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Design and Implementation of Remote Real-Time Monitor System for Prosthetic Limbs

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HIGHLIGHTS

- Real-time monitoring of amputees using a medical wireless sensor.
- Gait events are essential to control the prosthetic devices of lower limbs.
- IoT applies to the monitoring system that relies upon a non- IP network.
- One IP to four medical sensor lowers the data rate and the reduce energy consumption.

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ABSTRACT

Persons with Lower-limb amputations experience movement restrictions resulting in worsening their life quality. Wearable sensors are often utilized to evaluate spatial and temporal qualities and kinetic parameters that provide the mechanism to create interactive monitoring of the amputee prosthesis system. Gait events and detection of the gait phase of amputee movement are essential to control the prosthetic devices of lower limbs. This paper presents real-time monitoring to individuals with lower limb amputation by using a medical wireless sensor. However, the proposed system used four medical sensor nodes (such as gait, temperature, the pressure of blood, blood oxygenation (SpO2))for transmitted medical data by the RFB 24 to the sink node to collected data and upload by ESP32 to the Local cloud (Raspberry pi 4) by using Wi-Fi network, then design the web application for enable the doctor monitor the patient (lower-limb amputation (LLA)) and provide the reporter to on each patient, where local cloud provides the data to the web application. The conduction of this work is using one sink node to four nodes (patient) to reduce the data rate and the energy consumption. In this work, one IP to four medical sensor nodes lowers the data rate to 60%, and the energy consumption by the sensing nodes is lowered by 20% that using one IP instead of using five IP reduce the size of the transmitted packet.

1. Introduction

Generally, a wireless sensor network (WSN) describes a group of small computers to detect specific physics–related properties, such as voltage, vibration, moisture, current, power, and temperature [1]. There is tremendous progress in wearable technology with recent mobile and Internet communications devices and pervasive computing [2]. This technology opens up life-size potentials for monitoring (LLA) for a long time [3]. Amputees, particularly those living with diabetes, are vulnerable to losing the remaining leg, the healthy one because blood flows poorly to the limbs and exposes to skin damage [4]. Amputation is when a limb or part of the limb such as a finger, leg, foot, arm, hand, or toe is removed, usually because of injury, disease, or surgery. The artificial device replaces a missing part that is individually prescribed, designed, manufactured, and fitted to substitute for a lost part and restore lost function [5]. More importantly, prosthesis provides amputees with the opportunity to conduct functions, mainly walking, that could be impossible without the limb. Remote (LLA) monitoring is to create an enhanced life quality to the patient, whether they suffer from a disease that persists for a long time [chronic diseases] or recovers from one-time injury[6] Although cases of using remote patient monitoring (RPM) are initially limited in their applications, they have developed quickly, and that is attributed to tremendous progress occurring in wearable technology, which participates considerably in easing up the process of monitoring and tracking different statistics related to health matter and providing consistency through the whole process. Furthermore, biosensors are integrated into several forms such as watch and wristwear, patches, shoes, belts, clothing, and smartphone. Those devices have certain advantages for doctors and patients, which are the two main components of any program related to monitoring and therapy. They can be employed for treating more and more health-related conditions. This work provides a complete platform for mobile sensors, based upon easily purchased consumer components, for facilitating means characterized of being low-cost and competent to monitor patient health status with prosthetic legs [7]. It is possible to use pressure and temperature sensors to predict the remaining

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limb's health status (LLAs). A sensor system that can be operated directly on the skin-prosthesis interface is a non-invasive and invisible manner. This platform is working with an android mobile device to allow data capture from a wireless sensor unit and grant access to clinicians to be aware of results from sensors. This work presents the real-time monitoring too (LLAs) by using a medical wireless sensor using the esp33 microcontroller as a base node. The nRF24L01 wireless transceiver module is used for transmitting data from nodes to base nodes. In the rest of the paper, Part II presents the relevant work, section III details the proposed method, section IV highlights and discusses the results, and section V concludes the work.

2. Related works

This section presents a number of a researcher who works in lower limb prosthetic. Jiménez-Fabián, [8] presents control strategies related to robotic ankle systems inactive and semi-active lower-limb. The pertinent characteristics of hardware-level controllers and hardware configuration were also discussed. Moreover, the proposed control algorithms for the joints of other lower extremities, i.e., hip or knee, are also included, possibly applying them to the ankle device development. Hakonen et al. [9] provided a rundown of methods recommended for critical steps to digital surface electromyography signal processing. In addition, she addressed the main difficulties and upcoming trends of surface electromyography interfaces and recent applications where surface electromyography interfaces are adopted. Mathur, [10] conducted monitoring of the temperature of an interface at skin level in Prosthetic lower limbs by implementing an adaptive neuron-fuzzy inference strategy (ANFIS) for predicting the temperature of the in-socket residual limb. Besides, ANFIS belongs to the fused fuzzy nervous system family in which the fuzzy system is integrated into an adaptable framework in nature. This method was compared to our previous work by the use of Gaussian processes for machine learning. Xia et al. [11] applied the Recurrent Neural Network to measure eight healthy subjects. The Recurrent Neural Network results perform better than other methods when it comes to estimating a three-dimensional trajectory. Vempala et al. [12] worked in monitoring magnetic leg probes, the platform employed to calibrate the two systems of motion capturing; four optical markers were installed over four magnetic probes where the probes were in the middle of the optical markers. Kashef, [13] discovered that implementing a specific feature in a prosthesis structure is a trade-off between anthropomorphism, complexity, agility, and user comfort. The usefulness of incorporating a specific characteristic in the mechanism of an artificial finger largely depends on the intended application of the hand. Li et al. [14] presented a review of the leading technologies relevant to surface electromyography signals use in HRISsm, the benefits, and the challenges of using surface electromyography. Hong et al. [15] describe IoT-based remote control robots using block-based programming for computer information or major science colleges. The prototype is implemented on the LEGO Mind Storm EV3 robotics kit and Android app application block programming. Gaetano et al. [16] present, the electronic system of a prosthetic limb controlled by a wireless myoelectric armband was realized. The prosthesis provides the user feedback from the surroundings, such as the object's temperature and grip force applied by fingers on grabbed objects; it was designed modularly to adapt to different amputee types, thus satisfying a larger user category. Using a single motor to handle the whole hand simplifies the prosthesis control and saves on its cost and weight. EMG and IMU data are monitored remotely by the orthopedic that follows user rehabilitation by the Wi-Fi connectivity provided by Raspberry. Table1 Compare the present work with other work.

Table 1: Compare the present work with other work

Author	Discretion	The Proposed Work
[10] N. Mathur et al.	Adaptive neuro-fuzzy inference strategy (ANFIS) to predict the in-socket residual limb temperature	Presents the real-time monitoring too (LLAs) by using a medical wireless sensor (such as gait, temperature, the pressure of blood, blood oxygenation (SpO2)) using the esp33 microcontroller as a base node. The nRF24L01 wireless transceiver module is used for transmitting data from nodes to base nodes
[11] P. Xia	employs the deep architecture combining convolutional neural networks (CNNs) and recurrent neural networks (RNNs)proposed to estimate kinematic information for myoelectric control from multi-channel electromyogram (EMG) signals	
[15] S. Hong and Y. Hwang	The prototype shows that the IoT learner can enhance the capability of creativity, problem-solving, and efficiency in their thinking process	
[16] F. Gaetani et al.	All data are received through HM-11 BLE transceiver by Arduino board which processes them and drives actuators.	

2.1 Leach protocol

LEACH is the original hierarchical routing system for sensor networks. LEACH is an adaptive clustering method that uses randomized cluster head rotation to evenly distribute the energy load between the sensor nodes in the network. It is a very flexible and random (self-organizing) protocol [17,18]. LEACH utilizes a one-hop routing. Every WSN is split into clusters, and each cluster consists of a cluster header and normal cluster nodes. In this protocol, the head of the cluster is randomly chosen, and this role revolves around the rest of the sensor nodes to check the power balance of the network. The head of the cluster is directly connected to the monitoring station and stops the rest of the nodes as much as possible to reduce energy use. As stated in this protocol, Operation LEACH is split into various rounds, and each of these rounds consists fundamentally of two phases: one is the Setup phase, and the next is the Steady phase [19, 20]

3. Proposed work diagram

The wearable platform can communicate with many sensors. Still, for initial deployment, in prosthesis gait measurement and temperature sensors. It is possible to monitor the temperature and direction of the amputee subject's remaining limb by the medical team that determines the sampling rate. Furthermore, it is also possible to use a server to assess data backup data, an adequate space to store data locally on the secure digital card in the wearable sensor platform. Figure 1 shows the diagram of the wearable platform.

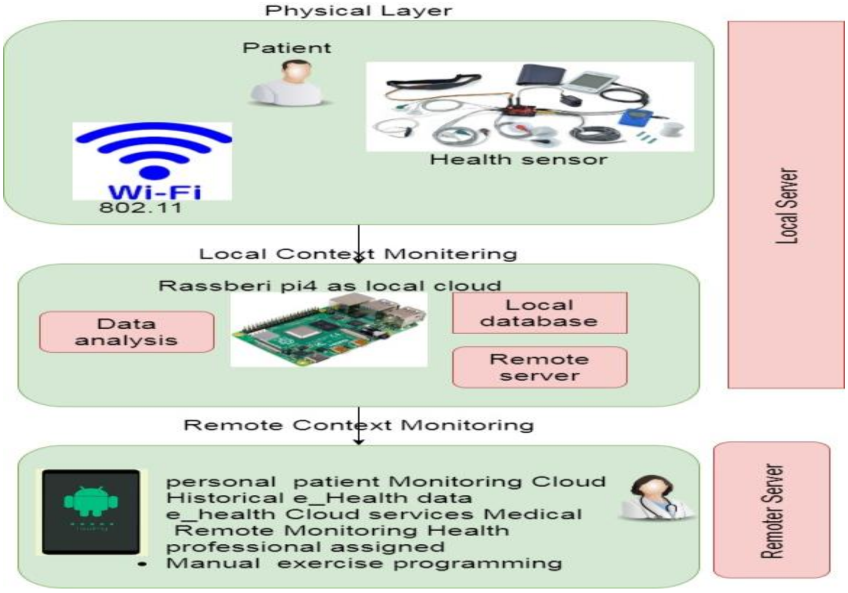

Figure 1: Block diagram of the proposed work

The main parts of the proposed system can be referred to as sensor nodes, sink nodes, and the local cloud. This work used the LEACH protocol of WSN to connect the base node to sink nodes, where each medical sensing node recorded and transitioned the information from the patient to the sink node using the RBF 2.4 GHz. The sink node representing ESP 32 receives encryption data packets and uploads them to the local cloud (raspberry pi4) via a Wi-Fi connection. The local's cloud collects the received data. It processes them to be visualized in the web portal or mobile application—the web portal reports about the data gathered and processed through visualizing for the doctor as shown in Figure 2.

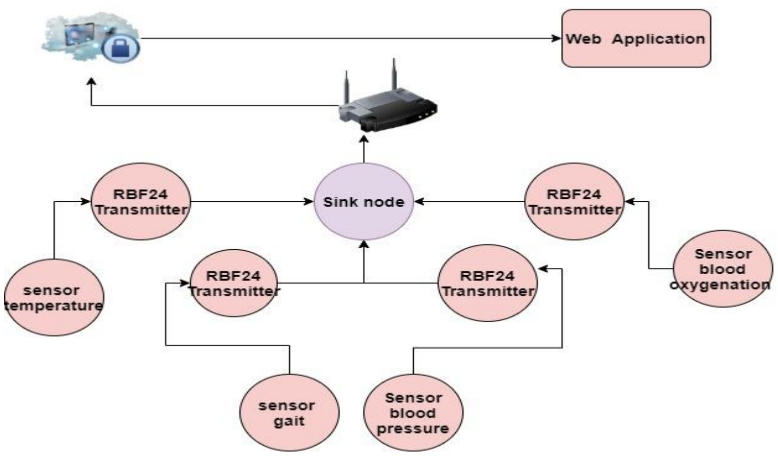

Figure 2: The proposed system's data flow diagram

As previously stated, four sensing nodes exist. Two are employed for detecting gait, blood pressure, temperature, blood oxygenation (SpO2) of a patient. In the diagram of the sensing nodes circuit, there is a 5 Volt – 3.3 Volt regulator. The reason behind using a regulator lies that the nNRF24L01 transceiver module requires a 3.3V power source, and the microcontroller with the used sensors requires a 5 Volt power source. The software tool IDE Adriano studio is used to develop the proposed algorithm based on C language. The development of the proposal algorithm work is shown in the flowchart in Figure 3.

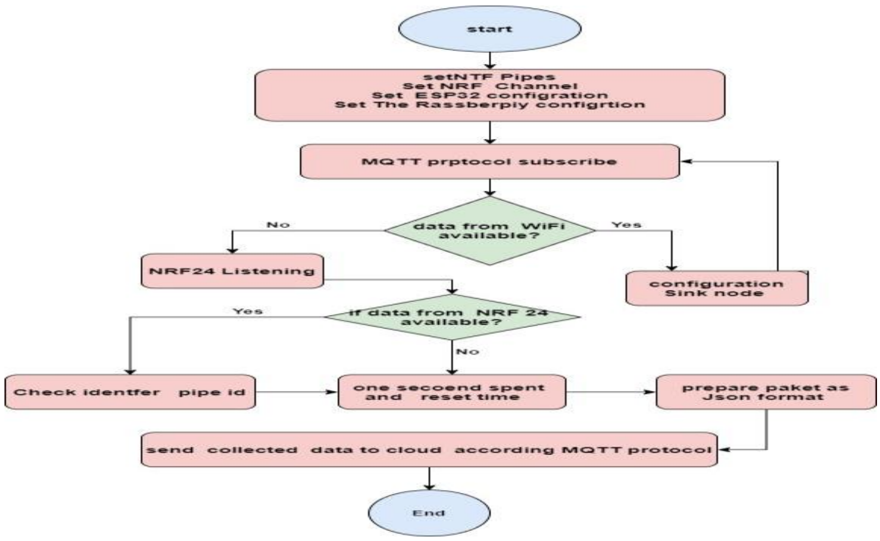

Figure 3: The proposed algorithm of the sink node

4. Results and discussion

This section describes the proposed algorithm steps of the sink node. Each medical node transmits data through The NRF24 model to the sink node, the ESP32 (sink node) receives and collects and processes data where the sink node uses the pipe number to identify the packet nodes. Then, data is separated by converting it to JSON format (javascript Object Notation), according to the requirement of the needed local cloud server needs a JSON format of data. After every round, the ESP32 checks whether a data packet (DP) is received from the server. Then, it checks whether there is a valid DP received from the server; the ESP32 would replay the server and be processed in line with the DP. After that, when DP asks about the state of the sink node, the sink node replays the server by its existing model. If DP possesses an instruction related to programming, the ESP32 would be reconfigured in line with the type of instruction. The connection between the server and the ESP32 module is conducted through a WIFI network, and the data can communicate among themes using the Message Queuing Telemetry Transport protocol. Then prepare local cloud to represent the raspberry pi 4 with 256 GB LPDDR4-3200 SDRAM for storing the data of each patient, the design the website application built for real-time monitor the state of the patient from doctor the web application provides the reports of each patient, the web application build by using tool HTML, CSS, JavaScript, My SQL database as shown in Figure 4.

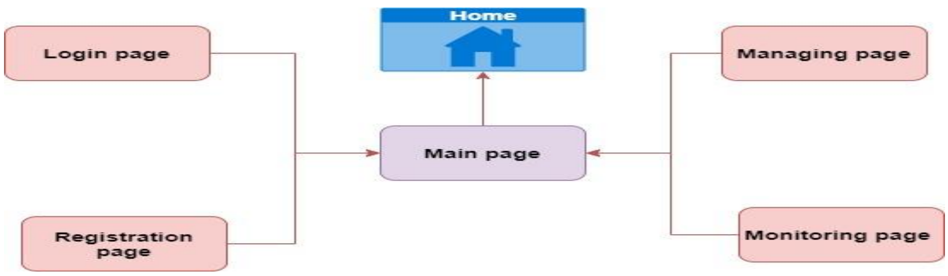

Figure 4: The Management and Browsing Website Map

The front page represents the home page, which permits a doctor to register or sign in. After that, the authorized personnel is capable of managing dashboards or widgets in line with needs. The doctor can monitor the condition of the patient(s) consistent with the necessity. This section will discuss the results obtained for the proposed system. In this system, the main result is to monitor the patient's condition with fewer IP addresses. Consequently, that will lead to fewer transmitted bits in each second and lower system power consumption concerning transmitting the DPS. The transmission of the data rate as described, in this system, there are two networks, the 1st one exists between the sensing node and sink node, and the 2nd one exists between the server and node. The 1st network uses no IP address, relying upon the non- IP network using the nRF24L01 modules. The 2nd network uses the design of the proposed system. It should be remembered that the process of transmitting in the proposed design would transmit fewer bits in each second than systems that rely only upon an IP – network. Basically, in this design, the DP of the nRF24L01 modules is composed of cyclic redundancy check, pipe addressing, preamble, and information. The pipe address comprises five bytes' preamble, and the cyclic redundancy check comprises one byte. After that, every nRF24L01 module transmits 7 * 8 = 56 bit/s, except for the data. The medical sensor data comprises six bytes (forty-eight-bit), then the nRF24L01 transmit fifty-six Bit/s + forty-eight Bit/s = one hundred four bit/s. when the same sensing nodes were implemented relying upon the IP network, the transmitted bit in each second would increase. Moreover, the DP of the IP network is composed of information, source IP, destination IP, source Media Access Control, and destination media access control. In the DP, there are two IP addresses and a Media Access Control address. Every IP address is composed of four bytes (thirty-two bit), and every Media Access Control address is composed consists of six bytes (forty-eight bit). The DP of the IP network is composed of four bytes + four bytes + six bytes + six bytes = twenty bytes (160 bit) except for the information required to be sent. Figure 5 shows the sensor signal.

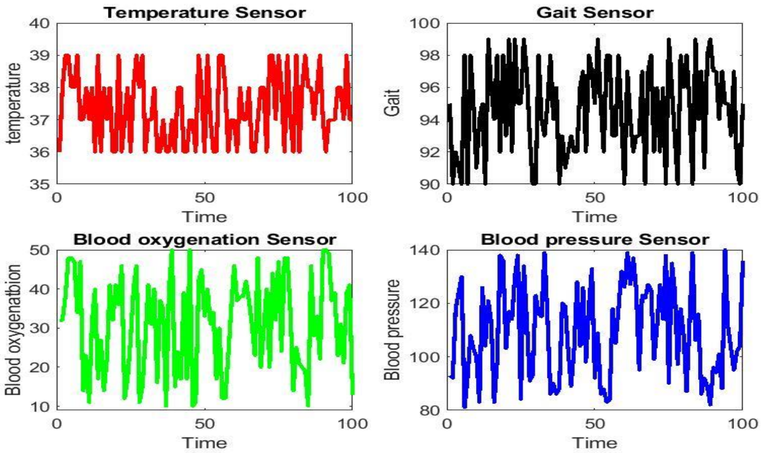

Figure 5: Monitoring the Medical Sensor signal in web application

This section will discuss the results of the proposed system. The design and the implemented algorithm for remote real-time monitoring of patients (lower limb amputees) approved that multiple nodes could be connected to a single IP address. Against IP-based WSN systems, the current proposed non- IP network system functions competently. It assists the designer in exploiting the same number of IPs to implement more sensing nodes. That represents the proposed system's key advantage and large scalability, high utilization, and low delays. Moreover, the proposed system does approve that when relying upon non- IP networks, that will participate in reducing power consumption in the wireless sensor networks. This design can complement the current system, using more sensing nodes and relying upon multi-hop architecture. The process of distributing sensing nodes could be on a broader map. Additionally, this design approves that if the designer relies upon the non- IP sensor network, it reduces the number of transmitted bits in each second; this rise can grant more effectiveness if large networks are used. Based on results it can be noticed that all the proposed system design would transmit 104 + 104 + 80 + 128 = 416 bit/s. Differently, the system depending upon IP network design transmits 376 + 376 + 272 + 432 = 1456 bit/s.

5. Conclusion

From the results obtained from the design proposed and real-time application monitor for lower limb amputees using a medical wireless sensor, the proposed system used four medical sensor nodes (such as temperature, gait, blood pressure, blood oxygenation (SpO2) depending upon the non-IP network. The key concluding observations are rundown: the proposed design for implementing the Iota that applies to the monitoring system relies upon a non- IP network. Moreover, it has two base nodes, the first is in active mode, and the second is in sleep mode (power-saving state), which is prepared to be active mode if required. The monitoring web portal can change easily and adapt to different conditions and circumstances based on customer needs. Besides, it has a debug terminal, allowing wireless reconfiguring of the base node with specific commands. In this work contribution, one IP to four medical sensor nodes lowers the data rate to 60%, and the energy consumption The proposed system approves that using the non- IP networks in real-time monitor for lower limb amputees using a medical wireless sensor to the Internet of things, the data rate and the power consumption can be reduced. The four sensing nodes can connect to the server with an IP address only. Furthermore, a debugging terminal that includes a command reference helper assists users in using commands.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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