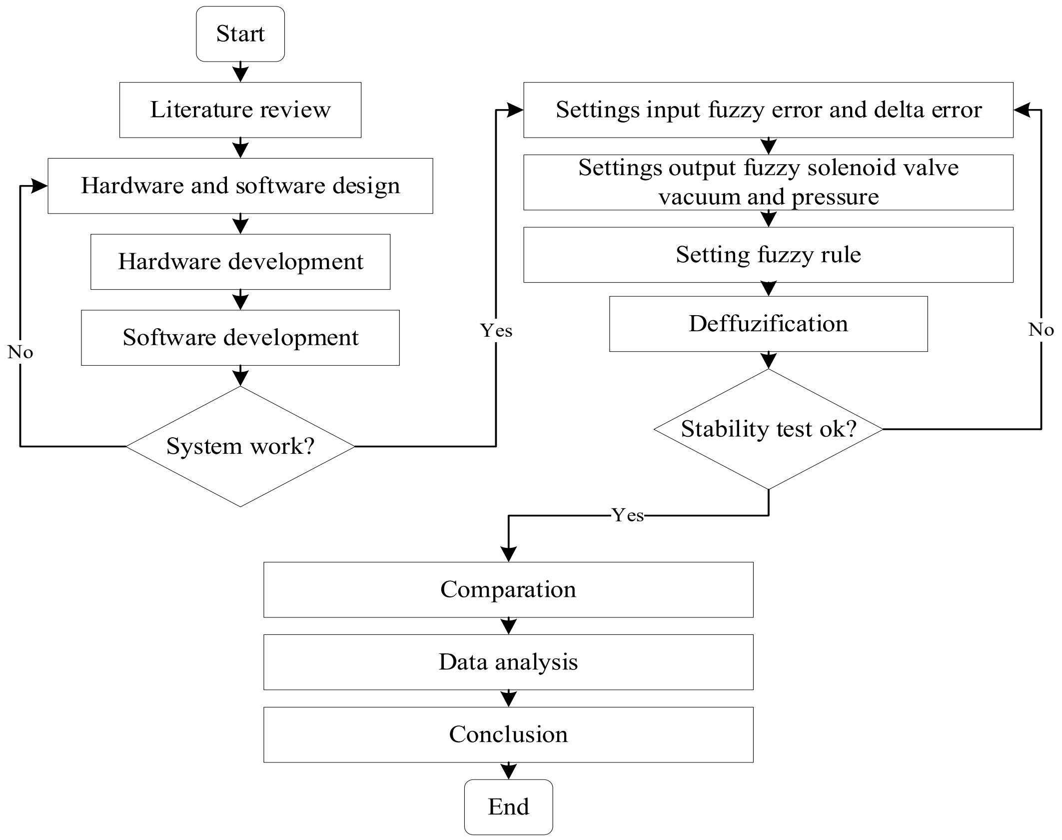



**Figure 1.** Flow chart of research activity.

After the hardware and software development has been completed, stability testing was performed, and basic functions were tested as well. Comparison is then the process to understand the relation and difference of the new system. Calibration should be conducted to understand how far the relation and influence of the control system to the final result of uncertainty. The calibration process uses a standard barometer and follows ISO 17025:2017 procedures at the BMKG Calibration Laboratory (LK-095). The results of the stability and uncertainty have been analysed to determine the efficiency of the calibration time.

### Hardware Design and System Description

The test chamber used in this study consists of a welded cylindrical steel body and front door with a solid steel frame and a large plexiglass pane sealed by an O-ring to ensure there are no leaks from the chamber. The operating range of the test chamber is 40 hPa to 1100 hPa, and the volume of the chamber is 234 litres. Figure 2 shows the schematic diagram of the system. Digital barometer used as an indicator to control the pressure inside the test chamber has an accuracy of 0.1 hPa with a pressure range from 500 hPa to 1100 hPa. The air inside the test chamber is connected directly to the digital barometer sensor. Pressure values read by the sensor are sent to the microcontroller via serial communication.

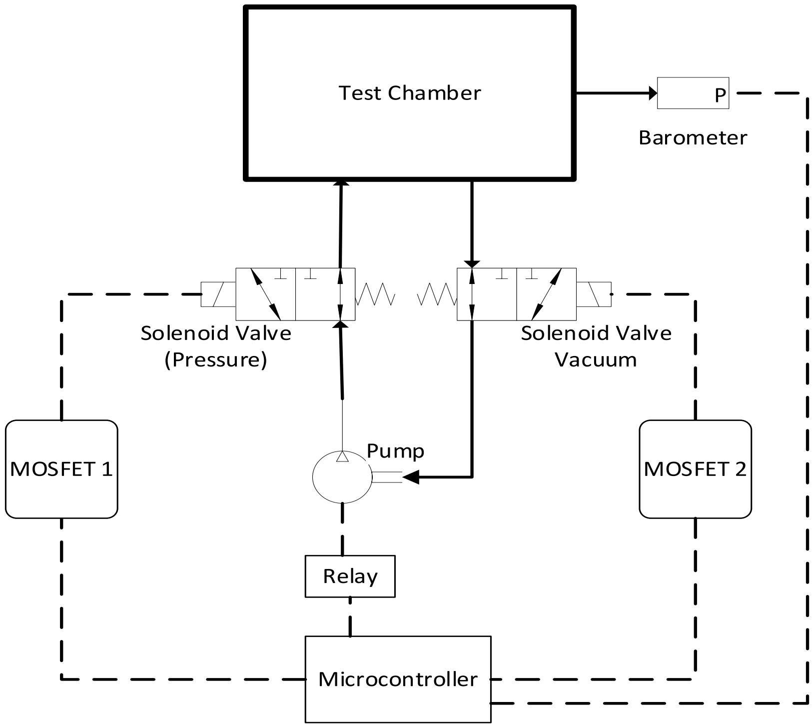
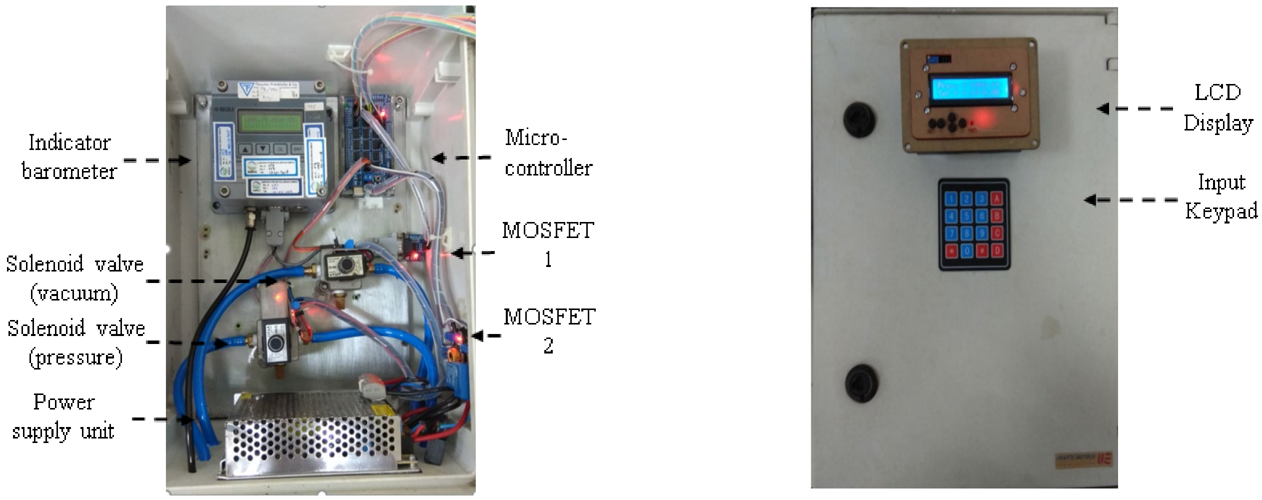



**Figure 2.** Schematic diagram of fuzzy logic controller for pressure sensor calibration chamber.

A vacuum pump is used to supply pressure or vacuum of the test chamber, and the exhaust nozzle and suction nozzle of the pump are connected to the solenoid valve. For this case, microcontroller control of the pump uses a relay. This design uses two solenoid valves; one solenoid valve is used to directing the air from the test chamber to the vacuum pump, and the other solenoid valve is applied to pressurise air from the pump to the test chamber. Each solenoid valve is driven by a Mosfet transistor to convert a 5-volt microcontroller signal output to a 24-volt solenoid valve working voltage. For further clarification, Figure 3(a) shows the inside view of the automatic chamber controller experimental device and Figure 3(b), the front view explores the LCD display and keypad installed in front of the device to make it easier for users to see the actual pressure inside a test chamber and to change the set-point.




(a) (b)

**Figure 3.** (a) Inside view and (b) front view of automatic pressure chamber controller.

## Calibration Experiment

The experiment was held at BMKG (Meteorological, Climatological, and Geophysical Agency) Meteorological Instruments Calibration Laboratory in Jakarta, Indonesia, where Figure 5 shows a set-up for the barometer calibration process. The standard barometer applied has a high full-scale accuracy laboratory standard digital barometer of 0.008% as well as 0.0001% resolution. The unit under test is an operational digital barometer with ±0.1 hPa accuracy at pressure range 500 – 1100 hPa and 0.01 hPa resolution. Before the experiment, the indicator barometer for the controlling chamber has been calibrated with 0.058 hPa uncertainty. During the test, the ambient air pressure and temperature were set up for 1011 hPa and for 23.5 °C, respectively. The rate of air leakage from the chamber was 0.04 hPa/s and Figure 5 shows the picture when calibration process carried out.

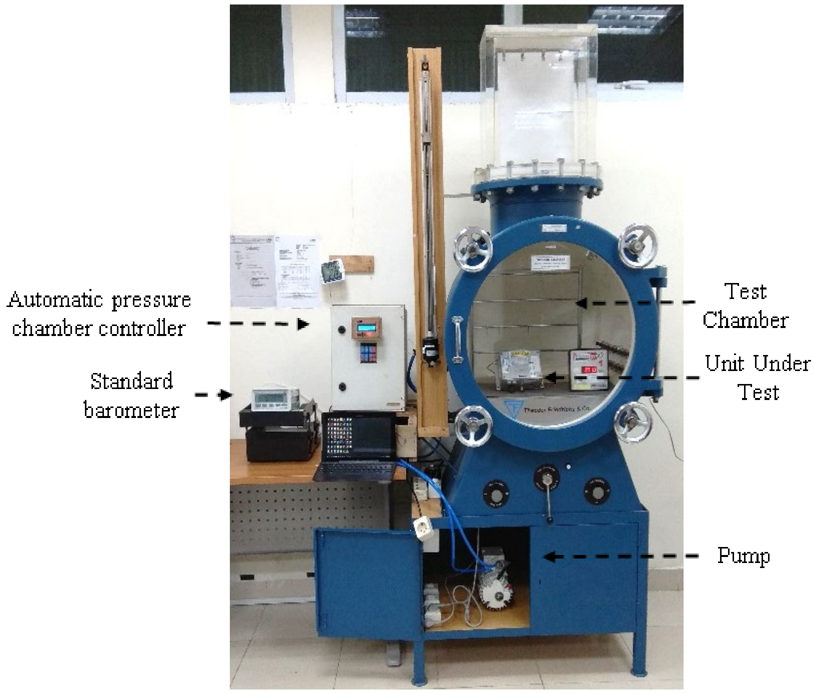



**Figure 5.** Calibration process.

### Software Design and Fuzzy Logic

The technique for fuzzy logic used in this study is Sugeno type fuzzy inference. Sugeno type fuzzy is more suitable for controlling the open/close state of a solenoid valve with an ‘on’ and ‘off’ concept [17]. The input for the fuzzy inference is the barometer sensor as well as the set-point value made by the operator. Both calculated inputs are divided into two parts, error and delta error. While the error is the difference between the actual pressure inside the test chamber and the set-point, delta error is a change of its error.

Error and delta error uses triangular membership function and converts into three linguistic terms to cover positive, zero, and negative value of error and delta error. All membership function ranges are selected according to experience, try and error method until they reach similar or better behaviour as certified calibration operator when performing pressure calibration.

Input error EN (less than zero hPa), EZ [-10 10] hPa, EP (more than 0 hPa). For delta error is DEN (less than zero hPa), DEZ [-1.5 1.5] hPa, DEP (more than zero hPa). The output of this system is a singleton value of open/close timing for solenoid valve, and the output for solenoid valve vacuum is NN (0 ms), ND (50 ms) and NX (1000 ms). For solenoid valve pressure is PN (0 ms), PD (50 ms) and PX (1000 ms). If the output value is 0 ms, the solenoid valve will then be in a fully closed state. If the output value is more than or equal to 1000 ms, the solenoid valve will then be in a fully open state. Figure 5 shows illustration of the fuzzification process.

Fuzzy rules use to interfere with the output [18] using the IF-THEN rule, and Table 1 displays the fuzzy rule base for solenoid valve vacuum and solenoid valve pressure. For solenoid valve pressure, the rule base is made by using the author’s experience and understanding of the system. Defuzzification is converted into the degree of membership function of the fuzzy and is set into solenoid valve open/close timing. Each rule weights its output level, $z_i$, by the firing strength of the rule, $w_i$.

$$Output=\frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i} \tag{1}$$

It is noted that the output is a weighted average of all rule outputs, where *N* is the number of rules. This method has less computationally intensive and simpler [19].

**Table 1.** The fuzzy rule for solenoid valve (vacuum) and solenoid valve (pressure).

| Error | | Delta error | | |
|---|---|---|---|---|
| | | DEN | DEZ | DEP |
| Solenoid valve (vacuum) | EN | NN | NN | NN |
| | EZ | ND | NN | ND |
| | EP | NX | NX | NX |
| Solenoid valve (pressure) | EN | PX | PX | PX |
| | EZ | PD | PN | PD |
| | EP | PN | PN | PN |

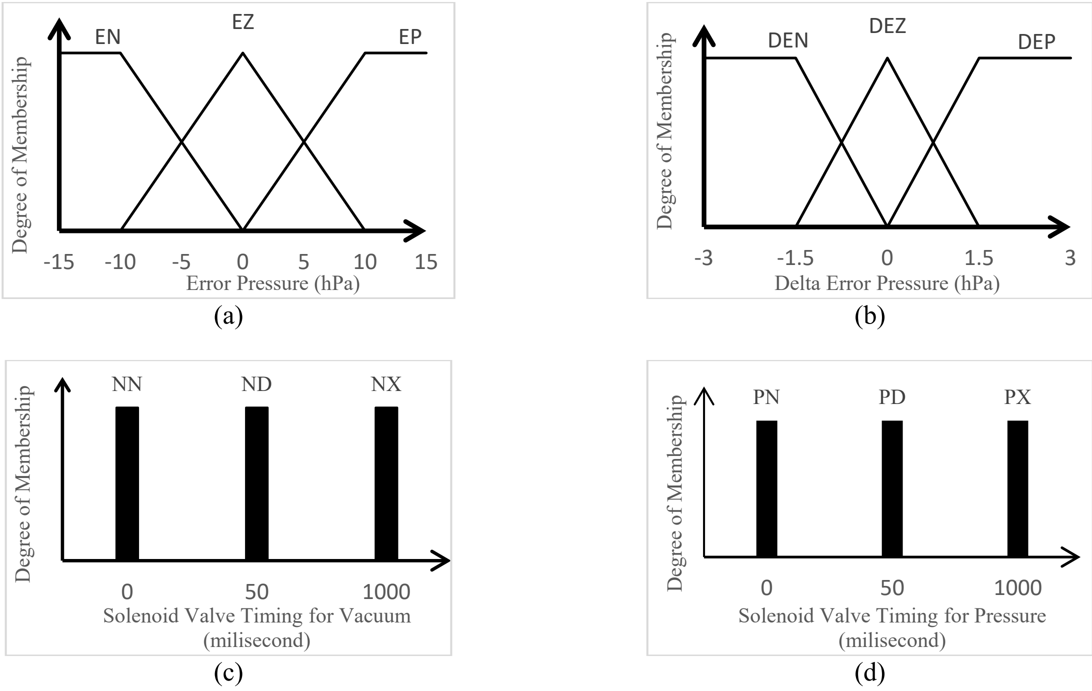



**Figure 5.** Fuzzification process. (a) input (error), (b) input (delta error), (c) output (vacuum), (d) output (pressure).

## RESULTS AND DISCUSSION

### Stability Analysis

Stability analysis is used to find uncertainty estimation and characterisation of pressure generators. This type-uncertainty characterises the fact that the measurement is constraint by the quantity fluctuation during the comparison between the pressure reference and the instrument under calibration [20]. The response of the test system is then displayed in Figure 6. The experiment starts at 950 hPa to set-point 1000 hPa. The system without fuzzy control can reach the set point in 17 seconds with an average rate of pressure change of 3.0 hPa/s, and an error against the set-point of 0.02%. The pressure oscillations are from a minimum value of 993.99 hPa and a maximum value of 1006.18 hPa with a maximum bias value of 12.19 hPa. The settling time of the pressure controller with fuzzy logic is 18 seconds with an average rate of change of pressure 3,1 hPa/s. The pressure oscillation is in the range of 998.99 hPa and 999,04 hPa. Therefore, the steady-state error is 0.09 hPa.

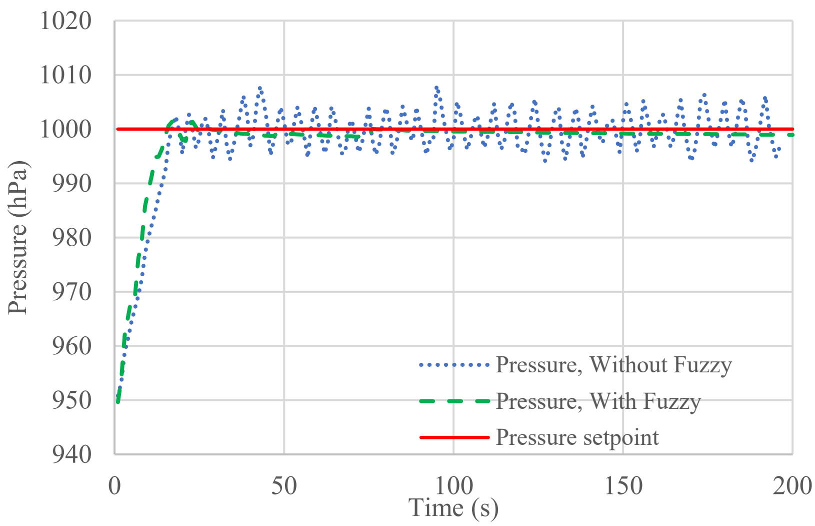
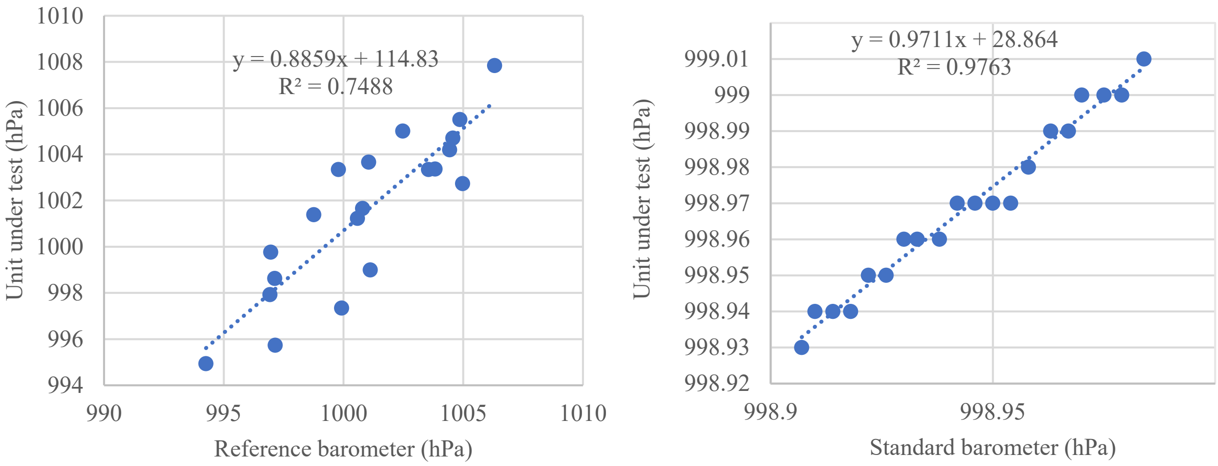



**Figure 6.** Time versus pressure for the pressure stability test.

### Calibration Analysis

The calibration was implemented by comparing the standard barometer and barometer under test at 1000 hPa. The first test was calibrated using a pressurised test chamber without fuzzy logic and having an average correction of -0.48 hPa and a standard deviation of 1.75 hPa. The calibration process using a pressurised test chamber with fuzzy logic produces the average correction of -0.02 hPa and the standard deviation 0.004. All of the results are explored in Figure 7(a) and 7(b), taking into account data distribution during the calibration test.

The uncertainty calculation method follows JCGM 100:2008 method [21]. From Table 3 and Table 4, there are four major sources of uncertainty that are most affected by the stability of the generator, such as repeatability or standard deviation of correction, display fluctuation from standard, display fluctuation from the unit under test, and stability of the media/pressure generator. The uncertainty of measurement shown in Table 3 and Table 4 is expressed at a minimum confidence level of 95 % with the coverage factor k = 2.




(a) (b)

**Figure 7.** Calibration data (a) without fuzzy logic and (b) using fuzzy logic.

Calibration data without fuzzy logic showed wide-spread of data distribution between 994 hPa to 1008 hPa. The $R^2$ correlation coefficient between standard barometer and unit under test was 0.7488, as shown in Figure 7(a). However, by using fuzzy logic, the data distribution shown in Figure 7(b) becomes narrower between 998 hPa to 999 hPa with $R^2$ correlation coefficient of 0.9763. The more narrower data distribution and higher data correlation will reduce the uncertainty from repeatability source.

The result of uncertainty from chamber controller without fuzzy is 12.16 hPa, and this uncertainty value is too large due to pressure fluctuations in the test chamber. The data distribution is very wide, as shown in Figure 7(a), and this is due to the contribution of the repeatability, display fluctuation from the standard barometer and hence greater of the uncertainty magnitude shown in Table 3.

From the uncertainty source shown in Table 4, the automatic pressure chamber controller with the fuzzy logic have less uncertainty value from repeatability, display fluctuation, and pressure media/generator stability is then able to achieve expanded uncertainty of 0.09 hPa or 10% of the uncertainty tolerance for atmospheric pressure measurement instrument, and that is met with the WMO regulation.

**Table 3.** Uncertainty calculation without fuzzy logic.

| Uncertainty source | | | Probability distribution | Standard uncertainty |
|---|---|---|---|---|
| | Repeat | 1.755 | normal | 0.392 |
| Standard barometer | Certificate | 0.025 | normal | 0.013 |
| | Drift | 0.032 | rectangular | 0.018 |
| | Display | 12.056 | rectangular | 3.480 |
| | Resolution | 0.0005 | rectangular | 0.000 |
| | Hysterisis | 0.002 | rectangular | 0.001 |
| | Temperature | 0.035 | Arcsine | 0.010 |
| Media/generator | Altitude | 0.0114 | rectangular | 0.003 |
| | Stability | 12.19 | rectangular | 3.519 |
| Unit under test | Resolution | 0.005 | rectangular | 0.003 |
| | Display | 12.91 | rectangular | 3.727 |
| | | | Combined uncertainty | 6.208 |
| | | | Expanded uncertainty ($U_{95}$), k=2 | 12.16 |

**Table 4.** Uncertainty calculation with fuzzy logic.

| Uncertainty source | | | Probability distribution | Standard uncertainty |
|---|---|---|---|---|
| | Repeat | 0.038 | Normal | 0.001 |
| Standard barometer | Certificate | 0.025 | Normal | 0.013 |
| | Drift | 0.032 | rectangular | 0.018 |
| | Display | 0.077 | rectangular | 0.022 |
| | Resolution | 0.0005 | rectangular | 0.000 |
| | Hysterisis | 0.002 | rectangular | 0.001 |
| | Temperature | 0.035 | arcsine | 0.010 |
| Media/generator | Altitude | 0.0114 | rectangular | 0.003 |
| | Stability | 0.09 | rectangular | 0.026 |
| Unit under test | Resolution | 0.005 | rectangular | 0.003 |
| | Display | 0.07 | rectangular | 0.020 |
| | | | Combined uncertainty | 0.047 |
| | | | Expanded uncertainty ($U_{95}$), k=2 | 0.09 |

## CONCLUSION

An automatic pressure chamber controller with fuzzy logic that regulates the air pressure in the pressurised test chamber by varying the opening and closing time of the solenoid valve has been developed. It proved to pressurise test chamber controller with the fuzzy logic more stable than that without fuzzy logic. Excessive data fluctuation did not occur during the calibration results in a smaller deviation among the data points. However, the final results of the uncertainty showed 0.09 hPa or 10 % accuracy, which surely met the WMO requirement. Indeed, the new fuzzy logic pressure controller can be principally used in daily related purposes.

## ACKNOWLEDGEMENT

The authors are very grateful to BMKG for allowing the atmospheric calibration facilities and resources used in this study. The authors are also very appreciative to Prof. Dr Masbah R.T. Siregar, APU, Department of Electrical Engineering, Faculty of Engineering, Institut Sains dan Teknologi Nasional, Indonesia.

## REFERENCES

[1] Goodman CJ, Griswold JDS. Climate impacts on density altitude and aviation operations. Journal of Applied Meteorology and Climatology 2018; 57(3): 517–523.

[2] Fultz AJ, Ashley WS. Fatal weather-related general aviation accidents in the United States. Physical Geography 2016. 37(5):1-22.

[3] World Meteorological Organization: 2014. Guide to meteorological instrument and observing practices.

[4] Jin W, Zuo S, Sun D, et al. Multi-channel automatic calibration system of pressure sensor. In: Proceedings of 2016 IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference, IMCEC 2016, Xi'an, China, pp. 506-510; 2017.

[5] Merlone A, Roggero G, Verza G Pietro. In situ calibration of meteorological sensor in Himalayan high mountain environment. Meteorological Applications 2015; 22(1): 847-853.

[6] Lopardo G, Bellagarda S, Bertiglia F, et al. A calibration facility for automatic weather stations. Meteorological Applications 2015; 22(1): 842-846.

[7] Madhu AS, Sethuram D, Vijayalakshmi V, et al. Automatic pressure calibration system for pressure sensors. FME Transactions 2019; 47: 111–115.

[8] Pornpatkul C, Suksathid W. Pressure control design by Fieldbus system for the pressure gauge calibration. In: 2013 13th International Conference on Control, Automation and Systems (ICCAS 2013). IEEE, 2013, pp. 1565–1570.

[9] Turk A, Hamarat A, Karaboce B. Comparison of manual and automated pressure calibration methods of medical pressure calibrator. IEEE Medical Measurements and Applications, MeMeA 2020 - Conference Proceedings 2020; 2: 1–6.

[10] Shiee M, Arman Sharifi K, Fathi M, et al. Air pressure control via sliding mode approach using an on/off solenoid valve. In: 20th Iranian Conference on Electrical Engineering (ICEE2012), Tehran, Iran, pp. 857–861; 2012.

[11] Essmat Abdul-Lateef W, Glebov NA, Hamed Farhood N, et al. Modelling and controlling of position for electro-pneumatic system using pulse-width-modulation (PWM) techniques and fuzzy logic controller. In: IOP Conference Series: Materials Science and Engineering 2020; 765: 012020.

[12] Kozlova LP, Kozlova OA. Application of fuzzy logic to control pumping equipment. In: Proceedings of 2017 IEEE 2nd International Conference on Control in Technical Systems, CTS 2017, St. Petersburg, Russia; 25-27 October, 2017.

[13] Singhala P, Shah DN, Patel B. Temperature control using fuzzy logic. International Journal of Instrumentation and Control Systems 2014; 4(1): 1-10.

[14] Magsumbol JAV, Baldovino RG, Valenzuela IC, et al. An automated temperature control system: A fuzzy logic approach. In: 2018 IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management, HNICEM 2018, Manila, Philippines, pp. 1-6; 2019.

[15] Lin Z, Zhang T, Xie Q, et al. Intelligent electro-pneumatic position tracking system using improved mode-switching sliding control with fuzzy nonlinear gain. IEEE Access 2018; 6: 34462–34476.

[16] Bağlar ET, Baysal CV. An Experimental Evaluation of Control Modes for Pneumatic Artificial Muscles Using Fast on/off

Valves. Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi 2020; 35: 401–412.
[17] Maisarah Mohd Sobran N, Mohd Salmi M, Bazli Bahar M, et al. Fuzzy Takagi-Sugeno method in microcontroller based water tank system. IAES International Journal of Robotics and Automation (IJRA) 2018; 7: 1.
[18] Burns R. Advanced Control Engineering. Oxford: Butterworth-Heinemann, 2001.
[19] Karakaya S, Ocak H. Fuzzy logic-based moving obstacle avoidance method. Global Journal of Computer Sciences: Theory and Research 2019; 9: 1–9.
[20] Duvernoy J. Guidance on the computation of calibration uncertainties. World Meteorological Organization, 2015.
[21] International Organization for Standardization Geneva ISO: 2008. Evaluation of measurement data — Guide to the expression of uncertainty in measurement.