RESEARCH ARTICLE OPEN ACCESS

Manuscripts received July 18, 2023; revised August 10, 2023; accepted August 12, 2023; Publish date: 25 September 2023
Digital Object Identifier (**DOI**): https://doi.org/10.35882/teknokes.v16i3.613

How to cite: Muhammad Ali Wafa, Moch. Prastawa Assalim Tetra Putra, Levana Forra Wakidi, and Shubhrojit Misra, "Measuring Instruments For Oxygen Concentration, Flow, Temperature, and Humidity In CPAP Equipped With Microcontroller Based External Data Storage (Temperature and Humidity)", Jurnal Teknokes, vol. 16, no. 3, pp. 146–155, September. 2023.

Measuring Instruments for Oxygen Concentration, Flow, Temperature, and Humidity in CPAP Equipped with Microcontroller Based External Data Storage

Muhammad Ali Wafa[1], Moch. Prastawa Assalim Tetra Putra[1], Levana Forra Wakidi[1], and Shubhrojit Misra[2]

[1] Department of Electromedical Engineering, Health Polytechnic Ministry of Health Surabaya, Indonesia
[2] Department of Electronics and Telecomunication Engineering, Jadavpur University, India

Corresponding author: Moch. Prastawa Assalim Tetra Putra (e-mail: prast77@poltekkesdepkes-sby.ac.id).
"This work was supported in part by Department of Electromedical Engineering, Health Polytechnic Ministry of Health Surabaya"

ABSTRACT The recommended approach for addressing sleep apnea in infants involves the utilization of CPAP therapy. A pivotal component of CPAP therapy is the inclusion of a humidifier, which serves to counteract potential hazards by introducing humidified air. The purpose of this study was centered on developing a compact, portable model to assess temperature and humidity parameters in CPAP humidifiers. The method utilized was the pre-experimental One Group Post Test Design. The contribution of this research lies in its ability to measure temperature and humidity in the CPAP humidifier using the SHT30 sensor. The sensor readings were processed using the Arduino Mega 2560 Pro Mini microcontroller. The measurement data was presented on a 20x4 LCD screen and had the capability to be stored using an SD Card, alongside the inclusion of a buzzer indicator on the tool. The results demonstrated that the highest error value for the temperature parameter was 1.8%, while the lowest was 0.49%. The expected conclusion is that these findings can be implemented effectively to assist operators in recording, measuring, and monitoring temperature and humidity in CPAP humidifiers and to facilitate monitoring of sleep apnea treatment procedures.

INDEX TERMS Sleep Apnea, Humidifier CPAP, Temperature, Humidity, SHT30 Sensor

I. INTRODUCTION

Oxygenation involves meeting the body's essential oxygen requirements, crucial for maintaining the body's metabolic processes, supporting life, and enabling the functions of different organs and cells. Prolonged oxygen deprivation exceeding four minutes can lead to brain damage and loss of consciousness. Obstructive sleep apnea hypopnea syndrome (OSAHS) has gained significant attention within the past five decades as a notable medical condition. Apnea signifies a cessation of breathing lasting over 10 seconds and is observed in both central sleep apnea (CSA) and obstructive sleep apnea (OSA). These two are distinguished by the absence of respiratory effort in CSA, as opposed to sustained yet ineffective respiratory effort in OSA. Hypopnea is defined as a reduction in ventilation of at least 50%, leading to a decrease in arterial saturation of 4% or more due to partial obstruction of the airway. [1] Sleep apnea/hypopnea syndrome (SAHS) is a condition characterized by a substantial occurrence rate, often linked to considerable health challenges and a notable potential for long-term risks and adverse outcomes. [2] Obstructive sleep apnea-hypopnea syndrome (OSAHS) is marked by recurring occurrences of diminished airflow (hypopnea) or complete interruption (apnea) caused by the collapse of the upper airway during sleep. [3] Continuous Positive Airway Pressure (CPAP) is a successful approach for managing sleep apnea/hypopnea syndrome (SAHS). CPAP therapy is the preferred treatment for the majority of patients, though its effectiveness is contingent on its consistent use. [4] Continuous Positive Airway Pressure (CPAP) is a medical apparatus employed to aid individuals who face breathing challenges while breathing naturally. CPAP serves as a straightforward yet efficient device extensively utilized for treating respiratory ailments, particularly in infants. [5] CPAP involves administering positive pressure to an infant's airway throughout their breathing cycle while they breathe spontaneously. [6] Since 1981, continuous positive airway pressure (CPAP) therapy has emerged as the treatment of choice for obstructive sleep apnea (OSA). [7] Continuous Positive Airway Pressure (CPAP) therapy is the favored approach for addressing obstructive sleep apnea syndrome (OSA). The effectiveness of CPAP in alleviating symptoms like daytime sleepiness, enhancing long-term survival, and preventing complications such as cardiovascular issues stemming from OSA has been verified. However, CPAP usage may lead to bothersome effects, including dryness in the nose, mouth, and throat, sneezing, nasal discharge, nasal blockage, sinus inflammation, swallowing of air, nosebleeds, discomfort related to the nasal mask, and conjunctivitis due to mask leakage. Among the most frequently cited side effects is dryness of the nose, mouth, and throat, affecting 30% to 66% of CPAP users. [8] Sleep apnea-hypopnea syndrome occurs not only in infants but also occurs in adults, affecting about 2% to 4% of middle-aged men and 1% to 2% of middle-aged women. It causes daytime sleepiness, decreases daytime functioning, and contributes to increased rates of traffic accidents and deaths from cardiovascular and cerebrovascular events. This syndrome arises from repeated narrowing of the upper airway during sleep, leading to frequent awakenings and subsequent sleep disturbances, as well as repeated short-term increases in blood pressure. [9] Obstructive sleep apnea is a progressively acknowledged condition characterized by recurrent narrowing or collapse of the upper airway during sleep. This results in either partial or complete obstruction, leading to instances of apnea, hypopnea, or a combination of both. This disorder triggers daytime drowsiness, cognitive impairment, and feelings of depression. It exerts its impact on virtually every bodily system, contributing to a higher occurrence of hypertension, cardiovascular ailments, strokes, pulmonary hypertension, cardiac irregularities, and compromised immune function. Additionally, it heightens the likelihood of accidents, presumably due to associated daytime sleepiness. The established benchmark for diagnosing sleep apnea is an overnight polysomnogram. Increasingly, split-night studies are becoming prevalent, allowing for faster implementation of treatment at a reduced expense. Various approaches are available for addressing sleep apnea, including weight loss, positional therapy, oral appliances, continuous positive airway pressure (CPAP), and upper airway surgical interventions. Among these, CPAP stands out as the most effective and widely employed therapy. However, complications associated with CPAP usage encompass issues like nasal congestion or dryness, mask discomfort, and feelings of claustrophobia. Enhancements such as heated humidifiers, advanced mask designs, and nasal steroids have improved patient tolerance to CPAP treatment. For those struggling with the sustained pressure of CPAP, bilevel positive-pressure therapy may be a consideration. Given the potential consequences, comprehensive treatment is necessary to enhance the quality of life and avert complications stemming from this condition. [10] Continuous positive airway pressure (CPAP) stands as the favored therapeutic approach for managing obstructive sleep apnea syndrome (OSAS). Nevertheless, a significant 60% of patients report discomfort related to nasal and pharyngeal symptoms. One potential solution to mitigate these adverse effects involves incorporating a heated humidifier. However, there is a dearth of comprehensive information on the efficacy of this strategy, and the specific criteria for its application remain insufficiently defined. [11] While its efficacy has been extensively recorded, the level of approval and sustained commitment to this therapy is still less than ideal. This is mainly due to negative psychological and physical effects that undermine acceptance and long-term adherence to the treatment. [12] Continuous Positive Airway Pressure (CPAP) generally used in moderate to severe cases. In several studies have stated effectiveness in enhancing quality of life and reducing cardiovascular health risks. [13] Studies have demonstrated that skillful application of CPAP can alleviate respiratory difficulties, reduce the need for extra oxygen support, contribute to the restoration and maintenance of remaining lung capacity, hinder blockages in the upper airway, lower the chances of lung collapse, and decrease occurrences of apnea, bradycardia, and cyanotic episodes. [14] In clinical practice, employing a heated humidifier with CPAP is generally considered discretionary, typically employed when a patient demonstrates signs of dryness in the nasal or oral areas, or during extended usage periods. [15] Two typical forms of humidity are in common use cold Passover humidity and heated humidity. Limited information exists regarding the impacts of these humidity variations on adherence to CPAP and nasal symptoms among individuals with sleep apnea. [16] Heated moisture has proven effective in addressing sleep apnea. For patients experiencing upper airway symptoms while using nasal CPAP, the introduction of heated humidity considerably enhanced CPAP adherence. In a brief-term investigation, individuals commencing nasal CPAP treatment were assigned either cold humidity, heated humidity, or no humidity randomly. Notably, nasal CPAP compliance markedly improved when patients received heated humidity. These crossover studies imply that introducing heated humidity during the initiation of nasal CPAP therapy could potentially enhance compliance. However, it's possible that only individuals with notable upper airway symptoms derive benefits from heated humidity. Additionally, incorporating heated humidity introduces significant expenses and intricacies to nasal CPAP treatment. [17] CPAP treatment incorporating heated humidity has been a conventional approach. However, this method does not eliminate all challenges, as the inclusion of a humidifier raises the expenses associated with CPAP therapy and introduces complications in its practical application. [18] While CPAP remains the primary therapeutic approach for obstructive sleep apnea (OSA), inadequate compliance remains a significant challenge undermining its effectiveness. Present information regarding the impact of incorporating heated humidification to enhance CPAP adherence shows contradictory results. [19] Pediatric obstructive sleep apnea leads to considerable health challenges, yet the effectiveness of CPAP therapy is hindered by low compliance, even though it is commonly applied for various conditions like neonatal respiratory distress and chronic obstructive pulmonary disease. [20]

Referring to the existing literature, in 2018 there is research with the title Humidity and Temperature Monitoring by Ibtihaj A. Abdulrazak. The purpose of this research was to make a measuring instrument that can monitoring temperature and humidity against weather climates with low cost and high performance, to provide accurate humidity and temperature measurements. This device uses the DHT22 sensor and displays the results on the 2x16 character LCD. In this research using Arduino Uno as a microcontroller to control the working system of this tool. However, some limitations were identified in this tool, including the appearance of the display used is too small and this tool it is also not equipped with an external data storage to store measurement results data. In this study still using room objects not on medical devices. [21] In 2019 there is research with the title Monitoring Temperature and Humidity of Server Room Using Latte panda and Thing Speak by T. H. Nasution, et al. The purpose of this research was to make design a temperature and humidity remote monitoring system and server room using Latte panda and Thing Speak to data cloud of monitoring result. This device uses the DHT11 sensor displaying in Thing Speak. In this research using Arduino GPIO on Latte panda as a microcontroller to control the working system of this tool. However, some limitations were identified in this tool, namely this tool still using the DHT11 sensor where the sensor still has a less accurate value and also has a limited measurement range in temperature parameters only being able to measure 0ºC – 50ºC. In addition, it allows for weaknesses in signal coverage because it only uses online mode (using WIFI) without being equipped with offline mode as an option in case of signal difficulties and also not equipped with an external data storage to store measurement results data. In this study still using room objects not on medical devices. [22] In 2021 there is research with the title Distant Temperature and Humidity Monitoring: Prediction and Measurement by Farrukh Hafeez, et al. The purpose of this research was to make a measuring instrument that can monitoring temperature and humidity with experiments are carried out in both outdoor and indoor settings. This device uses the DHT22 sensor displaying them on the app. In this research using NodeMCU ESP 8266 as a microcontroller to control the working system of this tool. However, some limitations were identified in this tool, namely this tool is not equipped with an external data storage to store measurement results data. In addition, it allows for weaknesses in signal coverage because it only uses online mode (using WIFI) without being equipped with offline mode as an option in case of signal difficulties. In this study still using room objects not on medical devices. [23]

Based on the review of the literature provided, it can be concluded that in previous studies further development of the tool could be carried out by making a measuring instrument with a portable model design that is more concise and easier to carry anywhere and is fitted with an external data storage system to accommodate a larger amount of measurement data because it has bigger storage space. The main purpose of making this tool is expected to assist operators in recording, measuring, and monitoring temperature and humidity in CPAP humidifiers and to facilitate monitoring of sleep apnea treatment procedures. Therefore, the authors intend to conduct research with the title "Measurement of Oxygen Concentration, Flow, Temperature, and Humidity in CPAP Equipped with Microcontroller-Based External Data Storage (Temperature and Humidity)". In this research using a mechanical design made with a portable model. Devices designed with portable models typically rely on battery power as their energy source. In practical terms, portable equipment necessitates low power consumption to ensure prolonged usage and facilitate convenient portability so easy to carry everywhere. [24] The Charger Module is employed to replenish the Lithium-Ion battery through the USB input. The Lithium-Ion battery is a contemporary advancement of the standard Lithium battery, offering rechargeable capabilities. Lithium batteries are known for their superior specific energy, superior efficiency, and extended lifespan. [25] One drawback of Lithium-ion batteries is their sensitivity to temperature changes. In systems that rely on batteries as their power source, when a battery is fully charged, its voltage usually exceeds its nominal voltage, while a battery that has been depleted of its charge has a lower voltage. To maintain a stable power supply voltage, a voltage step-up and step-down converter is commonly will be employed, given its ability to handle a wide input voltage range. [26] The design of this tool is also equipped with the MT3608 Voltage Step Up Module which functions as a DC-to-DC voltage step up circuit with an input voltage of 2 – 24V and an output voltage of up to 28V with a maximum current of 4A. Apart from using a mechanical design with a portable model, this part of the tool is also equipped with Enter, Up, Down, and Save buttons. This tool is also equipped with a buzzer as an indicator on the tool. The design of this tool uses several modules, including the OCS-3F sensor which is used for oxygen concentration and flow parameters, the SHT30 sensor which is used for temperature and humidity measurements, Microcontroller Arduino Mega 2560 Pro Mini, DS1307 RTC Module, Micro SD Card Adapter Module, Lithium Charger Module, and MT3608 Step Up Voltage Module. SHT30 is a sensor used to measure temperature and humidity. SHT30 has the highest average value temperature accuracy than sensor DHT11 and DHT22 for all three sensor nodes. [27] The Arduino Mega 2560 Pro Mini serves as a data processing microcontroller responsible for handling the data received from the sensor readings. In this microcontroller board offers 54 digital I/O pins, with 15 supporting PWM, along with 16 analog input pins, and 4 UART pins. [28] Arduino Mega is a great choice of microcontroller board for projects that require lots of input/output pins. [29] The Arduino Mega Pro Mini board is an Arduino model with a mini design making it easy to install in projects that have minimalist packaging. The sensor readings will be showcased on a 20x4 LCD with I2C connectivity. This LCD type can exhibit 20 characters in each of its four rows, making it possible to display a total of 80 characters at any given moment. [30] The I2C system comprises SDA and SCL channels. With only two pins, namely Pin 4 (SDA) and Pin 5 (SCL) I2C effectively can controls both 16x2 and 20x4 Character LCDs. The DS1307 RTC module functions as a Real Time Clock module, capable of receiving and storing time-related data such as day, date, month, and year in real-time, even accounting for months with 30 or 31 days. The DS1307 accurately tracks seconds, minutes, hours, day of the week, date of the month, month of the year, including leap years until the year 2100. [31] The primary advantage of the RTC module is its backup battery configuration which can ensures the continuous operation of the clock or calendar even during power failure. [32] In order to store data, the tool requires a Micro SD Card Adapter Module serving as an external data storage module that utilizes an SD Card device to store measurement results. The benefits of using an SD Card include its ample storage capacity, rapid data transfer speed, excellent flexibility, and robust data security. It is worth noting that all types of SD cards operate on a power consumption of 3.3 volts. [33] To facilitate communication between the microcontroller and SD cards, especially for reading or writing data, a communication system is essential to connect the two. SD cards offer two modes of connection that is SD Bus mode and SPI Bus mode. In SD Bus mode, communication with the microcontroller requires all pins of the SD card to be utilized. Meanwhile, SPI Bus mode enables communication with the microcontroller using just four pins that is Chip Select (CS), Clock Line (CLK), Data In (MOSI) pin, and Data Out (MISO) pin. The SPI bus interfacing mode is the most commonly used technique for connecting an SD card to a microcontroller. [34]

The contribution of this study is being able to measure temperature and humidity in the CPAP humidifier using the SHT30 sensor. This sensor is in charge of reading the temperature and humidity values in the CPAP humidifier. The reading results obtained by the SHT30 sensor are then processed by the Arduino Mega 2560 Pro Mini microcontroller which functions as a controller for the working system of the tool. Measurement data is displayed on a 20x4 LCD and can be stored efficiently using an external data storage facilitated by the Micro SD Card Reader Writer module with SD Card devices. Provision of external data storage is intended to increase data storage capacity, so that it can store more measurement data because it has a larger storage space. This tool is also equipped with a buzzer as an indicator on the tool. The expected goals can be applied to assist operators in recording, measuring, and monitoring temperature and humidity in CPAP humidifiers and to facilitate monitoring of sleep apnea treatment procedures.

II. METHOD

Measurement data collection in this research was conducted at the Ibnu Sina Gresik Hospital. The research employed the pre-experimental method, specifically the One Group Post Test Design, as the device was directly treated without assessing its initial state first, and the treatment results were subsequently compared to a control group. The independent variable in this research are temperature and humidity, while the dependent variable is the SHT30 sensor utilized to read the temperature and humidity values at the output of the CPAP humidifier. Lastly, the control variable is the Arduino Mega 2560 Pro Mini microcontroller, which played a crucial role in controlling the tools working system.

FIGURE 1. **CareFusion SiPAP Model M675**

In FIGURE 1 is a CPAP Humidifier Brand CareFusion SiPAP Model M675 in Ibnu Sina Gresik Hospital which is used as a comparison tool for the modules made in this research. Retrieval of measurement data carried out on the temperature parameter is as much as 4 data with each data being repeated 5 times. Measurements were made by setting the temperature on the CPAP humidifier 32ºC – 35ºC. Meanwhile, for data collection on humidity parameters, reading the results of the percentage of humidity follows the humidity value in the CPAP humidifier (there is no humidity setting in the CPAP humidifier). The CPAP equipment in the Ibnu Sina Gresik Hospital has a CPAP humidifier section that can be set. The specifications of the CPAP Humidifier device used at the Ibnu Sina Gresik Hospital are the brand CareFusion SiPAP Model M675.

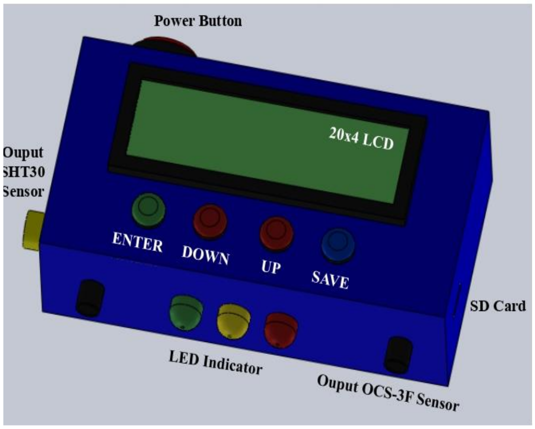

FIGURE 2. Mechanical Design Outside

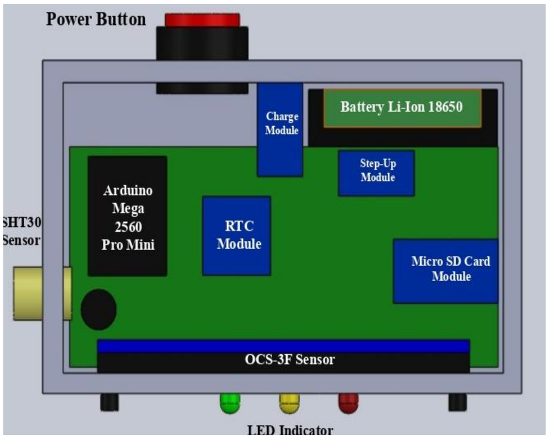

FIGURE 3. Mechanical Design Inside

In FIGURE 2 and FIGURE 3 is the result of the module's mechanical design made with a portable model. The Arduino Mega 2560 Pro Mini acts as the data processing microcontroller, handling data from the OCS-3F sensor (oxygen concentration and flow readings) and the SHT30 sensor (temperature and humidity readings). The results from both sensors are displayed on a 20x4 LCD. The DS1307 RTC module serves as the Real Time Clock, enabling date and time setting and acting as a reference for measurement time during data storage. To save data, the Micro SD Card Adapter Module is utilized, providing external data storage using an SD Card device. Since portable equipment often relies on batteries, the Lithium Charger Module is employed to recharge the Lithium-Ion battery through a USB input. Additionally, the tool features the MT3608 Voltage Step Up Module, which serves as a DC to DC voltage step-up circuit, accepting input voltages from 2 to 24V and outputting voltages from 5 to 28V with a current of 2A. Apart from using a mechanical design with a portable model, this part of the tool is also equipped with Enter, Up, Down and Save buttons.

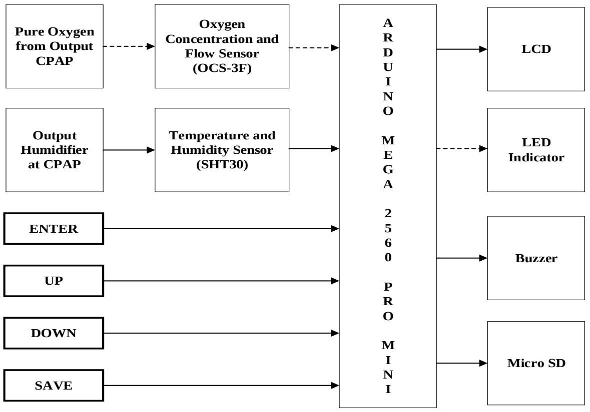

FIGURE 4. Block Diagram of Measuring Instruments for Oxygen Concentration, Flow, Temperature, and Humidity in CPAP Equipped with Microcontroller Based External Data Storage

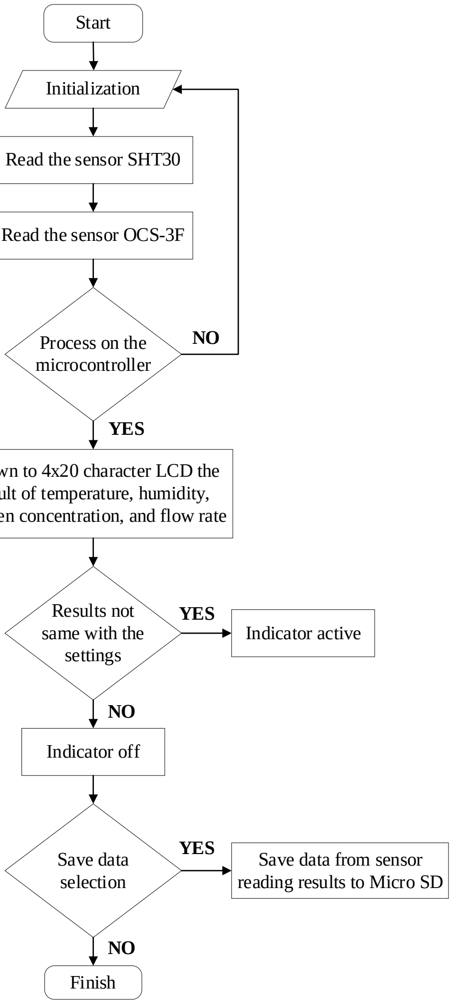

FIGURE 5. Flowchart of Measuring Instruments for Oxygen Concentration, Flow, Temperature, and Humidity in CPAP Equipped with Microcontroller Based External Data Storage

In FIGURE 4 is a block diagram of this research. On the block diagram the solid line is discussed by the researcher, while the dotted line is not discussed by the writer. The humidifier output on CPAP functions as input on the SHT30 sensor. Then the SHT30 sensor will read the temperature and humidity values at the output of the CPAP humidifier. The SHT30 sensor will be connected to the Arduino Mega 2560 Pro Mini microcontroller. The microcontroller functions to process data received from the SHT30 sensor then the results will be displayed on the 20x4 LCD. The results of the data can also be stored via external data storage using a Micro SD with an SD Card of 4 GB. The temperature and humidity parameters use a buzzer indicator as a hazard alarm indicator if the value is above or below the setting standard. The buzzer will sound when the measurement results are outside the operating environment range on CPAP for the temperature parameter in the range of 30 – 40ºC while for the humidity parameter it is in the range of 0 – 100%. This tool section is also equipped with Enter, Up, Down, and Save buttons.

In FIGURE 5 is a flowchart of this research. When the ON button is pressed, data initialization will occur first. Next, the first sensor reading will be carried out, namely the SHT30 sensor as a temperature and humidity sensor. Then proceed with reading the second sensor, namely the OCS-3F sensor as a sensor for oxygen concentration and flow. Once the readings from both sensors are acquired, the microcontroller proceeds to process the data collected from measurements. If, for any reason, the measurement data is not successfully read, the process will revert to the initial data stage. Conversely, if the measurement data is successfully read and processed by the microcontroller, it will be shown the results on the 20x4 LCD display. If the measurement data results do not align with the configured settings, it will cause the indicator to be active. The LED serves as an indicator for the parameters of oxygen concentration and flow, while the buzzer acts as an indicator for temperature and humidity. However, if the result from data measurements collected acquired in accordance with the settings, the indicator will inactive. The next process is the selection of saves data. If data storage is necessary, the user can opt to save it on a Micro SD. Conversely, if there is no need to store the measurement data, the tool's operation can be finished.

The data collection technique in this research was by measuring temperature and humidity at the output of the CPAP humidifier using a module that had been made using the SHT30 sensor. The measurement results will then be compared with the display on the CPAP humidifier whether the measurement readings made by the module have an error value that is far from what is set. The results of the measurement readings on the module are also used to determine the temperature and humidity values that will be delivered to the patient through the hose from the CPAP humidifier. The range of measurements made for data collection on the temperature parameter is 30ºC – 40ºC while for the humidity parameter the reading of the humidity percentage results follows the humidity value in the CPAP humidifier (there is no humidity setting in the CPAP humidifier). The following are the steps in collecting measurement data, namely: To conduct the measurement data collection for the CPAP humidifier monitoring device, a systematic approach is followed. Firstly, the created module is prepared, ensuring that the sensor module, Arduino Mega 2560 Pro Mini microcontroller, 20x4 LCD display, buzzer, and SD Memory Card are all properly assembled and connected. Next, the CPAP device and humidifier are set up for data collection in a controlled environment, simulating real-world usage conditions. Oxygen cylinders and compressors are also readied to supply the necessary oxygen and air to the CPAP device. Once the preparations are complete, connecting hoses are installed between the CPAP device and the oxygen cylinder, as well as the compressor, to ensure a secure and stable supply of oxygen and air. Another connecting hose is attached between the sensor module and the CPAP humidifier, allowing the monitoring of temperature and humidity parameters. With everything in place, the module, CPAP device, CPAP humidifier, oxygen cylinder, and compressor are all turned on according to the manufacturer's instructions. The temperature and humidity parameters at the output of the CPAP humidifier are then measured, with each measurement repeated five times for robust data collection. Measurement data results are recorded both on the module's LCD display and the CPAP humidifier's own display to cross-reference and verify the accuracy of the measurements. Upon completing the data collection process, the module, CPAP device, CPAP humidifier, oxygen cylinder, and compressor are turned off. The setup is then tidied up and returned to its original place, ensuring proper storage and safety protocols are followed. Lastly, to gain valuable insights from the collected data, thorough data analysis is performed. This analysis includes calculating the average, error, and standard deviation of the temperature and humidity data.

From the measurements taken, some data will be obtained, where each data is repeated 5 times for each measurement. From the results of the measurement data, an analysis of the calculation data is then sought which includes the average, error, and standard deviation between the values obtained for the temperature parameters listed on the LCD display module which is made with the display on the CPAP humidifier. The data analysis carried out aims to determine the final result of the tool that has been made and to determine the level of accuracy of the sensor used.

The mean or average value of the measurement is determined using Eq. (1). The average is calculated by dividing the sum of all values by the total number of data points in the set.:

$$\overline{x} = \frac{x1+x2\ldots+xn}{n} \quad (1)$$

In the formula, x represents the mean value obtained from n measurements, x1 represents the first measurement, x2 represents the second measurement, and x_n represents the n measurements.

Standard deviation is a measure that quantifies the extent of variability or dispersion within a data set, indicating the spread around the mean. The formula for standard deviation (SD) can be represented by Eq. (2):

$$SD = \sqrt{\frac{\sum(xi-\bar{x})^2}{(n-1)}} \quad (2)$$

Where xi represents the number of desired values, x represents the mean of the measurement results, and n represents the number of measurements.

% error reflects a measurement or system's accuracy deviation. The lower Error value represents the mean difference between each data point. Errors can signify discrepancies between the standard and the design or model. The formula for calculating the error is presented in Eq. (3):

$$\%ERROR = \frac{(x_n - x)}{x_n} \times 100\% \quad (3)$$

Where x_n represents the measured value from the machine calibrator and x represents the measured value from the design.

III. RESULT

Data collection on temperature and humidity parameters was carried out at the Ibnu Sina Gresik Hospital. Data collection was carried out at that location because the CPAP equipment facility at the Ibnu Sina Gresik Hospital has a CPAP humidifier section that can be set. Retrieval of measurement data carried out on temperature parameters as much as 4 data with each data repeated 5 times. Measurements were made by setting the temperature on the CPAP humidifier 32ºC – 35ºC. Retrieval of measurement data on the temperature parameter only uses 4 measurement data because it follows the temperature range that is generally used for setting CPAP humidifiers. The temperature setting that is often used in CPAP humidifiers is in the range of 32ºC – 35ºC. Meanwhile, for data collection on humidity parameters, reading the results of the percentage of humidity follows the humidity value in the CPAP humidifier (there is no humidity setting in the CPAP humidifier). After taking measurements, then calculate the average, error, and standard deviation of the results of the temperature measurement data that has been carried out. From the results of the measurement data, it was found that for the temperature parameter the highest error value was 1.8% with a standard deviation of 0.33°C and an average of 32.57°C while the lowest error value was 0.49% with a standard deviation of 0.09°C and an average of 35.17°C. Based on the datasheet, the tolerance limit for the SHT30 sensor error value on temperature and humidity parameters is ±3% so that the error value obtained is still within the tolerance limit of the sensor used.

TABLE 1
Temperature Measurement Results on 4 Data

Setting Temperature Humidifier	Mean (ºC)	Error (%)	SD (ºC)
32ºC	32.57	1.8	0.33
33ºC	33.17	0.5	0.09
34ºC	34.37	1.08	0.21
35ºC	35.17	0.49	0.09

Next, an error graph is obtained between the module used and the original CPAP humidifier which is obtained based on the measurement results on the temperature parameter. The graph below is the amount of error obtained from the 4-measurement data that has been taken where each data is repeated 5 times.

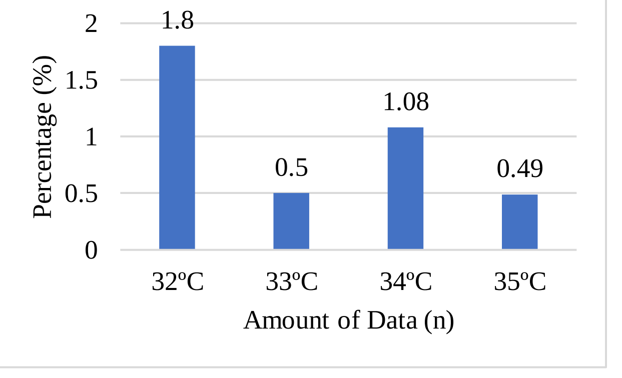

FIGURE 5. Graph of Error on Temperature Measurement

In FIGURE 5 shows a graph of the error obtained from measuring the temperature parameters using the original CPAP humidifier and tool module. Each measurement will result in an error from the calculation between the module made and the original comparator. From the results of the measurement data for the temperature parameter it was obtained that the highest error value was 1.8% and the lowest error value was 0.49%.

IV. DISCUSSION

Data collection for measurements is carried out by comparing with the display on the CPAP humidifier whether the measurement readings carried out by the module have an error value that is far from set. The measurement readings on the module are also used to determine the temperature and humidity values that will be conveyed to the patient through the tube from the CPAP humidifier. From the results of the measurement data, a calculated value is then sought which includes the average, error, and standard deviation between the values obtained for the temperature parameters listed on the LCD display module which is made with the display on the CPAP humidifier. In the measurement of temperature parameters carried out at the Ibnu Sina Gresik Hospital, error values were obtained of 1.8%, 0.5%, 1.08% and 0.49%. As for humidity parameter data collection, the reading of the humidity percentage results follows the humidity value on the CPAP humidifier (there is no humidity setting on the CPAP humidifier). So that the results of reading the humidity parameters obtained when using the CPAP humidifier at the Ibnu Sina Gresik Hospital were 99%. In the temperature parameter, the highest error value is 1.8% and the lowest error value is 0.49%. Based on the datasheet, the tolerance limit for the SHT30 sensor error value on temperature and humidity parameters is ±3%. The error value obtained from the module measurement results on the temperature parameter does not exceed the tolerance limit for the error value. So, it can be concluded that the measurement test module made is in good condition because it is still within the error tolerance value range of the sensor used.

The implementation of this research was carried out by developing from previous research, not comparing the error values between modules. Referring to the existing literature, in 2018 there is research with the title Humidity and Temperature Monitoring by Ibtihaj A. Abdulrazak. Based on the explanation in the research literature, this study has several limitations, including the screen display used is too small and this tool is also not equipped with an external data storage to store measurement data. In this study, room objects are still used, not medical devices. [21] In 2019 there is research with the title Monitoring Temperature and Humidity of Server Room Using Latte panda and Thing Speak by T. H. Nasution, et al. In this research has a few limitations, namely this tool still using the DHT11 sensor where the sensor still has a less accurate value and also has a limited measurement range in temperature parameters only being able to measure 0ºC – 50ºC. In addition, it allows for weaknesses in signal coverage because it only uses online mode (using WIFI) without being equipped with offline mode as an option in case of signal difficulties and also not equipped with an external data storage to store measurement results data. In this study still using room objects not on medical devices. [22] In 2021 there is research with the title Distant Temperature and Humidity Monitoring: Prediction and Measurement by Farrukh Hafeez, et al. In this research has a few limitations, namely this tool is not equipped with an external data storage to store measurement results data. In addition, it allows for weaknesses in signal coverage because it only uses online mode (using WIFI) without being equipped with offline mode as an option in case of signal difficulties. In this study still using room objects not on medical devices. [23] Based on previous research conducted in 2018, 2019 and 2021 described above, there are still deficiencies that can be developed. The implementation of this research was carried out by developing from previous research, not comparing the error values between modules. Developments that can be carried out in this study include using the SHT30 sensor to read temperature and humidity in the CPAP humidifier which has higher accuracy than the DHT11 sensor and DHT22 sensor, using the Arduino Mega 2560 Pro Mini microcontroller as a controller for the working system of the tool, equipped with the existing buzzer indicator. on the device, this tool is also equipped with external data storage with a 4GB SD Card so that it can store more measurement results because it has a large enough storage space.

The research employed the pre-experimental method, specifically the One Group Post Test Design, as the device was directly treated without assessing its initial state first, and the treatment results were subsequently compared to a control group. A limitation of this design is its lack of knowledge about the initial state, making it challenging to draw definitive conclusions from the obtained results. In the tool we made does have certain weaknesses or limitations that need to be addressed. On the display used on the module still relies on an LCD character, necessitating the use of additional buttons for settings. Maybe in further development you can use a touch screen display to minimize additional components. In addition, the main sensor used is the SHT30 sensor which has the highest accuracy compared to the DHT11 and DHT22 sensors, but the SHT30 sensor has a weakness in slow response time, so that when taking measurement data, it takes longer time to read the results. measurement. It is also advisable to understand the characteristics of the sensor as provided in the data sheet to prevent damage. The SHT30 sensor also has a fairly expensive price and is difficult to find in stores compared to the DHT11 and DHT22 sensors which are cheaper and easy to find in stores. Future developments You can use temperature and humidity sensors that are easy to find in shops with better sensitivity, accuracy and response time and are also found at affordable prices. Furthermore, in the tool that we make is also equipped with an external data storage which aims to store measurement data. Nonetheless, the stored data can only be displayed on an excel sheet in the form of raw measurement data without automatic calculations including errors, averages and standard deviations. Maybe in the next development it can be added with better and more sophisticated features to make it easier for operators to make measurements and data storage.

The expected benefits of making this tool are aimed at three things, namely benefits for operators, patients, and technicians. Operators are expected to be able to assist operators in recording, measuring and monitoring oxygen concentration and flow in the pure oxygen output section of the CPAP as well as temperature and humidity in the CPAP humidifier section. For patients, it is hoped that it can help minimize the possibility of harm to the patient and anticipate errors in giving oxygen doses at the pure oxygen output section of the CPAP as well as to maintain temperature and humidity in the CPAP humidifier section for the treatment of sleep apnea because it can prevent problems such as dry mouth, dry throat, chapped lips, nosebleeds, chest pain, and nose infections. For technicians, it is hoped that it can function as a tool to measure the suitability of values on the parameters used before the device is attached to the patient. This aims to determine the feasibility level of the CPAP tool whether it is suitable or not with the settings as well as to find out whether it is necessary to calibrate with an original CPAP calibrator that is in accordance with the standards.

V. CONCLUSION

Based on the results of planning, discussion, purpose of making modules, and analysis of measurement data that has been carried out, it can be concluded that this research tool is used as a CPAP humidifier monitoring tool that is designed to accurately measure and display temperature and humidity parameters using the SHT30 sensor. The design of this tool uses a portable model design to make it more compact and easier to carry anywhere. The contribution of this study is being able to measure temperature and humidity in the CPAP humidifier using the SHT30 sensor. This sensor is in charge of reading the temperature and humidity values on the CPAP humidifier. The reading results obtained by the SHT30 sensor are then processed by the Arduino Mega 2560 Pro Mini microcontroller which functions as a controller for the working system of the tool. Measurement data is displayed on a 20x4 LCD and can be stored efficiently using an external data storage facilitated by the Micro SD Card Reader Writer module with SD Card devices. Provision of external data storage is intended to increase data storage capacity, so that it can store more measurement data because it has a larger storage space. This tool is also equipped with a buzzer as an indicator on the tool. This tool section is also equipped with Enter, Up, Down, and Save buttons.

After measuring and collecting data on temperature parameters, the maximum error value observed was 1.8% and the minimum error value observed was 0.49%. Based on the sensor datasheet, the error value obtained from the results of these parameter measurements is within acceptable tolerance limits for the SHT30 sensor error value on temperature and humidity parameters, namely ±3%. In addition, the SHT30 type sensor that we used in this study has a high level of feasibility and accuracy and is not inferior to previous studies using DHT11 sensors and DHT22 sensors. Therefore, it can be concluded that the measurement test module is in good condition because the error is still within the tolerance limit of the sensor used. The expected goal of making this tool is to assist operators in recording, measuring, and monitoring temperature and humidity in CPAP humidifiers and to facilitate monitoring of sleep apnea treatment procedures.

Further research development can be carried out using a better LCD display, for example using Nextion. Then you can use other, higher sensors with good levels of accuracy, resolution, response time, and sensitivity in taking measurement readings for temperature and humidity parameters. In addition, it is also recommended to use the main sensor and other supporting components and modules that are cheap and easy to find in Indonesia so that it does not take much time to pre-order when buying overseas.

REFERENCES

[1] B. Izci and N. J. Douglas, "Obstructive sleep apnea-hypopnea syndrome*," *Obstr. Sleep Apnea Causes, Treat. Heal. Implic.*, vol. 2, no. 1, pp. 129–182, 2012, doi: 10.4103/2141-9248.96943.

[2] R. Golpe, A. Jimenéz, and R. Carpizo, "Home sleep studies in the assessment of sleep apnea/hypopnea syndrome," *Chest*, vol. 122, no. 4, pp. 1156–1161, 2002, doi: 10.1378/chest.122.4.1156.

[3] E. J. Olson, W. R. Moore, T. I. Morgenthaler, P. C. Gay, and B. A. Staats, "Obstructive Sleep Apnea-Hypopnea Syndrome," *Mayo Clin. Proc.*, vol. 78, no. 12, pp. 1545–1552, 2003, doi: 10.4065/78.12.1545.

[4] N. McArdle, G. Devereux, H. Heidarnejad, H. M. Engleman, T. W. Mackay, and N. J. Douglas, "Long-term use of CPAP therapy for sleep apnea/hypopnea syndrome," *Am. J. Respir. Crit. Care Med.*, vol. 159, no. 4 I, pp. 1108–1114, 1999, doi: 10.1164/ajrccm.159.4.9807111.

[5] A. Putra, Tri Bowo Indrato, and Liliek Soetjiatie, "The Design of Oxygen Concentration and Flowrate in CPAP," *J. Electron. Electromed. Eng. Med. Informatics*, vol. 1, no. 1, pp. 6–10, 2019, doi: 10.35882/jeeemi.v1i1.2.

[6] M. Jeeva Sankar, J. Sankar, R. Agarwal, V. K. Paul, and A. K. Deorari, "Protocol for administering continuous positive airway pressure in neonates," *Indian J. Pediatr.*, vol. 75, no. 5, pp. 471–478, 2008, doi: 10.1007/s12098-008-0074-x.

[7] G. H. Wiest *et al.*, "Initiation of CPAP therapy for OSA: Does prophylactic humidification during CPAP pressure titration improve initial patient acceptance and comfort?," *Respiration*, vol. 69, no. 5, pp. 406–412, 2002, doi: 10.1159/000064016.

[8] G. H. Wiest, J. Foerst, F. S. Fuchs, A. H. Schmelzer, E. G. Hahn, and J. H. Ficker, "In vivo efficacy of two heated humidifiers used during CPAP-therapy for obstructive sleep apnea under various environmental conditions," *Sleep*, vol. 24, no. 4, pp. 435–440, 2001, doi: 10.1093/sleep/24.4.435.

[9] R. Mathur and N. J. Douglas, "Family studies in patients with the sleep apnea-hypopnea syndrome," *Ann. Intern. Med.*, vol. 122, no. 3, pp. 174–178, 1995, doi: 10.7326/0003-4819-122-3-199502010-00003.

[10] A. Qureshi and R. D. Ballard, "Current reviews of allergy and clinical immunology Obstructive sleep apnea," *J Allergy Clin Immunol*, vol. 112, no. 4, pp. 643–651, 2003, doi: 10.1067/mai.2003.1813.

[11] G. Nilius, U. Domanski, K. J. Franke, and K. H. Ruhle, "Impact of a controlled heated breathing tube humidifier on sleep quality during CPAP therapy in a cool sleeping environment," *Eur. Respir. J.*, vol. 31, no. 4, pp. 830–836, 2008, doi: 10.1183/09031936.00161806.

[12] M. Duong, L. Jayaram, D. Camfferman, P. Catcheside, I. Mykytyn, and R. D. McEvoy, "Use of heated humidification during nasal CPAP titration in obstructive sleep apnoea syndrome," *Eur. Respir. J.*, vol. 26, no. 4, pp. 679–685, 2005, doi: 10.1183/09031936.05.00131504.

[13] M. W. Ryan S, Doherty LS, Nolan GM, "Effects of Heated Humidification and Topical Steroids on Compliance , Nasal Using Nasal Continuous Positive Airway Pressure," *J. Clin. Sleep Med.*, vol. 5, no. 5, pp. 422–427, 2009.

[14] T. E. Wiswell and P. Srinivasan, "Continuous Positive Airway Pressure," *Assist. Vent. Neonate*, pp. 127–147, 2003, doi: 10.1016/B978-0-7216-9296-8.50013-1.

[15] D. Chiumello *et al.*, "Effect of a heated humidifier during continuous positive airway pressure delivered by a helmet," *Crit. Care*, vol. 12, no. 2, pp. 1–8, 2008, doi: 10.1186/cc6875.

[16] C. A. Massie, R. W. Hart, K. Peralez, and G. N. Richards, "Effects of humidification on nasal symptoms and compliance in sleep apnea patients using continuous positive airway pressure," *Chest*, vol. 116, no. 2, pp. 403–408, 1999, doi: 10.1378/chest.116.2.403.

[17] M. J. Mador, M. Krauza, A. Pervez, D. Pierce, and M. Braun, "Effect of heated humidification on compliance and quality of life in patients with sleep apnea using nasal continuous positive airway pressure," *Chest*, vol. 128, no. 4, pp. 2151–2158, 2005, doi: 10.1378/chest.128.4.2151.

[18] M. T. Martins de Araújo, S. Barros Vieira, E. Corral Vasquez, and B. Fleury, "Heated humidification or face mask to prevent upper airway dryness during continuous positive airway pressure therapy," *Chest*, vol. 117, no. 1, pp. 142–147, 2000, doi: 10.1378/chest.117.1.142.

[19] C. Soudorn, D. Muntham, S. Reutrakul, and N. Chirakalwasan, "Effect of heated humidification on CPAP therapy adherence in subjects with obstructive sleep apnea with nasopharyngeal symptoms," *Respir. Care*, vol. 61, no. 9, pp. 1151–1159, 2016, doi: 10.4187/respcare.04536.

[20] S. Hawkins, S. Huston, K. Campbell, and A. Halbower, "High-flow, heated, humidified air via nasal cannula treats CPAP-intolerant children with obstructive sleep apnea," *J. Clin. Sleep Med.*, vol. 13, no. 8, pp. 981–989, 2017, doi: 10.5664/jcsm.6700.

[21] I. A. Abdulrazzak, H. Bierk, and L. A. Aday, "Humidity and Temperature Monitoring," *Int. J. Eng. Technol.*, vol. 7, no. 4, pp. 5174–5177, 2018, doi: 10.14419/ijet.v7i4.23225.

[22] T. H. Nasution, M. A. Muchtar, S. Seniman, and I. Siregar, "Monitoring temperature and humidity of server room using Lattepanda and ThingSpeak," *J. Phys. Conf. Ser.*, vol. 1235, no. 1, 2019, doi: 10.1088/1742-6596/1235/1/012068.

[23] F. Hafeez, U. U. Sheikh, A. Khidrani, M. A. Bhayo, S. M. Abdallah Altbawi, and T. A. Jumani, "Distant temperature and humidity monitoring: Prediction and measurement," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 24, no. 3, pp. 1405–1413, 2021, doi: 10.11591/ijeecs.v24.i3.pp1405-1413.

[24] W. D. Hill, "Battery," *English J.*, vol. 69, no. 5, p. 55, 1980, doi: 10.2307/817656.

[25] I. H. Sardar and S. Bhattacharyya, "A Short Review of Lithium-ion Battery Technology," *Int. J. Sci. Res. Sci. Eng. Technol.*, pp. 500–507, 2020, doi: 10.32628/ijsrset207295.

[26] F. Kurniawan, Lasmadi, O. Dinaryanto, B. Sudibya, and M. R. E. Nasution, "A novel boost-buck converter architecture for improving transient response and output-voltage ripple," *J. ICT Res. Appl.*, vol. 14, no. 2, pp. 149–164, 2020, doi: 10.5614/itbj.ict.res.appl.2020.14.2.4.

[27] S. H. Sasono, "Sensor Data Analysis On Monitoring And Control System Of Temperature And Humidity Based On Android In Soybean Seed Storage Room Using Nodemcu," *Jaict*, vol. 3, no. 1, p. 8, 2019, doi: 10.32497/jaict.v3i1.1290.

[28] S. Sarwito, I. R. Kusuma, and F. A. Cahyono, "Automatic Stacking Crane Prototype using Microcontroller Arduino Mega 2560," *Int. J. Mar. Eng. Innov. Res.*, vol. 1, no. 1, pp. 4–11, 2016, doi: 10.12962/j25481479.v1i1.1383.

[29] J. Shaik, "Smart Trolley Shopping for Automatic Billing & Assistance for Visually Impaired," *J. Eng. Sci.*, vol. 14, no. 04, pp. 155–164, 2023.

[30] D. S. M. Gulhane, "Voice based E-Notice Board using Android," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 9, no. VII, pp. 338–343, 2021, doi: 10.22214/ijraset.2021.36106.

[31] S. RezaKhan, A. Kabir, and D. Ara Hossain, "Designing Smart Multipurpose Digital Clock using Real Time Clock (RTC) and PIC Microcontroller," *Int. J. Comput. Appl.*, vol. 41, no. 9, pp. 39–42, 2012, doi: 10.5120/5573-7668.

[32] K. Paul Kuria, O. Ochieng Robinson, and M. Mutava Gabriel, "Monitoring Temperature and Humidity using Arduino Nano and Module-DHT11 Sensor with Real Time DS3231 Data Logger and LCD Display," *Int. J. Eng. Res. Technol.*, vol. 9, no. 12, pp. 416–422, 2020, [Online]. Available: https://www.researchgate.net/publication/347950991.

[33] * Konatham, N. Lakshmi, and P. Bala Nagu, "Area Optimized Design for Data Archival to SD Card," *Int. J. Eng. Trends Technol.*, vol. 6, no. 3, 2013, [Online]. Available: http://www.ijettjournal.org.

[34] O. M. S. M. B. Satheesh, B. Senthilkumar, T. Veeramanikandasamy, "Microcontroller and SD Card Based Standalone Data Logging System using SPI and I2C Protocols for Industrial Application," *Int. J. Adv. Res. Electr. Electron. Instrum. Eng.*, vol. 5, no. 4, pp. 2208–2214, 2016, doi: 10.15662/IJAREEIE.2016.0504002.