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Article

Design and Implementation a Wearable Vital Signs Monitoring System with Low Power Consumption and Measurement Validation

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Abstract: The importance of applying E-Health systems is considered as a standard for the advancement and well-being of people. Wearable devices classified as part of mobile health systems, which is considered as one of E-Health, used to monitor patients.They are widely used to monitor vital signs of patients outside the health institution's environment, compensating for the monitoring devices from the hospital. The most important challenges facing wearable health systems are the accuracy of measurement, power consumption, and compact size. The purpose of this reserch is to design a device that can be worn at a low cost and of a small size to provide comfort to the patient. . The results showed that the device is 99.37% accurate and statistical analysis was performed to test the error. Also, the results showed that the error of the device is small and that outlier values are rarely frequent, which means that the error does not affect the accuracy of the system.

Keywords: wearable device, vital signs monitoring, Arduino Nano, low power consumption, NTC thermistor, heart rate detection, temperature measurement, MAE, RMSE, patient monitoring

Introduction

One interesting subfield of e-health is wearable technologies that help monitor the vital signs and activities of patients. As an example, we mention a wearable vital sign monitoring system, which is part of this paper's area of interest.

Now in our time, everything has become small due to the development in our world Therefore, we created a device that can be used to measure the heartbeat and temperature of people who suffer from heart disease and other diseases, especially the elderly, we have designed this device to be small and easy to use, and easy to transport or carry with the person like a watch by the person and also we designed this device to be less consumption The electrical energy to maintain the battery for the longest possible time

Problem Statement

The patient vital signs monitoring process has a number of open issues, i.e. challenges, that we investigate and mention a number of them as the followings: The measurement accuracy of E-Health system devices are still challenging.

Measurement accuracy is very necessary to ensure the patient's health. Power consumption optimization in wearable devices is a real challenge. The cost is another important challenge, where cost is one of the constraints facing the use and distribution of any system. There are several objectives to be achieved in this project, as described in the followings: Monitor patient health. Improve and verify measurement accuracy. Minimize power consumption to extend battery life in the proposed device. The proposed design must be small in size and low cost. As a final result of this work, we craft the following contributions: The measurement accuracy of the proposed device has been improved. The power consumption and extend battery life has been improved. Small size and low-cost, the wearable device have been designing and implementing

Software Sections

Rather than requiring a physical press of the reset button before an upload, the Arduino Nano is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the FT232RL is connected to the reset line of the ATmega168 or ATmega328 via a 100 Nano farad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload. This setup has other implications. When the Nano is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Nano. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

Figure 1 : Arduino IDE

Hardware Sections

The system includes the Arduino source, the Arduino is considered an open source, where all the sensors are connected to the Arduino and it is also the main source for the project.
The Arduino is connected to a computer via USB to download the programming for the project, or we can also operate it via USB or by battery.
The goal of using Arduino is that it is cheap and easy to use.

Arduino NANO

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.0) or ATmega168 (Arduino Nano 2.x). It has more or less the same functionality of the Arduino Duemilanove, but in a different package. It lacks only a DC power jack, and works with a Mini-B USB cable instead of a standard one. The Nano was designed and is being produced by Gravitech. [1]

Figure 2: Arduino NANO

Arduino NANO Power:

The Arduino Nano can be powered via the Mini-B USB connection, 6-20V unregulated external power supply (pin 30), or 5V regulated external power supply
(pin 27). The power source is automatically selected to the highest voltage source. The FTDI FT232RL chip on the Nano is only powered if the board is being powered over USB. As a result, when running on external (non-USB) power, the 3.3V output (which is supplied by the FTDI chip) is not available and the RX and
TX LEDs will flicker if digital pins 0 or 1 are high.[1]

Arduino Nano Input and Output

Each of the 14 digital pins on the Nano can be used as an input or output, using pin Mode(), digital Write(), and digital Read() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions: [2]
Serial: 0 (RX) and 1 (TX): Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the FTDI USB-to-TTL Serial chip.
External Interrupts: 2 and 3: These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.

PWM: 3, 5, 6, 9, 10, and 11:. Provide 8-bit PWM output with the analogWrite() function.
SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK): These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.
LED: 13: There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off. The Nano has 8 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the analogReference() function. Additionally, some pins have specialized functionality:
I 2C: 4 (SDA) and 5 (SCL): Support I2C (TWI) communication using the Wire library (documentation on the Wiring website). There are a couple of other pins on the board:
AREF: Reference voltage for the analog inputs. Used with analogReference().
Reset: Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board. See also the mapping between Arduino pins and ATmega168 ports.

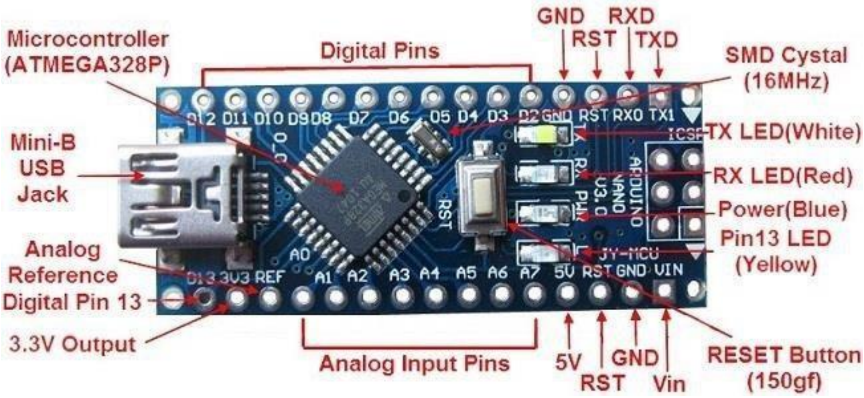


Figure 3 : Arduino NANO part

Why Arduino Boards
Arduino board has been used for making different engineering projects and different applications. The Arduino software is very simple to use for beginners, yet flexible adequate for advanced users. It runs Windows, Linux, and Mac.
Teachers and students in the schools utilize it to design low-cost scientific instruments to verify the principles of physics and chemistry. There are numerous other microcontroller platforms obtainable for physical computing. The
Netmedia's BX-24, Parallax Basic Stamp, MIT's Handyboard, Phidget, and many others present related functionality.
Arduino also makes simpler the working process of microcontroller, but it gives some advantages over other systems for teachers, students, and beginners.[3]

- Inexpensive
- Cross-platform
- The simple, clear programming environment
- Open source and extensible software
- Open source and extensible hardware

OLED Graphic Display
At the heart of the module is a powerful single-chip CMOS OLED driver controller – SSD1306. It can communicate with the microcontroller in multiple ways including I2C and SPI.
Thanks to the SSD1306 controller's versatility, the module comes in different sizes and colors: for example128x64, 128×32, with white OLEDs, Blue OLEDs and Dual Color OLEDs. The good news is that all of these displays are swappable.

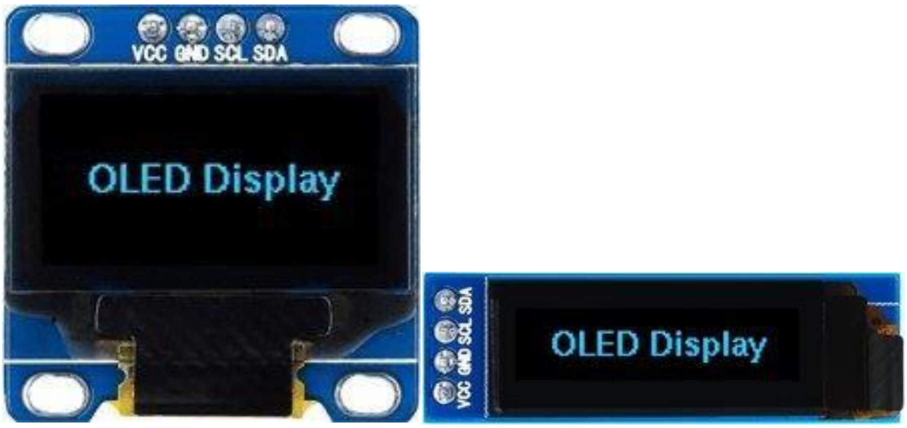


Figure 4 : OLED Graphic Display

An OLED display works without a backlight because it makes its own light. This is why the display has such high contrast, extremely wide viewing angle and can display deep black levels. Absence of backlight significantly reduces the power required to run the OLED. On average the display uses about 20mA current, although it depends on how much of the display is lit.
The operating voltage of the SSD1306 controller is from 1.65V to 3.3V while OLED panel requires 7V to 15V supply voltage. All these different power requirements are sufficed using internal charge pump circuitry. This makes it possible to connect it to an Arduino or any 5V logic microcontroller easily without using any logic level converter.[8]

Wiring OLED display module

Connections are fairly simple. Start by connecting VCC pin to the 5V output on the Arduino and connect GND to ground.

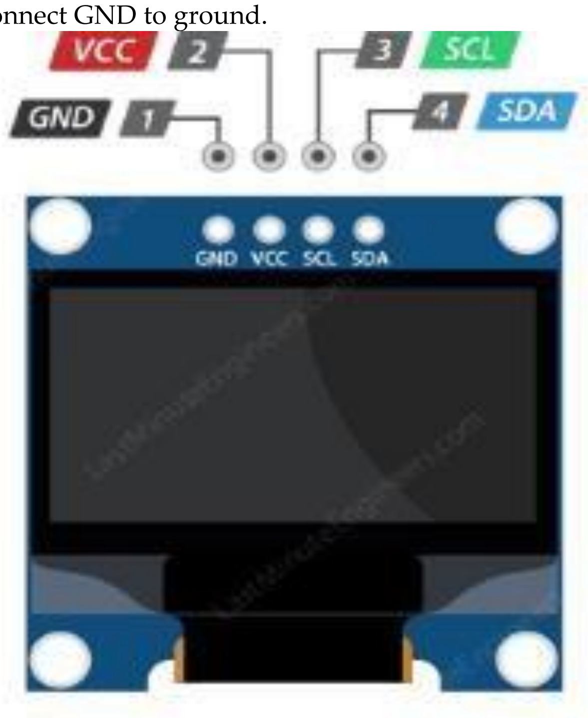


Figure 5 : Wiring OLED Display

Each Arduino Board has different I2C pins which should be connected accordingly. On the Arduino boards with NANO the layout, the SDA (data line) and SCL (clock line) are on the pin headers close to the AREF pin. They are also known as A5 (SCL) and A4 (SDA).
GND should be connected to the ground of Arduino

VCC is the power supply for the display which we connect the 5 volts pin on the Arduino.
SCL is a serial clock pin for I2C interface.
SDA is a serial data pin for I2C interface.

NTC thermistors

NTC thermistors are made from platinum alloy lead wires directly sintered into the ceramic body. They generally offer fast response times, better stability and allow operation at higher temperatures than Disk and Chip NTC sensors, however they are more fragile. It is common to seal them in glass, to protect them from mechanical damage during assembly, and to improve their measurement stability. The typical sizes range from 0.075 – 5mm in diameter.[4]

Figure 6 : NTC Sensor

NTC applications

NTC thermistors are used in a broad spectrum of applications. They are used to measure temperature, control temperature and for temperature compensation. They can also be used to detect the absence or presence of a liquid, as current limiting devices in power supply circuits, temperature monitoring in automotive applications and many more. NTC sensors can be divided into three groups, depending on the electrical characteristic exploited in an application.[5]

Current-time characteristic

Applications based on current-time characteristic are: time delay, inrush current limiting, surge suppression and many more. These characteristics are related to the heat capacity and dissipation constant of the NTC thermistor used. The circuit usually relies on the NTC thermistor heating up due to the current passing through it. At one point it will trigger some sort of change in the circuit, depending on the application in which it is used.

Voltage-current characteristic

Applications based on the voltage-current characteristic of a thermistor generally involve changes in the environmental conditions or circuit variations which result in changes in the operating point on a given curve in the circuit. Depending on the application, this can be used for current limiting, temperature compensation or temperature measurements.

NTC thermistor symbol

The following symbol is used for a negative temperature coefficient thermistor, according to the IEC standard.

Current Consumption Measurements

One of the most important challenges of the proposed system is power consumption because this parameter was related to battery life. The proposed system targeted the elderly outside the hospital.

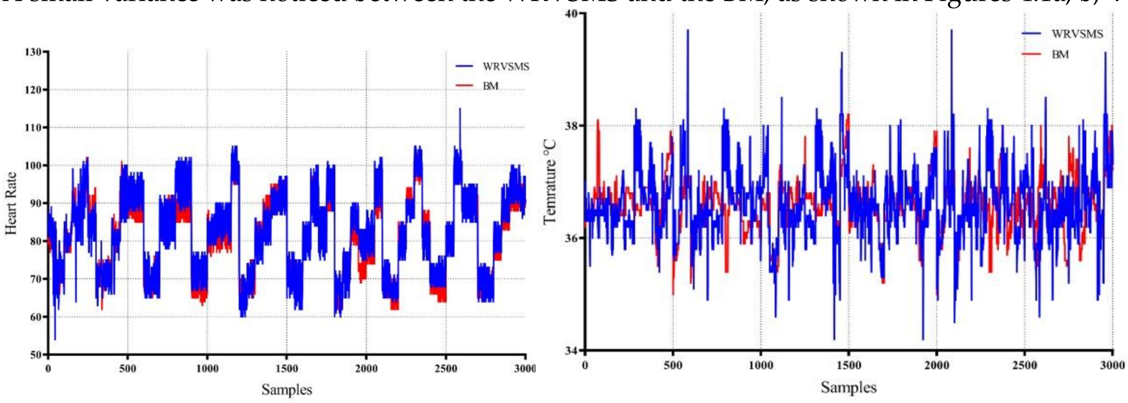
Materials and Methods

The study utilized a comprehensive design approach to develop and validate a wearable device capable of monitoring vital signs with high accuracy, low power consumption, and compact size. The research focused on integrating various components to create a system suited for continuous patient monitoring outside clinical settings. Arduino Nano was chosen as the primary microcontroller for its cost-effectiveness, compactness, and compatibility with multiple sensors. The sensors used included NTC thermistors for temperature measurement and optical sensors for heart rate detection. The system's software was programmed using the Arduino IDE, facilitating efficient control and data acquisition. The hardware was designed to minimize energy usage, thereby extending the device's battery life. Validation involved collecting 6,000 samples for temperature and heart rate, comparing results with benchmark medical devices. Statistical analyses, including MAE and RMSE calculations, confirmed the device's accuracy, revealing minimal error rates. A comparative analysis further highlighted the system's superior performance, achieving an accuracy of 99.37%. The methodology ensured a seamless blend of software and hardware optimization, aligning with the project's objectives of affordability, portability, and reliability. This structured approach underscores the potential of the proposed device to enhance patient monitoring in diverse settings while maintaining user convenience and operational efficiency.

Results and Discussion

Measurement Validation

In this section, a statistical analysis was calculated between the proposed device and the BM to verify system operation accuracy. As mention earlier in (chapter 3), 6000 samples were collected, 3000 each for temperature, heart rate, using the proposed device. Also, the same data was collected using BM. A small variance was noticed between the WRVSMS and the BM, as shown in Figures 4.1a, b, .



(a) (b)

Figure 15 : (a) variance of heart rate and (b) variance of temperature

4.2 Error Test

MAE, MAPE, and RMSE were calculated between WRVSMS and BM. The absolute error calculations were done to calculate the MAE for each, heart rate, and temperature, as shown in Figure 4.2 (a, b). . Figure 4.2a shows that the absolute error of heart rate was in the range of 0 to 27 bpm with an MAE of 3.9 bpm, and Figure 4.2b shows that the absolute error of temperature was in the range of 0 to 2.9 Celsius with an MAE of 0.47 Celsius. That shows there is a small error value between the WRVSMS and the BM when taking the whole errors as the same weight.

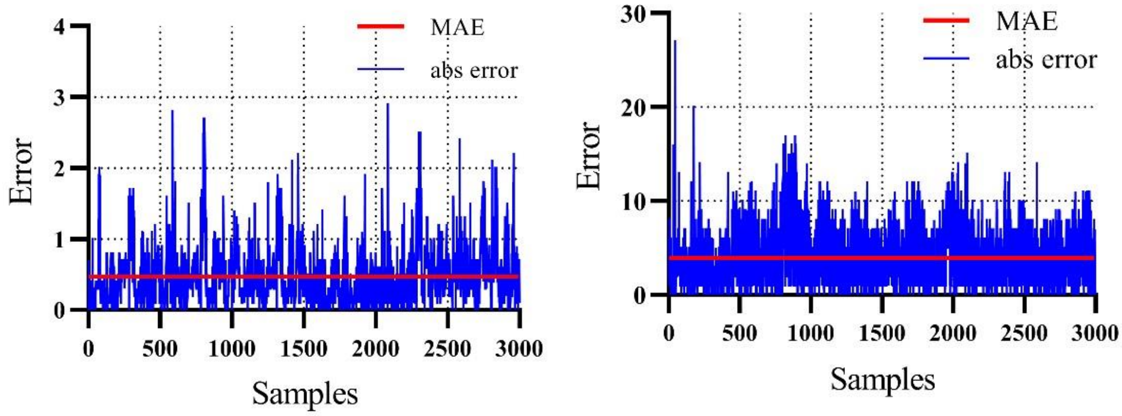


Figure 16: Absolute error and mean absolute error for (a) Heart rate, and (b) temperature between proposed device and BM

As mentioned before in chapter four (4.2.1), the MAE calculates the errors as the same weight; this method of calculation regrades the outliers. To take into consideration these outliers, the RMSE have to calculated, where the RMSE gives most of the weight to the big errors to expand the sight of view on it while reducing the weight of the small errors. In this way, the system is tested to know where it is giving a large error frequently or not. Figure 4.4a shows the Absolute error and the RMSE of the heart rate where the RMSE was 4.93. Figure 4.4b shows the absolute error and the RMSE of the temperature where the RMSE was 0.62.

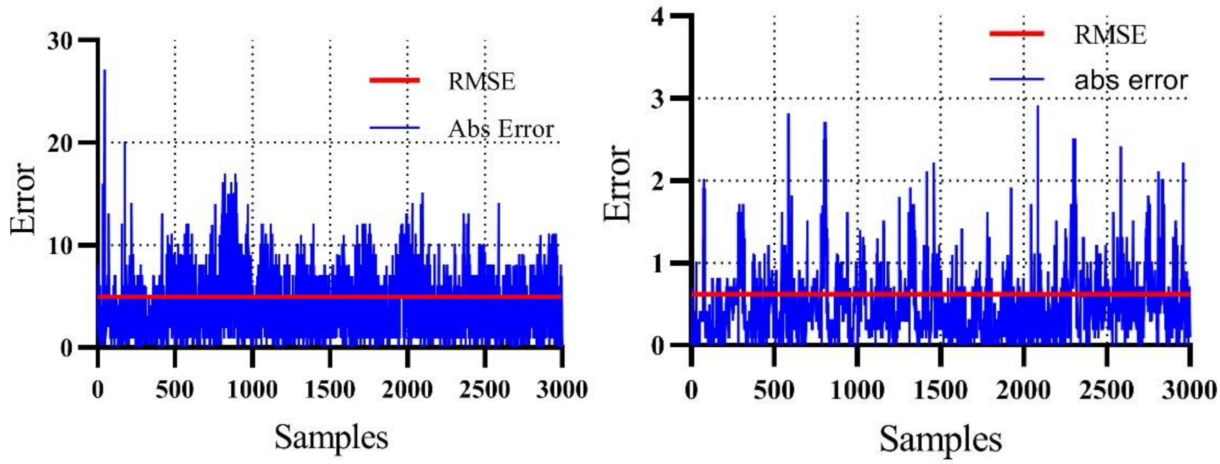


Figure 17 : Absolute error and root mean square error for (a) Heart rate, (b) temperature between proposed device and BM.

4.3 Accuracy Comparison

A comparison was made between the Proposed device and related work in terms of accuracy. This comparison showed the superiority of the system with an accuracy of 99.34%, 99.85%, heart rate, and temperature, respectively, depending on Equation 3.15. By taking the average of these three parameters, the overall accuracy was 99.37%. Figure 4.13 shows the comparison between the proposed device and other systems.

Conclusion

The project was successfully completed as it measures the temperature and heart rate of a person and what is distinguished in this project is that it is small and can be worn in the hand in the form of a watch and accompanies the person wherever he goes

The project measures the temperature and heart rate instantaneously. Once the finger is placed on the sensor.

1. The elderly patients monitored by using the proposed device
2. The accuracy of the proposed device reached 99.37%, compared to BM.
3. Statistical tests were taken, showing that the proposed device error was small and the outlier values were rarely frequent, which means the error did not affect the accuracy of the system. 4. Consumption was reduced

5. The device cost was approximately $12, a commercially inexpensive device for any patient to buy.

Future Work

We will develop the project in the future, as we will add several sensors such as a glucose sensor to measure the level of sugar in the blood, as well as the oxygen sensor in the blood.

Establish the process of giving insulin doses automatically at certain times that are entered into the project,

And we are working to improve the external appearance of the project for the better.

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