OCTAKNEE: A SMART KNEE HEALTH MONITORING SYSTEM

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Introduction:

1. Knee disorders such as osteoarthritis and ligament injuries significantly impact mobility and quality of life, with prevalence increasing globally. Traditional methods of knee health assessment rely on clinical imaging techniques such as X-rays and MRI, along with subjective patient-reported outcomes. However, these approaches provide only static and episodic insights, failing to capture real-time functional behavior of the knee during daily activities.
2. Laboratory-based gait analysis systems offer high accuracy but are expensive, require specialized infrastructure, and are not accessible for continuous monitoring. Consumer wearables, on the other hand, focus on basic metrics such as step count and lack the precision required for clinical interpretation.
3. A major limitation in existing systems is the absence of longitudinal monitoring, where gradual deterioration or recovery patterns in gait remain undetected between clinical visits. This creates a critical gap in early diagnosis and rehabilitation tracking.
4. To address these challenges, this project proposes **OctaKnee**, a low-cost wearable IoT-based knee health monitoring system that enables continuous gait analysis. By integrating inertial sensors with machine learning techniques, the system provides objective classification of knee health status.
5. Additionally, the system incorporates cloud-based data storage and a longitudinal insight generator to track recovery trends over time. An AI-powered chatbot further enhances accessibility by translating complex biomechanical data into understandable feedback, making the system suitable for real-world remote rehabilitation scenarios.

Objectives:

1. To develop a low-cost wearable IoT system for real-time knee motion monitoring
2. To extract biomechanical features such as RMS acceleration and gait cadence from sensor data
3. To implement a machine learning model for classifying knee health status
4. To develop a longitudinal insight system for tracking rehabilitation progress

5. To integrate an AI-based interface for user-friendly interpretation of results
6. To ensure the system is low-cost, scalable, and suitable for remote healthcare applications

Methodology:

1. The proposed system follows a multi-layered architecture consisting of data acquisition, processing, and user interaction layers.
2. At the hardware level, an ESP32 microcontroller is used to interface with an MPU6050 sensor for capturing acceleration and angular velocity, and a BMP180 sensor for measuring temperature. These sensors collect real-time biomechanical data related to knee movement. The collected data is transmitted via Wi-Fi to a cloud-based Firebase Realtime Database, ensuring continuous and synchronized data storage.
3. On the backend, a Python Flask-based system retrieves the data and performs preprocessing, including noise filtering and quality control checks such as variance and saturation validation. Feature extraction techniques are applied to derive meaningful parameters such as root mean square (RMS) acceleration, dominant frequency (gait cadence), and gyroscopic variance. These features represent the biomechanical characteristics of knee motion. A supervised machine learning model is trained using these features to classify gait patterns into three categories: Healthy, Recovery, and Impaired. Logistic Regression is selected as the optimal model due to its balance between accuracy and computational efficiency.
4. To enhance reliability, a statistical gating mechanism is implemented to detect uncertain predictions and avoid incorrect outputs. The system also includes a longitudinal insight generator that compares current session data with historical records to detect trends such as decline in walking speed or increase in impact load.
5. Finally, a web-based dashboard and an AI-powered chatbot interface are developed to present results and provide personalized feedback to users in an interpretable manner.

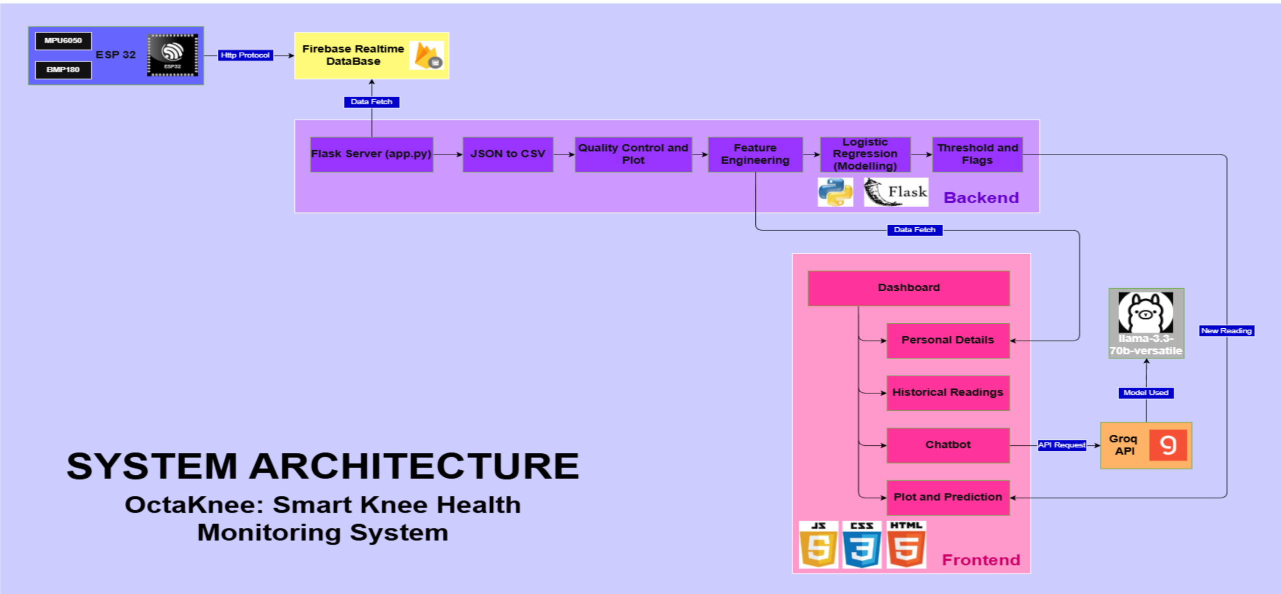

Figure 1: OctaKnee System Architecture

Result and Conclusion:

1. In conclusion, the OctaKnee system successfully demonstrates a low-cost, real-time knee health monitoring solution capable of continuous gait analysis.
2. The Logistic Regression model achieved an optimal balance between accuracy (80.6%) and latency, making it suitable for real-time deployment.
3. The integration of longitudinal tracking and AI-driven interpretation enhances usability and enables proactive rehabilitation monitoring. The system bridges the gap between clinical assessment and real-world monitoring, providing a scalable solution for remote healthcare.

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Future Scope:

The future scope of this project includes:

1. Clinical validation with larger datasets and real patient trials
2. Collect subject-independent validation cohort and paired lab-grade ground truth.
3. Refine features and explore calibrated probabilistic models for better uncertainty quantification