Introduction to Artificial Intelligence.

What is Artificial Intelligence?

Artificial Intelligence (AI) refers to the development of computer systems that can perform tasks normally requiring human intelligence. These tasks include learning from data, recognizing patterns, understanding natural language, making decisions, and solving complex problems.

In biomedical engineering, AI plays a vital role by enabling automated data analysis and providing accurate decision-support tools. This allows systems to detect abnormalities efficiently, reduce human error, and enhance the overall reliability of medical diagnoses.

Artificial intelligence and physiotherapy .

AI physiotherapy uses artificial intelligence to analyze movement patterns, provide real-time feedback, and create personalized treatment plans for patients. It can work as a virtual physiotherapist for home exercises, help monitor progress remotely, and assist clinicians with administrative tasks like generating reports. While it offers potential benefits like increased access and efficiency, it is intended to supplement, not replace, human physiotherapists, who provide crucial professional judgment and oversight.

How AI is used in physiotherapy.

- **Movement analysis and feedback:**

AI systems can use machine learning to analyze a patient's movements, identify deviations from proper form, and provide real-time, corrective guidance during exercises.

- **Personalized treatment plans:**

By analyzing a patient's medical history, goals, and progress, AI can help create and adapt treatment plans for better results.

- **Remote monitoring and support:**

AI-powered platforms can guide patients through exercises at home, track their progress remotely, and provide support through chatbots or virtual assistants.

- **Administrative assistance:**

AI tools can automate tasks such as generating patient notes, treatment plans, and referral letters, which helps reduce the administrative burden on physiotherapists.

- **Clinical decision support:**

AI can analyze large datasets to help physiotherapists predict outcomes and make more informed clinical decisions.

Benefits.

- **Benefits:**
    - Increased accessibility to therapy and support.
    - More personalized and potentially faster recovery.
    - Improved patient engagement and adherence to exercise programs.
    - Greater efficiency for clinicians through administrative support.

Dataset description.

A key unique aspect of our project is that the dataset used for training and evaluating the AI model was collected using our own exoskeleton arm prototype. The data was obtained directly from children affected by motor impairments, which makes the dataset highly specific, realistic, and representative of the target population. This allows the model to learn from real-world conditions rather than relying solely on public or simulated datasets, ultimately improving accuracy, reliability, and clinical relevance.

Collected Parameters or data.

The collected data is processed using artificial intelligence models to evaluate movement correctness, motor ability, level of engagement, and rehabilitation progress over time. The system integrates multiple sensors and actuators to provide a comprehensive assessment of the child's performance.

Collected Parameters

1. Force Sensor Parameters
A force sensor embedded inside a handheld ball is used to measure the child's grip strength and interaction level. The extracted parameters include:

- Force level (weak, moderate, strong)
- Maximum applied force
- Average force during exercise
- Grip stability

- Interaction duration

2. Motion Parameters (MPU Sensors)
MPU sensors are mounted on four joints to capture motion-related data. For each joint, the following parameters are recorded:

- Joint angle
- Angular velocity (gyroscope data)
- Linear acceleration (accelerometer data)
- Orientation and rotational motion
- Range of motion (ROM)

3. Motor Assistance Parameters
Motors placed at the wrist, arm, and shoulder joints provide movement initiation and assistance when the child is unable to initiate movement independently. The recorded parameters include:

- Motor activation state (active or assisted movement)
- Level of motor assistance
- Time before assistance is applied
- Duration of assisted motion

4. Performance and Interaction Parameters
Additional parameters are derived to assess overall performance:

- Reaction time
- Movement smoothness
- Exercise completion time
- Coordination between joints
- Number of movement errors

Purpose of Data Analysis

The collected parameters are analyzed to:

- Determine whether movements are performed correctly or incorrectly
- Evaluate grip strength and interaction level

- Assess motor ability and joint coordination
- Monitor rehabilitation progress over time
- Distinguish between voluntary and assisted movements

Data Preprocessing and Feature Extraction

The raw data collected from the force sensor, MPU sensors, and motor system undergoes several preprocessing steps to ensure accuracy, consistency, and suitability for artificial intelligence model training. Since the data represents real-time motion and interaction from children, preprocessing is essential to reduce noise, handle variability, and extract meaningful information.

Data Preprocessing

Several preprocessing techniques are applied to the collected data:

- **Noise Filtering:**
  Sensor readings are filtered to remove noise caused by involuntary movements, sensor drift, and mechanical vibrations. Low-pass and smoothing filters are applied to force and motion signals.
- **Normalization:**
  All sensor values are normalized to a unified scale to account for differences in strength, movement speed, and physical characteristics among children.
- **Segmentation:**
  Continuous sensor signals are segmented into individual exercise sessions and movement windows to allow consistent analysis of each performed task.
- **Outlier Removal:**
  Abnormal or incomplete readings caused by sudden interruptions, incorrect posture, or system instability are identified and removed.
- **Calibration and Synchronization:**
  Motion sensors are calibrated, and all sensor streams are time-synchronized to ensure accurate joint-level analysis.

Feature Extraction

After preprocessing, meaningful features are extracted from the sensor data to represent the child's motor performance and interaction quality. These features serve as inputs to the AI models.

Extracted Features Include:

- **Force-related Features:**
  - Maximum grip force
  - Average grip force
  - Force stability
  - Grip endurance
- **Motion-related Features:**
  - Range of motion for each joint
  - Joint angular velocity
  - Movement smoothness
  - Acceleration patterns
  - Inter-joint coordination
- **Motor Assistance Features:**
  - Percentage of assisted movement
  - Duration of motor assistance
  - Time before movement initiation
- **Performance Features:**
  - Reaction time
  - Exercise completion time
  - Number of movement errors

These extracted features provide a comprehensive representation of motor ability, engagement level, and rehabilitation progress, enabling accurate evaluation through artificial intelligence models.

AI-Based Rehabilitation Framework

The proposed system adopts a multi-level artificial intelligence framework to support real-time VR-based rehabilitation and long-term therapeutic monitoring. The AI framework is designed to evaluate movement quality, measure patient engagement, generate performance scores, and track rehabilitation progress in an integrated manner.

Real-Time Movement Classification

During VR-based exercises, real-time classification models are employed to evaluate the child's movements. These models analyze force, motion, and motor assistance data to provide immediate feedback.

The classification tasks include:

- **Movement correctness classification** (correct vs. incorrect movement)

Data used:-

- Joint angle
- Range of motion (ROM)
- Angular velocity
- Movement smoothness
- Coordination between joints
- Number of movement errors

- **Engagement classification** (active vs. assisted movement)

Data used:-

- Motor activation state
- Level of motor assistance
- Time before assistance
- Duration of assisted motion
- Reaction time

A Random Forest classifier is used due to its robustness, fast inference time, and suitability for real-time applications. The classification output is directly linked to the VR environment to provide instant feedback and guidance during gameplay.

Motor Performance Scoring

In addition to real-time classification, a regression-based model is used to generate a continuous motor performance score. This score provides a quantitative measure of the child's motor ability during each rehabilitation session.

The motor performance score is computed based on:

- Grip force intensity and stability
- Joint range of motion
- Movement smoothness
- Level of motor assistance
- Exercise completion time

An **XGBoost** regression model is employed to accurately estimate the motor performance score and reflect changes in the child's motor capabilities over time.

Therapy Progress Monitoring

To assess rehabilitation progress, the system tracks changes in the motor performance score across multiple sessions. **Trend analysis** is applied to evaluate improvement patterns, therapy effectiveness, and consistency of performance.

This progress monitoring approach allows therapists to objectively evaluate recovery, adjust therapy plans, and personalize rehabilitation exercises.