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USABILITY ASSESSMENT OF TECHNOLOGIES FOR REMOTE MONITORING OF KNEE OSTEOARTHRITIS

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Abstract: Knee osteoarthritis (OA) is a prevalent degenerative joint disorder that significantly affects the elderly population, leading to chronic pain, joint stiffness, and limited mobility. Early diagnosis and continuous monitoring are essential for effective management and to delay disease progression. This project introduces an innovative, wearable system for the detection and management of knee osteoarthritis using a combination of Micro-Electro-Mechanical Systems (MEMS) sensors, force sensors, and a vibration motor. The MEMS sensor continuously tracks knee joint angles and motion to identify abnormal movement patterns typically associated with osteoarthritic degradation. Complementing this, the force sensor evaluates the pressure applied to the knee during movement, providing insights into load distribution and joint strain. A vibration motor is employed to deliver localized therapeutic stimulation to the surrounding muscles, aiding in pain relief and enhancing joint flexibility. The system is built on a microcontroller-based architecture that processes sensor data in real time. It is also designed with future scalability in mind, allowing integration with Internet of Things (IoT) modules for remote health monitoring and tele-rehabilitation. This solution offers a non-invasive, cost-effective, and user-friendly method to support both clinical assessments and home-based management strategies for individuals at risk of or suffering from knee osteoarthritis. By leveraging sensor fusion and intelligent feedback mechanisms, this approach promotes early intervention, encourages patient engagement, and improves overall quality of life.

Keywords- Knee Osteoarthritis, MEMS Sensor, Force Sensor, Vibration Motor, Muscle Stimulation, Wearable Device, Joint Monitoring, IoT in Healthcare, Early Detection, Pain Management

1. INTRODUCTION

Accurate monitoring of joint angles in the ambulatory setting could provide important information regarding the progress of rehabilitation in patients with neuromuscular and musculoskeletal disorders, such as stroke, Parkinson‘s disease, osteoarthritis (OA), anterior cruciate ligament injury, and rotator cuff injury. Traditionally, kinematic analysis has been performed within laboratory settings using optoelectronic motion capture systems—the gold standard for human kinematic analysis—which utilize an array of infrared cameras to capture the positions of reflective markers placed on predefined anatomical landmarks to create a three-dimensional (3D) skeletal model. These systems are useful in clinical and research environments, but the availability of well-equipped gait laboratories in clinical settings is often lacking, and is limited by cost and technical expertise. Most importantly, assessments restricted to laboratory settings provide a narrow snapshot of function and do not capture natural free- living gait patterns, thus representing a severely under-sampled view of patients‘ conditions. Frequent, longitudinal monitoring of kinematic parameters in ambulatory settings could provide an objective assessment of physical function and disease progression, allowing the development of personalized treatments and rehabilitation programs to cope with dynamically changing functional performance levels. Much effort has been made to develop wearable sensors that can facilitate real-time, continuous joint health and movement monitoring in free-living conditions, including approaches that leverage near-infrared spectroscopy, bio-acoustics, electrical bioimpedance, and kinematic modelling. In particular, a wide range of sensing methodologies have been studied to enable kinematic modelling, such as inertial measurement units (IMUs), radio frequency, However, few wearable heterogeneous human body shapes, and6) accurate enough to support the 5 ◦ estimation accuracy suggested by the American Medical Association for movement analysis in a clinical context, which are important characteristics for long-term field study deployment. This project introduces a reliable, power efficient, and low cost wearable sensor designed for long-term monitoring of joint kinematics in the ambulatory setting. In particular, this sensor was developed to monitor the knee joint angles of patients with knee OA. The proposed sensing platform uses a retractable string sensor that is both bendable and stretchable. This soft sensor measures changes in the string length between two anchor points positioned at opposing segments of the joint during movements, which is analogous to the measurement of skin stretch over the joint, and uses data- driven modeling to estimate the joint angle. As a proof of concept, we focus on estimating the knee flexion/extension angle during level ground walking at different speeds. We show that our wearable system can be used to estimate knee angles with acceptable accuracy throughout the gait cycle and at varying walking speeds. The Internet of Things (IoT), also sometimes referred to as the Internet of Everything (IoE), consists of all the web-enabled devices that collect, send and act on data they acquire from their surrounding environments using embedded sensors, processors and communication hardware. Humans can interact with the gadgets to set them up, give them instructions or access the data, but the devices do most of the work on their own without human intervention. Their existence has been made possible by all the tiny mobile components that are available these days, as well as the always-online nature of our home and business networks. Connected devices also generate massive amounts of Internet traffic, including loads of data that can be used to make the devices useful, but can also be mined for other purposes. All this new data, and the Internet-accessible nature of the devices, raises both privacy and security concerns. Sensors or devices help in collecting very minute data from the surrounding environment. All of this collected data can have various degrees of complexities ranging from a simple temperature monitoring sensor or a complex full video feed. A device can have multiple sensors that can bundle together to do more than just sense things. For example, our phone is a device that has multiple sensors such as GPS, accelerometer, camera but our phone does not simply sense things.

Next, that collected data is sent to a cloud infrastructure but it needs a medium for transport. The sensors can be connected to the cloud through various mediums of communication and transports such as cellular networks, satellite networks, Wi-Fi, Bluetooth, wide-area networks (WAN), low power wide area network and many more. Every option we choose has some specifications and trade-offs between power consumption, range, and bandwidth. So, choosing the best connectivity option in the IOT system is important. Next, the information made available to the end-user in some way. This can achieve by triggering alarms on their phones or notifying through texts or emails. Also, a user sometimes might also have an interface through which they can actively check in on their IOT system. For example, a user has a camera installed in his house; he might want to check the video recordings and all the feeds through a web server. However, it‘s not always this easy and a one-way street. Depending on the IoT application and complexity of the system, the user may also be able to perform an action that may backfire and affect the system. For example, if a user detects some changes in the refrigerator, the user can remotely adjust the temperature via their phone.

2. LITERATURE SURVEY

Title: "EMG signals in co-activations of lower limb muscles for knee joint analysis"
Explanation: This study explores how electromyography (EMG) signals from co-activating lower limb muscles can be used to analyze knee joint dynamics. It’s crucial in detecting irregular muscle patterns associated with osteoarthritis and evaluating muscle coordination during movement.

Title: "A proof of concept system to analyze joint sounds in real time for knee health assessment in uncontrolled settings"
Explanation: This paper presents a real-time system to monitor knee joint health using acoustic signals (joint sounds). It supports OA diagnosis in everyday environments, providing an innovative, non-invasive way to detect cartilage damage and joint anomalies.

Title: "EMG signals in muscular co-activations for dynamic analysis of knee joint"
Explanation:This work builds on EMG signal analysis for dynamic assessment of knee movement. It is directly applicable to OA research where muscle activation abnormalities are a major symptom. It helps in evaluating real-time movement dysfunction.

Title: "Co-activation patterns of gastrocnemius and quadriceps femoris in controlling the knee joint during walking"
Explanation:Focuses on how specific muscles work together during walking, offering insights into gait alterations caused by osteoarthritis. It aids in designing rehabilitation protocols and sensor-based systems for detecting abnormal gait in OA patients.

Title: "Robust hand gesture recognition with double channel surface EMG wearable armband and SVM classification"
Explanation: While this paper is about hand gestures, it demonstrates how surface EMG and machine learning (SVM) can be used for wearable device applications. The techniques are transferrable to knee OA detection for identifying movement or pressure abnormalities.

Title: "Review of the preoperative planning of robot assisted knee arthroplasty"
Explanation: A comprehensive review of robotic assistance in knee replacement surgery. It's useful for understanding the technological advancements in treating severe OA and can guide system design for long-term OA monitoring and intervention.

Title: "Applications of computer-assisted surgery (CAS) in total knee arthroplasty (TKA)"
Explanation: Highlights how computer-assisted surgical techniques improve the precision of knee replacement. It underscores the importance of accurate joint modeling and movement analysis—relevant for systems aiming at early OA detection and decision-making.

Title: "Think Surgical TSolution-One® (ROBODOC) total knee arthroplasty"
Explanation: Describes a robotic system (ROBODOC) for knee surgeries. This illustrates advanced treatment options and shows how surgical data could inform preoperative planning and guide non-invasive detection systems before surgery becomes necessary.

3.PROPOSED SYSTEM

The proposed system addresses the limitations of existing methods by integrating MEMS sensors, force sensors, and muscle stimulation into a single wearable device. This system continuously monitors knee movement and pressure distribution, allowing for early osteoarthritis detection and immediate therapeutic intervention. The core components and functionalities of this system include: Knee Angle Detection: A MEMS accelerometer and gyroscope track knee movements in real-time, identifying irregular motion patterns associated with osteoarthritis. This data is processed using a microcontroller to detect abnormalities such as excessive knee bending, restricted motion, or uneven gait. Pressure Sensing: A force sensor detects pressure distribution on the knee joint, helping assess excessive strain or uneven weight distribution. High pressure in specific areas can indicate joint misalignment, which is a key indicator of osteoarthritis progression. Muscle Stimulation: A vibration motor is activated based on real-time data analysis to provide muscle stimulation. This helps in reducing pain, enhancing blood circulation, and preventing muscle atrophy in patients with limited mobility. Microcontroller-Based Processing: The system uses a microcontroller to process data from MEMS and force sensors, analyze movement patterns, and trigger necessary therapeutic actions. The processing algorithm can be adjusted based on user needs. Real-Time Alerts: The system generates alerts when abnormal pressure or motion patterns are detected, notifying the user to take preventive actions. IoT-Based Remote Monitoring: The device can be connected to a mobile application or cloud platform, allowing healthcare professionals to monitor patient data remotely. This helps in early intervention and personalized treatment plans. User-Friendly Interface:

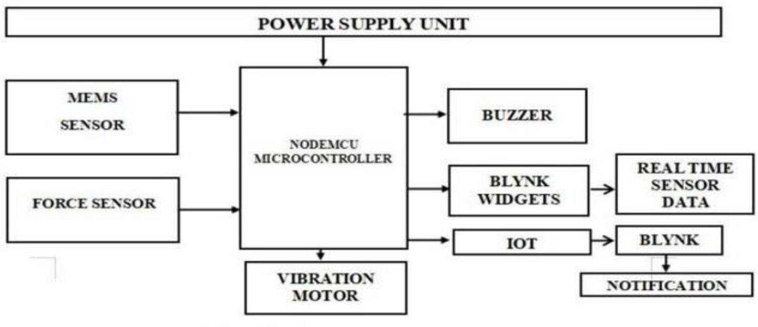

FIGURE 1. System Architecture Diagram.

Power supply is a reference to a source of electrical power. A device or system that supplies electrical or other types of energy to an output load or group of loads is called a power supply unit or PSU. The term is most commonly applied to electrical energy supplies, less often to mechanical ones, and rarely to others. Power supplies for electronic devices can be broadly divided into linear and switching power supplies. The linear supply is a relatively simple design that becomes increasingly bulky and heavy for high current devices; voltage regulation in a linear supply can result in low efficiency. A switched-mode supply of the same rating as a linear supply will be smaller, is usually more efficient, but will be more complex. An AC powered linear power supply usually uses a transformer to convert the voltage from the wall outlet (mains) to a different, usually a lower voltage. If it is used to produce DC, a rectifier is used. A capacitor is used to smooth the pulsating current from the rectifier. Some small periodic deviations from smooth direct current will remain, which is known as ripple. These pulsations occur at a frequency related to the AC power frequency (for example, a multiple of 50 or 60 Hz). The voltage produced by an unregulated power supply will vary depending on the load and on variations in the AC supply voltage. For critical electronics applications a linear regulator will be used to stabilize and adjust the voltage. This regulator will also greatly reduce the ripple and noise in the output direct current. Linear regulators often provide current limiting, protecting the power supply and attached circuit from over current. Adjustable linear power supplies are common laboratory and service shop test equipment, allowing the output voltage to be set over a wide range. For example, a bench power supply used by circuit designers may be adjustable up to 30 volts and up to 5 amperes output. Some can be driven by an external signal, for example, for applications requiring a pulsed output. Transformers convert AC electricity from one voltage to another with little loss of power. Transformers work only with AC and this is one of the reasons why mains electricity is AC. Step-up transformers increase voltage, step-down transformers reduce voltage. Most power supplies use a step-down transformer to reduce the dangerously high mains voltage (230V in UK) to a safer low voltage. The input coil is called the primary and the output coil is called the secondary. There is no electrical connection between the two coils; instead they are linked by an alternating magnetic field created in the soft-iron core of the transformer. The two lines in the middle of the circuit symbol represent the core. The low voltage AC output is suitable for lamps, heaters and special AC motors. It is not suitable for electronic circuits unless they include a rectifier and a smoothing capacitor. Voltage regulator ICs are available with fixed (typically 5, 12 and 15V) or variable output voltages. They are also rated by the maximum current they can pass. Negative voltage regulators are available, mainly for use in dual supplies. Most regulators include some automatic protection from excessive current ('overload protection') and overheating ('thermal protection'). The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and current.

4. RESULTS AND DISCUSSION

The knee osteoarthritis detection and management system has applications in multiple fields, including healthcare, sports medicine, physiotherapy, and rehabilitation. In healthcare, the system assists in early diagnosis and monitoring of osteoarthritis progression, allowing medical professionals to recommend timely interventions. For athletes and sports medicine specialists, it helps in assessing joint health, preventing injuries, and optimizing recovery plans. In physiotherapy, the system aids therapists in tracking patient progress, ensuring exercises are performed correctly, and adjusting therapy sessions based on real-time data. Elderly individuals with a high risk of osteoarthritis can use the device for continuous monitoring, reducing the likelihood of severe complications. Additionally, this system can be integrated into smart wearable technologies for home-based rehabilitation, allowing patients to manage their condition independently while staying connected to healthcare providers. The feasibility of the knee osteoarthritis detection system is assessed based on technical, economic, and user-friendliness factors. Technically, the use of MEMS sensors, force sensors, and vibration motors ensures high precision in detecting knee movements and joint pressure. The system's compatibility with IoT and cloud-based applications makes remote monitoring viable and effective. Economically, the system is cost- effective compared to frequent clinical visits and expensive diagnostic procedures, making it a viable solution for mass adoption. The affordability of components such as ESP32 and MEMS sensors further enhances feasibility. In terms of user-friendliness, the system is designed to be lightweight, portable, and easy to wear, ensuring convenience for users of all age groups. The device operates autonomously with minimal user intervention, making it accessible even for elderly individuals with limited technical knowledge. Overall, the system presents a feasible, scalable, and impactful solution for knee osteoarthritis detection and management. The knee osteoarthritis detection and management system has applications in multiple fields, including healthcare, sports medicine, physiotherapy, and rehabilitation. In healthcare, the system assists in early diagnosis and monitoring of osteoarthritis progression, allowing medical professionals to recommend timely interventions. For athletes and sports medicine specialists, it helps in assessing joint health, preventing injuries, and optimizing recovery plans. In physiotherapy, the system aids therapists in tracking patient progress, ensuring exercises are performed correctly, and adjusting therapy sessions based on real-time data. Elderly individuals with a high risk of osteoarthritis can use the device for continuous monitoring, reducing the likelihood of severe complications. Additionally, this system can be integrated into smart wearable technologies for home-based rehabilitation, allowing patients to manage their condition independently while staying connected to healthcare providers.

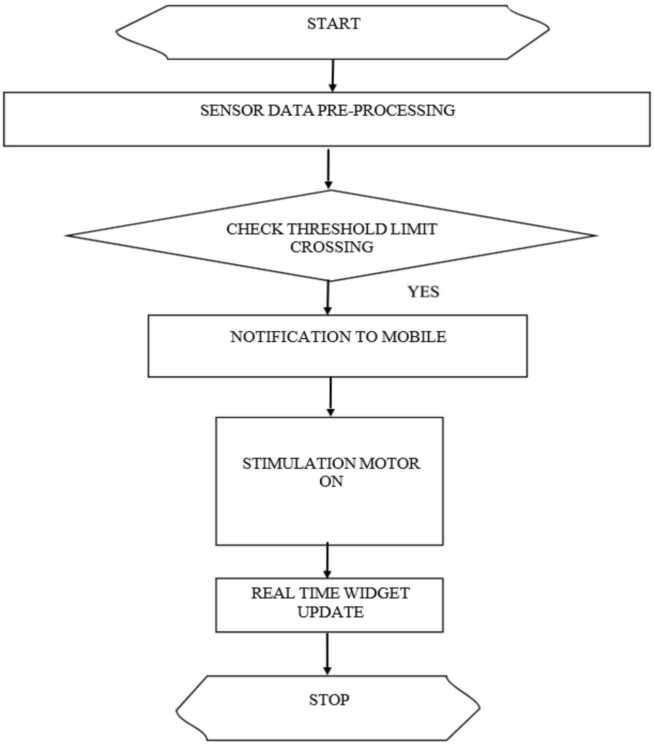

Fig 2: Working Model

5. CONCLUSION

The knee implant monitoring system using IoT provides a transformative solution for ensuring the long-term success of knee replacement surgeries. By integrating real-time sensors to track joint movement, pressure, temperature, and implant stability, this system enhances post-surgical care and helps in the early detection of potential complications. The ability to remotely monitor patient progress allows healthcare professionals to take proactive measures, reducing hospital visits and improving overall patient safety. With the advancements in IoT technology, this system not only enhances the quality of life for knee implant patients but also contributes to medical research by offering valuable data for future improvements. Ultimately, this project aims to bridge the gap between surgery and long-term patient care, ensuring a more effective and reliable knee replacement experience. Various research studies and technological developments have been conducted in the field of osteoarthritis detection and rehabilitation. Traditional diagnostic methods rely on X-rays, MRI scans, and clinical evaluations, which are effective but costly and inconvenient for continuous monitoring. Recent advancements in wearable health monitoring systems have introduced sensor-based approaches for joint movement analysis.

Several studies have explored the use of MEMS- based sensors for motion tracking and force sensors for pressure distribution analysis. Some existing systems use machine learning algorithms to analyze gait patterns and predict osteoarthritis risk. However, many of these solutions lack real-time therapeutic intervention, making them more suitable for diagnosis rather than management. The proposed system addresses this gap by integrating real-time muscle stimulation through vibration motors, enhancing therapeutic benefits. Additionally, IoT-based remote monitoring has been increasingly adopted in healthcare, allowing patients to receive medical advice without frequent hospital visits. By leveraging existing research and improving upon current technologies, the proposed system provides a comprehensive and effective approach for osteoarthritis detection, monitoring, and management.

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