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Cast Liner for Early Detection and Prevention of Skin Infections

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Abstract
The orthopedic cast immobilization is popular when dealing with the fracture and the fact that it is surrounded by the entire cast does not allow one to observe the condition of the skin at all times. When an individual is immobilized for a long period of time, the moisture level, temperature, humidity and skin pH can change and this can cause maceration of the skin, irritation, infection and patient discomfort. These complications are, in most instances, only revealed after the symptoms have become apparent, and this reflects the necessity of a preventive method of monitoring. This paper gives the design and development of a smart wearable cast liner that is aimed at monitoring the microenvironment under the orthopedic casts. The proposed system will combine the moisture, body temperature, environmental temperature and humidity sensors, and the skin pH. Microcontroller, which has the ability of wireless communication, is used to process sensor data to facilitate real-time monitoring and issue alerts in the event of abnormal conditions detected. Besides that, the coin vibration motors are also integrated to offer the patient controlled noninvasive itch relief. To show that the system is feasible, a working prototype of the system has been created. The proposed device will help patients and caregivers to detect unfavorable conditions at an early stage when they are immobilized. It will be possible to evaluate the system clinically in the future to find out how effective it is in the actual healthcare environment.

Keywords: *Orthopedic immobilization; Preventive healthcare; Skin microenvironment monitoring; Smart wearable liner; Wireless medical device.*

1. Introduction

Cast immobilization of the bones is commonly employed in the management of bone fractures, as well as post-surgical recovery. Fiberglass casts and Plaster of Paris casts are used to offer structural support to the damaged limb, as well as assist in healing the body, by limiting movement. In spite of the fact casts are effective in immobilization, they result in a closed system surrounding the affected area and as such, it becomes hard to continuously monitor the state of the skin under the cast. Depending on the length of the immobilization period, which can take a few weeks, a number of environmental and physiological changes might take place in the cast. The development of sweat, temperature rise, humidity, and skin pH change are normal causes that could lead to complications that include maceration of skin, irritation, itching, bacterial growth, and infection. These problems are usually not identified until the patient develops excessive discomfort or when they manifest themselves visually due to the removal of the cast in many clinical cases. The methods of current monitoring that are currently used mostly depend on patient-reported symptoms or regular clinical examination. These methods however do not permit monitoring of the skin microenvironment under the cast continuously. Subsequently, the early signs of complications can remain unknown which may result in the untimely diagnosis and premature castration of the cast in certain instances. The progress in wearable health equipment and embedded systems has given rise to new possibilities in creation of monitoring solutions that can be undertaken in restricted settings. The combination of sensors and wireless communication technology allows 24/7 monitoring and transmitting data in real-time. These systems would be able to promote preventive healthcare since they are used to detect poor conditions before they grow to severe complications. In this paper, the design and development of a smart wearable cast liner to be used to monitor the microenvironment underneath an orthopedic cast will be presented. The

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Page No: 301 - 306

suggested system will consist of several sensors, which will measure moisture, temperature, humidity and skin pH, as well as a microcontroller with wireless capacity to process and send the data. Moreover, there are vibration motors to deliver controlled itch treatment to patients. This work is aimed at proving a preventive monitoring strategy that will help enhance the comfort of patients and identify possible skin complications at an early stage during orthopedic immobilization.

1.1. Skin Complications During Cast Immobilization

Among the most frequent problems related to the long-term immobilization of the skin by the use of casts are skin complications. In cases where a skin is kept in a cast over an extended period, airflow is confined and moisture may also occur as a result of sweating. This may make the skin soft and cause maceration, which exposes the patient to more risk of irritation and infection. Also, elevated temperatures and moisture level within the cast may provide an ideal environment to the growth of microbes. During immobilization, patients normally get itchy and irritated, and in most instances they tend to put some objects into the cast to ease the itching process. This action may lead to additional damage of the skin and high chances of infection. Environmental and physiological conditions under the cast may be detected early with continuous monitoring of the parameters. It can be possible to give an early warning on the basis of the change in moisture, temperature, and pH of the skin, to intervene in a timely manner and eliminate complications.

1.2. Wearable Monitoring Systems in Healthcare

Modern healthcare has been very keen on wearable monitoring systems because of the capability of offering round-the-clock physiological monitoring. These systems are usually equipped with sensors, microcontrollers, wireless communication technology to receive and send data to be analyzed. The wearable devices have been commonly utilized in tracking the vital signs, physical activity, and environmental conditions. Wearable technology can be applied to the orthopedic treatment in the form of measuring the microenvironment under a cast without disrupting the immobilization process. It can be achieved by incorporating several sensors in a small and flexible form so that information about the patient can be gathered without causing any discomfort. The smart cast liner suggested is based on the embedded sensing technology and wireless communication that helps to develop a preventive monitoring system. The system integrates a number of sensing mechanisms and a patient comfort feature unlike the traditional methods that only consider a single parameter. This combined practice should enhance surveillance possibilities within the immobilization process.

2. Method

2.1. System Architecture

The Smart POP Cast Monitoring Device has its system architecture based on a layered system that comprises of sensing, processing, communication, application, and user interaction layers. Several sensors embedded in the POP cast at the sensing layer constantly inspect internal environments like body temperature, moisture level, humidity and pH changes. These parameters are the important signs of the possible infection, inflammation or pain under the cast. A microcontroller manages the processing layer and it acquires sensor data, preprocesses it and evaluates thresholds. It has a NodeMCU Wi-Fi controller that allows a wireless data transfer. The rechargeable battery pack and the step-down converters and power distribution board are used to manage power to stabilize operation. The sensor layer sends the processed sensor data to a cloud-based server with the help of Wi-Fi. The application layer is made up of a web-based dashboard that displays real-time measurements and constantly monitors abnormal conditions. The alert and interaction layer is also activated when threshold violation is reached. The user receives a notification and when he or she interacts with the bot, a chatbot interface is opened. This chatbot can offer surrounding support, medical advice, and preventive care depending on the recognized illness. The design enables real-time tracking, predictive care and automatic support without adding unnecessary bulk to make the product patient friendly, and can be installed within a POP cast.

2.2.Wearable Cast Liner Design

The intention of the wearable cast liner is to fit between the skin of the patient and the cast made of orthopedics. The electronic components are on the flexible printed circuit board (PCB) which is placed in the liner to enable the system to conform to limb shape. The flexible PCB is crucial in making sure that the device is comfortable to the patient at the same time being able to keep the sensors in the proper locations. The design enables the sensing part of the device to be in contact with the skin to enable correct measurements to be made. Orthopedic casts are bulky, hence the device needs to be light and compact. The liner is thus designed in such a manner that the discomfort is minimized, and all the requisite components are still included like sensors, microcontroller, power supply and vibration motors. Safety is also in the design, and the device should not be such that it produces a lot of heat or pressure that may have an impact on the patient.

2.3.Sensor Integration

The intention of the wearable cast liner is to fit between the skin of the patient and the cast made of orthopedics. The electronic components are on the flexible printed circuit board (PCB) which is placed in the liner to enable the system to conform to limb shape. The flexible PCB is crucial in making sure that the device is comfortable to the patient at the same time being able to keep the sensors in the proper locations. The design enables the sensing part of the device to be in contact with the skin to enable correct measurements to be made. Orthopedic casts are bulky, hence the device needs to be light and compact. The liner is thus designed in such a manner that the discomfort is minimized, and all the requisite components are still included like sensors, microcontroller, power supply and vibration motors. Safety is also in the design, and the device should not be such that it produces a lot of heat or pressure that may have an impact on the patient.

2.4.Hardware Implementation

The hardware system is created based on ESP8266 NodeMCU microcontroller, the core component that processes sensor data and allows wireless communication. The microcontroller receives signals of all the sensors connected to it and processes the information after which it sends it to the monitoring platform. The elements are placed on a printed circuit board which is incorporated into the liner structure. The shape is such that the surface of the sensing of the device is touching the skin during the installation of liner into the cast. The system contains two-coin vibration motors to have controlled mechanical stimulation. These motors are meant to minimize itching effects that patients feel when required to spend a long time in immobilization. This aspect will reduce chances of patients having objects inserted into the cast that may cause injury or infection. The system is developed to be used throughout the period of immobilization without excessive use of power.

2.5.Power Management System

A rechargeable battery system provides energy to the rest of the electric parts in the wearable by powering it. Different components need varying levels of voltage to operate thus step-down converters are applied to control and allocate power accordingly. The system also has a significant feature of power control since the device has to work long enough without constantly replacing batteries. The design will provide the ability to ensure the stable power supply to the sensors, microcontroller and vibration motors as well as ensure safe operation in the cast environment. Future enhancements can be centered on ensuring that power consumption is optimized, and the battery life is improved to ensure that the unit can be used over a long period during the entire immobilization time.

2.6.Data Acquisition and Communication

The microcontroller processes sensor data that has been gathered by the wearable liner, and sends it wirelessly using WiFi connectivity. Wireless communication can be used to monitor remotely without necessarily being able to touch the cast. At present, the system will be configured to send data to a web-based monitoring dashboard showing the sensor readings. This enables the caregivers or the medical care provider to see the conditions within the cast. Another aspect of the system architecture is the potential of incorporating a mobile application in future. The proposed application will enable patients and doctors to be warned in case sensor readings cross pre-determined threshold values. This practice

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Page No: 301 - 306

helps in preventative health care since it allows early identification of a health condition which can cause complications.

2.7.Proposed Experimental Setup for System Validation

A controlled experimental environment can be employed to approach the measure of the performance of the proposed device by simulating the environment within an orthopedic cast. With this design, the wearable liner may be fitted into a small structure that resembles the environment of a cast. To simulate the effect of sweating, moisture may be added gradually to the environment. Change in temperature and humidity could also be traced to see response of the system to environmental variation. It is then possible to analyze the device readings to find out whether the sensors are sensitive enough to spot any alterations on the environmental parameters. Such an experimental design will assist in testing the functioning of the system prior to the implementation of actual testing on patients. The further experimentation will be aimed at testing of wearability of the sensor, accuracy of the sensor and comfort of the patient during the extended use.

2.8.Software Methodology

The software system consists of integrated firmware, web-based monitoring board and an intelligent chatbot-based customer service module. The integrated firmware takes care of sensor configuration, data capture, signal authentication and wireless communication. Each parameter is given predetermined values of medical thresholds, including raising temperature, excessive moisture, rise of humidity and pH disproportion, which are determined according to clinical safety limits. The sensor data is sent on-the-fly to a dashboard that is connected to a cloud where the readings are shown in the form of visual indicators and charts. The dashboard keeps an eye on the incoming information and compares it with the preset thresholds. In case any of the parameters is out of limits, it automatically triggers a notification alarm. When the user engages the alert, he or she gets bounced to an inbuilt chatbot interface. The chatbot gives contextual advice according to the diagnosed abnormal condition. Questions can be posed by the user regarding any of the symptoms, precautions and immediate measures, e.g. whether the cast should be kept dry, should the user seek medical attention or should the user keep an eye on the situation. The chatbot is programmed with rule-based reasoning in combination with sensor context to provide applicable and comprehensible feedback.

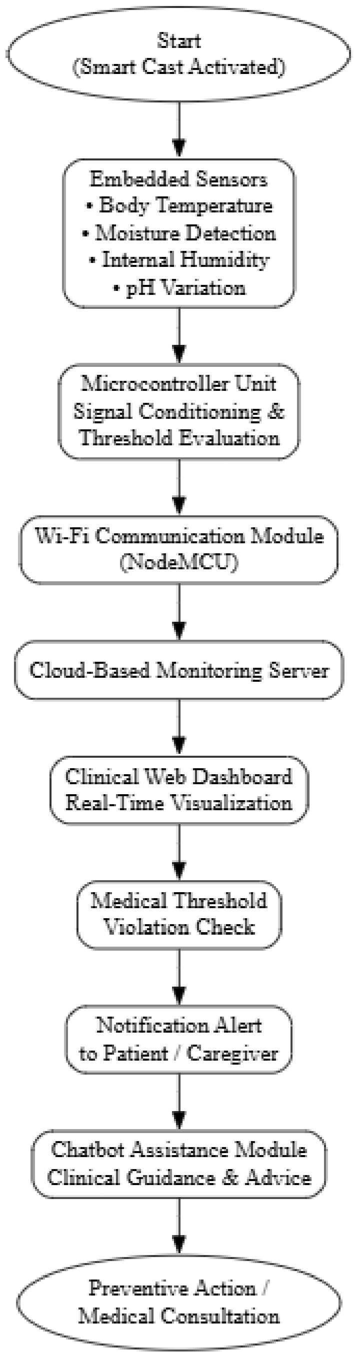

Figure 1 System Architecture

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March 2026
Page No: 301 - 306

3. Results and Discussion

3.1.Results

The resulting prototype of the smart cast liner system was built and tested to ensure that the sensing and monitoring devices had been properly functionalized. The integrated system could measure environmental parameters used in the conditions of an orthopedic cast such moisture, temperature, humidity, and pH of the skin. The sensors were willingly connected to ESP8266 NodeMCU microcontroller, which interpreted the measurements and provided an opportunity to transmit the data wirelessly. In the course of testing of the prototype set-up, the device was shown to display steady performance in a closed set-up that resembled the internal space of a cast. It allowed the sensors to record changes in the environmental conditions in case moisture and temperature changed. The readings pointed out that the system can record changes which might be linked to discomfort or possible skin complications. The microcontroller also had a wireless communication facility which was used to relay the data to a monitoring interface. The vibration motors that were fitted in the system were also tested to ensure that they are working as a comfort measure. When the motors ran, they caused controlled vibration feedback which meant that they could offer itch-relief benefits to patients when immobilized. In general, the prototype has proven that a small wearable device which is able to track several parameters through orthopedic cast is realizable.

3.2.Discussion

The outcomes of the prototype assessment indicate that it is possible to monitor the microenvironment under orthopedic casts continuously with the help of a small wearable device. The traditional method of treating the cast does not make it possible to directly observe the skin condition, which frequently contributes to the late diagnosis of complications. The suggested system will help to overcome this limitation by offering real-time data on the parameters related to skin health. Among the main findings made in the course of system evaluation was the capability of the sensors to react to the changes in the environment in a limited system. This implies that it will be possible to detect the conditions that could result in skin maceration or infection by monitoring the levels of moisture and humidity. Early identification of such changes will help the healthcare providers to make preventive action before complications arise to a serious extent. The system is also enhanced by the fact that it integrates wireless communication making it even more practical. Remote monitoring will also allow the caregivers or the healthcare professionals to get updates concerning the state of the patient without removing the cast. The methodology promotes the idea of preventive healthcare and minimizes the reliance on patient-self-reporting. Moreover, the introduction of vibration motors also adds a comfort feature to the patient that is typically not tackled as an aspect of the current monitoring systems. Cast patients often have itchy problems which they cannot safely relieve. This problem may be solved with the help of the controlled vibration mechanism and without the loss of the integrity of the cast. Despite the existing prototype proving to be a promising activity, more work is needed to enhance the system integration, miniaturization and durability. In practice, the operation of the system will need to be tested in hospitals in order to prove that it works well in real-life settings.

Conclusion

The paper has discussed the design and development of an intelligent wearable cast liner that could be used to monitor the microenvironment beneath orthopedic casts. The offered system is a combination of various sensors and a microcontroller as well as wireless communication in order to identify factors that can lead to skin irritation and infections during immobilization. The prototype showed that a small wearable device could be used to measure the environmental parameters of moisture, temperature, humidity, and skin pH. This paper emphasizes the possibility of using wearable healthcare technology and embedded systems in enhancing patient care in relation to the recovery of fractures. The proposed system can assist in minimizing complications related to the long-term use of casts by allowing its continuous monitoring and early identification of the undesirable conditions. The future developments of the system will consist in creation of specific mobile

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Page No: 301 - 306

software that will send notifications in real-time, redesign of the flexible PCB to be more comfortable to wear, and finally clinical trials, testing it on a patient in a hospital. Further development of the smart cast liner can guide the way to help the patient and the healthcare provider by enhancing the safety of orthopedic recovery and making the process safer and more efficient.

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