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# ARDUINO AND IOT-BASED OBSERVATION METHOD FOR MONITORING TEMPERATURE, HUMIDITY, AND AIR PRESSURE OF ELECTRON BEAM ACCELERATOR'S ROOM

## *METODE OBSERVASI BERBASIS ARDUINO DAN IOT UNTUK PEMANTAUAN SUHU, KELEMBABAN DAN TEKANAN UDARA DI RUANG AKSELERATOR ELEKTRON*

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## ABSTRACT

***ARDUINO AND IOT-BASED OBSERVATION METHOD FOR MONITORING TEMPERATURE, HUMIDITY, AND AIR PRESSURE OF ELECTRON BEAM ACCELERATOR'S ROOM.*** *The monitoring system for temperature, humidity and air pressure in the electron accelerator's room has been designed. This research is based on operational environmental monitoring procedures in the accelerator room that must be carried out before the accelerator operates. We offer a simple and adaptable monitoring solution for the electron accelerator room. Parameter data can be monitored using a smart device. Operators do not need to go into the accelerator room to carry out environmental monitoring. The proposed system uses Arduino technology and the Internet of Things (IoT). Data acquisition programming was performed using Arduino IDE and ESP8266 NodeMCU as microcontrollers. The microcontroller then transmits temperature, humidity, and pressure data parameters to the cloud server, where they are then displayed on the smart device via the Blynk app. The results show that the system that has been designed is able to read and store parameter readings on the sensors used and the system has been able to make decisions in the form of notifications about whether the Electron Beam Machine is ready or not to be operated.*

***Keywords****: Arduino, IoT, ESP8266 NodeMCU, temperature, humidity, air pressure*

## ABSTRAK

***METODE OBSERVASI BERBASIS ARDUINO DAN IOT UNTUK PEMANTAUAN SUHU, KELEMBABAN DAN TEKANAN UDARA DI RUANG AKSELERATOR ELEKTRON.*** *Desain sistem pemantauan suhu, kelembaban, dan tekanan udara kompresor pada ruang akselerator elektron telah dibuat. Penelitian ini dilakukan berdasarkan operasional prosedur pemantauan lingkungan pada ruang akselerator yang harus dilakukan sebelum akselerator beroperasi. Kami menyajikan sistem yang murah dan fleksibel untuk pemantauan ruang akselerator elektron. Data parameter dapat dipantau dengan menggunakan gawai pintar. Operator tidak perlu masuk ke ruang akselerator untuk melakukan pemantauan lingkungan. Sistem yang diajukan menggunakan teknologi Arduino dan Internet of Thing (IoT). Pemrograman akuisisi data dilakukan menggunakan Arduino IDE dan NodeMCU ESP8266 sebagai mikrokontroler. Data parameter suhu, kelembaban dan tekanan dari mikrokontroler kemudian dikirimkan ke cloud server dan ditampilkan melalui aplikasi Blynk pada gawai pintar. Didapatkan hasil bahwa sistem yang telah didesain mampu membaca dan menyimpan pembacaan parameter pada sensor yang digunakan serta sistem telah mampu mengambil keputusan berupa notifikasi apakah Mesin Berkas Elektron siap beroperasi atau belum.*

***Kata kunci****: Arduino, IoT, NodeMCU ESP8266, suhu, kelembaban, tekanan udara*

## INTRODUCTION

Low energy electron beam technology, such as that owned by the Research Center for Accelerator Technology, has been used for materials irradiation coating, vulcanization of natural rubber, curing batik coloring, and irradiation of hydrogel samples [1-3]. Besides that, the electron accelerator is also used for personal certification from companies, student practicum, MBKM (Merdeka Belajar Kampus Merdeka) and research. Low-energy


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accelerators have energies from 0.15 to 0.5 MeV [4]. Electrons with low energy only give dose to the target material's surface due to their shallow penetration depths (in the range of hundreds of microns) [5]. The Arjuna 1.0 electron beam machine (EBM) has an energy of 350 keV and an electron beam current of 10mA [6]. The advantages of the electron irradiation technique over conventional processes include greater product quality, no environmental contamination, low energy cost, reactions that take place at room temperature, ease of process management, and cheaper operating costs for mass production [7]. EBM Arjuna 1.0 works in a high voltage area of around 300kV, requiring about less than 60% humidity with a temperature of less than 24°C [8]. The operation of an electron accelerator requires preparation, including monitoring of environmental conditions in the accelerator room. Preparation is carried out by monitoring temperature, humidity, and air.

Currently, the monitoring of the temperature, humidity and air pressure is still done manually. The operator enters the operating room and reads each indicator. Environmental checks result in a decision on whether or not the EBM is ready to operate. However, manual checking has a safety risk to the operator. The risk is that the operator could get an electric shock due to the presence of a high voltage source, the electrical risk from the vacuum system, the blower, the cooler system that has been turned on, and the risk of being exposed to ozone gas which is harmful to breathing. Object irradiation is not done only once a day but repeatedly depending on the demand. Therefore, the ozone gases created from irradiation remain in the EBM room. However, humidity and room temperature must be checked every time irradiation is carried out. It is very hazardous and inefficient if the operator has to go back and forth to the room to check the parameters before starting operations. So, we need a remote monitoring system that is efficient, flexible and safe to facilitate EBM operators in carrying out their duties. IoT-based monitoring automation system can be the solution to reduce human involvement and labour while enhancing human comfort, safety, security, and practical operation.

Nowadays, sensor technology has advanced significantly. Sensors are making tasks like monitoring and interacting with the environment easier in tandem with advancements in Internet of Things (IoT) technology. Because of the rapid development of embedded systems [9], microcontrollers have both software and hardware components. The main selling point of microcontrollers is their extremely low power consumption, which explains why a significant portion of the applications in most areas of the electronics manufacturing business are implemented using embedded computer systems like microcontrollers [10]. Microcontrollers are single-board computers, a term that has gained popularity for small computers [11]. Even though there are other techniques for creating microcontrollers, Arduino has been consistently shown to be the most efficient [10]. The Arduino system consists of a single-board microcontroller set and a software framework that features an integrated development environment [12]. IoT connects multiple nodes via the Internet, allowing communication among peers of people, computers, and anything else as an object. Based on device recognition, tracking, and observance, nodes become more intelligent. IoT refers to critical components such as a sensor network, smart devices, radio frequency such as RFID, terminal computing systems, and the Internet in order to build an intelligent system [13,14].

Under the influence of the fourth industrial revolution, numerous research has been carried out to create temperature, humidity, and air pressure monitoring systems that use different microcontrollers and Internet of Things (IoT) technologies to monitor and make choices. Nayanasitachowdary et al. [15] built a system of environmental monitoring based on IoT using a robotic system. The interface system was created using ThingSpeak and an IoT platform, and the data was gathered using an Arduino Mega as the microcontroller. The system may collect data as a result, and it also benefits from energy savings. Khusnul et al. [16] developed the weather observation at BMKG based on IoT. The humidity and pressure sensors are used for data collecting and the NodeMCU microcontroller serves as an internet module on the Arduino IDE platform This research utilized cost-effective digital, real-time, and automated systems to monitor weather conditions, along with affordable components for the data acquisition system. Simanullang, et al. [17] developed and evaluated an integrated air quality system incorporating weather parameters. For collecting data from sensors, the Arduino Atmega2560 acts as a microcontroller. The output was then sent to a cloud server through wifi or the ESP8266 acting as an Arduino server, where it was then presented as information on a public web display. IoT and the Blynk app were also used by Mustafa A. et al. to develop and execute a smart home [18]. Homeowners can use computers or mobile devices to monitor household appliances thanks to this method. The server automation framework is established utilizing a Raspberry Pi 3 Model B+ and an Arduino Mega 2560. Current, voltage, power, energy, frequency, humidity, temperature, etc. are automatically monitored via relays. The data is displayed using the Blynk program. Roshahliza et al. implemented IoT to enable smart irrigation systems [19]. To monitor and manage water pumps, a NodeMCU microcontroller with a Wi-Fi interface, humidity, temperature, and soil moisture sensors is employed. The Blynk app for smartphones allows farmers access to information.

Low-cost sensors used with Arduino and the Internet of Things have been shown to operate well and generally adhere to the necessary standards. A microcontroller unit (MCU) such as an Arduino board is linked to certain input temperature, humidity, and air pressure sensors to develop a system that sends a notice when a specified threshold is surpassed. Pedro et al. [20] conducted research using five different sensors to test parameters such as temperature, relative humidity, and carbon dioxide concentration. Results showed that some low-cost sensors that were open-source and connectable to Arduino exhibited excellent behaviour and compliance with applicable standards. Another researcher, Amit Mankontia [20], built an intelligent manhole monitoring and detection system that included various sensors to monitor the manhole status, such as a level sensor, temperature sensor, tilt sensor, and gas sensor, using IoT technology. HTTP and web socket protocols were employed in this system to enable real-time communication [21].

Based on various studies and technologies, Arduino and IoT are considered sufficient and capable of being used in the EB accelerator room. Therefore, this research aims to design a mobile monitoring system powered by IoT using ESP8266 NodeMCU. This microcontroller was selected due to its low cost and ability to offer a complete and self-contained Wi-Fi networking solution [22]. The proposed system uses sensors such as temperature, humidity, and pressure gauge, while the Blynk application is used in smartphones to facilitate monitoring and decision-making related to parameters. The adoption of an IoT-based observation method for temperature, humidity, and pressure gauge in the EBM building could optimize the monitoring system as well as enhance energy efficiency and indoor environmental quality.

## METHODOLOGY

The main technology utilized in this system is Arduino and the Internet of Things (IoT), with the primary components being temperature, humidity, and air pressure sensors. The design is intended to function without the need for human personnel to monitor it on-site. Instead, the data is transmitted automatically to a server without any human-to-computer interaction. In order to accomplish this goal, a range of hardware and software elements are employed within an IoT framework.

Hardware:
- ESP8266 NodeMCU (Arduino Microcontroller)
- DHT11 Temperature and Humidity Sensor
- Pressure gauge

Software:
- Arduino Integrated Development Environment (Arduino IDE)
- Blynk Application (accessible on both IOS and Android platforms)

### Hardware Design

The Internet of Things (IoT) scheme using Arduino and Blynk involves using microcontroller boards and a mobile app to monitor and control various devices and sensors over the internet. Hardware design method shown in Figure 1.

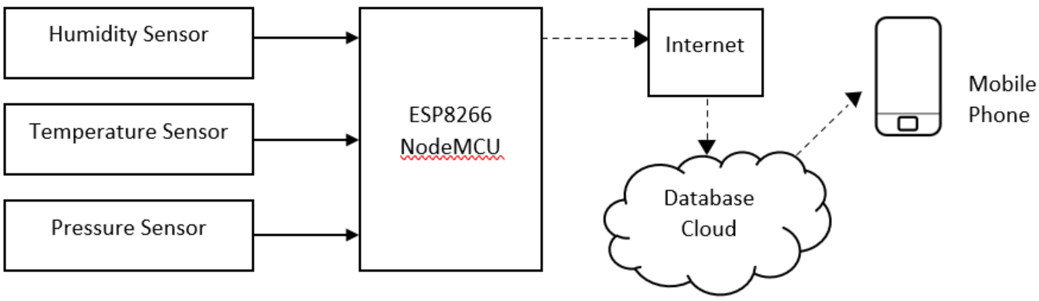


**Figure 1.** Hardware design method

The proposed method for Arduino and IoT-based observation, as illustrated in Figure 1, consists of multiple interconnected blocks controlled by a microcontroller. The ESP8266 NodeMCU microcontroller was chosen due to its low cost, complete, and self-contained Wi-Fi networking solution. Its various features make it an ideal choice for an IoT-based project, including 4 MB flash memory, 64 KB static random access memory (SRAM), and an 80 MHz clock speed, among other characteristics [22,23]. Figure 2 displays the NodeMCU ESP8266 configuration.

Data from sensors is collected by the ESP8266 NodeMCU microcontroller and then stored in the cloud database. A cloud database is a database that is stored in the cloud, making it easier to provision, configure, and manage data that is accessible via the internet. DataClouds are also referred to as communities, which consist of

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users with similar interests in data and information [24]. A cloud database is needed to store temperature, humidity, and air pressure data in the EBM room so that it can be accessed anytime and from anywhere using a mobile phone. Sensor data from the ESP8266 is connected to the internet and then stored or uploaded to the cloud. This cloud database has a storage capacity of approximately 1 TB. The data archival and retrieval tool of cloud computing is called a cloud database [25].

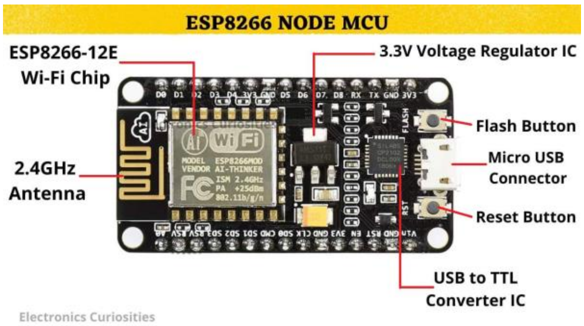


**Figure 2.** ESP8266 NodeMCU [26]

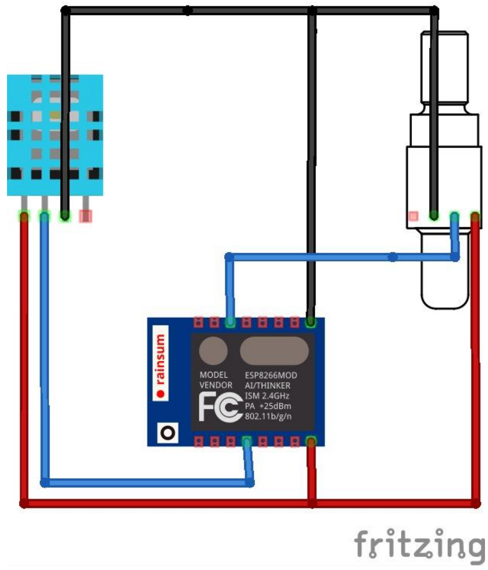


**Figure 3.** Hardware connection

The diagram in Figure 3 illustrates the hardware connections between the sensors and ESP8266 NodeMCU. The sensors include temperature sensors, humidity sensors, and air pressure sensors. The DH11 sensor was chosen for measuring temperature and humidity parameters [27]. Specifically, it is used to provide temperature and humidity readings for the accelerator room. As the EBM works in a high voltage area of around 300kV, the required humidity level is less than 60%, with a temperature of less than 24°C. The pressure sensor used in this system is the ASDX Series Silicon Pressure Sensor, and the threshold for air pressure in the accelerator room is 7-9 kg/m$^2$ [8].

## Software Design

The proposed system was programmed using the Arduino platform, which is designed to simplify the writing of codes without restricting the user's flexibility. The platform consists of an Integrated Development Environment (IDE) and a core library. The IDE is a simple source code editor with a toolbar that provides access to all programming functions. It also includes a serial monitor that facilitates sending and receiving of data from the board, making debugging easier without requiring additional software. The Arduino software is open source, and the compiled binary file is uploaded to the MCU board. In this project, the ESP8266 NodeMCU microcontroller was programmed to collect data from the temperature, humidity, and air pressure sensors, process the data, and send it to the server. Debugging was carried out to detect and fix errors in the code [22].

The Blynk application is an IoT-based platform that allows remote control of hardware and displays, stores, and visualizes sensor data. It consists of three major components: the Blynk app, the Blynk server, and the Blynk

Libraries. Blynk enables the creation of interfaces for projects using different widgets for control and display purposes, while the Blynk server allows communication between the smartphone and hardware. The Blynk libraries facilitate communication with the server and process commands. Hardware boards that are internet-enabled, such as the ESP8266, are suitable options for Blynk on the internet. There are four types of widgets available in Blynk: Controllers, displays, notifications, and interfaces. To enable a widget, settings such as virtual pins selection, data mapping, split/merge, decimals, send on release, and interval must be managed. Displays are the most common and useful widgets used, as they show incoming data [28].

**Interface System**

The function of an interface system is to connect one system to another system. In this IoT development, the interface system connects the ESP8266 NodeMCU microcontroller system with the Blynk application. The process starts from initializing the sensor and Arduino board which then reads temperature, humidity and air pressure sensor data. The data is collected by the microcontroller and sent to the Blynk application via the internet/Wifi connection. Transmitter and receiver configuration is very important in this case. The sensor data will be displayed in the Blynk application, and in this application a decision will be made whether the temperature, humidity and air pressure values correspond to the appropriate threshold for preparing EBM operations. Figure 4 shows how the system works.

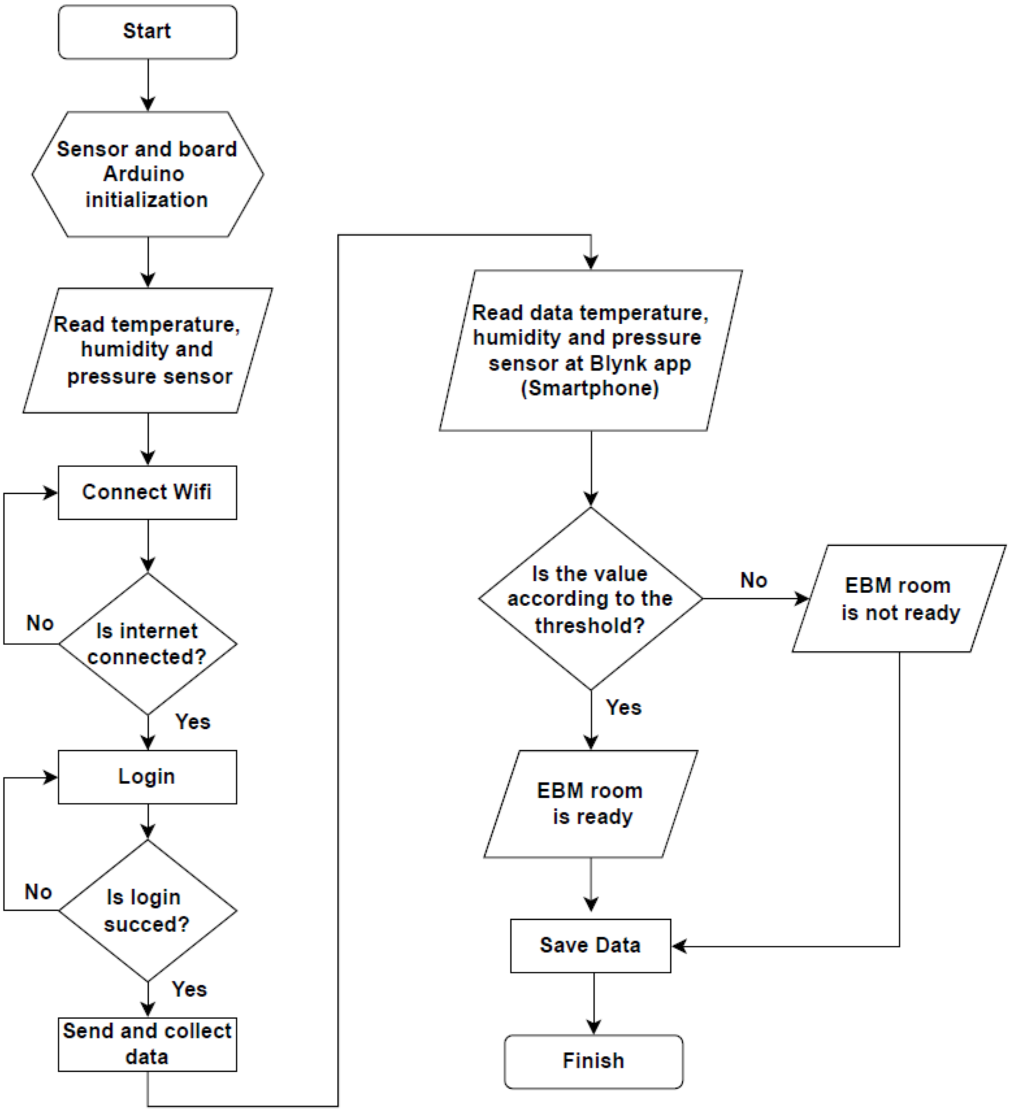


**Figure 4**. Monitoring program flow


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## RESULT AND DISCUSSIONS

The system that has been created is able to read, display, and send parameters of temperature, humidity and air pressure from the sensor to the device via the Blynk application, as shown in Table 1.

The application in this study is designed to be easy to use. In the initial display, some data needs to be input manually, such as the name of the operator and the name of the person in charge. The initial display of the application can be seen in Figure 5.

**Table 1**. Data sending parameters of temperature, humidity and air pressure

| Date | Temperature (°C) | Humidity (%) | Air Pressure (kg/m$^2$) | Operator | Supervisor |
|---|---|---|---|---|---|
| 06-Dec-2022 | 23 | 48 | 7.4 | Saefurrochman | Sukaryono |
| 23-Nov-2022 | 21 | 46 | 8.2 | Saefurrochman | Sukaryono |
| 22-Nov-2022 | 19 | 47 | 8.6 | Saefurrochman | Sukaryono |
| 22-Nov-2022 | 22 | 52 | 8 | Saefurrochman | Sukaryono |
| 10-Nov-2022 | 21 | 56 | 9 | Saefurrochman | Sukaryono |
| 09-Nov-2022 | 22 | 50 | 7.8 | Saefurrochman | Sukaryono |
| 03-Nov-2022 | 19.3 | 56 | 7.8 | Saefurrochman | Sukaryono |
| 02-Nov-2022 | 23 | 49 | 7.2 | Saefurrochman | Sukaryono |
| 01-Nov-2022 | 19 | 42 | 8.6 | Saefurrochman | Sukaryono |
| 28-Oct-2022 | 23 | 51 | 8.4 | Saefurrochman | Sukaryono |
| 25-Oct-2022 | 21 | 44 | 8 | Saefurrochman | Sukaryono |
| 21-Oct-2022 | 21 | 53 | 7.8 | Saefurrochman | Sukaryono |
| 20-Oct-2022 | 21 | 38 | 9 | Saefurrochman | Sukaryono |
| 01-Sep-2022 | 20 | 42 | 8 | Saefurrochman | Sukaryono |
| 21-Jul-2022 | 22 | 41 | 7.8 | Saefurrochman | Sukaryono |
| 20-Jul-2022 | 21 | 40 | 8 | Saefurrochman | Sukaryono |
| 19-Jul-2022 | 22 | 40 | 8 | Saefurrochman | Sukaryono |
| 18-Jul-2022 | 20 | 45 | 7.6 | Saefurrochman | Sukaryono |
| 18-Jul-2022 | 21 | 40 | 7.2 | Saefurrochman | Sukaryono |
| 15-Jul-2022 | 22 | 40 | 7.2 | Saefurrochman | Sukaryono |
| 13-Jul-2022 | 22 | 34 | 8 | Saefurrochman | Sukaryono |
| 12-Jul-2022 | 22 | 39 | 8 | Saefurrochman | Sukaryono |
| 04-Jul-2022 | 22 | 40 | 7.5 | Saefurrochman | Sukaryono |

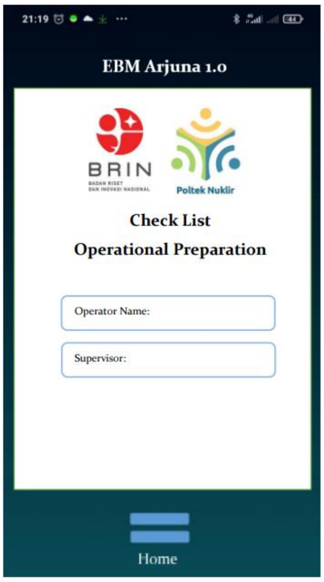


**Figure 5**. Display for Initial display

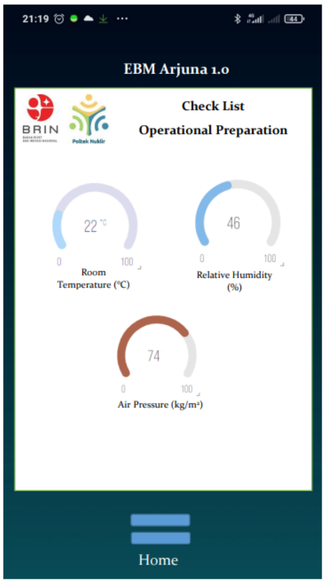


**Figure 6**. Display monitoring parameter

Figure 6 is a display of the Blynk application that has been made. Temperature, humidity and air pressure sensors connected to the microcontroller then send reading data to the device and give a message whether the EBM (Electron Beam Machine) is ready for use or not. Such parameters are connected to the ESP8266 NodeMCU board to build a system that sends a notification when a certain threshold is exceeded. The principle of drawing conclusions is that if all parameters have been read, then conclusions can be drawn and displayed in the results stage. The conclusion is obtained from the results of each parameter whether it is within the threshold value or not. Room temperature threshold values range from 21-24 °C, relative humidity is 50-60%, while air pressure is 7-9 kg/m$^2$ [8]. If one of the parameters does not meet the criteria, a red circle will appear with the words "EBM is not ready", whereas if all values meet the threshold, "EBM is ready". The results of monitoring program are displayed in Figures 7 and 8.

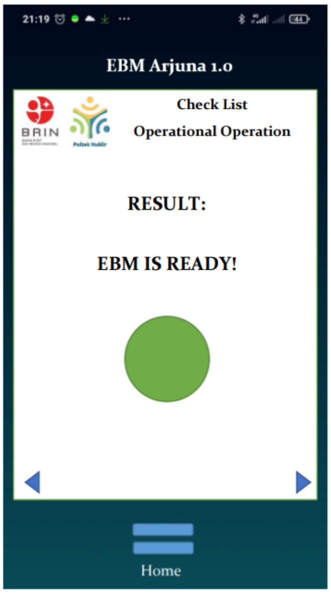


**Figure 7**. Indicator EBM is Ready

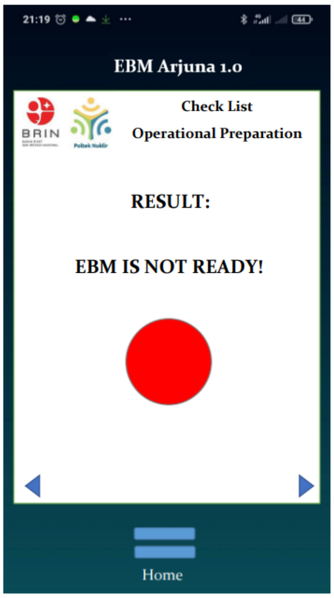


**Figure 8**. Indicator EBM is not ready

Temperature, humidity, and air pressure are crucial parameters that need to be taken into account prior to operating the EBM. These factors are closely related to the performance of the EBM, particularly in preventing overheating of its components during operation, maintenance, and routine functional tests. Even though the EBM is equipped with a cooling system, it is important to maintain room temperature and humidity levels as they can impact the lifespan of components within the room. High humidity levels can lead to condensation, increasing the corrosion rate of materials. Conversely, excessively low humidity can result in the buildup of static electricity, posing a risk to electronic devices [29]. Additionally, it is essential to verify that the air compressor maintains sufficient air pressure to ensure that the valves inside the EBM can open and close properly.

After confirming that the EBM is suitable for use, the EBM operation can be carried out immediately. The EBM operation is carried out according to the needs of researchers/users. A notification will appear later on the smartphone with this application installed. This notification, especially crucial for supervisors, is useful for the safe operation of the EBM. Figure 9 is the display of the notification that appears on the user's smartphone.

For validation, the results displayed in the Blynk application with measurement data are compared (see Figure 10). From the picture, the temperature, humidity, and air pressure parameter data displayed in the Blynk application are the same as of results the direct measurement data (sensor). It can be seen that the lines and points are squeezed together on the graph. With this design, the measurement time becomes faster, more practical, and more efficient. This application will greatly help the operation of the electron beam.


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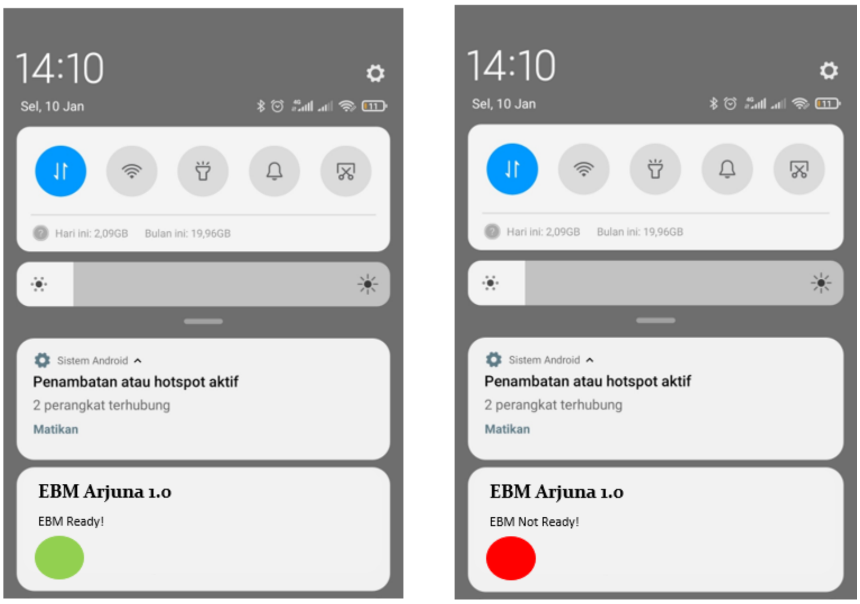


**Figure 9**. Notification on smartphone users

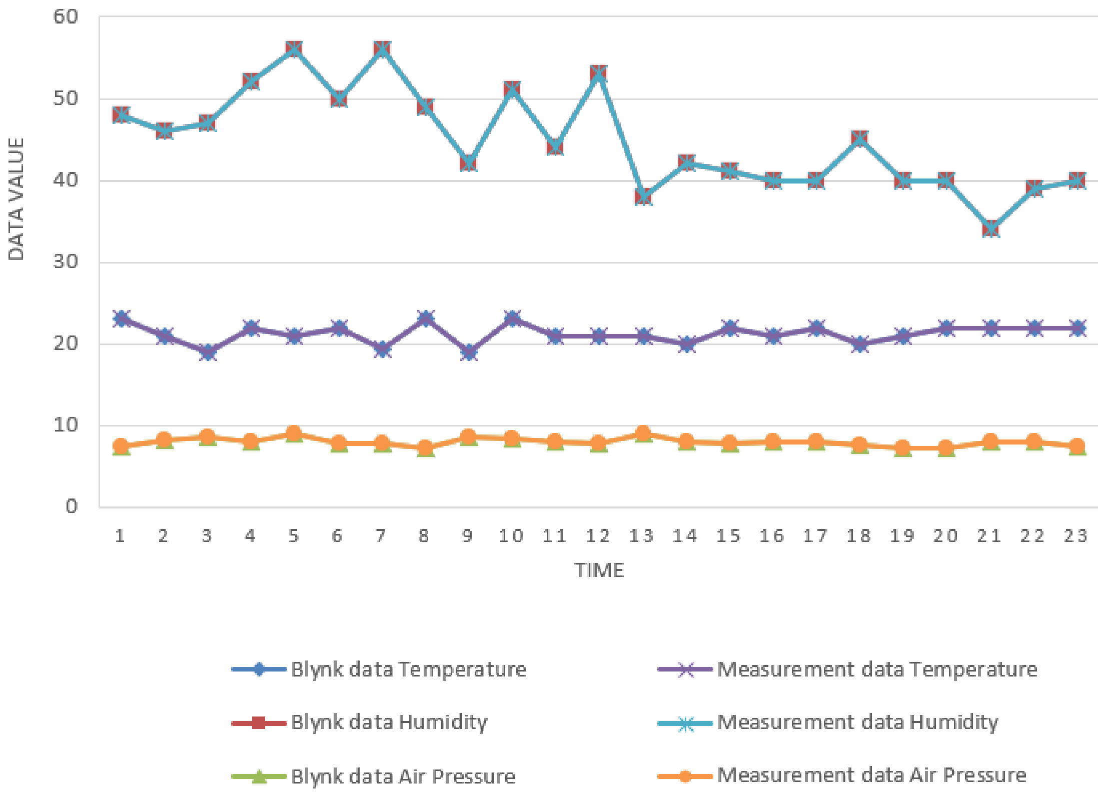


**Figure 10.** Data Comparison Between Blynk Application and Sensor Data

## CONCLUSION

The design of a mobile monitoring system for the temperature, humidity, and pressure gauge of the compressor in an electron accelerator's room based on IoT using the ESP8266 NodeMCU microcontroller has been made. The Blynk application on a smartphone (as a mobile monitor) can read and save parameter data from the sensors used. In addition, the system has been able to make decisions to determine whether EBM is ready to operate or not by predetermined values.

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## REFERENCES

[1] D. S. Pudjorahardjo, "Aplikasi Mesin Berkas Elektron di Pusat Teknologi Akselerator dan Proses Bahan - BATAN," in *Pertemuan dan Presentasi Ilmiah Teknologi Akselerator dan Aplikasinya*, 2006, vol. Edisi Khus, no. Juli, pp. 70–77, [Online]. Available: https://karya.brin.go.id/id/eprint/2919/.

[2] S. Widodo *et al.*, "Policy review on research, development, and applications of particle accelerator in Indonesia," in *AIP Conference Proceedings*, 2021, vol. 2381, no. November, p. 020106, doi: 10.1063/5.0066284.

[3] W. Andriyanti, D. Darsono, E. Nuraini, L. Indrayani, and M. Triwiswara, "Aplikasi Teknologi Mesin Berkas Elektron pada Proses Pewarnaan Batik Katun dengan Pewarna Alami Menggunakan Metode Curing," *GANENDRA Maj. IPTEK Nukl.*, vol. 23, no. 1, p. 39, Jun. 2020, doi: 10.17146/gnd.2020.23.1.5860.

[4] S. Sabharwal, "Electron Beam Irradiation Applications," in *Proceedings of PAC2013*, 2013, pp. 745–748, [Online]. Available: https://accelconf.web.cern.ch/pac2013/papers/weyb3.pdf.

[5] M. Murdoch *et al.*, "A new proposed validation method for low energy electron beam processing of dry spices," *Innov. Food Sci. Emerg. Technol.*, vol. 81, no. September, p. 103141, Oct. 2022, doi: 10.1016/j.ifset.2022.103141.

[6] S. Sudiyanto, "Pengujian Awal Sistem Instrumentasi & Kendali Unit Vakum Mesin Berkas Elektron 350 keV/10 mA Tipe Remote Manual," *GANENDRA Maj. IPTEK Nukl.*, vol. 6, no. 1, pp. 9–14, Jan. 2003, doi: 10.17146/gnd.2003.6.1.198.

[7] T. Abou Elmaaty, S. Okubayashi, H. Elsisi, and S. Abouelenin, "Electron beam irradiation treatment of textiles materials: a review," *J. Polym. Res.*, vol. 29, no. 4, p. 117, Apr. 2022, doi: 10.1007/s10965-022-02952-4.

[8] Badan Riset dan Inovasi Nasional, "Safety Analysis Report of Electron Beam Machine 300 keV/20 mA," Yogyakarta, 2021.

[9] L.-D. Liao *et al.*, "Design and Validation of a Multifunctional Android-Based Smart Home Control and Monitoring System," *IEEE Access*, vol. 7, pp. 163313–163322, 2019, doi: 10.1109/ACCESS.2019.2950684.

[10] H. K. Kondaveeti, N. K. Kumaravelu, S. D. Vanambathina, S. E. Mathe, and S. Vappangi, "A systematic literature review on prototyping with Arduino: Applications, challenges, advantages, and limitations," *Comput. Sci. Rev.*, vol. 40, p. 100364, May 2021, doi: 10.1016/j.cosrev.2021.100364.

[11] Y. Güven, E. Coşgun, S. Kocaoğlu, H. G. Ezİcİ, and E. Yilmazlar, "Understanding the Concept of Microcontroller Based Systems To Choose The Best Hardware For Applications," *Res. Inven. Int. J. Eng. Sci.*, vol. 6, no. 9, pp. 38–44, 2017, [Online]. Available: https://www.researchinventy.com/papers/v7i9/F07093844.pdf.

[12] F. Restuccia *et al.*, "ARTe: Providing real-time multitasking to Arduino," *J. Syst. Softw.*, vol. 186, p. 111185, Apr. 2022, doi: 10.1016/j.jss.2021.111185.

[13] M. R. M. Veeramanickam, B. Venkatesh, L. A. Bewoor, Y. W. Bhowte, K. Moholkar, and J. L. Bangare, "IoT based smart parking model using Arduino UNO with FCFS priority scheduling," *Meas. Sensors*, vol. 24, no. October, p. 100524, Dec. 2022, doi: 10.1016/j.measen.2022.100524.

[14] B. K. Mohanta, D. Jena, U. Satapathy, and S. Patnaik, "Survey on IoT security: Challenges and solution using machine learning, artificial intelligence and blockchain technology," *Internet of Things*, vol. 11, p. 100227, Sep. 2020, doi: 10.1016/j.iot.2020.100227.

[15] K. Nayanasitachowdary and M. Padmaja, "A Real and Accurate GPS based Environmental Monitoring Robotic System using IoT," in *2021 Fifth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC)*, Nov. 2021, pp. 242–247, doi: 10.1109/I-SMAC52330.2021.9640769.

[16] K. Ain *et al.*, "Development of IoT-based weather observers at BMKG (meteorology, climatology and geophysics agency)," in *AIP Conference Proceedings*, 2020, vol. 2314, no. December, p. 040011, doi: 10.1063/5.0034949.

[17] R. Simanullang, S. Soekirno, and H. A. Larassari, "Design and analysis of air quality monitoring system PM 10 and PM 2.5 integrated with weather parameters (a case study on Margonda Raya street Depok)," *J. Phys. Conf. Ser.*, vol. 1528, no. 1, p. 012053, Apr. 2020, doi: 10.1088/1742-6596/1528/1/012053.

[18] M. A. Omran, B. J. Hamza, and W. K. Saad, "The design and fulfillment of a Smart Home (SH) material powered by the IoT using the Blynk app," *Mater. Today Proc.*, vol. 60, pp. 1199–1212, 2022, doi: 10.1016/j.matpr.2021.08.038.

[19] R. M. Ramli and W. A. Jabbar, "Design and implementation of solar-powered with IoT-Enabled portable irrigation system," *Internet Things Cyber-Physical Syst.*, vol. 2, no. August, pp. 212–225, 2022, doi: 10.1016/j.iotcps.2022.12.002.

[20] P. F. Pereira and N. M. M. Ramos, "Low-cost Arduino-based temperature, relative humidity and CO2 sensors - An assessment of their suitability for indoor built environments," *J. Build. Eng.*, vol. 60, no. March, p. 105151, Nov. 2022, doi: 10.1016/j.jobe.2022.105151.

[21] A. Mankotia and A. K. Shukla, "IOT based manhole detection and monitoring system using Arduino," *Mater. Today Proc.*, vol. 57, pp. 2195–2198, 2022, doi: 10.1016/j.matpr.2021.12.264.

[22] J. Chigwada, F. Mazunga, C. Nyamhere, V. Mazheke, and N. Taruvinga, "Remote poultry management system for small to medium scale producers using IoT," *Sci. African*, vol. 18, p. e01398, Nov. 2022, doi: 10.1016/j.sciaf.2022.e01398.

[23] Handson Technology, "Handson Technology User Manual V1.3 ESP8266 NodeMCU WiFi Development Board: Getting Started User Guide." Handson Technology, pp. 1–24, [Online]. Available: https://handsontec.com/dataspecs/module/esp8266-V13.pdf.

[24] H. Yue, L. Guo, R. Li, H. Asaeda, and Y. Fang, "DataClouds: Enabling Community-Based Data-Centric Services Over the Internet of Things," *IEEE Internet Things J.*, vol. 1, no. 5, pp. 472–482, Oct. 2014, doi: 10.1109/JIOT.2014.2353629.

[25] Z. Yan-hua, F. Lei, and Y. Zhi, "Optimization of Cloud Database Route Scheduling Based on Combination of Genetic Algorithm and Ant Colony Algorithm," *Procedia Eng.*, vol. 15, pp. 3341–3345, 2011, doi: 10.1016/j.proeng.2011.08.626.

[26] Electronics Curiosities, "ESP8266 Node MCU board specifications and pins descriptions," 2021. https://www.electronicscuriosities.com/2021/08/esp8266-node-mcu-board-specifications.html (accessed Feb. 03, 2023).

[27] ArduinoGetStarted.com, "Arduino - Temperature HUmidity Sensor - LCD." https://arduinogetstarted.com/tutorials/arduino-temperature-humidity-sensor-lcd (accessed Feb. 09, 2023).

[28] P. E. Tham *et al.*, "Sustainable smart photobioreactor for continuous cultivation of microalgae embedded with Internet of Things," *Bioresour. Technol.*, vol. 346, p. 126558, Feb. 2022, doi: 10.1016/j.biortech.2021.126558.

[29] Prism Specialties, "Is Humidity Bad for Your Electronics?," 2020. https://www.prismspecialties.com/blog/2020/06/10/is-humidity-bad-for-your-electronics/ (accessed Feb. 10, 2023).