Integrating Splint for Real-Time Monitoring of Fracture Healing Process

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Abstract- The creation and application of Smart Splints for Fracture Healing, a ground-breaking method of fracture care, is presented in the proposed method. A range of sensors, including strain gauges, temperature, pressure, accelerometers, and gyroscopes, are strategically integrated in the suggested splints to track bone stability and recovery progress in real time. Data from these sensors is gathered and processed by a microprocessor, which is run by an energy-harvesting system or rechargeable battery. Wi-Fi is used by the system to provide wireless communication in order to send data to a cloud platform or mobile app. By enabling prompt interventions, improving the healing process, and offering individualized, data-driven insights, this breakthrough seeks to revolutionize fracture care. Static casts and splints are used in the standard fracture therapy method, which makes it impossible to track dynamic changes in the healing process. In order to overcome this constraint, the proposed method integrates a wide range of sensors, making it possible to continuously monitor limb movement, splint strain, temperature variations, fracture site pressure, and muscle activation. The Smart Splint technology provides a more sophisticated understanding of the healing process by processing this data in real time, allowing medical professionals to customize treatment regimens to meet the specific needs of each patient. This initiative is a major development in fracture care, building on earlier work in sensor technology for healthcare purposes. To sum up, the Smart Splints for Fracture Healing initiative presents a fresh and comprehensive method of treating fractures. With wireless communication enabling instantaneous data transmission and real-time monitoring of many parameters, the device opens up new possibilities for preventive and individualized fracture therapy. Through the utilization of cutting-edge technologies, this initiative advances the field of healthcare by focusing on patient-centered and data-driven solutions, hence improving fracture treatment quality and patient outcomes.

Keywords – Fracture Healing, Continuous Monitoring, Smart Splint, Sensors, IoT

I. INTRODUCTION

One common orthopedic difficulty is fractures, which call for efficient care techniques to promote the best possible healing. Conventional fracture care approaches use immobile casts and splints, which are unable to actively track the advancement of bone healing. This restriction leads to a one-size-fits-all approach to treatment and delayed interventions. By developing Smart Splints for Fracture Healing—a state-of- the-art device that incorporates a number of sensors within the splint itself—the proposed concept fills this gap. With the help of this invention, vital indicators including limb mobility, splint strain, local temperature variations, fracture site pressure, and muscle activation may be monitored in real time. The Smart Splint seeks to transform fracture management by offering rapid, individualized, and data-driven insights into the healing process by utilizing the power of these sensors in conjunction with wireless connection and data processing.

Step 1: Sensor Integration and Embedding of Smart Splints, this involves adding strain gauges, temperature sensors, pressure sensors, accelerometers, gyroscopes, and electromyography (EMG) sensors to the splints.

Step 2: Microcontroller Operation and Data Processing are the main part of this project where the battery and decision making properties where include.

Step 3: Wi-Fi is used by the Smart Splints to create wireless communication, which allows data to be sent to a specified mobile application or cloud platform.

II. PROPOSED ALGORITHM

2.1 Sensor Integration and Embedding –

The architecture of the Smart Splints for Fracture Healing system is shown in the figure 1, which shows how its interconnected parts work together to continuously monitor and evaluate bone healing. Accelerometers and gyroscopes to record limb movement and orientation; strain gauges positioned to measure forces on the splint; temperature sensors to track changes in local temperature; pressure sensors to measure pressure at the fracture site. Together, these sensors create an extensive network that is integrated into the splint and provides a multifaceted view of the healing process.

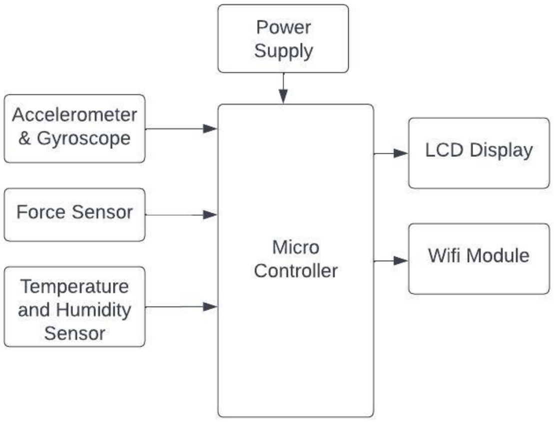

Figure 1. Block Diagram

1) Accelerometers and Gyroscopes: Accelerometers detect sudden movements and record changes in velocity in order to quantify acceleration. Gyroscopes measure angular velocity, which gives information on limb alignment and movement patterns as well as the rate of rotation. When combined, these sensors provide a thorough awareness of limb activity, which is especially helpful in situations such as limb fracture rehabilitation. It also helps to monitor and control limb movement and orientation.

2) Strain Gauge: The forces applied to a splint during movement can be measured by placing strain gauges strategically on the splint. These gauges give important information on the stress the splint is under, which helps determine how effective it is and how it affects the damaged limb. They do this by identifying material deformations brought on by applied forces. This data is essential for maximizing splint design and guaranteeing appropriate comfort and support during the healing process.

3) Temperature Sensor: A splint's temperature sensors track variations in the surrounding environment, providing information on the thermal state of the damaged area. This information is useful in evaluating circulation, inflammation, and any issues that may arise throughout the healing process. These temperature- sensing devices aid in patient comfort and successful management by monitoring changes in temperature. They also give medical practitioners important information that helps them optimize the rehabilitation environment for the wounded limb.

4) Pressure Sensor: By carefully placing pressure sensors at the fracture site, data on the forces acting on the wounded region may be obtained in real time. This data is useful for managing rehabilitation, evaluating the effect of extraneous variables on the fracture, and making sure that the pressure used is within acceptable bounds for the best possible healing. By using these sensors to monitor pressure, the total comprehension of the biomechanical environment at the fracture site is improved, which leads to more effective and individualized therapy.

2.2. Microcontroller Opertion and Data Processing –

The brain of the system are a central microcontroller that uses Arduino technology to gather and interpret data from the variety of sensors. The effective analysis of the dynamic characteristics captured by the sensors is ensured by this data processing unit. An energy-harvesting system or rechargeable battery integration offers a reliable power source for ongoing monitoring. Clarifying the crucial function of the microcontroller in the Smart Splints system is the main goal. The microcontroller, which is either energy harvesting or rechargeable battery- powered, is the core processing unit for the collected data. Initially, the microcontroller gathers information from a variety of embedded sensors, including strain gauges, temperature, pressure, accelerometers and gyroscopes. Important details on bone stability and the status of healing are included in this raw data set. By using logic or algorithms built into its programming, the microcontroller processes this input in real-time. By evaluating and analyzing the incoming data, these algorithms let the microcontroller make defensible choices about the condition of the fracture and the rate at which the healing process is progressing. The statement also emphasizes the difficulties in performing this activity, including power management, processing speed of the data, and general performance optimization of the microcontroller. Ensuring effective use of the rechargeable battery or the energy-harvesting system to ensure prolonged gadget performance are examples of power management challenges. Real-time monitoring depends on the speed at which data is processed, and improving the microcontroller's performance entails resolving problems with responsiveness, precision, and dependability while making judgments using sensor data.

2.3. Data Fusion Formula –

While several sensors and algorithms are used in a complete system such as the Smart Splints for Fracture Healing, particular mathematical formulae can be created based on desired parameters and sensor outputs. This is an example of a broad data fusion representation:

$F_{total} =[w1.F_{accel-gyro} + w2.F_{strain} + w3.F_{temperature} + w4.F_{pressure}$

F_{total}: Total force or parameter to be assessed. (w1, w2, w3, w4, w5): Weights assigned to each sensor data based on their importance.

($F_{accel-gyro}$, F_{strain}, $F_{temperature}$, $F_{pressure}$): Force or parameter measured by accelerometers-gyroscopes, strain gauges, temperature sensors, and pressure sensors respectively.

By combining data from all sensors with weights that may be adjusted, this formula provides a flexible way to prioritize different inputs according to the needs of the system and the particular circumstances surrounding the fracture. Optimizing the accuracy and efficacy of the system can be achieved by calibrating the weights according to clinical input and experimental data.

2.4. Wireless Communication and Data Transmission –

The wireless module makes it possible for data to be transmitted over Wi-Fi with ease, enabling the Smart Splint to connect to a cloud platform or mobile app. Real-time surveillance of bone stability is made possible by this networked system, giving patients and medical professionals quick insights into the course of the healing process and enabling prompt actions based on individual data. The establishment of smooth wireless communication inside the system depends on the integration of Wi-Fi technology. This wireless connectivity forms the spine of an intricate data distribution system by acting as a conduit for the transfer of vital information from the Smart Splints to a specific mobile application or cloud platform. Ensuring the security and efficiency of the data transmission process is achieved via the diligent implementation of protocols and methods. It is impossible to overestimate the importance of real-time data transmission as it makes it possible to instantly present patients and healthcare practitioners with individualized insights.

In addition to improving the precision of tracking bone stability and healing advancement, this immediate feedback loop enables prompt treatments based on real-time data analytics. Furthermore, the project deliberately views cloud platforms as a crucial part of this ecosystem for communication. The benefits of using cloud- based solutions for data storage, processing, and accessibility are significant. Cloud solutions offer a centralized, scalable repository that allows medical personnel to access patient data from a distance. This enhances collaboration among medical specialists and expedites the decision-making process, which together lead to more efficient and individualized fracture care. There is a clear commitment in this wireless communication stage to data-driven interventions and recovery process optimization. The Smart Splints project represents a paradigm change in fracture treatment by effectively fusing real-time insights with the possibility of cloud-based data management. It showcases an invention that has the revolutionary capacity to completely rethink the conventional approach to fracture management.

Together, these three painstakingly planned stages demonstrate the creativity and potential benefits of the Smart Splints for Fracture Healing, ushering in a new era of individualized and data-driven medical treatments.

III. EXPERIMENT AND RESULT

The various outcomes of the proposed method is discussed in this section. Furthermore, the electronic components are put together, and the sensors are positioned within their enclosures and linked to the electronic board. After the model is ready, the Arduino board needs to be programmed to obtain the data from the sensors, and a tiny circuit with the required electronic components needs to be designed in order to connect the sensors. The data used in this investigation were directly pulled from the serial transmission between the PC and the Arduino board. A Bluetooth or Wi-Fi-enabled device, such as a tablet or smartphone, may readily receive this data. It is noteworthy to mention that a single contact temperature and pressure are obtained by digitally processing the temperature and the pressure sensors. The arm splint was fastened to the arm that was first scanned for 1.5 hours in order to test it with the sensors attached to the Arduino board. Every three seconds, the Arduino serial monitor gathered sensor data, which was then transferred to Excel for graphing. The gathered data are displayed and discussed in the sections that follows,

1) 3D Modelling

The following image represents the 3D printing process of the designed model.

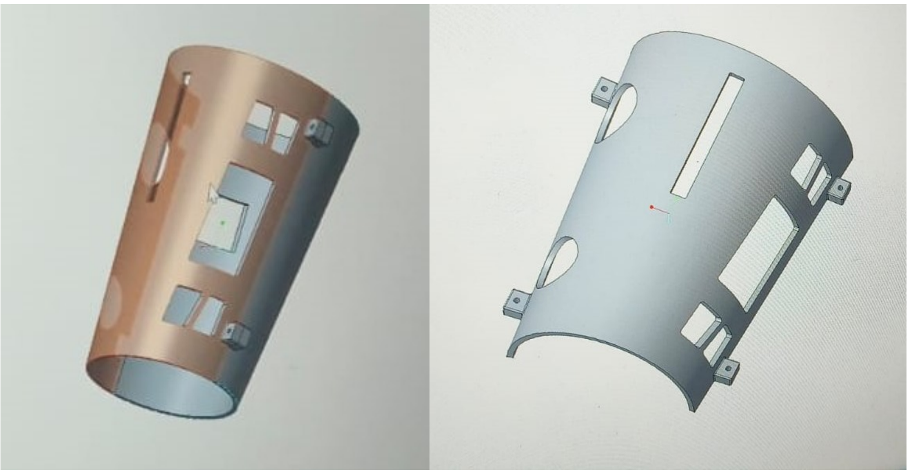

Figure 2. 3D Model Image

2) Temperature

In Figure 3, the mean temperature of the temperature sensor in contact with the skin is shown in the graph.

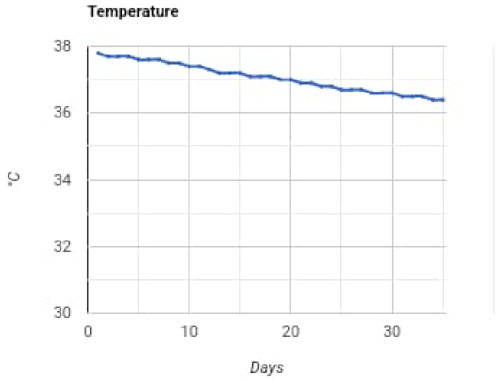

Figure 3. Temperature Graph

It is evident that the skin-contact sensors recorded a temperature marginally below the average human body temperature of 36 °C. The goal of this study, using these sensor, is for the clinicians to find any increase or decrease in temperature from historical records. These measurements alone allow for the precise detection of temperature variations, which may indicate an infection or inflammation in the affected area.

3) Pressure

The surface area of the utilized sensor is 1 cm^2. The mean pressure that the pressure sensors picked up is displayed in Figure 4. The graph shows that a pressure of 60 gf/cm2 is observed in a normal state. In order to maintain the joint's position during therapy, this pressure is created by the splint's normal pressure applied to the body. In order to simulate an inflammatory response, a force is exerted over the splint during the tests between minutes 6 and 12. The sensors pick up on this variation, registering a pressure shift of 60 to 100 gf/cm2.

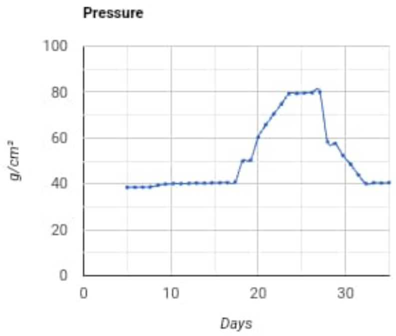

Figure 4. Pressure Graph

Both the historical and actual pressure are displayed on the graph. With this data, a specialist can determine whether the pressure is more or lower than it was in the preceding days to determine whether an inflammatory process is occurring in the location. The data may be reviewed by the physician as often as needed. As a result, the sensors precisely detect the increase in mass inside the splint when the pressure is increased as a result of the area becoming inflamed.

Research on both humans and animals has been done for about 50 years, demonstrating the link between medical disorders and temperature patterns. An area's temperature fluctuation is caused by local blood flow and cell metabolism. Although blood flow is the most essential element, temperature increases are typically the outcome of an increase in these factors. Furthermore, there may be a decrease in blood supply to the afflicted areas due to certain disease processes, various stages of bone growth, or the healing of fractures. Additionally, some changes in surface temperature will result from this.

The weight of the cloth in a traditional arm splint may cause neck ache when worn. Furthermore, because of the poor skin and device hygiene, allergies and itching may result from inadequate ventilation and the difficulty of bathing. The difficulty patients have managing traditional cast implants during some everyday activities is another drawback. This study suggests using a number of sensors to identify potential issues throughout the course of treatment. The length of the therapy has no bearing on how the data are gathered and interpreted. In fact, the collection may be done on a periodic basis, contingent upon the needs of the specialist physician and the progression of the injury. Data collection is therefore done as an indication that the system is functioning.

It is evident from the charts produced by the sensors that it is quite feasible to identify changes in temperature, angular variation, and pressure inside the splint. Furthermore, placing additional temperature sensors under the splint would enable the creation of a digital map showing the various regions beneath the splint. This data, which measures temperature variations on the skin's surface, shows both hot and cold reactions, which could coexist if pain linked to inflammation triggers a rise in sympathetic activity. It is possible to determine the area's progress at any point during the course of treatment by continuously monitoring these data. This makes it feasible to identify any vascular, muscle, or joint issues early on, before the immobilization splint is removed, or through severe symptoms that may indicate damage that is frequently irreversible. The temperature that the skin-contact sensor recorded is somewhat below room temperature. The temperature gradient that exists on the sensor surface is the cause of this. About 40% of the sensor surface is in touch with the skin. The splint covers the remaining surface, however it is not in contact with the skin. This feature causes a temperature differential between the sensor's various sites. Thermal conductivity causes the metallic surface to gravitate toward equilibrium. The ultimate temperature the sensor measures is not the same as the actual skin temperature. This feature, however, has little bearing on the sensor's primary function, which is to detect small temperature variations.The sensors accurately detect pressure, temperature, and angular velocity. Furthermore, the splint is correctly placed, yet these sensor detects flawlessly.

IV.CONCLUSION

This work's primary goal was to research, design, and produce an intelligent immobilization splint that would track many aspects of an injury's actual progression. This allows real-time data to be obtained for the diagnosis of any form of issue that is not detectable with conventional splints. With the current state of technology, immobilization splints can be made specifically for each patient using advanced manufacturing techniques based on reverse engineering, 3D digitization, and fused deposition modeling. Additionally, understanding these characteristics may shorten the healing period because some therapies are applicable to this type of splint but not to standard splints. This paper presents an intriguing and plausible evolution of the conventional splints, giving them the moniker "intelligent." This type of splint truly demonstrates the enormous potential it offers. Future research is suggested to address the following improvements, though:

- Incorporating a sensor to identify skin color changes into functional splints based on rehabilitation procedures during the immobilization phase; this would enable the detection of bruising and redness and provide additional data for the diagnostic process. • Integration during the immobilization period into functional splints based on rehabilitation procedures. Because of this, a battery would need to be included in order to create a fully autonomous system.

By incorporating these sensors and demonstrating that it is possible to detect difficulties in the treatment of injuries using immobilization splints, the primary goal of this work has been concluded.

REFERENCES

[1] Mohammed Y Aalsalem, Wazir Zada Khan, Wajeb Gharibi, Nasrullah Armi "An intelligent oil and gas well monitoring system based on Internet of Things" International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET),2017.

[2] Sayeda Islam Nahid, Mohammad Monirujjaman Khan " Toxic Gas Sensor and Temperature Monitoring in Industries using Internet of Things (IoT)" International Conference on Computer and Information Technology (ICCIT)2021

[3] S.Vivekanandan , Abhinav Koleti, M Devanand Autonomous industrial hazard monitoring robot with GSM integration International Conference on Engineering (NUiCONE)2013

[4] Meer Shadman Saeed, Nusrat Alim Design and Implementation of a Dual Mode Autonomous Gas Leakage Detecting Robot International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST)2019

[5] A.Sandeep Prabhakaran Mathan N Safety Robot for Flammable Gas and Fire Detection using Multisensor Technology International Conference on Smart Electronics and Communication (ICOSEC)2021.

[6] Ashutosh Mishra; Shiho Kim; N S Rajput" An Efficient Sensory System for Intelligent Gas Monitoring Accurate classification and precise quantification of gases/odors" International SoC Design Conference (ISOCC) 2020.

[7] Qiang Luo; Xiaoran Guo; Yahui Wang; Xufeng Wei "Design of wireless monitoring system for gas emergency repairing" Chinese Control and Decision Conference (CCDC) 2016.

[8] Mohammed Y Aalsalem; Wazir Zada Khan; Wajeb Gharibi; Nasrullah Armi "An intelligent oil and gas well monitoring system based on Internet of Things" International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET) 2017.

[9] C.Nagarajan and M.Madheswaran - 'Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter' - Journal of ELECTRICAL ENGINEERING, Vol.63 (6), pp.365-372, Dec.2012.

[10] C.Nagarajan and M.Madheswaran - 'Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis'- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011.

[11] C.Nagarajan and M.Madheswaran - 'Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques'- Taylor &; Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011.

[12] C.Nagarajan and M.Madheswaran - 'Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis'- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.

[13] Nagarajan C., Neelakrishnan G., Akila P., Fathima U., Sneha S. "Performance Analysis and Implementation of 89C51 Controller Based Solar Tracking System with Boost Converter" Journal of VLSI Design Tools & Technology. 2022; 12(2): 34–41p.

[14] C. Nagarajan, G.Neelakrishnan, R. Janani, S.Maithili, G. Ramya "Investigation on Fault Analysis for Power Transformers Using Adaptive Differential Relay" Asian Journal of Electrical Science, Vol.11 No.1, pp: 1-8, 2022.

[15] G.Neelakrishnan, K.Anandhakumar, A.Prathap, S.Prakash "Performance Estimation of cascaded h-bridge MLI for HEV using SVPWM" Suraj Punj Journal for Multidisciplinary Research, 2021, Volume 11, Issue 4, pp:750-756

[16] G.Neelakrishnan, S.N.Pruthika, P.T.Shalini, S.Soniya, "Perfromance Investigation of T-Source Inverter fed with Solar Cell" Suraj Punj Journal for Multidisciplinary Research, 2021, Volume 11, Issue 4, pp:744-749
[17] C.Nagarajan and M.Madheswaran, "Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation" has been presented in ICTES'08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007
[18] M Suganthi, N Ramesh, "Treatment of water using natural zeolite as membrane filter", Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022
[19] M Suganthi, N Ramesh, CT Sivakumar, K Vidhya, "Physiochemical Analysis of Ground Water used for Domestic needs in the Area of Perundurai in Erode District", International Research Journal of Multidisciplinary Technovation, pp: 630-635, 2019