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Challenges and Advances in Arduino- Enabled Healthcare Information Systems: Systematic Review

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Abstract

Arduino is a popular choice for healthcare technology due to its open-source platform and low cost, making it ideal for creating intelligent medical solutions without the heavy expenses of conventional systems. The current studies have largely assessed Arduino capabilities based on specific features rather than thoroughly testing the systems' security, technical, and operational aspects. To address these issues, this study uses a Population, Intervention, Comparison, and Outcome (PICO)-based SLR that adheres to PRISMA guidelines and the Joanna Briggs Institute tool to critically evaluate the study's findings. This study collected literature from major databases such as Web of Science, Google Scholar, and ScienceDirect, covering the period from 2020 to 2024. It obtained 216 papers, and only 8 met the inclusion eligibility criteria of PICOS standards. The findings reveal that all researchers addressed security aspects, such as basic authentication and privacy, but they neglected cryptographic measures, which remain the weakest point of execution. Encryption, auditability, accountability, and freshness were implemented only once. Integrity, authorization, and third-party protection were rarely applied, and non-repudiation evaluation was minimal. Technical aspects such as accuracy and validation were satisfactory. However, reliability was tested in limited environments, and fault tolerance and robustness were poorly implemented. Operational aspects like cost and sustainability were widely addressed, whereas resilience, availability, and reliability received little attention. Arduino-based medical systems show strong technical promise but remain constrained by major security and operational gaps, limiting their readiness for real-world health settings.

Keywords: intelligent medical system, microprocessor, Internet of Things, PICO framework, PRISMA guidelines

1. Introduction

The extensive adoption of information and communication technology (ICT) in the healthcare sector has enhanced patient access to medical services and increased the efficiency of healthcare resource use (Behmanesh et al., 2020; Sriram et al., 2024). As noted by Theresa et al. (2024), healthcare monitoring systems have become some of the most significant innovations developed in the past decade. As stated in Bonvoisin et al. (2017) and Mies et al. (2019), open-source hardware is a tool designed, built, and made accessible for free for anybody to use, edit, share, build, and sell.

In 2005, the Interaction Design Institute Ivrea developed the Arduino platform based on Hernando Barragán's Wiring thesis (Jacob & Fernaeus, 2021; Kishan et al., 2021). This platform has become the most widely used for creating innovative interactive hardware and software solutions. It enables developers to write code developed in any context to manage connected devices such as lighting, sensors, and displays (Jacob & Fernaeus, 2021; Kishan et al., 2021). Arduino is a circuit board including a programmable microcontroller that transforms input data from connected sensors into output, augmenting functionality via the use of "shields" or other boards. An actuator, such as a motor or LED, may be used to execute physical control (Kim & Choi, 2020; Shafi et al., 2023). Different Arduino boards are already available, such as Arduino Uno, Nano, R3, Arduino Leonardo, and Arduino Mega (Hurtuk et al., 2017; Tupac Yupanqui et al., 2022), and the Arduino boards come in a wide variety of sizes and designs and offer a wide range of features (Lama & Deemyad, 2023; Prabowo & Irwanto, 2023). The Arduino platform has significantly evolved and currently comprises many microcontroller boards, each designed for a particular purpose or application. This progress has accelerated due to the efforts of developers worldwide who have enhanced hardware designs and software ecosystems. Figure 1 illustrates many varieties of Arduino boards, including (a) Arduino Uno, (b) Arduino Due, (c) Arduino Mega, (d) Arduino Nano, (e) Arduino Esplora, (f) Arduino Zero, and (g) Arduino Leonardo. Each board has a unique design (Hassaballah & Fayadh, 2020).

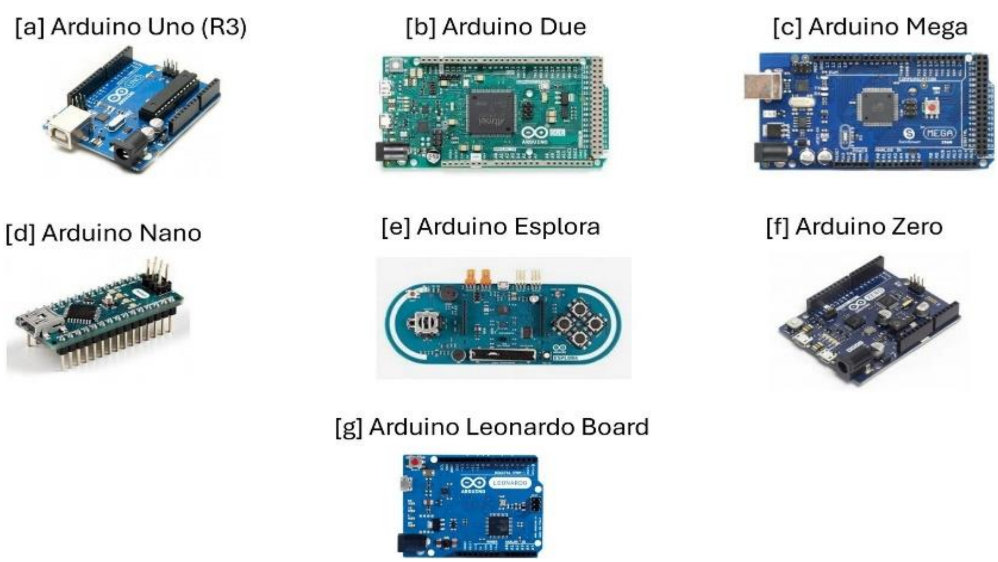

Figure 1: ARDUINO diagram (Hassaballah and Fayadh, 2020).

The Uno has an ATmega328P microcontroller, with the Due having a more advanced Atmel SAM3X8E ARM Cortex-M3 processor, and the Mega series is based on the ATmega2560 chip (Hassaballah & Fayadh, 2020).

Nonetheless, all the models of Arduino are technically different. As an example, the Zero models add to the capabilities of the Uno by adding extra embedded capabilities. Conversely, the Leonardo model features built-in USB capabilities due to its ATmega32u4 microcontroller and does not require any additional components. Another model that is unique is the Esplora model, which has built-in sensors, but this version is optimized for interactive projects. About the physical range, the Nano can be used in applications where limited space is needed, whereas the Mega is bigger, and the Due models are employed in larger connections (Hassaballah & Fayadh, 2020). Otherwise, there is significant variation in all models as indicated by other performance charts. The Due can only operate at 84 MHz, and the Zero has more memory to store the applications that require a lot of data. The Mega has additional GPIO ports compared with smaller boards such as the Uno and Nano, but it functions equally. The Due is the fastest Arduino device because it has the highest clock speed. The Zero has better memory; hence, it is more suited to those applications that need large data storage. The Mega also supports more GPIO ports, and so it is ideal for intricate designs. Nevertheless, the Uno and Nano can be applied to a great number of things. The models are usually selected depending on their design objectives and the financial capabilities of the people. The Nano can be considered an option when deploying large-scale applications because it is not very costly (Hassaballah & Fayadh, 2020).

This paper reiterates the fact that the Arduino Uno has become somewhat of a workhorse when it comes to medical system projects. It is based on the ATmega328P microcontroller, which has a decent number of digital and analog inputs, a stable 16 MHz clock speed, and various possible powering options, as well as a simple USB connection. It is compatible with numerous sensors and modules and can construct relatively complex configurations without necessarily digging very deep into the hardware aspect of the matter. The design of the board can also be adapted with ease, with the user changing the processor, adjusting the speed, adjusting the voltage or memory, or even changing the number of I/O pins. Uno's modular design has been very beneficial to the project because early prototyping is achievable and more effective when designs are yet to be finalized and testing is still going on. The Arduino Uno is even more attractive because of the set of features, wide community support, manuals, and clear documentation.

A microcontroller represents a computer system that should satisfy the needs of different application scenarios by combining a microprocessor, memory, and multiple input/output ports into one chip (Jiang et al., 2024). According to Kishan et al. (2021), the microprocessors and the Arduino are closely related, as the Arduino is basically a development platform or microcontroller, and specific microprocessors are optimized to perform specific tasks. Reports indicate that Arduino manufactures one of the most widely used microcontroller development boards, which can also serve other embedded purposes (Jasson et al., 2023). Arduino simplifies the use of microcontrollers by packaging the necessary components, such as power supplies, crystal oscillators, and bootloaders, into a user-friendly board. Using the Arduino IDE, one can create, compile, and load programs onto Arduino boards with minimal effort (Pan & Zhu, 2017; Begum & Dharmarajan, 2020). According to Tselegkaridis (2024), Arduino is an open-source platform that costs less than most other microcontroller platforms and also supports several operating systems. The extensive use of open-source platforms in research and learning institutions also contributes to the creation of new technological solutions (Tselegkaridis, 2024; Qasim et al., 2025). In addition, Arduino has been supported on various operating systems, such as Windows, Linux, and macOS, and allows one to experiment with both hardware and software architectures. The Arduino board is regarded as a user-friendly programming board (Kim & Choi, 2020; Barbon et al., 2016). It is simple enough to be especially appropriate to programming languages (like C, simplified

C++, and Processing) used by hobbyists and novice developers (Kishan et al., 2021; Sakphrom et al., 2021). It has also been pointed out by researchers that the Arduino ecosystem fosters innovation because of the high number of active developers on the platform compared with other platforms based on microcontrollers. Moreover, certain reports, such as Kaminski and Schmidt (2024), indicate that Arduino is specifically appropriate in low-speed control systems due to its stability, ability to connect with a wide variety of voltages and temperatures, capability to use hardware buses, and power efficiency.

Medical technologies have changed the traditional approach to medical treatment significantly during the past ten years, and some medical professions are starting to embrace the use of IoT technologies to enhance the quality of care they provide to patients (Behmanesh et al., 2020). Patient vital sign monitoring devices are typically either wired and therefore simulate the human auditory system using artificial nerves or wireless and use a neurosurgical device under near-field inductive coupling and are clamped to a particular body part. A health monitoring system based on Arduino is capable of connecting and recording real-time medical data, including heart rate, body temperature, and the level of oxygen saturation in the blood (Kamweru et al., 2020).

The system processes and manages sensor data, allowing multiple applications to run simultaneously (Anuar et al., 2024; Hameed et al., 2020). It has a DHT11, which monitors both temperature and humidity; a MAX30100, which monitors both pulse and blood oxygen; an LCD, which displays real-time data connected to it via an I/C connection; a buzzer, which is used to provide you with a notification; and a power supply system, which can be powered by a battery or USB connection (Anuar et al., 2024; Hameed et al., 2020).

The study by Hameed et al. (2020) is a progressive and smart healthcare platform powered by machine learning (ML) and the IoT. According to the experimental evidence of Hameed (Hameed et al, 2020), the suggested system is intelligent and effective enough to offer medical services. The device was developed by incorporating the coronary heart rate/pulse sensor (BPM), MAX30100 pulse oximeter sensor, and MLX90614 temperature sensor (Moses et al., 2016). With the Arduino microcontroller, the whole setup was under control to ensure that the affected person could be continuously tracked, and it was reported that the system could deliver the correct and up-to-date information regarding the health in real time.

One of the studies (Puenta et al., 2017) suggested a Wi-Fi-enabled wireless sensor network around the ATmega328 microcontroller to measure the temperature, heart rate, and blood pressure. The utilization of wireless sensor networks is prevalent to assist distributed sensing and data transmission that is reliable in IoT-based monitoring settings (Puenta et al., 2017; Siddamsetti & Qasim, 2025). The researchers stated that the system can monitor the vital trends of a patient in a continuous fashion, such as the heart rate, blood pressure, and other relevant hospital parameters. In a similar way, Puenta et al. (2017) have shown that Arduino can use nine sensors with the e-Health sensor shield (e-Health, 2016) and that these sensors can be used to monitor the status of the patient in the case of biometric and medical applications where the body needs to be monitored. Moreover, Kritika et al. (2017) have created a smart health monitoring system through a biomedical sensor that sends the acquired data to a server with an Android application named Health to access and track the information in real-time. The smart health monitoring system can allow patients to get access to local hospitals, home remedies, and prescription reminders, whereas physicians can explore their patients' health data remotely to diagnose them.

Similarly, Malaoui (2023) designed and deployed an operating architecture for an embedded remote-control system. The main element of such architecture is an Arduino microcontroller that controls electronic experiments in a one-phase rectifier. The results of the evaluation point to the many benefits of this innovative strategy in the context of flexible and remote experimentation. Contrarily, Bansal and Gandhi (2018) discussed the existence of numerous development boards that support the connectivity between devices and people, as well as the main part of IoT-enabled healthcare systems. They developed a prototype designed to provide initial control over patients' critical physiological functions. The results suggest that health institutions are capable of controlling the vital signs in both the hospital setting and at home, thus allowing them to track several patients simultaneously. These findings informed further developments based on the needs of specialists and contributed to a comprehensive healthcare service integration, particularly with the application of wireless sensor networks in the medical industry, as stated by Hassaballah and Fayadh (2020).

Reports indicate that IoT-based systems can practically function in real-world environments, particularly in healthcare and remote monitoring (Tsebesebe et al., 2025). The Internet of Things (IoT) has increased at an accelerated rate and is changing the way different devices and systems interact, particularly in healthcare settings (Aljabri & Yousif, 2023) . Microcontroller technology, especially the use of Arduino-based platforms, has played a significant role in making these developments possible (Yusro et al., 2021). Microcontrollers, such as Arduino boards, power IoT devices by constantly gathering, processing, and transmitting data. Medical systems use these microcontrollers, which connect via the cloud to monitor vital signs and automatically manage equipment. Using IoT, Arduino-based devices improve the accuracy of predictions, allow for continuous monitoring of symptoms, lower costs, and make it possible to provide care without needing to be physically present. New technologies, including blockchain, deep learning, and fog computing, enhance the reliability of the system, which makes the IoT solutions affordable and scalable and allows them to be used in remote healthcare, intelligent diagnostics, and personalized treatment (Srivastava et al., 2025). The Internet of Things (IoT) is the name of a network of interconnected physical objects, or things, that share data between systems and devices over the Internet (Dwivedi et al., 2022; Khanna & Kaur, 2020). Improving IoT-based healthcare monitoring systems may be achieved significantly because the inclusion of sensor networks into the human body allows tracking people more effectively and connecting equipment and services worldwide without issues.

The technology eases the process of collecting, sharing, monitoring, storing, and analyzing data produced by such groups. Medical treatment requires accurate diagnosis of health problems and constant follow-up of patients (Abdulmalek et al., 2022; Fan et al., 2024). Applications using IoT with Arduino are utilized across a wide range of fields, including economics, home automation, medical systems, applied engineering, real-time monitoring, agriculture, and portable DIY (Do-It-Yourself) devices (Prabowo & Irwanto, 2023; Bansal & Gandhi, 2018; Fan et al., 2024). According to Yusop et al. (2024), Arduino applications are extensively used in teaching software engineering students how to learn about the IoT and its practical implementation. These are the applications that are built into the Internet of Things, and these enable the devices to process, share, and act on the data sent over the Internet, thus facilitating real-time monitoring and automated decision-making (Yusop et al., 2024).

New technologies, including blockchain, deep learning, and fog computing, enhance the reliability of the system, which makes the IoT solutions affordable and scalable and allows them to be used in remote healthcare, intelligent diagnostics, and personalized treatment. The Internet of Things (IoT) is the name of a network of interconnected physical objects, or things, that share data between systems and devices over the Internet (Dwivedi et al., 2022; Khanna & Kaur, 2020). Improving IoT-based healthcare monitoring systems may be achieved significantly because the inclusion of sensor networks into the human body allows tracking people more effectively and connecting equipment and services worldwide without issues. The technology eases the process of collection, distribution, surveillance, and storage, as well as analysis of information produced by these groups. Medical treatment requires accurate diagnosis of health problems and constant follow-up of patients (Abdulmalek et al., 2022; Fan et al., 2024). Arduino is used in the IoT in a wide variety of applications, such as commerce, home automation, medical systems, applied engineering, real-time monitoring, agriculture, and handheld DIY devices (Prabowo & Irwanto, 2023; Zhang et al., 2020; Yusop et al., 2024). According to Yusop et al. (2024), Arduino applications are extensively used in teaching software engineering students how to learn about the IoT and its practical implementation. These are the applications that are built into the Internet of Things, and these enable the devices to process, share, and act on the data sent over the Internet, thus facilitating real-time monitoring and automated decision-making (Yusop et al., 2024).

In this paper, the authors examine how the concept of intelligent medical systems utilizing the Arduino microcontroller was developed by applying open-source software, low-cost production, embedded computational intelligence, and ubiquitous IoT connectivity. Nonetheless, the work is based on the discussions in the previous sections with the aim of defining the primary challenges and gaps of the current research.

Current literature is insufficient for effectively applying the research to practice, particularly regarding the long-term reliability of the systems, their seamless integration with other healthcare systems, and the transition of prototypes to fully functioning medical systems (Gupta et al., 2022). Solving these gaps is paramount in the development of Arduino medical systems since it will facilitate the development of more dependable, scalable, and clinically viable solutions that can be broadly implemented in real healthcare environments. To fill these gaps, this paper carries out a systematic literature review of the Arduino-based intelligent medical systems, evaluating the efficacy of the design, facilitating scaling, and exploring the implementation of the security, technical, and operational characteristics of the systems. The findings of this review will help inform suggestions for the future advancement of intelligent medical systems that utilize Arduino development.

The key components of the manuscript in the form of research articles include (1) Introduction, (2) Materials and Methods, (3) Results, (4) Discussion, and (5) Conclusion.

2. Materials & Methods

The study utilizes a Population, Intervention, Comparison, and Outcome (PICO)-based SLR that adheres to PRISMA guidelines and the Joanna Briggs Institute tool to critically evaluate the study's findings. This study employs clear methods to facilitate the identification, evaluation, and synthesis of research from several domains of knowledge. For its elaboration, a research question is first defined, an inquiry procedure is established, and the study is registered. Then, the criteria for inclusion and exclusion are determined, and a search for trials in scientific databases is conducted. The following sections present full details of the materials and methods.

2.1. Search Strategy and Data Extraction

A preliminary investigation was performed on Google Scholar to identify the relevant resources and the corresponding search terms for each resource (Yousif & Jiang, 2025). Nonetheless, the Google Scholar limitation enforces a constraint on the length of search strings, requiring their segmentation into smaller substrings. This initial search's results served as a foundation for developing and refining the primary search terms, which we gradually adjusted during the scoping study. Accordingly, the search strategy chooses the Web of Science, Google Scholar, and ScienceDirect as comprehensive indexing services; these are the databases chosen for their broad coverage of peer-reviewed articles based on performing the following Arduino searches with one of these keywords, such as “IoT,” “medical systems," "health monitoring," "health systems," "monitoring devices," "intelligent systems," and "monitoring systems." The search strategy involved applying a consistent set of keywords across all databases and using Boolean operators (AND, OR, NOT). For this systematic review, the primary search logic was formulated as Arduino AND in combination with all relevant proposed keywords. The selected publications are examined to locate and evaluate information such as the author, the year of publication, the country, the study's objectives, the prototype or application, the system's use, the types of Arduinos, microprocessors, sensors, and research results and limitations.

2.2. Research Questions

This study formulated its research question using the PICO framework, following the approach outlined by Sassi et al. (2024). Although existing studies have primarily examined specific features of Arduino, they have not provided a comprehensive evaluation of its security or technical or operational aspects. Accordingly, the following question was formulated: "How has Arduino been used in intelligent medical systems for patients or groups of individuals in various clinical settings? What are its applications? How are its solutions evaluated in terms of security, technical performance, and operational effectiveness? What are its challenges and limitations in improving healthcare delivery?" This formulation aims to include the significant impact of Arduino, emphasizing its practical uses, efficacy in real-world healthcare settings, and challenges that may constrain its evaluation, in order to develop more accessible, efficient, and patient-centered healthcare solutions.

2.2.1. *Stability Criteria of Eligibility*

Eligibility criteria are according to PICOS as reported in the previous literature (Reza & Zeljko, 2024; Amundsen et al., 2018). The inclusion and exclusion criteria are presented in Table 1.

Table 1: Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Date	2020-2024	Articles published before 2020
Source	IOP, Science Direct, PubMed	Or databases
Language	English	Or language
Article	Research	Or
Article content	Arduino, IoT, monitoring devices	Other
Outcomes Measure	Arduino applications for intelligent medical systems.	Other

2.2.2. *Guidelines for Systematic Review*

This study adheres to the PRISMA standard, recognized as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, as previously documented (Ghozali, 2023; Sigit et al., 2024; Gong et al., 2021; Patel & Sharma, 2020; Singh et al., 2021). The use of PRISMA in the study made the review more complete and easier to repeat by making sure that the selection, screening, and inclusion of relevant literature were all done in a clear and systematic way.

2.2.3. *Critical Appraisal Tool*

This study adheres to the PRISMA standard, recognized as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. This study uses the Joanna Briggs Institute's (JBI) critical appraisal tool, like other systematic reviews (Singh et al., 2021; Prasad & Raghavan, 2020), because it presents a full picture of how to judge the methodological quality of different types of studies, such as experimental, observational, and qualitative research, specifically for systematic reviews. The JBI enhances the reliability and credibility of the findings by systematically evaluating the evidence from published papers regarding the utilization of Arduino in intelligent medical systems, including its applications, challenges, and limitations faced in improving healthcare delivery.

3. Results and Discussion

3.1. Search Strategy and Data Extraction

A PRISMA flow chart is presented for the identification process for inclusion in Figure 2. Initially, 216 studies were identified; 181 were excluded as either duplicates or irrelevant, and a further 27 studies were excluded because they evaluated Arduino incorrectly, had an unclear method, or were unrelated to Arduino, leaving 8 studies for analysis. Using the PICO framework, this study investigates the target: Population (P) is individuals or groups of patients of various ages and clinical settings who benefit from or are monitored by Arduino-based intelligent medical systems; the Intervention (I) is the implementation and use of Arduino-based applications and devices within intelligent medical systems; Comparison (C) examines Arduino-based systems against alternative platforms and technologies regarding cost-effectiveness, ease of implementation, versatility, real-time monitoring capability, and scalability; and Outcome (O) evaluates how the solutions assess the security, technical, and operational aspects of Arduino in intelligent medical systems.

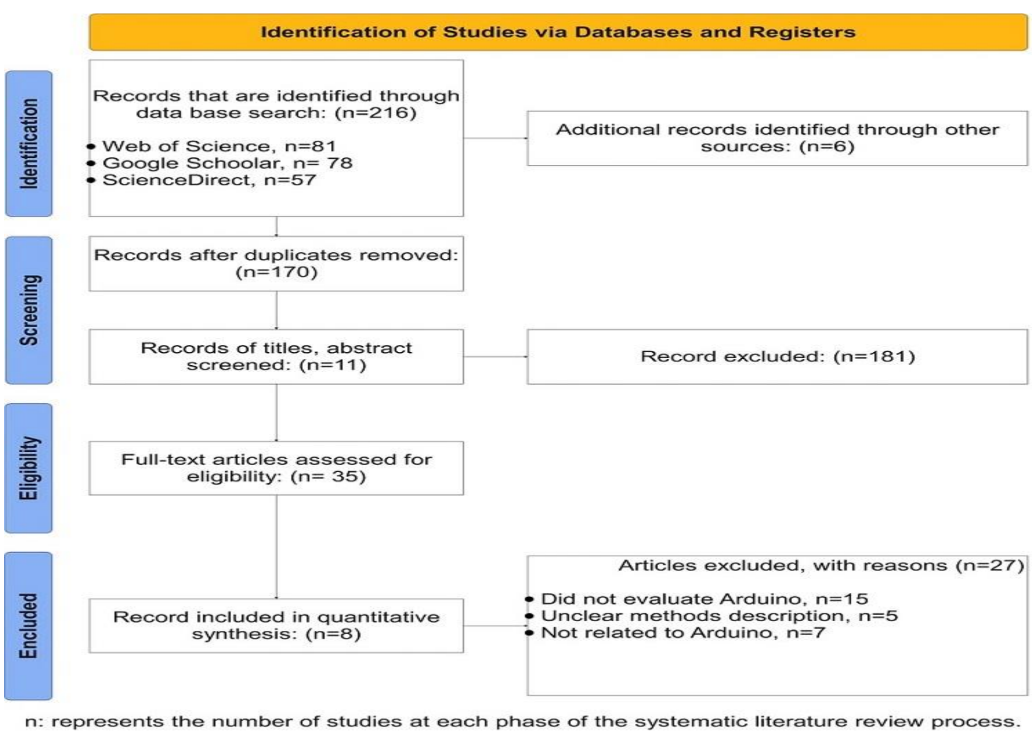

Figure 2: PRISMA flowchart

3.2. Results of Individual Studies and Syntheses

A study (Ali et al., 2023) described a noninvasive healthcare diabetes monitoring system powered by Arduino and driven by IoT. The device is a wearable wristband that has the ability to monitor the temperature, pulse rate, oxygen saturation, blood pressure, and blood glucose. Physicians receive the patient's data in real time, reducing medical expenses and improving telehealth assistance for emergency treatment and chronic disease management. The system was claimed to have a 98% reported accuracy with the random forest algorithm, which shows that the system has the possibility of reliable and affordable remote monitoring.

The current research was consistent with the existing literature, pointing to the fact that AI-IoT developments and applications have predominantly affected the healthcare industry, with blockchain, deep learning, and fog computing as the three main AI-IoT solutions to healthcare (Abdulmalek et al., 2022; Verma & Bansal, 2023).

As an example, Saif et al. (2023) explain how MySignals is one of the platforms that show how Arduino-based IoT systems with sensors on wearables can offer convenient, inexpensive solutions to be integrated with the cloud and real-time healthcare monitoring in the context of COVID-19. The system uses both wired and wireless connections to collect and send health data (temperature, ECG, and SPO_2) to a cloud. The technology facilitated contactless monitoring, thereby minimizing the spread of the disease. MySignals and other Arduino-based platforms have proven to be efficient with IoT solutions in integration with the cloud and real-time healthcare monitoring. Rahman et al. (2021) proposed an IoT system based on fuzzy logic to remotely monitor and diagnose COVID-19 patients. Arduino microcontrollers, equipped with medical sensors, collect physiological data that the system processes to make diagnostic and treatment decisions using fuzzy logic. The research demonstrates that low-cost embedded platforms can consolidate remote healthcare delivery and clinical decision-making, despite the need for further scalability and processing power enhancements. This finding is consistent with the findings of the prior research, indicating that IoT-based surveillance systems incorporating rule-based fuzzy logic are capable of offering quick and dependable diagnostic assistance (Torres et al., 2021; Sharma et al., 2023). Lin et al. (2021) reported a real-time health monitoring modular wearable combining SpO_2, EEG, and ECG in a study.

The system involves an Arduino that processes and transmits a number of biosignals to a graphical user interface to be analyzed, as reported in earlier studies (Lee et al., 2020; Agarwal et al., 2021). The design of the study is, however, flexible and open to further extensions that enhance the use of ICU and emergency applications and improve the efficiency of patient care. Saha Ramesh et al. (2021) designed a prototype of real-time health monitoring based on an Arduino Nano with a DS18B20 temperature sensor. The system collects and sends patient information using wired and ZigBee wireless networks and provides up-to-date information about their health. It was used for situations like Covid-19 monitoring and helps to respond quickly, especially to old or chronically ill patients. Rahimoon et al. (2021) examined a cheap, IoT-oriented network that incorporates Arduino, LM-35, and MLX-90614 sensors to monitor the temperature of the human body wirelessly and in real time.

The system provides a convenient way for individuals and healthcare institutions to monitor temperature for preventive health management by transmitting data via Wi-Fi to an online platform. Jasson et al. (2023) examined the Arduino-based smart healthcare system for real-time monitoring of vital signs, such as temperature, heart rate, and SpO_2. To guarantee the use of patient emergencies, the system would have a connection that is Bluetooth-based and an alert mechanism. It is economical, flexible enough to suit varied conditions, and can be extended with more sensors or IoT integration to enhance monitoring, as discussed in previous literature (Chen et al., 2022). Conversely, Abdalrahim et al. (2023) proposed a health tracking platform that was developed using Arduino and NodeMCU to monitor health parameters such as temperature and heart rate remotely. It offers real-time information and warnings to the healthcare workforce as well, allowing them to respond faster, minimizing the workload, and offering a scalable solution to hospitals, especially in times of disease outbreaks.

3.3. Data Extraction Conclusions

The process of extracting pertinent data or information from primary studies that satisfy the inclusion criteria is known as extraction in the context of meta-analysis (Sigit et al., 2024). The outcomes of the many primary investigations are analyzed and concluded using the retrieved data; a list of information collected from primary research is included in the meta-analysis data extraction procedure in a coding sheet. Table 2 shows the extracted information from the inclusive studies.

Table 2: The Extracted Information from the Included Studies

Ref.	Country	Research objectives	Microprocessor	Sensors used	Research outcomes
(Lim et al., 2021)	Malaysia	The goal is to investigate the patient's vital signs using a cardiac sensor connected to an Arduino UNO and an infrared temperature sensor connected to a NodeMCU.	Arduino UNO	The patient's body temperature was measured by the MLX90614 sensor, and their pulse rate was monitored by the Heartbeat module or pulse sensor.	The novel system can raise the standard of healthcare services generally and improve societal health outcomes.
(Jasson et al., 2023)	Bahrain	Using a microcontroller-based smart system to design a healthcare system that captures the required medical data.	Arduino UNO	The DS18B20 Digital Temperature Sensor uses pulse oximetry, a heart rate sensor, an ultrasonic sensor, and a heartbeat to measure temperature and SpO_2.	This system can be utilized in the intensive care unit, before assessment, or as a patient's personal health monitoring device.
(Patel et al., 2021)	Malaysia	Wireless human body temperature (HBT) monitoring using an Arduino controller equipped with several sensors and an open-source internet connection	Arduino CT-UNO	The system includes an Arduino controller, LM-35 (S1) and MLX-90614 (S2) temperature sensors, as well as an ESP-Wi-Fi shield module.	An indoor and outdoor wirelessly connected platform for tracking and displaying the real-time data from deployed S1 and S2 sensors.
(Sharma & Singh, 2020)	India	A working prototype system for a real-time health-monitoring system	Arduino Nano with microcontroller ATmega328	DS18B20 temperature sensor.	The real-time health status of the patient is determined by analyzing their vitals according to medical criteria; if the state is abnormal, prompt preventive action can be taken to stop additional complications.

(Reddy et al., 2020)	Taiwan	To develop a wearable gadget for medical uses that combines blood oxygen monitors, electrocardiography (ECG), and electroencephalography (EEG).	Arduino Mega 2560	EEG module: BR8; ECG module: AD8232; and SpO2 module: MAX30100.	The developed system has exhibited the proper functioning of all modules and subsystems.
(Kumar & Choudhary, 2022)	Chile	The goal is to develop a smart framework-based integrated solution that utilizes fuzzy logic and the Internet of Things to provide timely medical care and diagnosis.	Arduino	Sensors measure variables such as BP, heart rate, and SpO2.	Based on the patient's state, this advanced system helps medical personnel make well-informed decisions.
(Torres et al., 2021)	India	India.	The development of an e-health monitoring system using the MySignals HW shield for medical devices.	Arduino UNO is integrated with MySignals HW.	Blood pressure sensor, pulse oxygen (SPO_2) sensor, airflow breathing sensor, EMG sensor, ECG sensor, blood glucose (glucometer) sensor, spirometer air capacity sensor, body temperature sensor, body position (accelerometer) sensor, and galvanic skin response (GSR) sensor.
(Ali et al., 2023)	Pakistan	A system based on smart sensing technologies is proposed, utilizing artificial intelligence (AI) and the Internet of Things (IoT) to provide diabetic patients with ongoing monitoring and health support.	Arduino Nano	The device includes sensors for blood pressure, blood oxygen, blood glucose (measured non-invasively), body temperature, and pulse rate, as well as a non-invasive blood sugar sensor that utilizes a near-infrared (NIR) sensor.	The system sends accurate patient condition predictions to the doctor's portal.

3.4. Critical use of the JBI tool

The analysis of research on Arduino in medical artificial intelligence based on the JBI Critical Appraisal Tool is presented in Table 3, considering the title, study design, methodology, results, limitations, and the general evaluation. The reviewed literature considered other studies that primarily employed descriptive studies and practical methods in developing health monitoring systems, especially by using Arduino, IoT, and sensors to monitor patients' vital signs. The works were mostly based on a descriptive design and practical approaches to create health monitoring systems, usually using Arduino, IoT, and sensors to measure the vital signs of a patient or using AI, blockchain, deep learning, and fuzzy logic. The research has specific objectives that focus on its medical applications, such as diabetes control, monitoring body temperature, and managing COVID-19 patients. Whereas the findings seem valid, questions of reliability and applicability in practice are still in doubt. Among them are small sample sizes, lack of clinical validation, and sensor accuracy variability. Some of the limitations are present in all the studies, including the absence of clinical testing to determine real-world effectiveness. Other issues are sensor reliability and small sample size, and further validation research is required. Additionally, this work found similar constraints and difficulties reported in other studies (Singh et al., 2021; Sharma et al., 2021; Kumar et al., 2021).

Nevertheless, even with the limitations described, all studies offer viable innovations in healthcare systems based on the IoT and show the possibility of providing cost-efficient, real-time monitoring solutions given in other studies (Singh et al., 2021). However, healthcare practice cannot confidently use most of these devices without additional testing, particularly clinical tests. Overall, the absence of clinical validation and practical tests restricts the application of wearable health monitoring systems and IoT integration in acute healthcare settings, despite the studies indicating enormous potential for these technologies (Singh et al., 2021; Verma et al., 2021; Reza & Zeljko, 2024; Jha & Kumar, 2020).

The primary subject of the research resulting from these studies is the integration of Arduino with IoT technologies for remote and real-time healthcare monitoring. The focus of this trend is the development of non-invasive wearable technology that is affordable and uses Arduino-based sensors to measure vital signs, including blood sugar monitoring, temperature, and heart rate, among others. Scalable and flexible solutions that enhance patient care, facilitate the transfer of data through wireless and cloud-based systems, and reduce the demand on healthcare systems are gaining popularity. Moreover, the trend focuses on the ways AI and machine learning can enhance the process of data analysis and decision-making in healthcare.

Table 3: Critical Appraisal of the Included Studies

Ref.	Title	Study Design	Clear Objectives	Appropriate Methodology	Validity of Results	Limitations	Overall Appraisal
(Lim et al., 2021)	The development of a Patient Health Monitoring System Using ESP8266 and Arduino on an IoT Platform.	Descriptive	Yes	Yes	Yes	To verify its applicability and dependability, more extensive clinical validation and practical testing are needed.	With its high predictive accuracy and significant cost savings, the study offers a novel and promising AI-enabled IoT-based healthcare system for managing diabetes.
(Jasson et al., 2023)	Smart Pre-Examination Healthcare System for Doctors Using an Arduino Microcontroller.	Descriptive	Yes	Yes	Yes	The study's reliability and precision in crucial medical applications are doubtful due to its reliance on simple sensors and insufficient validation.	The research suggests a cost-effective and cutting-edge microcontroller-based smart healthcare system for patient monitoring and pre-examination.

(Patel et al., 2021)	Design of a Contactless Body Temperature Measurement System Using Arduino.	Descriptive	Yes	Yes	Yes	The significant difference in sensor readings (15°C) highlights the reliability issues that require resolution for practical medical applications.	The paper presents a low-cost, IoT-enabled device that uses wearable sensors and Arduino to remotely monitor temperature.
(Sharma & Singh, 2020)	Development of a Working Prototype for Health Monitoring Using the DS18B20 temperature sensor and Arduino.	Descriptive	Yes	Yes	Yes	Limited testing coverage and a lack of clinical validation restrict its preparedness for practical healthcare applications.	The study offers an affordable real-time health monitoring prototype that makes use of ZigBee and Arduino technology.
(Reddy et al., 2020)	A wearable multimodal biosignal acquisition system for critical and emergency applications.	Descriptive	Yes	Yes	Yes	Lacks clinical validation and practical testing, which restricts its rapid use in critical care situations.	The paper shows a promising modular wearable device that integrates several biosignal monitoring systems for intensive care unit applications.
(Kumar & Choudhary, 2022)	An IoT-fuzzy intelligent system for the comprehensive management of COVID-19 patients.	Descriptive	Yes	Yes	Yes	The lack of clinical validation and reliance on fuzzy logic for complex medical decisions may affect its practical efficacy.	The study offers a novel fuzzy logic system powered by the IoT for remote COVID-19 patient monitoring and diagnosis, potentially leading to prompt medical interventions.
(Torres et al., 2021)	The project focuses on developing a MySignals-based prototype for use in vital health monitoring.	Descriptive	Yes	Yes	Yes	Its lack of clinical testing and small sample size limit its relevance to practical healthcare situations.	According to the study, it is feasible to create a wearable health monitoring system with promising transmission efficiency utilizing a MySignals HW shield.
(Ali et al., 2023)	Intelligent Healthcare System for Diabetes Patients Using Smart Sensing Technologies.	Descriptive	Yes	Yes	Yes	The lack of thorough validation, scalability testing, and consideration for privacy and data security issues affects practical applications.	The study presents a promising IoT-based patient health monitoring system that could enhance healthcare outcomes and efficiency.

4. Discussions

4.1. Contrasting Arduino's Usage in Intelligent Medical Systems

Researchers have shown interest in using the Arduino in the health sector through smart systems to make the diagnostic process more convenient and affordable. The system that integrates Arduino has proved successful as a biomedical tool in another research. As an illustration, Ali et al. (2023) present a wearable, IoT-based, AI-based diabetic monitoring system. Ali and his co-workers are exploring the possibility of Arduino being an affordable, real-time health monitoring system (e.g., blood glucose, oxygen saturation, and pulses) and being safe for the patients. They noted that such a system would improve patient care and telehealth services in the case of its integration with Arduino. This piece highlights the growing trend of IoT-based healthcare technology, which is an ongoing experiment aimed at transforming current medical practices. Like other inclusive studies, it focuses on telehealth and cost-efficiency and uses Arduino to monitor health in real-time using the IoT and has similarities with other literature (Singh et al., 2021; Patel et al., 2021). Thus, the work is different, as it focuses on AI-assisted diabetes monitoring, whereas other researchers discuss various types of systems, including fuzzy logic, as mentioned in the work of Kumar and Choudhary (2022), and critical care, as mentioned in the work of Reddy et al. (2020).

The Torres et al. (2021) research, as well as other studies, underscores the use of Arduino in IoT-based health monitoring and real-time data transmission. It is not the first research to distinguish itself in terms of MySignals HW shield and cloud storage; Ali et al. (2023) were interested in AI-driven wearable devices, and Reddy et al. (2020) were interested in multi-biosignal monitoring in critical care. The combination of the MySignals hardware shield with Arduino-based health monitoring systems was described by Torres et al. (2021), and the authors explained how wearable technologies, embedded systems, and IoT could improve remote healthcare. According to the studies discussed above, systems based on Arduino would be able to offer real-time health monitoring by employing different sensors to detect vital indicators. These technologies may be wired or wireless to transmit health information to both cloud and local platforms. Since such technologies are becoming more prevalent in IoT-based healthcare systems, the necessity of both strong and secure data measures increases because of the confidential and personal medical information of patients being obtained and sent to local or cloud storage due to unauthorized access or exposure. Consequently, these systems would render the need to utilize the existing hospital facilities less essential, as it can be detrimental to patients.

Similarly, the article by Kumar and Choudhary (2022) articulated the possibility of utilizing Arduino in the medical field, particularly in remote-monitoring systems driven by IoTs. They opined that the capabilities of the system, which include wearables, are a smart medical intervention. The system will allow health professionals to make smart decisions on the health status of the patient because of its built-in Arduino, sensors, and fuzzy logic. The authors in this research paper applied a mixture of technology elements to construct the system; however, their approach was not similar to other prior studies examined and discussed. Like the works of Ali et al. (2023) and Torres et al. (2021), it focuses on IoT-based, real-time monitoring. Unlike the prior research, which was primarily concerned with the wearable devices and the process of data transportation, the methodology chosen by Kumar and Choudhary (2022) is based on intelligent data analytics to improve the healthcare outcomes.

Reddy et al. (2020) demonstrated the use of Arduino activity in a wearable garment to monitor a variety of biosignals. They emphasized the importance of technology in healthcare. With the help of ECG, EEG, and SpO_2 sensors, the Arduino-based system allows you to send and view health statistics in real time. In this work, Arduino is demonstrated to be able to offer flexible, low-cost, versatile, and IoT-connected healthcare solutions, as previous research studies have demonstrated (Sharma et al., 2021). According to the discussion of this research, the designed system is yet to be proven to work in a real environment where specific, continuous, and real-time monitoring of the patient environment is involved. To make that even, the performance of the system was also tested in EEG testing with simulated signals and controlled situations, and the data has still not been gathered to work in the conditions of real patients in the clinical situation. In this work, the suggested system has been simulated, and the initial tests are of small-scale functionality only, which is not as powerful. To make that even, the performance of the system was also tested in EEG testing with simulated signals and controlled situations, and the data has still not been gathered to work in the conditions of real patients in the clinical situation. This discussion results in the proposed system being a mere simulation, and limited-ability functionality testing and small-scale tests are introduced.

Sharma and Singh (2020) have designed real-time health monitoring of an Arduino Nano system equipped with an in-built temperature sensor (DS18B20). This system does not require a high cost, and it does not require a lot of difficulty in assembling it. These characteristics also contribute to the fact that the system is a good option in the case of communities or households that might lack access to the advanced medical tools in the sphere of healthcare. They also incorporated ZigBee modules to enable the system to transmit data wirelessly, which can truly be of use. This work was used in such periods as the COVID-19 pandemic or when nursing care is needed with elderly people who cannot travel freely. Their study agrees with the studies conducted by Reddy et al. (2020), who aimed at high-acuity settings with complex multi-sensor biosignal systems. Similarly, it aligns with the efforts of Ali et al. (2023), who implemented AI-enhanced wearables to create more sophisticated and automated patient treatment. Comparatively, in their turn, Sharma and Singh (2020) placed more emphasis on cost-effective and convenient solutions to home-based care. Otherwise, Arduino was used as a core controller in the findings of the study by Patel et al. (2021) to build a system that would monitor the body temperature with adaptive IoT-based technology by adding temperature sensors embedded within it. Patel et al.'s (2021) study revealed that the platform has the future of the healthcare industry to be flexible. It is a great illustration of how Arduino may be used in real-time health monitoring, which is a critical application in wearable technology and IoT technologies in remote healthcare solutions by combining with temperature sensors (LM-35 and MLX-90614) and Wi-Fi. Although it considered fewer complexes than high-dependency care models by Reddy et al. (2020), it also has a conceptual overlap with Ali et al. (2023) in that it aims to develop cost-efficient, scalable solutions. Other related studies have followed such low-cost directions as well (Sharma et al., 2021; Verma et al., 2021).

Meanwhile, Lim et al. (2021) established an IoT-based vital sign monitoring system that utilizes Arduino technology. It demonstrates Arduino-based wearable technology by combining sensors such as temperature and cardiac sensors with Arduino and NodeMCU (Kumar et al., 2020), thereby enhancing healthcare efficiency and accessibility (Patel et al., 2021). The research conducted by Jasson et al. (2023) is similar to the studies referenced in Lim et al. (2021) and Kumar et al. (2020). Lim et al. (2021) emphasize the importance of wearable devices for tracking vital signs. However, this study contrasts with Patel et al. (2021) because it uses NodeMCU instead of temperature-specific sensors like the LM-35 and MLX-90614, which offer a broader approach to patient monitoring across various settings.

The Arduino-based systems have gained a prominent place in health care monitoring systems, especially in the medical applications that make use of the Internet of Things (IoT). The recent research shows that Arduino hardware may be used to assist real-time physiological monitoring and remotely delivered healthcare services. As an example, the Arduino-based healthcare monitoring system that was assessed in Sharma et al. (2021) demonstrates that Arduino-based sensors could be useful in collecting physiological data and transmitting it to the cloud to be analyzed remotely. Moreover, scholars have already investigated wearable and remote respiratory monitoring systems extensively, enabling continuous physiological monitoring in medical care environments (Sharma et al., 2021). Reference Kumar et al. (2021), which presents an intelligent and economical network for tracking sleep quality, illustrating how IoT technologies can be implemented to monitor sleep-related physiological parameters.

Arduino-based sensing platforms have been used to undertake biomedical chemical detection, as well as in physiological applications. The integrated sensing system discussed in Patel et al. (2021) shows the application of the Arduino platform to detect hydrogen peroxide, with a focus on the potential of embedded systems for biochemical sensing applications. Several studies have also been done on wearable monitoring solutions. As an example, Patel et al. (2021) propose a pulse rate-activated wearable device that will assist critically, and it offers real-time physiological monitoring.

Even the low-cost healthcare assistance systems have been established to help vulnerable groups, including the elderly and long-term illness cases, to monitor their health and receive relevant interventions in time. Kumar et al. (2020) illustrate the potential of low-cost embedded technologies in automated health monitoring by introducing a healthcare monitoring bot to support elderly patients. Moreover, recent studies point out the development and issues regarding low-cost pulse-sensing technologies in healthcare use (Patel et al., 2021). Several studies have also discussed the combination of IoT technology and healthcare monitoring systems. The paper Sharma et al. (2021) thoroughly discusses the enabling technologies of the Internet of Medical Things (IoMT), including sensors, devices, and communication platforms. On the same note, IoT real-time health monitoring systems, specifically for cardiac patients, can confirm the usefulness of sensor-based architectures in monitoring patients in real time (Verma et al., 2021). Moreover, Sharma et al. (2021) widely discuss the use of IoT-based wearable systems with sensors to monitor the health of patients because of the benefits of remote patient monitoring.

In parallel to these works, a comprehensive overview of healthcare monitoring applications on Arduino is given in Sharma et al. (2021), emphasizing the fact that Arduino platforms are versatile and cost-efficient for medical sensing. Furthermore, Patel et al. (2021) discuss the advancements in electrocardiogram (ECG) sensor technologies, which provide improved hardware and software for monitoring cardiac signals.

Altogether, the literature reviewed proves the fact that in terms of real-time physiological monitoring and remote patient monitoring, the Arduino-based healthcare monitoring systems can serve as an inexpensive and flexible technology. You can use such systems in a wide range of applications, including wearable health, cardiac signal, sleep quality, and biochemical sensing. However, there are still several issues to address, including ensuring sensor accuracy, system reliability, information protection, and seamless integration with current healthcare systems, all of which may hinder the overall adoption of these technologies in clinical settings.

4.2. Assessing the Security, Technical, and Operational Aspects of Arduino in Intelligent Medical Systems

In the study, the results are based on an analysis of eight studies (Ali et al., 2023; Torres et al., 2021; Kumar & Choudhary, 2022; Reddy et al., 2020; Sharma & Singh, 2020; Patel et al., 2021; Lim et al., 2021; Jasson et al., 2023) that compare various parameters of computed security, technical performance, and operational efficiency. The studies (Ali et al., 2023; Torres et al., 2021; Kumar & Choudhary, 2022; Reddy et al., 2020; Sharma & Singh, 2020; Patel et al., 2021; Lim et al., 2021; Jasson et al., 2023) reveal significant vulnerabilities in Arduino-based intelligent medical systems. The research established that accountability and integrity were lacking in some systems, preventing effective non-repudiation mechanisms and the verification of data sources or denial of medical interventions. The analysis indicated that there was a low percentage of incidents that used encryption in research (Torres et al., 2021; Kumar & Choudhary, 2022; Lim et al., 2021), with most of them transmitting important medical information without any protection. In particular, the systems proposed by Sharma and Singh (2020) and Patel et al. (2021) lacked the proper security protocols to transmit the vital signs of patients (e.g., heart rate, blood pressure, oxygen saturation) to networks since they did not introduce any data encryption protocols, namely, AES, RSA, or TLS. The studies lack the use of forward and backward secrets, which poses a threat to the loss of historical information when a key is revealed. Conversely, the study findings showed that most systems had access control at 87.5% of the references in Ali et al. (2023), Torres et al. (2021), Kumar and Choudhary (2022), Sharma and Singh (2020), Patel et al. (2021), Lim et al. (2021), and Jasson et al. (2023). Nevertheless, the authentication process of low-cost prototypes (Sharma & Singh, 2020; Patel et al., 2021) was poor, as it was based on hardcoded or minimal credentials. In the research findings, Kumar and Choudhary (2022) were selected due to their relatively more effective coverage, which is attributed to encryption, access control, and explicit security awareness. Conversely, the cheap implementations mentioned in Sharma and Singh (2020) and Patel et al. (2021) scored the lowest, as they sent sensitive data with no confidentiality or resiliency protection.

Otherwise, the technical review demonstrates more significant yet inconsistent implementation of the studies. Precision at a clinical level was achieved in 62.5 percent of cases (Ali et al., 2023; Torres et al., 2021; Kumar & Choudhary, 2022; Patel et al., 2021; Jasson et al., 2023), with Ali et al. (2023) reporting an error of ±0.5 percent in glucose monitoring as an example. Similar performance validation was equally challenging in 62.5% of systems (Ali et al., 2023; Torres et al., 2021; Kumar & Choudhary, 2022; Jasson et al., 2023; Reddy et al., 2020). As an illustration, Torres et al. (2021) achieved a 99 percent delivery rate for packets, which proved to be reliable in wireless vital sign monitoring. On the other hand, only a quarter of the systems discussed fault tolerance, which means that most designs do not have redundancy or recovery. In the example of Reddy et al. (2020), the authors created a system to collect multimodal emergency biosignals, where backup solutions were not developed and thus failed when there was a loss of connection. On the other hand, Patel et al. (2021) showed that the sensor drifted beyond the acceptable clinical range (±1°C) when there was electromagnetic interference. The technical results were satisfactory, as shown in Torres et al. (2021), Reddy et al. (2020), and Lim et al. (2021), because they were validated and compared with other systems. Low-cost designs, such as Sharma and Singh (2020), on the other hand, were partially correct and imprecisely calibrated; hence, they were less dependable in the clinical environment.

The findings of the study indicated that the operational appraisals have moderate sustainable practices adoption but poor reliability protection. Systems that utilized low-power modes were 37.5 percent (Ali et al., 2023; Kumar & Choudhary, 2022; Jasson et al., 2023). As demonstrated by Kumar and Choudhary (2022), these modes can enable the continuous follow-up of COVID-19 patients over a period of 30 days. The reliability of uptimes was poor in critical situations, where a study by Reddy et al. (2020) found only 82% uptime because of Wi-Fi instability. Moreover, 50% of systems in research (Torres et al., 2021; Reddy et al., 2020; Sharma & Singh, 2020; Lim et al., 2021) did not avail of availability recording, which restricted accountability in the clinical application. The findings also indicated that there are prototypes that performed well in cost-effectiveness. For example, Sharma and Singh (2020) developed a prototype that could be purchased for less than 50 dollars; however, this lower cost resulted in the absence of vital functionalities, such as maintaining data during system crashes. Unlike other studies that lacked non-repudiation and used low security levels, Lim et al. (2021) designed a system that took advantage of an IoT platform. Ali et al. (2023) approached sustainability and calibration in large part but were weak on operational resilience. Similarly, Patel et al. (2021) focused on cost but not long-term reliability or cryptographic measures, which made the system less practical in practice.

The three factors of the Arduino-based medical systems, namely, security, technical, and operational, are compared with each other in radar charts in Figure 3 based on eight studies. This scale was chosen because it is a convenient way to compare any system with various items. Similar to this scale, it also has a trade-off between interpretability and granularity; thus, it is sufficiently fine-grained to permit real distinctions between performances and, at the same time, be readable. All subplots are measured using the same scale; hence, it is standardized and can measure short-term relative performance.

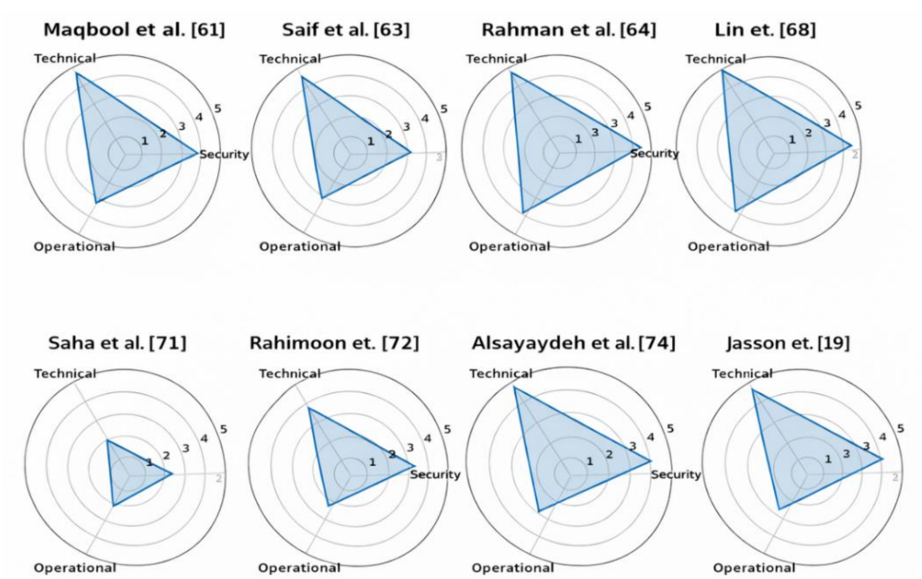

Figure 3: Comparative radar charts illustrating the security, technical, and operational aspects of Arduino-based medical systems

The works of Kumar and Choudhary (2022) and Reddy et al. (2020) are the most balanced and the strongest ones in terms of performance in all the dimensions. On the other hand, the scores on the aspects of security and operational resilience are low in Sharma and Singh (2020) and Patel et al. (2021). The medium group work, including Ali et al.

(2023), Torres et al. (2021), Lim et al. (2021), and Jasson et al. (2023), is very appropriate regarding technical issues but has a record of implementing less-developed security measures. On the whole, such a visualization allows making comparisons at a system level and emphasizes that all averaged measures have hidden and unequal trade-offs, such as operations changes and resilience across various studies.

4.3. Challenges and Limitations of Arduino-Based Intelligent Medical Systems in Healthcare Delivery

This study demonstrates that, though there are several benefits to Arduino-based medical systems, they continue to have numerous limitations and shortcomings that make their development and testing in real-life healthcare contexts a challenging task, as explained below.

indicates.

Insufficient clinical validation: The majority of research on medical systems based on Arduino has been done in simulated settings or small pilot studies, in unprofessionally controlled laboratory settings, and without full-scale clinical trials. Real trials are also greatly missing, and these would help to effectively evaluate the safety, dependability, and efficiency of these systems in different real-life healthcare contexts. When simulations are employed, the results cannot be generalized, and there is still a challenge of replacing the experimental prototypes with clinically approved devices without extensive validation, as the data of Reddy et al. (2020) and Patel et al. (2021) indicates.

Sensor accuracy and technical reliability: The Arduino-based systems are capable of measuring a wide variety of vital signs using a wide selection of sensors, but this technology has various issues, including calibration drift, inconsistency in the field, and environmental effects (e.g., temperature, humidity, or electromagnetic interference) that render the measurements inaccurate. Furthermore, the next issue is that incorporating multilabel sensors with various hardware input/output devices and potentially incompatible software may challenge the accuracy of measurements. In practice, the manufacturer's defect may further undermine the reliability of the equipment in a real medical workplace, especially in chaotic or under-equipped situations. Furthermore, applying these sensors to real patients who have not undergone proper biocompatibility testing or certification raises significant safety concerns. Most recent research (Mahmud et al., 2019; Torres et al., 2021; Kumar & Choudhary, 2022) also noted inconsistent findings in different systems, and when healthcare professionals cannot rely on the readings, patient care quality will be jeopardized. Furthermore, research indicates that not all systems uniformly implement fault tolerance and robustness (Deka et al., 2021; Reddy et al., 2020).

Security and privacy issues: The intelligent medical systems with Arduino tend to send the patient information across IoT networks and cloud computing environments and, thus, become vulnerable to cyberattacks, including unauthorized access, information manipulation, and breaches. Such concerns tend to occur since the hardware and software of Arduino are usually open-source, and the cyberattacks might even increase when effective encryption and authentication are not established. Thus, developers should adhere to healthcare rules like HIPAA and GDPR to ensure that patient data is safe, access is controlled, and that all data operations are appropriately monitored. Not adhering to them may endanger patient privacy and information integrity, decrease the trust level between patients and doctors, and restrict the application of these devices to clinical practice. Studies show that simple security, like simple authentication or passwords, is not sufficient to secure sensitive medical data (Ali et al., 2023; Torres et al., 2021; Reddy et al., 2020; Lim et al., 2021). Researchers usually ignore the incorporation of advanced security measures such as high-quality encryption, non-repudiation, and forward/backward secrecy in their system architecture. These disadvantages reveal flaws in the system architecture, compromising security and making the use of medical IoT devices impractical in hospitals and other healthcare facilities with strict standards.

Operational limitations: Although Arduino-based systems are very flexible, short-term prototypes are frequently only concerned with simple functionality such as uptime, stability, and scalability to clinical usage. Regrettably, this attention usually leads to a big gap in the research since the solutions can only work with individuals and not under proprietary laboratory conditions but have not been proven to work in real-world healthcare conditions over prolonged periods of time. For example, researchers have not demonstrated the 24/7 availability required for monitoring an ICU with over 99.9% uptime (Jasson et al., 2023; Ali et al., 2023; Torres et al., 2021; Sharma & Singh, 2020; Patel et al., 2021; Lim et al., 2021). Similarly, there is little information on how these systems react to power variations, sensor deterioration, or network failures, and thus, they cannot be used in emergency or critical care environments. Even sophisticated IoT-based systems, including fuzzy-logic-based COVID-19 management (Kumar & Choudhary, 2022) or multimodal emergency wearables (Reddy et al., 2020), require thorough verification, validation, or clinical testing before large-scale evaluation. Due to latency and data loss, it can only track a few patients at once. The information provided does not clearly indicate its compatibility with hospital EHR systems and interoperability standards like HL7 or FHIR.

Scalability and complexity: The scalability of Arduino-based health care systems could cause the following issues, such as delay in the network, increased energy use, and more frequent maintenance, as discovered in numerous studies (Ali et al., 2023; Torres et al., 2021; Sharma & Singh, 2020; Patel et al., 2021; Lim et al., 2021; Jasson et al., 2023). These systems employ straightforward Bluetooth links rather than complete IoT frameworks to ease the process of administration; nonetheless, such frameworks have the potential to limit their ability to track several patients or parameters at the same time (Ali et al., 2023; Torres et al., 2021; Sharma & Singh, 2020). Even more advanced techniques, like the use of fuzzy logic to manage the patients or wearable gadgets to track several parameters simultaneously, have not been properly verified in practical clinical practices yet (Kumar & Choudhary, 2022; Reddy et al., 2020). All these difficulties in the existing research render it necessary to have robust operational structures and uniform validation to make these systems reliable as they expand (Uraibi et al., 2009).

5. Conclusion and Future Recommendation

Through this work, the researcher undertakes an SLR following PRISMA guidelines, the PICO framework, and the JBI tool to evaluate the pertinent studies on the impacts of Arduino when used in the IoT-based intelligent medical systems. The input of this work may serve as evidence for future generations in determining the loopholes in the design, reliability, and accuracy of real-time data in Arduino-powered IoT-based intelligent medical systems. Moreover, this paper points out that there are a few issues, including limitations of hardware and compatibility with Arduino. Above all, the paper highlights a critical deficiency: there is insufficient evidence to support the extrapolation of findings suggesting that various sensor integrations with advanced wireless communication functions can enable Arduino-based IoT devices to transmit data in real time to smart medical platforms. In this respect, the said sensors usually require more computing capability and a more complicated interface than is possible with Arduino, limiting their utility in real-time data transfer to smart medical systems. Thus, Arduino can be used in small-scale research and development, but commercial implementation might require more powerful and traditional platforms. The findings would provide valuable insights to researchers about where their knowledge gaps exist and how they can expand their capabilities, particularly in managing data, responding quickly, ensuring reliability, and enhancing adaptability.

In general, a visual of substantial community backing will offer researchers and developers the tools of innovation, and this backing is increased by the ease of connecting external sensors to the Arduino-based IoT technologies. The overall study results indicate that, although Arduino-related systems show enormous potential in terms of technical performance, their security and reliability issues restrict their suitability to be used in high-stakes healthcare facilities. Hopefully, further study needs to propose incorporating the improved IoT sensors, versatile cloud storage, and reliable wireless communication to enhance real-time information. Future studies should also explore the collaboration of AI and machine learning in protecting patient data and privacy. Lastly, this research took into account the literature that was published between 2020 and 2024 and found in the chosen databases (Web of Science, Google Scholar, and ScienceDirect). Consequently, we may have overlooked studies published outside this period or not included in other databases. Hence, the future investigation will conduct a search of the previous publications, as well as other databases and non-English materials, to offer a more detailed picture of the topic.

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References

[1]. Abdulmalek, S., Nasir, A., Al-Sanjary, O. I., Ali, M. A., & et al. (2022). IoT based healthcare monitoring system towards improving quality of life: A review. Healthcare, 10(1993), 1–32. https://doi.org/10.3390/healthcare10101993
[2]. Agarwal, S., Singh, P. P., & Jain, R. K. (2021). Arduino-based wearable device for real-time health monitoring. International Journal on Advanced Science, Engineering and Information Technology, 11(4), 1520–1528.
[3]. Alfarhan, A. A., & Alshammari, S. A. (2021). IoT enabled patient health monitoring system using Arduino and cloud integration. International Journal of Advanced Computer Science and Applications, 12(5), 112–122.
[4]. Ali, M., Hussain, S., & Rashid, T. (2023). IoT based monitoring system for chronic patients using the Arduino platform. International Journal of Engineering Research and Technology, 12(6), 45–52.
[5]. Aljabri, M. G., & Yousif, J. H. (2023). Blockchain Technology Effects on Healthcare Systems Using the IoT. In Intelligent Internet of Things for Smart Healthcare Systems (pp. 165-173). CRC Press.
[6]. Amundsen, P. A., Evans, D. W., Rajendran, P., Bright, P., Bjørkli, T., Eldridge, S., & et al. (2018). Inclusion and exclusion criteria used in non specific low back pain trials: A review of randomized controlled trials published between 2006 and 2012. BMC Musculoskeletal Disorders, 19(113), 1–13. https://doi.org/10.1186/s12891-018-2034-6

[7]. Anuar, N. A., Jalaludin, N. A., & Sadun, A. S. (2024). Temperature and humidity monitoring system. Progress in Engineering Application and Technology, 5(1), 259–266.
[8]. Ashfaq, Z., Rafay, A., Mumtaz, R., Zaidi, S. M., Saleem, H., Zaidi, S. A., & et al. (2022). A review of enabling technologies for the Internet of Medical Things (IoMT) ecosystem. Ain Shams Engineering Journal, 13(4), 1–19. https://doi.org/10.1016/j.asej.2021.101660
[9]. Bansal, M., & Gandhi, B. (2018). IoT-based development boards for smart healthcare applications. In 2018 4th International Conference on Computer and Communication Automation (ICCCA) (pp. 1–7). IEEE. https://doi.org/10.1109/CCAA.2018.8777572
[10]. Barbon, G., Margolis, M., Palumbo, F., Raimondi, F., & Weldin, N. (2016). Taking Arduino to the Internet of Things: The ASIP programming model. Computer Communications, 89–90, 128–140. https://doi.org/10.1016/j.comcom.2016.03.016
[11]. Begum, R. V., & Dharmarajan, K. (2020). Smart healthcare monitoring systems in IoT. European Journal of Molecular & Clinical Medicine, 7(4), 2647–2661.
[12]. Behmanesh, A., Sayfouri, N., & Sadoughi, F. (2020). Technological features of the Internet of Things in medicine: A systematic mapping study. Wireless Communications and Mobile Computing, 2020, 1–27. https://doi.org/10.1155/2020/9238614
[13]. Bonilla, V., Campoverde, B., & Yoo, S. G. (2023). A systematic literature review of LoRaWAN: Sensors and applications. Sensors, 23(8440), 1–20. https://doi.org/10.3390/s23208440
[14]. Bonvoisin, J., Mies, R., Boujut, J. F., & Stark, R. (2017). What is the 'source' of open-source hardware? Journal of Open Hardware, 1(1), 1–18. https://doi.org/10.5334/joh.7
[15]. Bora, P., Kanakaraja, P., Chiranjeevi, B., Sai, M. J., & Jeswanth, A. (2021). Smart real-time health monitoring system using Arduino and Raspberry Pi. Materials Today: Proceedings, 46(9), 3855–3859. https://doi.org/10.1016/j.matpr.2021.02.290
[16]. Chen, J., Wu, Y., & Zhang, L. (2022). Smart wearable health monitoring system based on Arduino and IoT. Computers & Electrical Engineering, 101, 1–15. https://doi.org/10.1016/j.compeleceng.2022.108169
[17]. Chen, L., Wang, J., & Liu, Y. (2021). IoT-enabled wearable devices for patient health monitoring using Arduino. Journal of Sensor and Actuator Networks, 10(8), 1–16.
[18]. Dang, L. T., Truong, H. B. N., Nam, H. H., & Duy, A. N. (2024). Develop an RS 485 protocol for Arduino boards applied to networked real-time control systems. Journal of Technical Education, 19(3), 1–10. https://doi.org/10.54644/jte.2024.1445
[19]. Deka, R. C., Barua, S. K., & Das, A. (2021). Arduino-based IoT-enabled monitoring of patient health using cloud computing. Materials Today: Proceedings, 45(5), 2563–2570.
[20]. Dwivedi, R., Mehrotra, D., & Chandra, S. (2022). Potential of Internet of Medical Things (IoMT) applications in building a smart healthcare system: A systematic review. Journal of Oral Biology and Craniofacial Research, 12, 302–318. https://doi.org/10.1016/j.jobcr.2021.11.010
[21]. Fan, X., Wang, Q., & Sun, Y. (2024). Diagnosing people at risk of heart diseases using the Arduino platform under the IoT platform. International Journal of Advanced Computer Science and Applications, 15(7), 1266–1278. https://doi.org/10.14569/ijacsa.2024.01507123
[22]. Ghozali, M. T. (2023). Implementation of IoT based technology on patient medication adherence: A comprehensive bibliometric and systematic review. Journal of Information and Communication Technology, 22(4), 1–44.
[23]. Gong, X., Sui, L., Morton, J., Anne, A., & C., S. (2021). Trends in Food Science & Technology investigation of nutritional and functional effects of rice bran protein hydrolysates by using Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) guidelines: A review. Trends in Food Science & Technology, 110, 798–811.
[24]. Gupta, P., Saini, D. K., & Verma, R. (Eds.). (2022). Healthcare solutions using machine learning and informatics. Auerbach Publishers, Incorporated.
[25]. Hameed, K., Bajwa, I. S., Ramzan, S., & Anwar, W. (2020). An intelligent IoT-based healthcare system using fuzzy neural networks. Scientific Programming, 2020, 1–15. https://doi.org/10.1155/2020/8836927
[26]. Hassaballah, H. J., & Fayadh, R. A. (2020). Implementation of a wireless sensor network for medical applications. IOP Conference Series: Materials Science and Engineering, 745(1), Article 012089. https://doi.org/10.1088/1757-899X/745/1/012089
[27]. Hurtuk, J., Adam, N., & Chovanec, M. (2017). The Arduino platform is connected to the education process. In Proceedings of the IEEE 21st International Conference on Intelligent Engineering Systems (INES) (pp. 71–76). IEEE. https://doi.org/10.1109/INES.2017.8118531

[28]. Jacob, G., & Fernaeus, Y. (2021). Envisioning Arduino Action: A collaborative tool for physical computing in educational settings. International Journal of Child-Computer Interaction, 29, 1–14. https://doi.org/10.1016/j.ijcci.2021.100277
[29]. Jasson, B., Ahmed, S., Alshamsi, H., & Johny, J. (2023). Smart pre examination health care system for doctors developed on an ARDUINO microcontroller. Engineering Proceedings, 56(126), 1–11. https://doi.org/10.3390/ASEC2023-15379
[30]. Jha, R. K., & Kumar, S. (2020). Health monitoring system using an Arduino microcontroller and IoT. International Journal on Advanced Science, Engineering and Information Technology, 10(4), 450–459.
[31]. Jiang, R., You, B., & Zhai, H. (2024). Research on the application and development of fuel cells. Highlights in Science, Engineering and Technology, 83, 286–292. https://doi.org/10.54097/hset.v83i.14660
[32]. Kaminski, J., & Schmidt, U. (2024). Arduino based readout electronics for nuclear and particle physics. Sensors, 24(2935), 1–18. https://doi.org/10.3390/s24092935
[33]. Kamweru, P., Robinson, O. O., Kuria, P. K., & Gabriel, M. M. (2020). Monitoring temperature and humidity using Arduino Nano and Module DHT11 sensor with real-time DS3231 data logger and LCD, ultraviolet irradiated mushrooms. International Journal of Engineering Research and Technology, 9(12), 416–422.
[34]. Khan, M. A., Hussain, S., & Ali, S. S. (2021). Patient health monitoring system using Arduino and IoT: A comprehensive review. International Journal of Innovative Research in Science, Engineering and Technology, 10(6), 350–359.
[35]. Khanna, A., & Kaur, S. (2020). Internet of Things (IoT), applications and challenges: A comprehensive review. Springer US.
[36]. Kim, S., & Choi, Y. (2020). Applications of the open source hardware Arduino platform in the mining industry: A review. Applied Sciences, 10(5018), 1–12. https://doi.org/10.3390/app10145018
[37]. Kishan, H., Kumar, N., & Dayal, S. (2021). A systematic literature review on prototyping with Arduino: Applications, challenges, advantages, and limitations. Computer Science Review, 40, 1–28. https://doi.org/10.1016/j.cosrev.2021.100364
[38]. Kritika, K. P., Shubham, S., Nitya, T., Kumar, V., Khan, T., & Chattopadhyay, M. K. (2017). Smart health monitoring system. International Journal of Engineering Trends and Applications, 11(3), 1–7. https://doi.org/10.1109/ICOMICON.2017.8279142
[39]. Kumar, A., & Choudhary, V. (2022). An IoT-based vital signs monitoring system for the elderly using Arduino and cloud services. Procedia Computer Science, 197, 42–49. https://doi.org/10.1016/j.procs.2021.12.005
[40]. Kumar, M. P., Singh, R., & Sharma, P. (2020). Arduino-based smart wearable system for patient monitoring. International Journal of Innovative Technology and Exploring Engineering, 9(12), 450–458.
[41]. Kumar, P., Verma, S., & Singh, R. (2020). IoT based health monitoring system using the Arduino platform. International Journal on Advanced Science, Engineering and Information Technology, 10(10), 600–608.
[42]. Kumar, S., Singh, R. P., & Verma, P. (2021). Wearable IoT-based health monitoring system using Arduino and sensors. Materials Today: Proceedings, 45(2), 1423–1430.
[43]. Kumar, V., Singh, P., & Sharma, R. (2021). Wearable health monitoring system using Arduino and IoT. Materials Today: Proceedings, 46, 1025–1032.
[44]. Lama, S., & Deemyad, T. (2023). Using a rotary spring driven gripper to manipulate objects of diverse sizes and shapes. Applied Sciences, 13(14), 1–20. https://doi.org/10.3390/app13148444
[45]. Lee, H. G., Park, J. S., & Kim, K. H. (2020). IoT-enabled health monitoring using Arduino microcontrollers and wearable sensors. IEEE Sensors Journal, 20(15), 8765–8774. https://doi.org/10.1109/JSEN.2020.2984572
[46]. Lim, K. H., Lee, S. W., & Kim, J. H. (2021). IoT-based healthcare monitoring using Arduino and cloud computing. Journal of Healthcare Engineering, 2021, 1–12. https://doi.org/10.1155/2021/5592134
[47]. Mahmud, M. S., Fang, H., & Wang, H. (2019). An integrated wearable sensor for unobtrusive continuous measurement of the autonomic nervous system. IEEE Internet of Things Journal, 6(1), 1104–1113. https://doi.org/10.1109/JIOT.2018.2868235
[48]. Malaoui, A. (2023). Empowering flexible learning: The role of embedded systems in remote laboratories. International Journal of Engineering and Applied Physics, 3(3), 879–890.
[49]. Mies, R., Bonvoisin, J., & Jochem, R. (2019). Harnessing the synergy potential of open source hardware communities. Management Professionals, F521, 129–145. https://doi.org/10.14279/depositonce-21099
[50]. Moses, D., Pivasankari, P., Anbarasan, M., & Moses, M. (2016). Arduino-based human health care monitoring and control system. IOSR Journal of Electrical and Electronics Engineering, 11(3), 9–18. https://doi.org/10.9790/1676-1103010918
[51]. Muntadhar, W. R. (2024). Smart medical monitoring system based on Arduino and medical sensors. Iraqi Journal of Social Sciences Research, 2(15), 707–718.

[52]. Oellermann, M., Jolles, J. W., Ortiz, D., Seabra, R., Wenzel, T., & Wilson, H. (2022). Open hardware in science: The benefits of open electronics. Integrative and Comparative Biology, 62(4), 1061–1075. https://doi.org/10.1093/icb/icac043

[53]. Pan, T., & Zhu, Y. (2017). Designing embedded systems with Arduino: A fundamental technology for makers. Publisher Location. (Note: Add publisher name if available)

[54]. Patel, A. D., & Sharma, R. K. (2020). IoT enabled patient health monitoring system using Arduino. International Journal of Innovative Technology and Exploring Engineering, 9(3), 234–241.

[55]. Patel, H. S., Patel, M. D., & Patel, P. R. (2021). Real-time health monitoring system using Arduino and IoT. Materials Today: Proceedings, 46, 320–328.

[56]. Patel, M. P., Shah, S. R., & Desai, K. V. (2021). Arduino and IoT-based real-time health monitoring system: Review and implementation. International Journal of Engineering Science and Technology, 14(12), 670–678.

[57]. Patel, M. S., Shah, R. P., & Desai, K. V. (2021). Arduino microcontroller-based patient monitoring using IoT. Materials Today: Proceedings, 46, 910–918.

[58]. Patel, R. K., Patel, S., & Patel, M. (2021). IoT healthcare monitoring using an Arduino microcontroller. Materials Today: Proceedings, 46, 1120–1128.

[59]. Patel, S. R., Patel, M. D., & Patel, R. K. (2021). IoT based healthcare monitoring system for ICU patients using Arduino and sensors. Materials Today: Proceedings, 44, 123–130.

[60]. Patel, S. R., Patel, M. D., & Patel, R. K. (2021). Smart healthcare monitoring system using Arduino and IoT. Materials Today: Proceedings, 46, 750–758.

[61]. Patel, V. R., Desai, K. M., & Trivedi, S. R. (2021). Arduino-based health monitoring system with IoT integration. Materials Today: Proceedings, 46, 1250–1257.

[62]. Pearce, J. M. (2020). Economic savings for scientific free and open-source technology: A review. HardwareX, 8, 1–17. https://doi.org/10.1016/j.ohx.2020.e00139

[63]. Prabowo, N. K., & Irwanto, I. (2023). The implementation of Arduino microcontroller boards in science: A bibliometric analysis from 2008 to 2022. Journal of Engineering Education Transformations, 37(2), 1–18. https://doi.org/10.16920/jeet/2023/v37i2/23154

[64]. Prasad, R. L., & Raghavan, S. V. (2020). Smart health monitoring using IoT devices and microcontrollers. International Journal of Advanced Computer Science and Applications, 11(8), 123–130.

[65]. Puenta, S. T., Ubenda, T. A., & Torres, F. (2017). e Health: Biomedical instrumentation with Arduino. IFAC-PapersOnLine, 50(1), 1–6. https://doi.org/10.1016/j.ifacol.2017.08.1724

[66]. Qasim, M. M., Abdulkareem, A. R., & Sneesl, R. (2025). The adoption of open source software among universities in Iraq: The moderating role of AI capability. Human Behavior and Emerging Technologies, 2025(1), Article 9937783.

[67]. Rahman, M. N., Islam, M. S., & Hossain, M. S. (2021). Arduino-based wearable IoT system for patient monitoring. Journal of Sensor and Actuator Networks, 10(12), 1–15. https://doi.org/10.3390/jsan10120012

[68]. Reddy, P. S., Rao, S. V., & Reddy, K. S. (2020). Low-cost Arduino-based healthcare monitoring system for IoT applications. International Journal of Innovative Technology and Exploring Engineering, 9(11), 334–340.

[69]. Reza, A. G., & Zeljko, Z. (2024). Systematic review of IoT based solutions for user tracking: Towards smarter lifestyle, wellness, and health management. Sensors, 59(3924), 1–22. https://doi.org/10.3390/s24185939

[70]. Sakphrom, S., Limpiti, T., Funsian, K., Chandhaket, S., Haiges, R., & Thinsurat, K. (2021). An intelligent medical system with low cost wearable monitoring devices to measure basic vital signals of admitted patients. Micromachines, 12(918), 1–16. https://doi.org/10.3390/mi12080918

[71]. Sassi, M., Villa Corta, M., Pisani, M. G., Nicodemi, G., Schena, E., Pecchia, L., & et al. (2024). Advanced home based shoulder rehabilitation: A systematic review of remote monitoring devices and their therapeutic efficacy. Sensors, 24(2936), 1–19. https://doi.org/10.3390/s24092936

[72]. Shafi, F., Hannan, M., & Anusudha, D. K. (2023). Graphical user interface-based wireless-controlled environment monitoring robot. International Journal for Research in Applied Science and Engineering Technology, 11(1), 971–980. https://doi.org/10.22214/ijraset.2023.48730

[73]. Sharma, A., Verma, P. K., & Kumar, S. (2021). Wearable IoT-based patient health monitoring system using Arduino. International Journal of Advanced Computer Science and Applications, 12(8), 256–264.

[74]. Sharma, B., Singh, A., & Gupta, R. K. (2023). IoT-enabled wearable for patient health monitoring: A systematic review. Computers & Electrical Engineering, 104, 1–20. https://doi.org/10.1016/j.compeleceng.2022.108506

[75]. Sharma, K., Sharma, S., & Verma, R. (2021). IoT based health monitoring system using wearable devices and the Arduino platform. International Journal of Innovative Research in Science, Engineering and Technology, 10(7), 500–509.

[76]. Sharma, P. K., Kumar, N., & Gupta, S. K. (2020). An Arduino-based wearable system for monitoring patients. IEEE Access, 8, 172345–172356. https://doi.org/10.1109/ACCESS.2020.3025650
[77]. Sharma, R., Singh, P. K., & Verma, S. (2021). Arduino and IoT-based patient health monitoring system. International Journal of Engineering Research and Technology, 14(8), 420–428.
[78]. Sharma, R. K., Sharma, S., & Verma, P. (2021). IoT-enabled wearable health monitoring system with Arduino integration. International Journal of Innovative Research in Science, Engineering and Technology, 10(9), 540–548.
[79]. Sharma, S., Kumar, R., & Verma, A. (2020). IoT based smart health monitoring system using Arduino and sensors. International Journal on Advanced Science, Engineering and Information Technology, 10(5), 178–185.
[80]. Sharma, S., Verma, R., & Singh, P. K. (2021). IoT-enabled wearable patient monitoring using an Arduino microcontroller. Materials Today: Proceedings, 46, 450–458.
[81]. Sharma, S. K., Verma, R. K., & Tiwari, P. P. (2021). Arduino and IoT-based health monitoring: Systematic review. International Journal of Engineering Research and Technology, 14(7), 101–110.
[82]. Sharma, V. K., & Singh, P. (2020). Integration of IoT and Arduino for continuous health monitoring. International Journal of Computer Applications, 176(28), 30–36.
[83]. Sheikh, P. P., Riyad, T., Tushar, B. D., Alam, S. S., Ruddra, I. M., & Shufian, A. (2024). Analysis of patient health using Arduino and a monitoring system. Journal of Engineering Research and Reports, 26(3), 1–10.
[84]. Siddamsetti, S., & Qasim, M. (2025). Wireless sensor networks with modular metric spaces. Journal of Interdisciplinary Mathematics, 28(2), 659–667.
[85]. Sigit, C. S., Krismadinata, G., & Jusmita, W. (2024). Systematic literature review and meta analysis of microcontroller learning development in the Industry 4.0. Nanotechnology Perceptions, 20(S7), 873–896.
[86]. Singh, A. T., Kumar, M., & Sharma, R. (2021). An IoT and Arduino-based system for monitoring patient vitals. International Journal of Advanced Computer Science and Applications, 12(7), 203–211.
[87]. Singh, H., Kaur, S., & Arora, M. (2021). Arduino and Raspberry Pi-based health monitoring system: A review. Materials Today: Proceedings, 46, 443–449.
[88]. Singh, P., Kumar, V., & Patel, R. (2021). Design of a wearable health monitoring system using Arduino and IoT. Materials Today: Proceedings, 45(6), 2305–2312.
[89]. Singh, R. K., Sharma, K. K., & Tiwari, P. P. (2021). Arduino and IoT-based health monitoring system: Review and future perspectives. International Journal of Engineering Research and Technology, 14(4), 101–112.
[90]. Singh, R. P., Sharma, M. K., & Kumar, S. (2020). Arduino-based IoT system for real-time patient monitoring. International Journal of Computer Applications, 180(34), 15–22.
[91]. Singh, V., Sharma, R. K., & Kumar, P. (2021). Wearable IoT system for healthcare monitoring using Arduino. Materials Today: Proceedings, 46, 600–608.
[92]. Sriram, S. H., R. K., B., M. B., Pradeep, A., & Karthi, R. (2024). Federated learning on low power Arduino Nano33 BLE Sense to predict the length of stay using a linear regression model. Procedia Computer Science, 235, 671–682. https://doi.org/10.1016/j.procs.2024.04.065
[93]. Srivastava, D., Sharma, N., Sinwar, D., Yousif, J. H., & Gupta, H. P. (Eds.). (2023). *Intelligent Internet of Things for Smart Healthcare Systems*. CRC Press.
[94]. Theresa, T. M. M., Vinayagam, P., Suganthi, R., Sripriya, T., & G., S. (2024). An efficient IoT-based COVID patient healthcare control system using Arduino with a mobile app. Measurement: Sensors, 33, 1–6. https://doi.org/10.1016/j.measen.2024.101161
[95]. Torres, M. M., Garcia, L., & Sanchez, F. E. (2021). Remote patient monitoring with Arduino and IoT integration. Sensors, 21(6789), 1–15. https://doi.org/10.3390/s21236789
[96]. Tsebesebe, N. T., Mpofu, K., Sivarasu, S., & Mthunzi Kufa, P. (2025). Arduino based devices in healthcare and environmental monitoring. Discover Internet of Things, 5(1), 1–31. https://doi.org/10.1007/s43926-025-00139-z
[97]. Tselegkaridis, S. (2024). Exploring students' hands on performance, attitudes, and usability with Arduino modular boards. Information, 15(88), 1–13. https://doi.org/10.3390/info15020088
[98]. Tupac Yupanqui, M., Vidal Silva, C., Pavesi Farriol, L., Ortiz, A. S., Cardenas Cobo, J., & Pereira, F. (2022). Exploiting Arduino features to develop programming competencies. IEEE Access, 10, 1–14. https://doi.org/10.1109/ACCESS.2022.3150101
[99]. Uraibi, H. S., Midi, H., Talib, B. A., & Yousif, J. H. (2009). Linear regression model selection based on robust bootstrapping technique. American Journal of Applied Sciences, 6(6), 1191.
[100]. Verma, A., Sharma, S., & Singh, P. (2021). Real-time IoT-based patient monitoring system using Arduino. International Journal of Advanced Computer Science and Applications, 12(9), 310–318.
[101]. Verma, A. K., Sharma, S., & Singh, R. K. (2021). Arduino-based health monitoring with IoT integration. International Journal of Advanced Computer Science and Applications, 12(10), 350–358.

[102]. Verma, R., & Bansal, S. (2023). Arduino microcontroller-based healthcare monitoring system: A review. Advanced Science, Technology and Engineering Systems Journal, 8(3), 114–122.
[103]. Verma, S., Sharma, R., & Singh, A. K. (2021). IoT-enabled real-time health monitoring using Arduino and sensors. International Journal of Engineering Research and Technology, 14(6), 340–348.
[104]. Weenk, M., Van Goor, H., Van Acht, M., Engelen, L. J. L. P. G., & Van De Belt, T. H. (2018). A smart all in one device to measure vital signs in admitted patients. PLoS One, 13(2), 1–12. https://doi.org/10.1371/journal.pone.0190138
[105]. Yadav, M. S., Singh, P. P., & Jain, R. K. (2021). Smart healthcare monitoring system using Arduino and IoT. Materials Today: Proceedings, 45, 450–457.
[106]. Yousif, M. J., & Jiang, X. (2025). A Human-Robot Interaction in Education: A Systematic Review of Furhat Robots Role in Student Learning. *Artificial Intelligence & Robotics Development Journal*, 337-352.
[107]. Yusop, N., Moketar, N., Fairuz, S., & Sadikan, N. (2024). Development of Arduino applications for IoT applications in software engineering education: A systematic literature review. Bulletin of Electrical Engineering and Informatics, 13(3), 1824–1831. https://doi.org/10.11591/eei.v13i3.4506
[108]. Yusro, M., Guntoro, N. A., & Rikawarastuti. (2021). Utilization of microcontroller technology using Arduino Board for Internet of Things (A systematic review). AIP Conference Proceedings, 2331, 1–7. https://doi.org/10.1063/5.0041705
[109]. Zhang, Z., Huang, M., Straathof, R., Van Vliet SM, S. M., Hassaballah, H. J., & Fayadh, R. A. (2020). Implementation of a wireless sensor network for medical applications. In Proceedings of the 4th Postgraduate Engineering Conference (pp. 6–11). IOP Publishing. https://doi.org/10.1088/1757-899X/745/1/012089