Prestieesci Research Review

A STUDY ON THE RESEARCH AND DEVELOPMENT OF HIGHLY ENERGY-EFFICIENT ELECTRONIC CIRCUITS FOR BODY SOUND MONITORING APPLICATIONS

Yan Linbo*, Muhammad Ezanuddin Abdul Aziz

Lincoln University College, 47301 Petaling Jaya, Selangor D. E., Malaysia.

Corresponding author: Yan Linbo, Lincoln University College, 47301 Petaling Jaya, Selangor D. E., Malaysia,

Email: yanlinbo_6054@qq.com

ABSTRACT

This work mainly aims at energy-efficient electronic circuit development for monitoring body sound, especially non-invasive real-time health diagnostics. The high increase in the wearables of health devices has brought about low-power advancement circuits to continuously monitor physiological signals, including heartbeats, lung sounds, and many other internal body sounds- the essentials in disease detection and management. This study focuses on ultra-low-power sensors, analog-to-digital converters, and efficient signal-processing techniques that reduce power consumption without compromising data accuracy. The problem is that wearable health technology often struggles to balance its performance and its energy efficiency: these devices are usually battery-operated, so they need to run for so long without frequent recharging. This system integrates a sensor module to collect heart sound signals; data processing is controlled by the controller module, an Arduino Mega 2560 R3. Interaction between the user and the interface occurs on the TFT LCD screen, and storage of the information obtained is done using the SD card. The ESP8266 Wi-Fi module provides remote monitoring with wireless connectivity. Energy harvesting technologies and thermoelectric systems are the next type of space where the author spends his work, enhancing device autonomy through harvested ambient energy sources. The results show that this is entirely feasible in the realm of wearable health monitoring systems and low-power, which can continuously monitor body sounds-a promising solution for health care management. This research, therefore, contributes toward the development of healthier, long-lasting, and efficient health monitoring devices with emerging potential in handling real-time chronic condition management and early disease detection.

KEYWORDS: Energy-efficient electronic circuits, Body sound monitoring applications, Wearable health devices, Low power sensors.

INTRODUCTION

There is a plethora of information available in the sounds made by the human body that might be used for health monitoring and disease identification. For example, cardiopulmonary signals have been widely used in hospitals for decades to diagnose heart and lung diseases. Foetal heart rate, which may be heard, is an important measure of the baby's vital signs and should be known. The absence of tissue adhesions and the success of the abdominal surgery may both be ascertained by listening to the bowel sound. Modern advancements in digital signal processing and high-performance circuits have made it possible to design one-of-a-kind sound monitoring and diagnostic devices that make use of the physiological sounds produced by different individuals (Ban et al., 2023). So, unlike the commonly used diagnostic tools that utilise dynamic power transfers, like X-ray scanning and ultrasound detection, sound-based diagnosis and monitoring do not pose any danger to people's bodies, either now or in the future. In most cases, sensors consist of three parts: a sound sensor for wirelessly tracking the wearer's vitals, a portable base station (PBS) for small, mobile devices, and a server to store, organise, and provide users with their recorded health data. Recent developments in integrated circuits, wireless communication, mobile networks, and sensor technologies have made it possible to create sound sensors with very low power consumption, ideal for everyday use. The rising demand for wearable health monitoring electronics has directed much research into developing highly energy-efficient electronic circuits, especially for body sound monitoring (Demolder et al., 2021). The devices monitoring the vital sounds for heartbeats and lung activity necessitate low-power circuits so that these monitors will last long with batteries while still giving the most accurate performance. The challenge is optimizing power consumption without sacrificing data quality. Recent studies highlight circuit design innovations and energy-efficient processing as well as power management techniques in the quest to compactuate and make wearable electronics rugged. This work reviews recent work and development activities carried out to improve energy efficiency for running, and real-time body sound monitoring (Kim et al., 2023).

BACKGROUND OF THE STUDY

Large contributions have been brought about by the growing demands for wearable health monitoring devices in the development of highly energy-efficient electronic circuits, particularly for body sound monitoring applications. Such devices measure various physiological parameters, such as heart rate, respiration rate, and internal body sounds, which are critical in real-time health diagnostics and chronic disease management. A further basic challenge in designing such systems is the tradeoff between good performance and low power consumption since many wearables rely on battery operation and must run for some duration between recharges. Traditionally, body sound monitoring devices have incorporated stethoscopes and pulse oximeters, which are somewhat power-intensive, thereby constraining their portability and practical use for continuous monitoring (Sempionatto et al., 2021). Recent developments in ultra-low-power electronics, particularly ultra-low-power sensors, analog-to-digital converters, and signal-processing units, lay the groundwork for better body sound monitoring technologies. These frontiers aim to minimize power consumption for each component while still ensuring correct and reliable measurements. This is critical for wearable health devices that have to be compact while ensuring long-term usability. Further, new directions to wireless communication protocols and energy harvesting have now managed fresh avenues for less reliance on traditional sources of power (Kang et al., 2024). Low-power wireless protocols like BLE and Zigbee support high-data transfer and low power, making body sound monitoring systems interact with mobile phones or any remote device with an extended length of battery durability. The energy harvesting methods include piezoelectric and thermoelectric systems using ambient energy sources (such as movement or body heat) to power these devices for better energy autonomy. The integration into this application for monitoring sounds within the body should be aimed at transforming how one tracks health conditions and their management through real-time and non-invasive user monitoring (Kwon et al., 2023). This is where the demand for energy-efficient circuits forms the epicentre of smart health-monitoring devices, where long lifespan performance with more comfort on the user's side and in the manner of accuracy in gathering data are in great demand. This study is focused on research developments that are currently going on for body sound monitoring and identifies promising solutions for creating sustainable, energy-efficient electronic circuits (Lee et al., 2024).

PURPOSE OF THE RESEARCH

This research develops highly energy-efficient electronic circuits for specific purposes of body sound monitoring, meaning power consumption can be reduced even further while maintaining high performance and accuracy. Advanced circuit designs, low-power sensors, and techniques for energy-efficient signal processing can thus be explored to set up the possibility of continuous, real-time health monitoring with minimal energy usage. The study also sets the goal of making the wearable technology device more sustainable and autonomously capable of functioning for longer periods without exhausting their energy and recharging more frequently. To that end, it would advance more practical, reliable, and long-lasting means of developing solutions for non-invasive health monitoring technologies.

LITERATURE REVIEW

This field of development of energy-efficient electronic circuits for body sound monitoring applications rapidly advances and continues to be driven by increased demand for wearable health monitoring devices for continuous, non-invasive data gathering. The systems that can detect and analyze physiological sounds such as heartbeats, lung sounds, and blood flow become integral to remote health monitoring, early disease detection, and personal health care. The main challenge still lies in reducing power consumption without sacrificing either accuracy or reliability in sound measurements. Most conventional body sound monitoring devices, including stethoscopes and portable ECGs, have often been bounded by high energy requirements, which severely degrade the usability of these devices for a long period in wearable form factors (Lim et al., 2021). In recent years, a lot of research has aimed toward designing low-power electronic circuits that could sustain continuous operation over long periods without requiring frequent recharging. Advances in low-power analog-to-digital converters (ADCs), amplifiers, and signal-processing units have opened up ways of capturing and converting body sound signals into useful information without considerably wasting power. These circuits are typically built with substantial attention paid to power management, allowing the system to period plastically enter low-power states, such as between measurements of sound. Further, innovations in low-power sensors have been instrumental in keeping the energy footprint of body sound monitoring systems low, enabling them to be fabricated into compact wearable devices (Mahmood et al., 2022). Energy-efficient signal processing techniques are another key area of research. The DSP algorithm was adapted to limit the computational load to have a sound analysis of high quality. The implementation of noise reduction and feature extraction algorithms is incorporated for efficiently processing audio data so that only relevant information is transmitted or recorded. More research in this line would be on energy harvesting technology piezoelectric to thermoelectric systems and its use to extend battery life for those devices by tapping into the ambient energy from the wearer's movement or body heat (Park et al., 2023). Other areas would be in wireless communication technologies, such as low-power protocols like BLE. These enable data transmission while not depleting the battery resources. Such advancements open the possibility of autonomously operating wearable health devices for long periods through real-time continuous monitoring of body sounds for early diagnosis and personalized healthcare management. Increasing demands for more sustainable and efficient wearable health technologies make this research in low-power circuit design, energy harvesting, and wireless communication constantly important to work over the limitations and enable the next generation of body sound monitoring systems (Zhou et al., 2024).

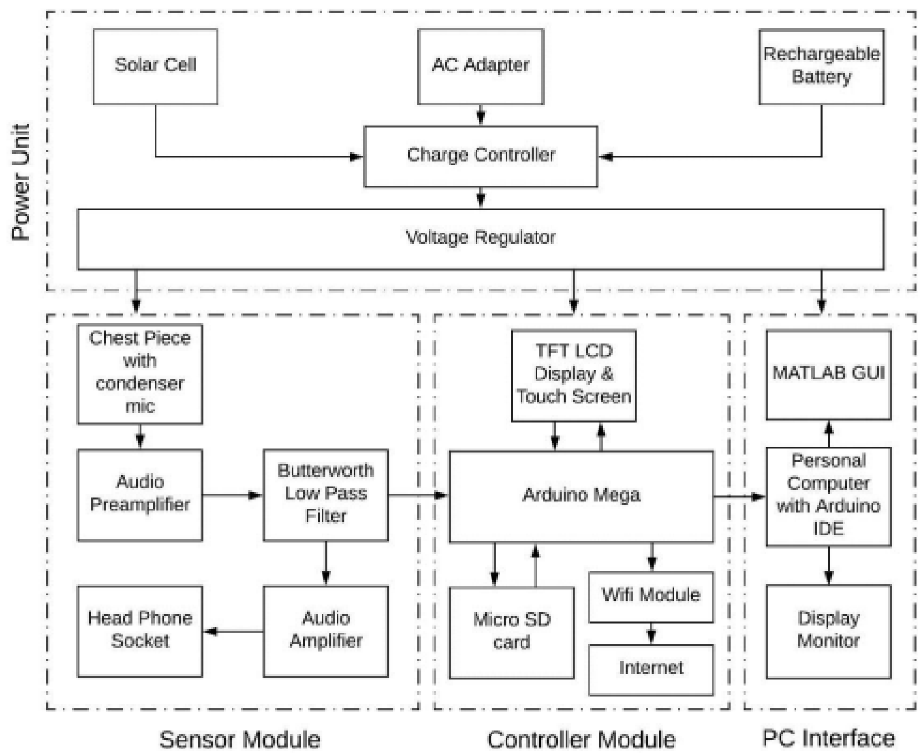
RESEARCH QUESTION

1. How can efficient circuit designs improve the performance of a body sound monitoring system?

METHODOLOGY

The suggested system is primarily composed of four parts: The Sensor Module is in charge of collecting the heart rate analogue signal and transmitting it to the controller. The controller module acts as the brains of the operation, analysing cardiac sound data for fundamental analysis, storing the acquired signals on an SD card, establishing wireless connections with a personal computer, and regulating the TFT LCD module's User Interface (UI). The power unit draws electricity for the whole system from a wide range of sources, some of which are renewable and others of which are not. The acquired heart sound signal is subjected to thorough analysis via the usage of PC Interfacing. Each module is examined in detail in the sections that follow.

Figure 1: Block Diagram



CONTROLLER MODULE

This cardiac acquisition system's brain is the Controller Module. It manages and carries out every fundamental function intended for the heart sound acquisition system. The controller is an Arduino Mega 2560 R3 board. A 2.4-inch TFT touchscreen LCD has been used to construct the acquisition system's onboard user interface. An SD card slot is included inside the TFT LCD module. Thus, it was also used to store data on an 8GB memory card. The ESP8266 Wi-Fi module improves the system's remote monitoring capabilities and gives it an IOT flavour. Using a USB connection and a PC with the Arduino IDE already installed, PCG is shown on the LCD monitor for improved signal visualisation. Considering each of these factors, the module's deliverables are:

- Data on heart sounds is stored on SD cards.
- Using Wi-Fi to transmit the heart sound data
- The procedures are carried out using a touchscreen-based user interface.
- Analysis of heart sound at a basic level
- Connecting to a Personal Computer
- Show the signal on the computer screen.

ARDUINO MEGA

The ATmega2560 microprocessor powers the open-source Arduino Mega 2560 R3 hardware platform. Arduino boards are a kind of hardware that anybody with little to no technical experience can program and operate. Fig. 2 depicts the Arduino Mega 2560's whole construction. The following factors are considered while deciding whether to include this gadget in this work:

Two 5V and 3.3V voltage regulators provide the freedom to control the voltage for other hardware modules that are connected to it.

- The Arduino Mega has more I/O pins, a larger size, and more memory.
- The open-source Arduino IDE programming software is compatible with all Arduino boards.
- The Arduino Mega is specifically designed for complicated projects that need extra memory or intricate processes like 3D printing or signal processing.
- There are three methods to power the board: using a USB cable, transferring a code to the board, or using the board's Vin, power port, or battery.
- This board has a resettable poly-fuse that keeps the computer's USB port from overheating when there is a lot of electricity passing through it.

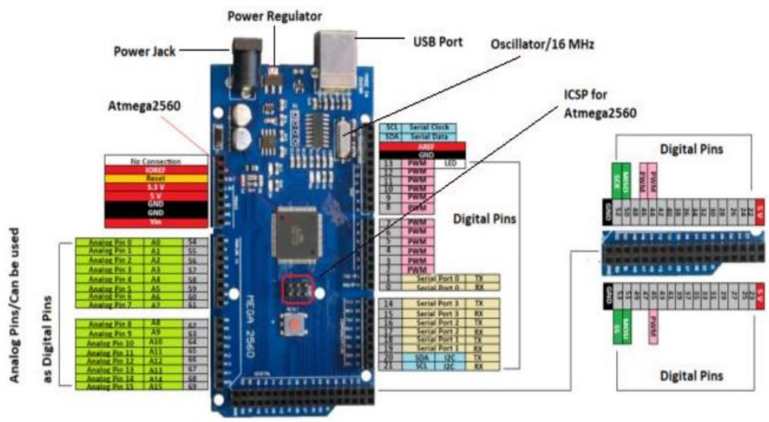


Figure 2. Unplugging the Arduino Mega 2560 R3

Table 1 provides a high-level overview of the Arduino Mega 2560 R3's technical specifications.

Table 1: Arduino Mega Technical Specifications

Specification	Value	Specification	Value
Microcontroller	ATmega2560	Flash Memory	256 KB of which 8 KB used by boot loader
Operating Voltage	5V	SRAM	8 KB
Input Voltage (recommended)	7-12V	EEPROM	4KB
Input Voltage (limits)	6-20V	Clock Speed	16 MHz
Digital I/O Pins	54 (of which 14 provide PWM output)	DC Current per I/O Pin	40 mA
Analog Input Pins	16	DC Current for 3.3V Pin	50 mA

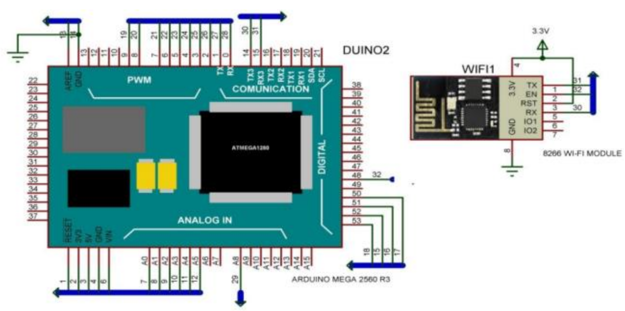
The Wi-Fi Module ESP8266

This project incorporates an ESP8266 Wi-Fi module to turn the acquisition system into an Internet of Things platform. Despite being connected to the acquisition system, the module is not presently carrying out any specific function. This module is fully integrated for the next projects aimed at IoT deployment. Here is a quick overview of the ESP8266 and an explanation of the hardware connection. An inexpensive, stand-alone wireless transceiver that might be used for end-point Internet of Things advancements is the ESP8266 Wi-Fi module. Employing the TCP/UDP connection protocol makes it possible for the heart sound acquisition system to be connected to the internet. The Arduino Mega must employ a series of AT instructions via UART with a defined Baud rate (by default, 115200) to connect with the ESP8266 Wi-Fi module. The ESP8266 can

- 802.11 b/g/n 2.4 GHz Wi-Fi that supports WPA and WPA2,
- GPIO stands for general-purpose input/output.,
- The serial communication protocol of the Inter-Integrated Circuit (I^2C),
- Conversion from analogue to digital (10-bit ADC)
- The serial communication protocol known as the Serial Peripheral Interface (SPI),
- DMA (Direct Memory Access) and I^2S (Inter-IC Sound) share pins with GPIO.
- UART (on certain pins, as well as the option to activate a transmit-only UART on GPIO2)
- PWM, or pulse-width modulation.

Hardware Connection: Fig. 3 displays the hardware connection that is already in place for the acquisition system.

Figure 3: Interface Between the Arduino Mega Board and the ESP8266 Wi-Fi Module



Module for SD cards

Heart sound data files cannot be stored on Arduino boards due to their limited storage capacity. Therefore, the data must be stored on an external storage device. The SD Card Association (SDA) created the Secure Digital, or SD card, non-volatile memory card format for use in portable electronics. Here, the heart sound signal data is stored in bulk on an SD card. The information is kept in.txt files. No additional module is needed in this operation since the TFT LCD module has an SD card port integrated right in. The Arduino Mega is directly linked to the pins that correspond to the SD cards in the TFT LCD. The connections of the corresponding pins are

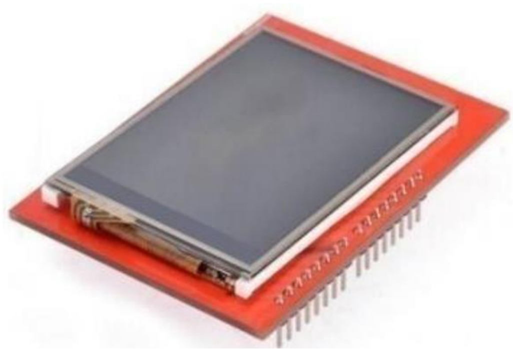
TFT LCD Pin	Arduino Pin	TFT LCD Pin	Arduino Pin
SD_CS	Pin 53	MOSI/SD_D0	Pin 51
SD_SCK	Pin 52	VCC	3.3 V
MISO/SD_DI	Pin 50	GND	GND

Researchers utilise an 8 GB memory card for our work. The maximum RAM needed for each 4-second heart sound data set is 200 KB. It is possible to store around 35,000 data samples on the memory card. Figure 21 depicts the interface circuit between the Arduino Mega and the memory card.

UI & TFT LCD Module

A direct user interface is necessary to operate the full heart sound acquisition equipment. In this work, the user interface is designed using a 2.4-inch TFT touchscreen LCD. The developed user interface asks the user for the patient's name, age, and weight after showing the welcome message. The sensor choice page was then routed, and the functionality page appeared based on the user's input. Here, the user may touch the respective functionalities shown in the user interface to save, analyse, transmit, or observe the signal. The standard picture of a 2.4-inch TFT touch LCD module is shown in Fig. 4.

Figure 4: The Display is a 2.4-inch TFT Touch LCD

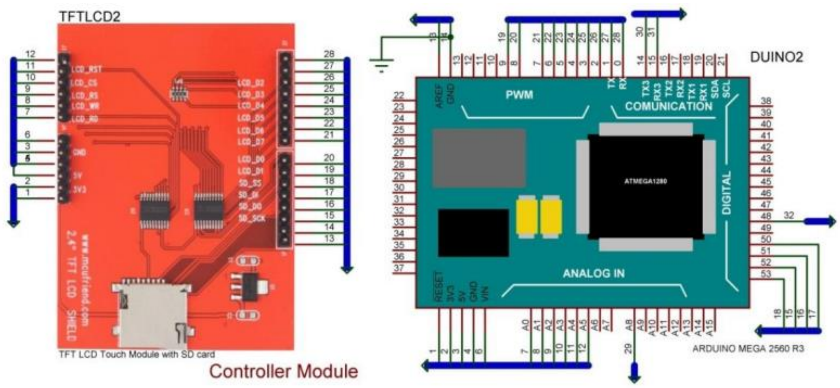


The used TFT module's short specifications are as follows:

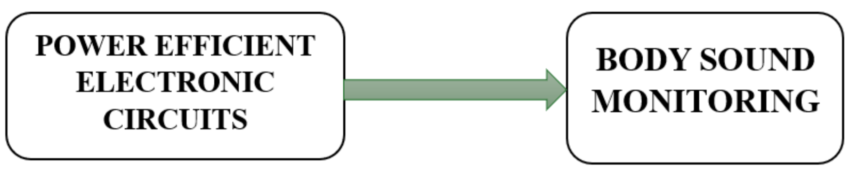
- 2.4" touchscreen TFT LCD
- 240 × 320 pixels
- 3.3V is the operating voltage.
- Modes of operation: 8-bit and SPI
- Interface IC: Interface ILI9341
- There is an SD card option for data storage.
- Interfaces with Arduino are simple (a free library is provided).

The LCD module is a plug-and-play shield that allows the Arduino UNO boards to have an LCD screen placed right on top of them. However, the Arduino Mega boards (i.e., 50, 51, 52, and 53) have different SD card ports, thus an additional wire has been added to enable the module. Fig. 5 illustrates the link in detail.

Figure 5: Arduino Mega Board Compatibility with LCD and SD Card Interface



Conceptual Framework



RESULTS

The testing of controller modules includes the interfacing of the following: PC, Wi-Fi, TFT LCD, and SD card. Every test case makes use of the Arduino Mega and the Arduino IDE.

PC Interfacing

Since Arduino requires particular instructions to function, PC interfacing is necessary from the very beginning. The Arduino IDE is a Windows program that translates C code into machine code and then uploads it to Arduino boards. A Windows PC has the Arduino IDE software installed after downloading it from the official website. Now, with an integrated USB connector and a USB cable, Arduino boards may be directly linked to personal computers. They may begin the interfacing process in the Arduino IDE by going to the "Tools" menu and choosing the appropriate ports and boards. In Fig. 6, researchers can see the PC connected to the Arduino board and the pre-installed Arduino IDE.

Figure 6: Computer-Arduino Board Interfacing

SD Card Interfacing

The initial step in SD card interfacing is to connect the SD card to the Arduino module, following the connection illustrated in Figure 5. Then, after connecting the PC and Arduino boards via USB, the 'Read Write' SD card library sample was uploaded to the boards. This example reads and writes directly to the memory card, as the name suggests. The wrong file format of the memory card caused the SD card identification to fail on the very first attempt. The standard file systems that the Arduino SD library is compatible with are FAT16 and FAT 32. They need to format the SD card to use the FAT16 or FAT 32 file system before they can put it into the SD card slot. Following that, the read/write operation worked without a hitch.

Interface Testing for TFT LCD Touchscreen Screens and User Interfaces

The LCD shield is an excellent addition to an Arduino UNO. Additionally, it works well with Arduino Mega; however, an additional wired connection is necessary because of differences in the SD card connectors. After configuring the shield for the LCD and touch screen, the user only has to connect it above the Arduino Mega. However, as a result of production variations, the touch screen requires calibrating. Utilising the MCUFRIEND_kvb library samples, researchers have conducted calibration and visual testing. Only after that will the intended user interface have been tested for every potential error message. Views of the proposed user interface are shown in Figure 7. Patient data is received by the user via the figure's window 7 (a). Every input field's mandatory validation is also functioning properly. To begin collecting data, window 7 (b) prompts the user to choose the kind of sensor. The heart sound acquisition sensor is the only one that this window can presently take data from. The remaining fields are intended for use in other projects. The acquisition system will include many sensors in the future to enable the simultaneous collection of data. The primary interface for working with the heart sound signal is Windows 7 (c). The 'SEND' and 'analyse' operations are left as future scope since they are not working at the moment. By pressing the "SAVE" button, the heart sound signal may be saved immediately to the memory card together with the patient's initial information. Researchers have designed and tested a rigorous validation system to detect and prevent system faults (such as a missing memory card or a malfunctioning one) and odd user input (such as inputting a number instead of a name or an integer for an age). The memory card missing issue is seen in Figure 7 (d).

Figure 7. Different Windows of the Designed User Interface (a) Window for Patient Information (b) Window for Sensor Selection (c) Window for Functionality (d) Error Related to Memory Card Validation

Sensor Module Interfacing

Arduino Mega boards typically accept analogue signals as input and process them using the internal analog-to-digital converter (ADC). These 16 dedicated analogue pins allow for seamless connection with sensor modules. A four-analog-pin TFT LCD touchscreen module may execute a variety of operations. To gather or analyse data, the remaining ports may be connected to any sensor module. Analogue pin 8 is now assigned to the heart sound signal sensor so it can carry out its intended function. There are additional analogue pins that may be used for acquiring signals of any kind. Thus, the sensor choice window is now part of the UI design and will be left for future improvement. To save the signal to the memory card, the built-in ADC of the Arduino Mega transforms the analogue signal into digital form. The specified specifications state that the Arduino ADC can reach a sampling rate of up to 77 kHz and has a 10-bit resolution. Even with SD card write and execution delays, the obtained heart sound signal sampling rate is close to 5 kHz. For a heart sound signal, which typically ranges from 10 to 500 Hz, this is much higher than the Nyquist Rate.

Wi-Fi Module Interfacing

However, at the moment, it is not transmitting data wirelessly, even if the Wi-Fi module is a part of this project for the Internet of Things deployment. The AT commands were used to correctly connect this module with the acquisition system. Researchers have successfully verified all hardware connections and basic communication between the Arduino and Wi-Fi module. Adding a single line of code to the main Arduino program enables data transmission and reception via the Internet, making it easy to transmit data.

DISCUSSION

The work presented here works on the development of energy-efficient electronic circuits for body sound monitoring systems, which should be implemented in a manner that utilizes less power in a way that does not compromise the accuracy and reliability of physiological data that are monitored. One of the big challenges with wearable health devices would be to optimize energy usage while keeping high performance, primarily since these devices must constantly run for considerable periods and are not constantly recharged. An important role in reducing the energy consumed is played by low-power sensors, analog-to-digital converters, and signal processing techniques. The system under development in this research makes it possible to realize real-time health monitoring as presented by embedding components such as Arduino Mega microcontroller, ESP8266 Wi-Fi module, and SD card storage for the heart sound data. The design is particularly notable for using low-power wireless communication protocols, such as Wi-Fi, for remote monitoring. It, therefore, enhances the usability of the device in everyday scenarios, though at the same time, no matter to what extent and levels the system managed to reach, it has yet to realize full deployment concerning the use of the Wi-Fi module, and there is a need for further work in enabling efficient wireless data transmission. With the capabilities of low power-consumption body sound signal collection and storage, coupled with a very user-friendly interface on the screen of the TFT LCD, this continuous noninvasive health monitoring system gives a great approach to real-time analyses and remote monitoring. That provides it with a good competitive advantage in wearable health technology so that anyone can have more convenience and sustainability in monitoring their health. In general, only with further research concerning energy harvesting, signal processing, and further development of wireless transmission capabilities shall long-term functionality and scalability be enhanced.

CONCLUSION

The development of energy-efficient circuits for monitoring body sound leads to a significant advancement in wearable health technology. This study highlights the need to optimize the power consumed while maintaining high accuracies in the detection and analysis of physiological sounds such as heartbeats and lung activity. Using low-power sensors with advanced signal processing algorithms and wireless communication technologies such as BLE and Wi-Fi makes it possible for these devices to provide continuous, real-time health monitoring using minimum energy. It further enhances the autonomy of the devices when utilizing techniques of harvesting energy and through this allows it to decrease frequent recharging procedures and enhance long-term usability. Apart from this, an easy-to-use interface that could be in the form of a TFT LCD touchscreen along with stable data storage on SD cards would ensure accessibility and ease of use for healthcare professionals as well as patients. As demand for non-invasive, wearable health monitoring solutions remains something that is required, focus on the design of energy-efficient circuits will have to be put together to establish sustainable, reliable, and cost-effective devices. The real value of this study is that it brings into the present evolutionary journey of smart health-monitoring systems vibrant developments that would help in better management of diseases, earlier diagnosis, and improved personalized care to society with new, energy-saving wearable devices.

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