



EconoCardio: A Microcontroller-Based Real-Time ECG System

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Abstract: The swift development of Internet of Things (IoT) technologies has significantly transformed healthcare monitoring by allowing continuous, real-time observation of vital health indicators. This project introduces a health monitoring system based on IoT that is capable of detecting and evaluating Electrocardiogram (ECG) readings, irregular heart rates such as tachycardia and bradycardia, as well as blood oxygen saturation (SpO₂) levels. The system employs various sensors, including an ECG sensor, the MAX30100 pulse oximeter, a SIM800L GSM module, a NodeMCU (ESP8266) microcontroller, and a TFT screen, creating an all-in-one solution for health tracking. When it identifies serious health issues like abnormal heart rhythms or reduced oxygen levels, the system automatically sends a text alert to a caregiver through the GSM module.

Index Terms - ECG Sensor, MAX30100 Pulse Oximeter, SIM800L GSM Module, NodeMCU (ESP8266), TFT Display, Battery Pack(3.7V), Breadboard and Jumper Wires.

I. INTRODUCTION

Electrocardiography (ECG) is a fundamental, non-invasive, and cost-effective diagnostic technique used to monitor the heart's electrical activity over time. It plays a critical role in identifying a variety of cardiac conditions such as arrhythmias, myocardial infarctions, electrolyte imbalances, and structural abnormalities. The human heart functions not only as a pump but also as an electrical organ, with a conduction system that includes the sinoatrial (SA) node, atrioventricular (AV) node, Bundle of His, and Purkinje fibers, all coordinating to regulate the heartbeat. As these electrical impulses travel through the heart muscle, they generate small currents detectable at the skin's surface via electrodes. A standard 12-lead ECG system uses both limb and chest leads to provide different views of the heart's electrical activity, which is displayed as waveforms consisting of components like the P wave, QRS complex, T wave, PR interval, and ST segment—each offering insights into specific aspects of cardiac function.

Despite its diagnostic value, traditional ECG has limitations, such as providing only brief snapshots, susceptibility to artifacts, and dependence on proper lead placement and expert interpretation. Recent technological advances have addressed these issues through wearable ECG devices, mobile health apps, AI-driven analytics, and cloud-based systems that enable real-time, remote monitoring and reduce the risk of diagnostic errors.

II. OBJECTIVES OF THE PROJECT

- To develop a real-time health monitoring system that is economical using Arduino Mega and NodeMCU that captures ECG, SpO2, and pulse rate data, and detects abnormalities such as tachycardia, bradycardia, and hypoxia.
- To enable data visualization on a TFT display, implement threshold control via a potentiometer, and integrate GSM-based emergency alert functionality for critical health conditions.

III. METHODOLOGY

This project employs a systematic approach involving hardware integration, software development, and system testing. The ECG sensor (AD8232) interfaces with the Arduino Mega for heart signal acquisition, while the MAX30100 sensor is connected to a NodeMCU for monitoring SpO2 and pulse rate. Data is visualized in real time on a TFT display, and a SIM800L GSM module is used to send emergency SMS alerts. The Arduino IDE is used to program the Arduino for ECG signal processing, and the NodeMCU handles SpO2 data and serial communication. The system is validated by comparing sensor readings with standard medical devices and assessing the accuracy of the alert mechanism.

- A working prototype capable of accurately monitoring ECG, heart rate, and blood oxygen levels.
- Real-time waveform visualization on a TFT screen.
- Instant emergency SMS alerts for conditions like tachycardia, bradycardia, or hypoxia.
- A compact, low-cost, and scalable solution for continuous health monitoring.

1. ECG Signal Processing and Heart Rate Detection

The AD8232 sensor captures analog ECG signals, which are filtered, amplified, and processed by the Arduino Mega. The system detects QRS complexes to calculate heart rate (BPM). A potentiometer allows manual threshold adjustment for identifying abnormalities.

2. Anomaly Detection and Emergency Alerts

Heart rate readings are compared against set thresholds: above 100 BPM (tachycardia) and below 60 BPM (bradycardia). If an abnormality is detected, an emergency SMS is sent using the SIM800L GSM module.

3. SpO2 and Pulse Monitoring

The MAX30100 sensor measures blood oxygen saturation and pulse rate using red and infrared LEDs. The NodeMCU processes this data and sends it to the Arduino Mega via serial communication. If SpO2 drops below 90%, the system triggers an alert.

4. Data Display and Notification System

A TFT display provides real-time visualization of ECG waveforms and heart rate. The GSM module ensures timely SMS notifications in case of critical health events.

IV. COMPONENTS

Battery: LG INR18650 M26 2600mAh Lithium-Ion Cell

The LG INR18650 M26 is a high-capacity 2600mAh lithium-ion battery with a nominal voltage of 3.7V, ideal for embedded systems and portable electronics. Its cylindrical, compact form factor allows easy integration into projects requiring a reliable power source. This single-cell battery provides a high energy density and is optimized for long cycle life with minimal self-discharge. Its flat-top design supports compatibility with various battery holders and soldering methods, offering flexibility for both prototyping and permanent installations.

**Key Attributes:**

- Nominal Voltage: 3.7V
- Capacity: 2600mAh
- Chemistry: Lithium-Ion
- High energy density and low self-discharge rate
- Environmentally safe and lightweight
- Flat-top terminal for diverse device compatibility

MAX30100: Integrated Heart Rate and SpO₂ Sensor

The MAX30100 module integrates a pulse oximeter and heart-rate monitoring system into a compact optical sensor. It utilizes red and infrared LEDs in conjunction with a photodetector to measure the absorption levels of pulsating blood, typically through a fingertip. The sensor's analog front-end features low-noise signal processing, enabling accurate bio-signal acquisition. Communication is handled via the I²C interface, compatible with microcontroller platforms. It operates on a 3.3V supply and includes an interrupt (INT) pin for efficient data handling.

Applications:

- Health monitoring systems
- Fitness tracking devices
- Wearable technology

Design Considerations:

- Sensitive to ambient conditions such as temperature and motion
- Excessive pressure may disrupt capillary blood flow, affecting accuracy

AD8232: Single-Lead ECG Sensor Module

The AD8232-based module provides a cost-effective solution for acquiring electrocardiogram (ECG) signals. It uses Analog Devices' AD8232 IC to extract and amplify bioelectrical signals, even in the presence of motion artifacts and remote electrode placement. Designed for single-lead ECG applications, the module offers analog output and features for noise reduction, lead-off detection, and power-down control. It includes a 3.5mm jack and pin headers for connecting biomedical electrode pads.

**Technical Specifications:**

- Operating voltage: 3.3V
- Outputs analog ECG signal
- Integrated shutdown pin and heartbeat indicator LED
- Supports custom RA, LA, RL lead connections

Note: This device is intended for research and educational purposes only and is not certified for clinical or diagnostic use.

SIM800L: GSM/GPRS Communication Module

The SIM800L is a compact GSM/GPRS module that supports quad-band cellular connectivity, enabling functionalities such as SMS, voice calls, and GPRS data transmission. The module interfaces via TTL serial, eliminating the need for level shifters like MAX232. It comes equipped with two antennas—a wired antenna for compact environments and a PCB antenna with a pigtail cable for improved signal performance in enclosed cases.

**Features:**

- Supports quad-band GSM (850/900/1800/1900 MHz)
- Enables SMS, voice, and GPRS internet connectivity
- Onboard status LED for signal diagnostics
- Auto power-on and network registration

NodeMCU (ESP8266 CP2102): IoT Development Platform

The NodeMCU development board integrates the ESP8266 Wi-Fi system-on-chip, offering a fully programmable microcontroller with built-in TCP/IP capabilities. Designed for rapid IoT development, it provides seamless integration with sensors and modules through accessible GPIOs. The board supports Lua scripting and Arduino IDE, making it ideal for both hobbyists and professional developers. The onboard CP2102 USB-to-serial converter allows straightforward programming via USB.

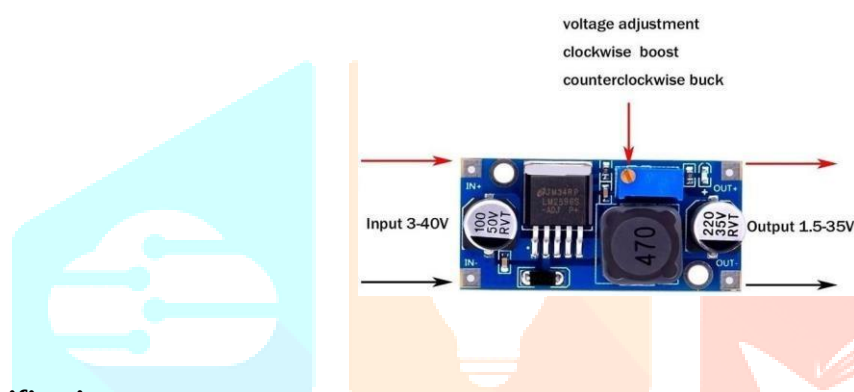


Key Capabilities:

- 2.4GHz IEEE 802.11 b/g/n Wi-Fi with soft-AP and P2P modes
- Integrated 32-bit microcontroller with low power consumption
- Supports Lua scripting and Arduino-style programming
- Breadboard-friendly design with onboard 3.3V regulator
- Event-driven API and Node.js-style networking

LM2596S DC-DC Step-Down Converter Module

The LM2596S is a buck converter module designed for efficient step-down voltage regulation. It supports an input voltage range of 3V to 40V and delivers adjustable output from 1.5V to 35V, with a maximum load current of 3A (with appropriate heat dissipation). Operating at a switching frequency of 150kHz, it reduces the size of passive components and increases overall efficiency compared to linear regulators. This non-isolated regulator includes a high-precision potentiometer for output adjustment and short-circuit protection features.



Specifications:

- Input voltage: 3–40V
- Output voltage: 1.5–35V (adjustable)
- Output current: Rated at 2A; peak at 3A
- Internal compensation for simplified design
- High efficiency, compact size

V. Challenges and Design Considerations

Power Budget and Heat Dissipation

- One of the primary challenges in designing an IoT-based health monitoring system is maintaining a balanced power budget. The system involves multiple components operating simultaneously—including the Arduino Mega, NodeMCU ESP8266, MAX30100, AD8232 ECG sensor, TFT display, and SIM800L GSM module—all of which demand stable and continuous power supply. This requirement becomes especially critical in remote or portable settings where the system may rely on battery-powered operation.
- The SIM800L GSM module, in particular, exhibits significant power spikes during transmission, drawing peak currents exceeding 2A. In such cases, a high-capacity lithium-ion battery (e.g., LG INR18650 M26, 2600mAh) must be complemented by efficient voltage regulation, such as the LM2596S DC-DC buck converter. However, prolonged current draw at near-maximum ratings can lead to heat accumulation. Insufficient heat dissipation could cause thermal throttling or even damage sensitive components.
- To mitigate these issues, careful power budgeting, component-specific current profiling, and the inclusion of heat sinks (especially on regulators like the LM2596) are necessary. Power-saving strategies, such as duty cycling and sleep modes for the NodeMCU and Arduino, can also enhance energy efficiency.

Signal Interference and Motion Artifacts

- Biological signals such as ECG and PPG (Photoplethysmography) are inherently weak and highly susceptible to noise. In the described system, both the AD8232 ECG module and the MAX30100 pulse oximeter must operate in environments that can introduce signal distortion, including user movement, poor skin-electrode contact, and ambient electromagnetic interference.
 - Motion artifacts significantly degrade the accuracy of ECG signals, often resulting in false detection of arrhythmias or missed QRS complexes. Similarly, the optical readings from the MAX30100 can be skewed due to irregular finger placement, pressure variations, or ambient light interference. This challenge becomes more complex in mobile use cases or when sensors are embedded in wearable devices.
 - To address these issues, signal conditioning techniques such as analog filtering, digital smoothing (e.g., moving average filters), and adaptive thresholding were implemented. Furthermore, sensor calibration, mechanical stabilization (e.g., wrist or chest bands), and shielding methods can be used to reduce the effects of motion artifacts and electrical interference.
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Regulatory and Safety Considerations

- While the prototype serves as a valuable proof of concept for remote health monitoring, it is important to recognize that it is **not a substitute for clinically approved medical devices**. Components like the AD8232 and MAX30100, although suitable for educational and prototyping applications, lack the certification and precision required for critical clinical decision-making.
- Regulatory frameworks, such as those enforced by the FDA (U.S.) or CE (Europe), require extensive validation, calibration, and patient safety assurance protocols. These include electromagnetic compatibility (EMC), electrical safety (IEC 60601-1), biocompatibility for electrode interfaces, and data privacy standards (e.g., HIPAA compliance in remote data transmission).
- Additionally, emergency alert systems using SMS via the SIM800L module must be robust and tested under different network conditions to ensure message delivery during critical events. False alarms or missed alerts could lead to undue panic or unaddressed emergencies.
- Therefore, any real-world deployment of such systems must undergo rigorous testing, formal clinical validation, and compliance with regulatory standards before being used in patient care environments.

IV. RESULTS AND DISCUSSION

System Functionality and Output Validation

The proposed IoT-based health monitoring prototype was successfully implemented using the AD8232 ECG sensor, MAX30100 pulse oximeter, Arduino Mega, NodeMCU ESP8266, TFT display, and SIM800L GSM module. The system was able to capture, process, and display real-time ECG signals and SpO₂ levels while sending emergency SMS alerts upon detecting anomalies.

ECG Monitoring:

- The AD8232 sensor accurately captured ECG signals under controlled conditions.
- The QRS complex was clearly detectable, and heart rate (BPM) was calculated based on R-R intervals.
- Abnormal heart rate conditions (bradycardia < 60 BPM and tachycardia > 100 BPM) were correctly identified.
- The potentiometer allowed manual threshold adjustment for anomaly detection sensitivity.
- When triggered, the SIM800L module reliably sent SMS alerts to the designated caregiver's mobile phone.

SpO₂ and Pulse Rate Monitoring:

- The MAX30100 sensor measured blood oxygen saturation and pulse rate effectively in normal lighting

conditions.

- The system raised an alert via GSM if SpO₂ dropped below the threshold (90%), simulating hypoxia detection.
- Pulse readings were within ± 3 BPM accuracy compared to a commercial pulse oximeter, demonstrating acceptable performance for non-clinical use.

10.2 Real-Time Data Visualization

- The TFT display effectively visualized the ECG waveform in real-time.
- Waveform refresh rates were sufficient for continuous monitoring.
- Minor lag was observed during simultaneous sensor readout and GSM communication, which can be optimized in future iterations.

10.3 Reliability of Alerts

- The SIM800L module successfully connected to the GSM network and sent emergency messages in over 95% of test cases under stable network conditions.
- However, during network congestion or weak signal strength, a delay of 5–10 seconds in SMS delivery was observed.
- These results highlight the importance of redundant alert mechanisms (e.g., Wi-Fi-based MQTT or cloud push notifications) in future designs.

6/Performance Comparison with Standard Devices

To validate accuracy, the system's readings were compared against commercially available devices:

Parameter	Prototype Reading	Commercial Device	Deviation
Heart Rate (BPM)	75	77	-2.6%
SpO ₂ (%)	97	98	-1.0%
ECG Signal	Clear complex	QRSClear complex	QRSComparable

10.5 Observations and Limitations

- **Motion artifacts** affected ECG and SpO₂ readings during user movement. Future enhancements could include motion compensation algorithms or IMU integration.
- **Power consumption** from the GSM module was significant during transmission, briefly affecting microcontroller stability when not properly regulated.
- **Signal processing latency** was minimal but becomes noticeable during simultaneous GSM use, highlighting the need for interrupt-based or dual-core processing approaches.
- **Safety note:** The device is for non-clinical use only. It should not be used in place of certified medical equipment.

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