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Research on orthopaedic intelligent medical healing system

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Abstract: *The process of fracture healing is similar to the process of gradual hardening of concrete; in the process of fracture healing, there are micro-movements at both ends of the bone, and the stresses borne by the fixation device and the distribution of the stresses are different in different postures; in the process of fracture healing, the micro-movements are reduced, the hardness and the strength are increased, and the inductive force of the device also changes with the passage of time.Based on the lack of intuitive data in the current bone healing research and taking into full consideration the shortcomings of the existing market products, this paper discusses the exploration of orthopaedic intelligent medical healing system in the construction of real-time monitoring and intelligent medical system. It is hoped that it will help the development and innovation of orthopaedic intelligent medical technology.*

Keywords: *smart healthcare, orthopaedic healing aid system, pressure sensors, real-time monitoring, data analysis*

1. Background and significance of development

1.1. R&D Background

In today's Internet era, with the continuous development of information technology in various fields, digital medicine has emerged. Digital medicine is an emerging frontier science that combines digital medical diagnostic technology, treatment technology and detection technology with the help of information technology and the research and practice of modern medicine in recent years. Digital orthopaedics is an emerging digital medical discipline that closely combines orthopaedic clinic and computer digital technology, which is a cross-discipline involving biomechanics, human anatomy, material science, mechanical engineering, three-dimensional geometry, electronics, informatics and other fields with Internet of Things technology as the aid and orthopaedics as the basis[1].

Bone external fixation brace is a common non-surgical treatment method, which is widely used in the fields of fracture treatment and bone defect repair. This treatment method promotes bone healing by supporting and stabilising the fracture site, but traditional bone external fixation scaffolds can only provide static support, and do not provide real-time monitoring and dynamic adjustment, and the bone external fixation scaffolds still have the problems of cumbersome manual operation, high requirements for operation techniques, unavoidable manual errors, unavoidable digital adjustments and chemical measurements, as well as various limitations brought about by the structural defects of the scaffolds themselves. This limits the effectiveness and accuracy of its treatment to a certain extent.

In order to overcome the limitations of traditional bone external fixation braces and to further improve the effectiveness of fracture treatment, the Orthopaedic Intelligent Medical Healing Aid System has emerged. The system combines advanced pressure sensor technology and intelligent data processing algorithms with real-time monitoring and precise adjustment capabilities. By combining the resistive pressure sensor with the screws of the external fracture fixation bracket, the system is able to achieve real-time monitoring and quantitative analysis of stress changes at the fracture site, providing doctors with effective treatment references.

1.2. Current status of research at home and abroad

Fracture external fixation brace is one of the devices used for the treatment of femur, tibia, humerus and other fracture fixation. Its basic principle is to make use of the balance of force condition, the force generated by the deformation of the steel pin is added to the fracture end surface to promote the early healing of the fracture. It has been proved by years of clinical practice that this fixator can better produce

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compression stimulation stress on fracture healing, which is conducive to fracture healing, and has the characteristics of simple structure and easy to use[2].

Overseas, some important research institutes and universities are actively working on the research and development of orthopaedic intelligent medical healing systems. For example, researchers at Stanford University in the United States have developed a smart fracture fixation brace system called "SmartCast", which monitors the pressure distribution and movement of the fracture site in real time by means of pressure sensors and accelerometers, so as to provide precise treatment adjustments. Researchers at the National University of Singapore have developed the "SMART-SKIN" system, which uses flexible pressure sensors on the surface of the skin to monitor the pressure at the fracture site in real time, and transmits the data to the doctor with the support of wireless transmission technology to achieve precise treatment adjustments. In 2021, engineering and orthopaedic experts at the University of Arizona collaborated to develop an ultra-thin wireless sensing device that can monitor bone health over time. Called Bone Surface Electronics, it features soft mechanics, an ultrathin form factor, and a miniature multimodal bio-interface consisting of sensors and optoelectronics directly attached to the bone surface[3]. The potential of this fully implantable device class was demonstrated by real-time recording of bone strain, Millikvin-resolution thermography and delivery of optical stimuli in a freely moving small animal model.

Numerous universities and research institutes in China have also taken the initiative to participate in the research of orthopaedic intelligent medical healing system. Researchers from the University of Chinese Academy of Sciences have developed an intelligent orthopaedic healing system that uses pressure sensors in combination with fixation brackets to monitor pressure changes at the fracture site in real time, providing doctors with a precise basis for treatment decisions. In addition, China's major medical academies are also developing smart orthopaedic materials to achieve precise treatment of fracture sites through adaptive and intelligent properties.2023 Dr. Ying Chen's team at the Department of Traumatology and Orthopaedics, China-Japan Friendship Hospital, applied the OrthoSpin six-axis smart exoskeleton to successfully treat a patient with a complex old fracture[4].The OrthoSpin six-axis smart exoskeleton system has the features of intelligent personalised treatment, minimally invasive treatment of fracture, and enhanced patient's ability to improve the patient's health. The OrthoSpin six-axis intelligent external frame system features intelligent personalised treatment, minimally invasive treatment of fractures, and enhanced patient experience and comfort. The system uses computerised artificial intelligence to precisely control the length, rotation and angle of the fracture site through an adjustable external brace. During the treatment process, a personalised adjustment plan was developed based on the patient's individual circumstances and the external fixation shaft was gradually adjusted to achieve precise fracture repositioning 2 days after the operation. This case demonstrates the ability to precisely control fracture repositioning through computer artificial intelligence assistance and personalisation, improving treatment outcomes and patient experience.

1.3. Significance of research and development

China is a large country with a large population, with the aging trend of China's population in recent years, the number of elderly people in China as a group continues to increase, due to the decline in physical function, making the incidence of orthopaedic diseases among the elderly has increased significantly, leading to the growth of demand for orthopaedic implantable medical devices in China. According to the data, the population aged 65 and above is 216.76 million, accounting for 15.4% of the national population[5].The incidence of orthopaedic diseases has a very high correlation with age. With the increase of age, the probability of the human body suffering from orthopaedic diseases such as bone fracture, scoliosis, spondylosis, arthritis, and joint tumour rises sharply.

At present, with the continuous development and progress of medical technology, orthopaedic medical devices are also constantly innovated and improved, and more and more innovative products and technologies are applied in orthopaedic surgery treatment. Currently, orthopaedic surgery has entered into minimally invasive, personalised and precise, and the design and processing requirements for orthopaedic devices have also increased. However, the commercially available fracture external fixation brackets are composed of external fixation screws connected to external fixation brackets, which can be used for various types of fractures of the limbs of the body, but their functions are relatively single, mainly to maintain the stability and position of the fracture, and to reduce the risk of fracture dislocation.

By reading the literature and referring to the products in the market, this paper considers the significance of orthopaedic intelligent medical healing aid system in the following aspects:

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1) It is conducive to saving medical resources and reducing the cost of treatment for patients.

2) It is conducive to the collection of data related to pressure changes, which can then be analysed to provide doctors with practical and reliable first-hand data for analysing the patient's recovery situation, and to facilitate the doctors' provision of precise guidance for the patient's recovery.

3) In the current orthopaedic device industry market scale further expansion and policy support, the fracture external fixation bracket device is multi-functional, innovative and feasible, the market prospect is broad.

2. Design options

2.1. Programme concept

The fracture healing process is similar to the process of gradual hardening of concrete; during the fracture healing process, there are micro-movements at both ends of the bone, and the fixation device is subjected to different stresses and stress distributions in different postures; during the fracture healing process, the micro-movements are reduced, the hardness and strength are increased, and the inductive force of the device is changed over time.

This proposal designs an orthopaedic intelligent medical healing aid system that combines software, hardware and artificial intelligence algorithms, which achieves real-time pressure monitoring of the fracture site by combining a resistive pressure sensor with a fracture external fixation bracket. Through the resistance-voltage conversion module and microcontroller, the data collected by the pressure sensor is converted into voltage value, and the change rule of stress corresponding to the voltage change is found out through experimental research and data analysis. Meanwhile, a master-multi-slave LORA networking mode is adopted to achieve that the slave transmits the stress value to the host and transmits the data to the WeChat applet through the WIFI module to achieve the monitoring and statistics of the data.

2.2. Overall design and operation process

The specific process is shown in Figure 1.

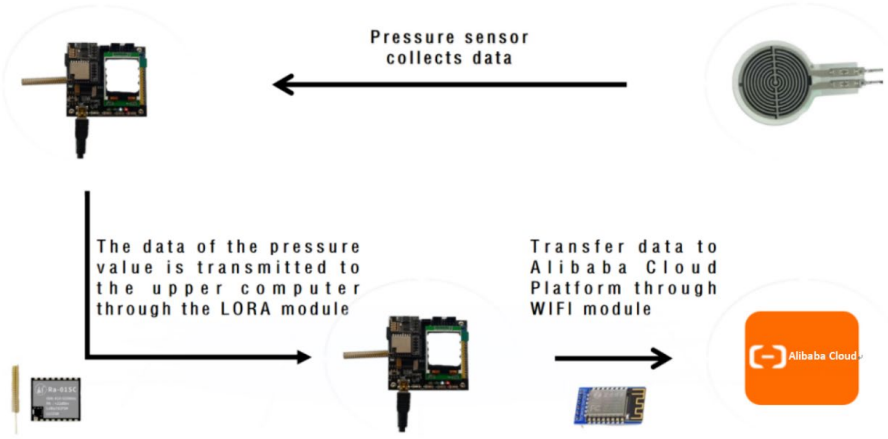

Figure 1: Flowchart

2.3. Hardware component

2.3.1. Selection of Sensors

The selection of sensors requires a clear definition of the application area and specific requirements of the pressure sensor. The requirements for sensors in orthopaedic intelligent medical healing aid systems relate to the following areas:

Precision and accuracy: Sensors need to be highly accurate and precise in measuring pressure to ensure that pressure distribution at the fracture site can be accurately monitored. This is important for doctors to make treatment decisions and for rehabilitation programmes.

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Pressure range and sensitivity: Sensors need to cover a wide pressure range to accommodate pressure variations in different fracture situations. In addition, the sensor also needs to have high sensitivity to sense small pressure changes.

Durability and stability: As orthopaedic treatments are often used over long periods of time, the sensors need to have good durability and stability. They should be able to withstand prolonged mechanical stress, withstand changes in humidity and temperature, and be unaffected by external interference to ensure continuous and reliable operation.

Size and Flexibility: Since the sensor needs to be in contact with the patient and placed on the skin or in a fixation bracket, its size needs to be small enough to be worn comfortably. In addition, the sensors need to be flexible and adaptable enough to accommodate the morphology and movement of different fracture sites.

Real-time monitoring and data transmission: Sensors should be able to monitor and collect pressure data in real time and transmit the data to the physician or system for real-time diagnosis and treatment adjustment. The sensor needs to provide suitable interfaces and communication methods so that data can be transmitted and processed efficiently.

Safety and biocompatibility: Sensors need to have good safety and biocompatibility and not cause damage or allergic reactions to the patient's skin and body tissues. Ensure that the sensor material is non-toxic, non-hazardous and fully compatible with the human body.

Orthopaedic intelligent medical healing aid system has very strict requirements for sensors, and the performance of the sensors directly affects the quality and effect of treatment. Therefore, when developing and selecting sensors, the above requirements need to be fully considered to ensure that the sensors can be reliably applied in orthopaedic medical field.

2.3.2. The WIFI Communication Connection

The WIFI wireless communication module is used to connect to the applet after configuring through the network, and real-time pressure data is transmitted to the applet, and the core technology points are serial communication and telegram transmission.

The advantage of WIFI module is that WIFI transmission has the advantages of stronger RF signals, low power consumption, and improved security, etc. The cloud platform can be used as a data sharing platform and software application platform. At the same time, the cloud platform has the following advantages compared to traditional servers: in terms of flexibility, developers can increase their own configuration online in real time, with a large scalable space, and flexible deployment according to the needs; in terms of security, the cloud server has a natural anti-ARP attack and MAC spoofing, snapshot backups, and the data is permanently not lost to ensure the safety of the data, and the traditional servers do not have the function in this regard; in terms of reliability, the cloud server is based on server clusters, so the hardware redundancy. In terms of reliability, cloud servers are based on server clusters and therefore have higher hardware redundancy and lower failure rates, while traditional servers have relatively less hardware redundancy and higher failure rates.

2.3.3. LORA Networking

LORA technology is an ultra-long-distance wireless transmission scheme based on spread spectrum technology, which has the characteristics of long transmission distance, low working power consumption, and many nodes in the network, etc. The LORA module of this system uses sx1278 chip, which has strong anti-interference, and the transmission distance can reach three kilometres, and the communication is stable. Its advantages include:

Long-range communication: LORA modules can achieve communication distances of several kilometres, enabling them to meet the needs of a wide range of applications.

Low Power Consumption: The LORA module uses low-power technology to achieve long battery life, which is suitable for many low-power application scenarios.

High anti-jamming: LORA module adopts frequency shift keying modulation technology, which has strong anti-jamming ability and still maintains the communication quality in the complex electromagnetic environment.

Low cost: LORA modules are less expensive to manufacture and more cost competitive compared to other wireless communication technologies.

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High reliability: The transmission protocol of LORA module adopts forward error correction technology, which can effectively reduce the data transmission error rate and improve the reliability of data transmission.

2.3.4. Voltage Conversion Module

Resistance-voltage conversion module is a common circuit module, used to convert the resistance change into the corresponding voltage output signal, in the orthopaedic intelligent medical healing system, the bone in the healing process will lead to the displacement of the bone external fixation bracket, squeezing the pressure sensor, the pressure sensor to feel the pressure change will lead to the change of the resistance value, through the resistance-voltage conversion module can be obtained a specific voltage output value, the signal can be transmitted to the microcontroller to complete the conversion. After the resistance-voltage conversion module, a specific voltage can be obtained and the signal output value can be transmitted to the microcontroller to complete the conversion.

The following is a detailed description of the hardware module Resistance-Voltage Conversion Module:

A resistance-to-voltage conversion module typically consists of a resistor as the sensor element, a precision operational amplifier, and other related components. Its main function is to convert changes in resistance to a voltage output in order to measure and monitor resistance changes.

Principle of operation: The voltage across the sensor resistor is converted to an output voltage by an operational amplifier. When the resistance in the circuit changes, the voltage across the sensor resistor changes accordingly. The operational amplifier receives the voltage across the sensor resistor and amplifies it, then converts the amplified signal into a voltage output signal. The magnitude of this output signal and the relationship between the voltage and the sensor resistor is determined based on the overall circuit design and amplifier configuration.

To improve accuracy and stability, resistance-to-voltage conversion modules typically employ precision operational amplifiers and use a stable reference voltage as a datum. Resistance temperature compensation and calibration techniques may also be employed to eliminate temperature-related effects and provide a more accurate output. In addition, resistance-to-voltage conversion modules often require an external power supply to power them and have interfaces to other modules or systems. The interface may be analogue, such as a voltage input/output port, or digital, such as a serial communications or bus interface. This allows easy data exchange and control with other hardware modules or control devices.

Depending on the specific application requirements, select the appropriate resistance-to-voltage conversion module for accurate and reliable conversion of resistance changes to voltage output.

2.4. Software component

2.4.1. Wechat Small Program

WeChat applets have the advantages of small memory occupation and data visualisation, which are suitable for fracture patients and orthopaedic surgeons to use. This system is equipped with a set of WeChat applets and uploads the bone stress value at the patient's broken bone to the AliCloud platform through Lora networking and WiFi module, and connects to the WeChat applets using the MQTT protocol to achieve data visualisation. It can realise the functions of weather forecast, medical news browsing, healing degree monitoring and data abnormality alarm, etc. It can facilitate the doctors to view the stress value at the patient's broken bone, help the doctors to understand the patient's recovery situation more quickly, and improve the efficiency of patient's recovery. Patients can also learn about their own healing status through the app, reducing the cost of travelling to and from the hospital for treatment.

AliCloud, as the middle layer connecting business applications and devices, shields a variety of complex device interfaces to achieve rapid access to devices; at the same time, it provides powerful open capabilities to support industry users to quickly build IoT business applications. Devices can be accessed through fixed networks, 2G/3G/4G/5G, NB-IoT, Wi-Fi and other networks, and use LWM2M/CoAP or MQTT protocols to report monitoring data to the applet, which can also send control commands to the devices.

AliCloud is superior:

Access-independent: any way to connect, any device to connect, in rainy days and other harsh environments in the scene, can still play the use.

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Reliable security: Cloud-based platform system installation and deployment with system clustering, virtual machine reliability, etc. Flow control, data encryption, sensitive information shielding, etc. to strengthen business reliability. Network reliability strategy is reflected in 1+1 mutual backup, Pool mode, API Server module, database module.

Elasticity Scaling: Define your own elasticity scaling policies, configure regular or periodic monitoring policies through the visual console, and dynamically adjust the elastic cloud server instances to ensure smooth and healthy operation to meet business needs while reducing resource investment.

Ability to open: Ali's years of professional hardware development and customisation capabilities, combined with the depth of self-developed virtualisation optimisation technology, to provide ultra-high-performance experience.

2.4.2. A predictive model for fracture healing based on grey prediction and regression analysis

Regression analysis is a statistical method used to explore relationships between variables and predict future values. It describes the relationship between the independent variable (the explanatory variable) and the dependent variable (the explained variable) by creating a mathematical model. The goal of regression analysis is to find the best-fit line or curve that explains and predicts the way the dependent variable changes with the independent variable. Regression analysis can be done using different methods, the most common being linear regression. Linear regression assumes a linear relationship between the independent and dependent variables and attempts to find a straight line that minimises the difference between the predicted and true values. Other types of regression analysis methods include polynomial regression, logistic regression, and non-linear regression.

A grey forecasting system is a method used to predict and analyse data. It uses a grey model to process the data and this model can be used to speculate future trends by performing grey correlation analysis and grey prediction on the data. Grey prediction system is mainly based on grey system theory, by dividing the sample data into grey data and white data, and making predictions based on the characteristics of white data. Its advantage is that it can make predictions with fewer data samples and can better handle data containing uncertainty.

Since the value of bone stress at the patient's broken bone changes frequently during the patient's rehabilitation, generating a large amount of data, polynomial regression can be used to build a model using basic data, and the grey prediction model can be used to predict a small amount of future data. Moreover, polynomial regression can better fit nonlinear data, and by introducing higher-order terms, it can more accurately describe the complex relationships of the data, a feature that can compensate for the limitation of grey prediction systems to linear relationships. By combining polynomial regression and grey prediction model, a new combined model was constructed to predict the bone stress values at the broken bones of future patients, and the results obtained were good.

Some scholars have already studied the bone stress prediction algorithm, Zhu Jianmin et al. designed the live goat fracture model to obtain the daily average stress of the trauma section during the fracture healing process of the live goat and used this method to establish a new interest model based on the weakened buffer operator and GM (1, 1) equidimensional neo-interest model[6]. Zhao Fuwang et al. proposed a combined prediction model based on grey neural network according to the idea that neural network can effectively correct grey prediction model[7]. The above studies were conducted from different perspectives, and the results were all better.

3. Innovative points and application prospects

3.1. Innovative points

(1) The use of multiple wireless communication modules: the system uses a WIFI module, a LORA module, and a linear voltage conversion module, which allows the measurement data to be transmitted to the monitoring terminal in real time. This allows healthcare professionals to remotely monitor the patient's recovery and improves the treatment effect.

(2) Reliable Data Measurement: The system can accurately measure the micromotion and stress distribution at both ends of the bone during fracture healing, which is an intuitive data that is missing in current medical research. By analysing these data, doctors can better understand the patient's recovery and target treatment plans to improve treatment results.

(3) Multi-point measurement: the system can be connected to the bone external fixation bracket in

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different positions of the pressure sensor measurement data to get the corresponding points of pressure monitoring data, the data will be uploaded to the WeChat app through the degree of fracture healing prediction model analysis can be obtained by the patient's degree of healing of different fracture points.

(4) Further advancement of research: the system can not only be used for patients' rehabilitation monitoring, but also provide more detailed data for medical research. By analysing the data of bone stress changes, the mechanism and influencing factors of fracture healing can be further studied, providing a more scientific theoretical basis for fracture treatment.

3.2. Application prospects

Digital orthopaedics is a field with broad market prospects. The application of digital orthopaedic technology can provide more accurate guidance for orthopaedic surgery, reduce the difficulty and risk of surgery, and improve the success rate of surgery, which is getting more and more attention and favour. The following are some aspects of the application prospects of orthopaedic intelligent medical healing aid system:

(1) Market size: The global orthopaedic market is huge and is expected to continue to grow in the future. The application of orthopaedic intelligent medical healing aid system can improve the efficiency and accuracy of surgery, reduce the risk of surgery and patient pain, favoured by the market.

(2) Technological advancement: the continuous progress and development of orthopaedic intelligent medical healing aid systems will drive the development of the digital orthopaedics market. With the continuous improvement of digital orthopaedic technology, the performance and quality of digital orthopaedic products will also continue to improve, so as to meet the needs of the medical market for digital orthopaedic technology.

(3) Population aging: The global trend of population aging is obvious, and the demand for orthopaedic treatment of the elderly population is also increasing. Orthopaedic intelligent medical healing system can improve the efficiency and accuracy of surgery, shorten the recovery period, and meet the orthopaedic treatment needs of the elderly population.

(4) Medical cost pressure: With the rising medical cost, the application of orthopaedic intelligent medical healing system can reduce the operation cost and patient's recovery time, reduce the pressure of medical cost, favoured by medical institutions and insurance companies.

4. Conclusion

In summary, the orthopaedic intelligent medical healing aid system brings new possibilities and challenges to orthopaedic medicine, and is expected to improve the effectiveness and accuracy of fracture treatment. With the continuous development and innovation of the technology, we have reason to believe that the Orthopaedic Intelligent Medical Healing System will be widely used in the future clinical practice and make important contributions to the further development of the field of orthopaedic medicine.

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