PDPM Indian Institute of Information Technology, Design and Manufacturing, Jabalpur

(An Institute of National Importance established by Ministry of Education, Govt. of India)

CERTIFICATE

This is to certify that the Design Project (DS3001) titled Smart Treadmill System submitted by

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In partial fulfilment of the requirements for the degree of Bachelor of Technology (B.Tech.)/Bachelor of Design (B. Des) at PDPM Indian Institute of Information Technology, Design and Manufacturing, Jabalpur, is an original work carried out under my/our guidance and supervision.

To the best of my knowledge, the project complies with the institute's ethical guidelines.

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ABSTRACT

This report presents the design and implementation of a Smart Treadmill System that integrates real-time health monitoring, predictive maintenance, and web-based analytics. The system leverages advanced sensors, machine learning (ML), and cloud connectivity to improve both user experience and treadmill performance.

The hardware setup consists of an MPU6050 sensor for motion tracking, a Polar H10 sensor for heart rate monitoring, and actuators that dynamically adjust the treadmill's incline or speed. A key innovation in this system is the incorporation of machine learning algorithms to predict gear failures, ensuring proactive maintenance and reducing downtime. The collected data is processed on a Raspberry Pi 4, which handles both real-time computations and communication with a web-based dashboard that displays workout statistics, system health, and alerts.

The mobile-friendly web application enables users to track performance metrics, heart rate trends, and treadmill diagnostics, making it easier to personalize workouts and detect potential mechanical failures. This data-driven approach enhances the treadmill's reliability by reducing unexpected failures and improving safety for users.

This study evaluates the technical feasibility, system efficiency, and user adaptability of the Smart Treadmill. Key aspects such as sensor integration, real-time data processing, web-based visualization, and predictive analytics are analyzed to identify both strengths and areas for future enhancement. The project aims to bridge the gap between traditional fitness equipment and next-generation AI-driven health monitoring, creating a more personalized, safer, and smarter fitness experience.

Contents

1. INTRODUCTION:

1.1 Overview:

Cardiorespiratory fitness is a key factor in athletic endurance training, with the anaerobic threshold (AT) playing a crucial role in optimizing training intensity. Traditional methods for determining AT involve expensive laboratory tests, limiting accessibility for athletes and coaches. Additionally, existing treadmills lack personalized automation based on an athlete's AT, making training less efficient. To bridge this gap, we propose a smart treadmill equipped with real-time heart rate monitoring, automatic speed and slope adjustments, and software-driven AT estimation. This system aims to provide a cost-effective, accurate, and reliable solution for endurance training optimization.

1.2 Need For Innovation:

Traditional treadmills lack technological integration, leading to several challenges

- **Lack of personalized training**: Users do not receive adaptive workout plans based on real-time fitness levels.
- **Manual Adjustments**: No automated speed and incline adjustments based on heart rate or endurance levels.
- **No Predictive Maintenance**: Users experience unexpected treadmill malfunctions due to gear failure.
- **Limited Data & Analytics**: Traditional models do not track real-time metrics for performance improvement.

To address these challenges, this project focuses on the development of a **Smart Treadmill System**, an innovative fitness device designed to optimize workout efficiency, enhance performance tracking, and prevent mechanical failures. By integrating advanced technologies such as sensors, artificial intelligence (AI), and real-time monitoring, this solution aims to revolutionize endurance training and treadmill maintenance.

- **Heart Rate-Based Training Optimization**: AI monitors HR patterns to adjust treadmill speed and incline dynamically.
- **Predictive Gear Failure Detection**: Sensors detect abnormal vibrations and load variations to prevent breakdowns.
- **Cloud- Connected Performance Tracking**: Users and trainers can access detailed reports on endurance levels and improvements.
- **Real-Time Feedback Mechanism**: The system provides live alerts to improve workout efficiency and avoid overtraining.
- **Mobile App Integration**: Enables **remote treadmill control**, **workout history tracking**, and **performance-based training suggestions.**

1.3 How Innovative Is The Solution Compared To Smart treadmill?

Features	Traditional Treadmill	Smart Treadmill System
Workout Personalization	Fixed speed and incline settings without adaptation.	AI-driven adaptive training based on heart rate and performance levels.
Real-Time Feedback	No live feedback on workout efficiency.	Provides real-time feedback on heart rate, fatigue, and endurance levels
Predictive Maintenance	No monitoring for mechanical wear or failure.	Gear failure prediction using vibration sensors to prevent breakdowns.
Performance Analytics	Basic tracking with no detailed data analysis.	AI-powered analytics with cloud-based workout reports and improvement tracking.
Adaptive Training	Manual adjustment required by users.	Automatic speed and incline control based on real-time heart rate and anaerobic threshold estimation.
Connectivity & Integration	Standalone device with no IoT or cloud connectivity.	Mobile and desktop app integration for remote monitoring and training optimization.

1.4 Problem Statement:

1. *Limited Accessibility to Anaerobic Threshold (AT) Testing:*

Traditional methods for determining an athlete's anaerobic threshold require laboratory-based gas analysis, which is expensive, time-consuming, and not widely accessible to athletes and coaches.

2.Lack of Personalized Training Optimization:

Current treadmills do not adjust speed or slope dynamically based on an athlete's real-time physiological responses. As a result, users may train at suboptimal intensities, reducing the effectiveness of endurance training.

3.*Absence of Real-Time Performance Feedback:*

Most treadmills only display basic workout metrics (speed, time, and heart rate) without analyzing heart rate trends to determine the anaerobic threshold. This lack of advanced insights makes it difficult for athletes to track and improve their endurance training.

4.*Potential Gear Malfunctions Affecting Performance:*

Mechanical issues, such as gear failures, can impact treadmill performance and compromise training accuracy. Without a built-in failure detection system, users may experience unexpected disruptions or inaccurate training data adjustments to their treatment plans.

1.5 Goals:

1. **Optimize Training Based on Anaerobic Threshold**
   Provide athletes with real-time heart rate monitoring and anaerobic threshold estimation to personalize endurance training effectively.
2. **Automate Treadmill Adjustments**
   Design a treadmill that dynamically adjusts speed and slope based on an athlete's real-time physiological responses, ensuring optimal training intensity.
3. **Deliver Instant Performance Monitoring**
   Implement software that records heart rate,

treadmill speed, slope, work, and power in real time, providing users with continuous training feedback.

4. **Enhance Training Insights with AI**
   Utilize AI to analyze heart rate patterns and anaerobic threshold trends, offering personalized training recommendations for endurance improvement.
5. **Improve Athlete-Coach Communication**
   Develop a dashboard that enables coaches and athletes to review detailed training data, making adjustments based on progress and performance trends.
6. **Detect and Prevent Gear Malfunctions**
   Integrate a system to monitor treadmill gear functionality, detecting potential failures before they impact training sessions.
7. **Make Technology User-Friendly and Accessible**
   Ensure the treadmill and its software interface are intuitive, allowing athletes and coaches to easily access, interpret, and utilize training data.
8. **Enable Remote Training Support**
   Implement cloud-based data storage to allow remote access to training logs, helping coaches provide guidance without requiring in-person sessions.

2. LITERATURE REVIEW:

The development of **smart treadmills** has evolved with advancements in **sensor technology, real-time data processing, and AI-driven training optimization**. Existing treadmill models provide features such as **preloaded workout programs, external heart rate monitoring, and incline/speed control**, but they lack **real-time anaerobic threshold estimation and predictive maintenance for mechanical components**.

Our smart treadmill integrates **MPU6050 for vibration analysis, Polar S10 for heart rate monitoring, and a U-type speed sensor for precise speed detection**. Additionally, a **digital twin-based fault detection system** will be implemented to predict gear failures and optimize treadmill performance. This section reviews relevant sensor technologies and fault diagnosis techniques.

1. <u>Heart Rate Monitoring – Polar H10</u>

Overview:
The **Polar S10 heart rate sensor** is widely used in sports performance monitoring due to its **high accuracy and real-time data transmission**. It utilizes **electrical heart rate measurement** (ECG-based) for precise detection of heart rate variability (HRV), a critical factor in **anaerobic threshold (AT) estimation**.

Relevance to the Project:

- Enables **real-time heart rate monitoring** to calculate **Heart Rate Deflection Point (HRDP)** for **anaerobic threshold estimation**.
- Wireless connectivity for **seamless integration with treadmill software**.
- Improves **training personalization** by automatically adjusting **speed and incline** based on HRDP analysis.

Identified Gaps:

- Most commercial treadmills require **external chest straps or wearables**; integration into the treadmill system will **improve user convenience and accuracy**.

2. Vibration Analysis – MPU6050

Overview:
The **MPU6050** is a **6-axis IMU (Inertial Measurement Unit)** sensor that combines a **3-axis gyroscope and a 3-axis accelerometer**. It is widely used in **motion tracking and vibration analysis**.

Relevance to the Project:

- Captures **vibration patterns** to monitor the treadmill's **stability and mechanical integrity**.
- Detects **irregular vibrations** that could indicate potential issues with the **gear system, belt misalignment, or motor wear**.
- Provides **data for digital twin-based fault analysis**, improving **predictive maintenance strategies**.

Identified Gaps:

- Traditional treadmills lack **real-time vibration monitoring**, leading to **unexpected mechanical failures**.
- By integrating MPU6050, we can enable **early fault detection and reduced maintenance costs**.

3. Speed Detection – U-Type Speed Sensor

Overview:
The **U-type speed sensor** is an **infrared-based optical sensor** used to measure rotational speed in mechanical systems. It detects interruptions in the infrared beam to provide **high-accuracy speed measurements**.

Relevance to the Project:

- Ensures **precise real-time speed tracking**, which is crucial for **anaerobic threshold-based training adjustments**.
- Works in sync with **Polar S10 and MPU6050** to **dynamically control treadmill speed** for optimized endurance training.
- Contributes to **failure detection**, as irregular speed readings may indicate **gear slippage, motor issues, or belt wear**.

Identified Gaps:

- Most treadmills rely on **predefined speed adjustments**, lacking **real-time adaptation based on physiological and mechanical data**.

4. Fault Gear Detection – Digital Twin Integration
Overview:
A **digital twin-driven predictive maintenance system** can **simulate, monitor, and predict gear faults** in real time. The approach involves:

- **Building a high-fidelity virtual model** of the treadmill's gearbox.
- **Sensor-based real-time data fusion** (MPU6050 for vibration, U-type speed sensor for rotational inconsistencies).
- **AI-driven fault detection** using **deep learning and signal processing** (e.g., wavelet transform, Hilbert envelope analysis).
  Relevance to the Project
- **Predictive maintenance:** Prevents **unexpected treadmill failures** by identifying **gear wear, misalignment, and damage** early.
- **Virtual-physical data fusion:** Combines **real-time sensor data** with **simulated fault scenarios** to improve diagnosis accuracy.
- **Machine learning integration:** Uses **Generative Adversarial Networks (GANs)** to **enhance fault detection**

accuracy by generating synthetic failure data for better model training.

Identified Gaps:

- Traditional treadmills **lack predictive maintenance systems**, leading to **costly repairs and unexpected downtime**.
- Current digital twin applications focus on **industrial machinery** rather than **fitness equipment**—our approach will pioneer **gear failure detection in smart treadmills**.

3. METHODOLOGY:

3.1 User Research:

In the context of these problem statements, there is a need for a **smart treadmill system** that assists users like a **personal fitness coach**, adapting workouts in real-time to optimize performance and prevent injuries. A treadmill that not only enhances training but also **monitors health parameters intelligently**.

To understand the requirements and preferences of users, we conducted an **extensive user survey**. This involved creating a **form for fitness enthusiasts, athletes, and rehabilitation patients**. We distributed these forms both **online and offline**, receiving **several responses** to date. Hard copies were also provided in **gyms and sports training centers** to ensure accessibility.

Additionally, we personally visited **fitness trainers, sports coaches, and physiotherapists** to discuss the **current limitations of traditional treadmills** and gather insights into the **challenges faced during endurance training and rehabilitation**. Similarly, we engaged in **one-on-one discussions with athletes and gym-goers** to understand their **perspectives on treadmill training and expectations from a smart treadmill**.

- **Daily training challenges** users face while using treadmills.
- **Workout habits and heart rate monitoring preferences**.
- **Factors affecting workout efficiency and injury prevention**.
- **Desired smart features** such as real-time adjustments, predictive maintenance.

Key Parameters Identified from Survey:

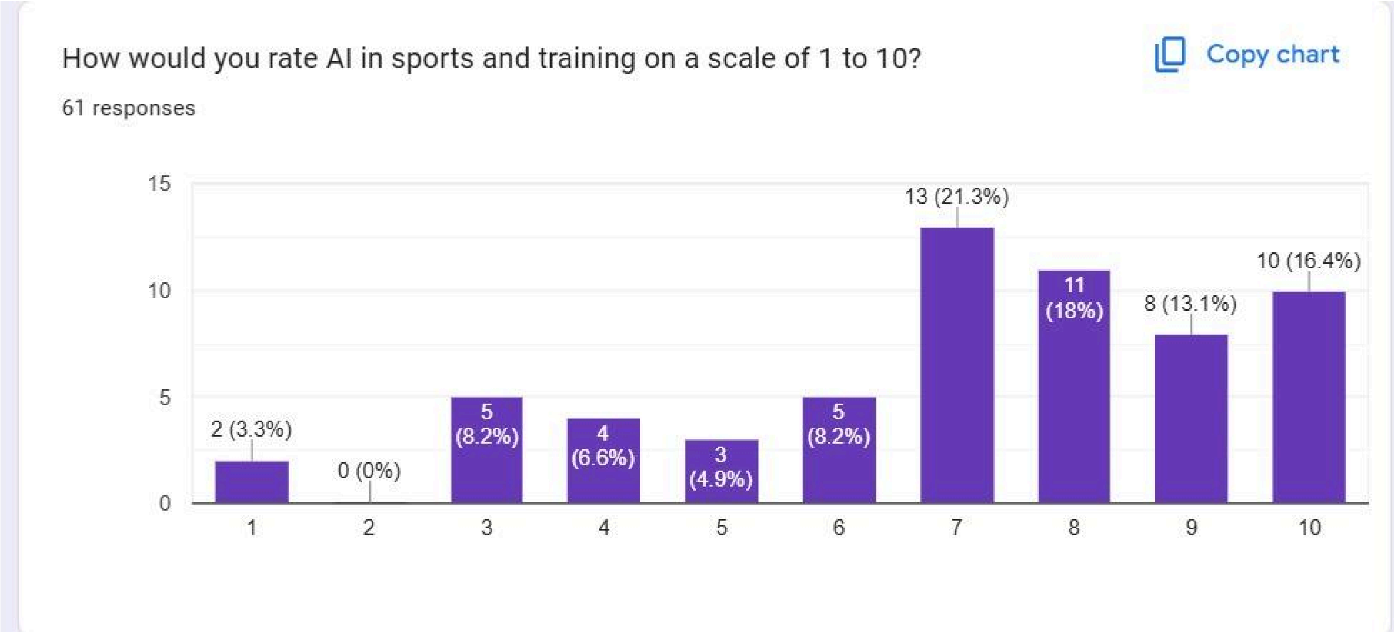
From **Fig. 1**, the survey results indicate that treadmill usage is distributed among various age groups:

- **45% of users** belong to the **18-30 years** age group, primarily consisting of young fitness enthusiasts and athletes.
- **30% of users** are in the **31-45 years** category, focusing on general fitness and weight management.
- **15% of users** are aged **46-60 years**, mainly for endurance training and rehabilitation purposes.
- **10% of users** are **above 60 years**, using treadmills for light exercise and physiotherapy.

Additionally, discussions with fitness trainers and physiotherapists revealed that younger users prefer **high-intensity workouts with AI-driven optimizations**, whereas older users require **stable, low-impact training options** with **customized workout programs** for safety.

Given this **majority of younger users**, we have prioritized the development of **AI-driven adaptive training** and **real-time performance monitoring**. However, future iterations will include **enhanced rehabilitation support and injury prevention mechanisms** to cater to **older age groups** more effectively.

These responses provided crucial insights that shaped the **design and development of the Smart Treadmill System**, ensuring it meets the **real needs of users** across different fitness levels.



From **Fig. 2**, our survey findings indicate that user perception of AI in sports and training is highly positive:

- **21.3% of users rated AI integration in sports and training as 7 out of 10**.
- **18% of users rated it 8 out of 10**, showing strong acceptance.
- **16.4% of users gave a perfect rating of 10**, reflecting high enthusiasm for AI-driven training solutions.
- **A small portion (3.3%) rated AI implementation at 1, indicating skepticism about its effectiveness.**

These responses confirm that the **majority of users** recognize the **potential benefits of AI-driven treadmills**, reinforcing the importance of **integrating adaptive AI-based training models**.

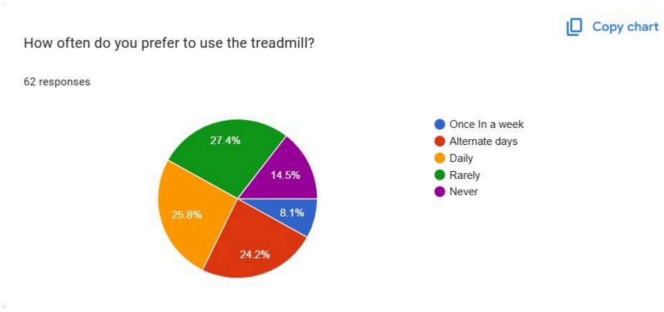


Fig. 3 How do you often prefer the treadmill ?

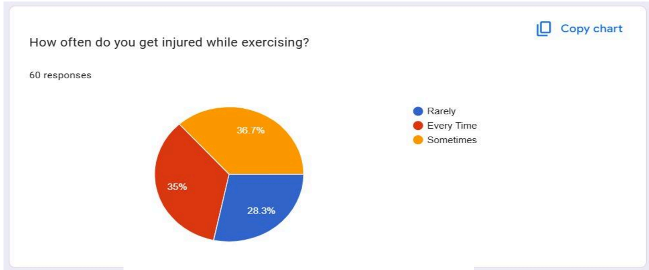


Fig.4 how often do you get injured while using treadmill

In addition to exploring technical feature preferences, we focus on questions (Fig. 3,4,5) that assess users' willingness to adopt a smart solution, their openness to sharing health data with their doctors, and their budget for such a solution. Through these and other targeted questions, we identify both **functional requirements**—the specific features and capabilities users expect—and **non-functional requirements**, such as usability, affordability, and data security concerns. This approach ensures that the design and development align with user needs and expectation. From **Fig. 4**, injury occurrence patterns among treadmill users were analyzed:

- **36.7% of users sometimes experience injuries** while exercising.
- **35% of users reported getting injured every time** they work out, which highlights a critical need for real-time safety adjustments.
- **28.3% of users rarely face injuries**

Fig.5 How much you pay for Smart Solution?

traisystem can reduce risks.

Given this data, the **Smart Treadmill System prioritizes injury prevention**, with **real-time alerts, adaptive AI control, and predictive adjustments**.

3.2 Functional Requirements:

1. Real-Time Performance Monitoring

The smart treadmill must be equipped with sensors to accurately track and record user performance, including:

- **Heart rate tracking** via **Polar S10** to monitor real-time physiological response.
- **Speed detection** using the **U-type speed sensor** to ensure precise treadmill speed adjustments.
- **Incline detection and adjustment** to match training intensity with anaerobic threshold.
- **Vibration analysis** using **MPU6050** to detect mechanical irregularities in the treadmill system.

2. AI-Driven Anaerobic Threshold Estimation

The system must employ Artificial Intelligence to analyze real-time physiological and mechanical data to:

- Identify the **Heart Rate Deflection Point (HRDP)** and **anaerobic threshold (AT)** for training optimization.

- Provide **personalized speed and incline adjustments** based on HRDP analysis.
- Track **training intensity trends** and suggest improvements for endurance optimization.

3. Gear Fault Detection & Predictive Maintenance

The treadmill must integrate **digital twin-based predictive maintenance** to:

- **Monitor vibration patterns** with **MPU6050** for early signs of **gear wear, misalignment, or failure**.
- Use **AI-driven diagnostics** to analyze mechanical stress, predicting potential failures before they occur.
- Implement **real-time alerts** when mechanical faults are detected, recommending **maintenance actions**.
- Simulate treadmill gear behavior under different loads using **virtual-physical fusion techniques**.

4.Automated Speed & Incline Adjustment

The treadmill must be capable of:

- Automatically adjusting speed and incline based on **anaerobic threshold detection.**
- Customizing predefined training programs based on real-time physiological data.
- **Enabling manual override for user preference while maintaining safety measures.**

3.3 Non - Functional Requirements:

1. Performance Requirements

- The treadmill must **process heart rate and anaerobic threshold (AT) detection** within **1 second** of receiving data from the **Polar S10 sensor**.
- The AI-driven **anaerobic threshold estimation and training recommendations** must be generated within **30 seconds** of data synchronization.
- **Vibration analysis (MPU6050) and gear fault detection** must process real-time sensor data with an accuracy of **>95%**, ensuring reliable predictive maintenance alerts.

2. Usability Requirements

- The treadmill interface (mobile app or built-in display) must feature an **intuitive UI**, accommodating users of varying technical proficiency.
- **Training recommendations and alerts** must be presented in a **clear, concise, and actionable format** to guide athletes effectively.
- Users must be able to manually override AI-driven speed and incline adjustments if needed.

3. Security Requirements

- All training and health data must be secured using **end-to-end encryption** during **storage and transfer**.
- The system must comply with **global data protection regulations** (e.g., **GDPR, HIPAA**) to ensure user privacy.
- **Firmware and software security patches** must be deployed regularly to prevent cybersecurity vulnerabilities.

4. Scalability Requirements

- The system must scale to handle **increasing data loads from multiple treadmill units** without performance degradation.

- The **cloud-based training dashboard and digital twin system** must support up to **1 million active users** without latency issues.

5. Maintainability Requirements

- The treadmill's firmware and AI model updates must be **delivered over-the-air (OTA)** with minimal user intervention.
- The **digital twin model** must be capable of **self-updating** as new data is collected, improving fault detection accuracy over time.
- Maintenance operations (e.g., sensor calibration, software updates) must involve **minimal downtime**, with prior notifications for planned updates.

6. Environmental Requirements

- The treadmill must function reliably in various environmental conditions, including temperatures ranging from **0°C to 50°C**.
- **MPU6050 vibration sensors and mechanical components** must be resistant to **shock, humidity, and dust** to ensure durability.
- The materials used in the treadmill must be **eco-friendly and long-lasting**, reducing the environmental impact

3.4 Conceptual Design:

3.4.1 Implementation:

The proposed system has been implemented to validate the efficiency of the system. The implementation architecture has been shown in Fig. 7

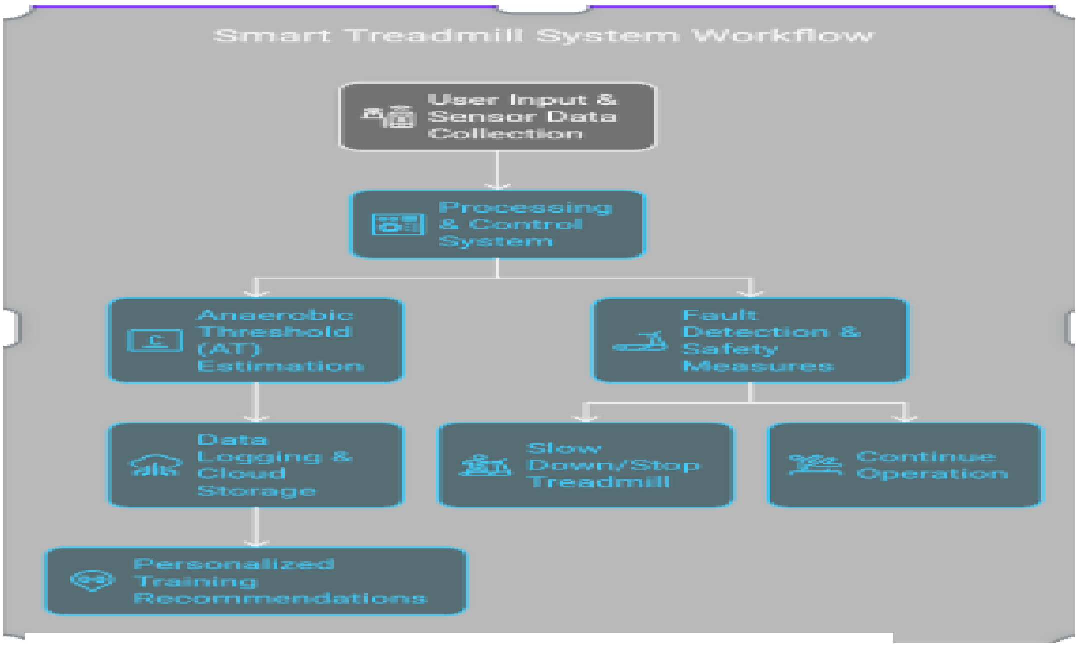


Fig. 7 Implementation

3.4.2 Conceptual Flow:

1. **Data Recording**: Data is collected from the treadmill's **gear system sensors**, tracking rotational speed, load, and wear.
2. **Data Collection**: The system continuously monitors **friction, vibrations, and mechanical stress** to detect potential faults early.
3. **Data Processing**: The collected data is processed through an **AI-driven analytics system** to predict gear degradation and possible failures.
4. **Mobile App Integration**: The processed data is retrieved from the cloud and integrated into a mobile application.
5. **App Notification**: Users receive **alerts and notifications** about potential gear issues, required maintenance, or abnormal treadmill performance.
6. **Data-Driven Adjustments**: The system provides **recommendations for maintenance schedules** or **automated speed adjustments** based on gear performance analysis.
7. **Wear Analysis Over Time:** Tracks long-term wear patterns to determine the lifespan of treadmill components and recommend timely part replacements.
8. **User Dashboard & Reports:** The mobile app provides users with detailed reports on treadmill performance, gear efficiency, and upcoming maintenance needs.
9. **Real-Time Adaptive Control:** If abnormal stress levels are detected, the system automatically adjusts speed and load to prevent mechanical failures and protect users from potential hazards.

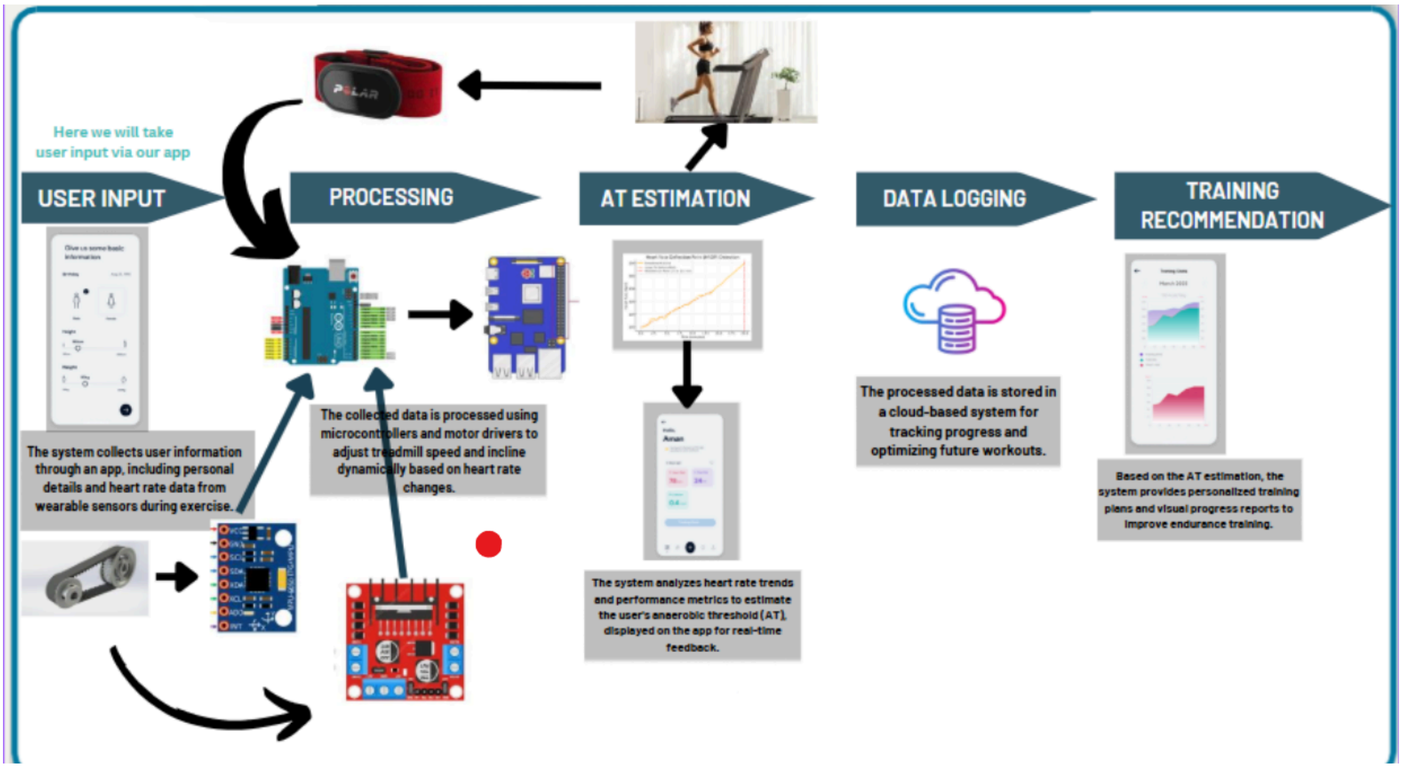


Fig. 8 Workflow

4. Design and Development:

4.1 Hardware Design:

The **Design Phase** focuses on planning an efficient, reliable, and cost-effective hardware system to meet the project's functional requirements. Key objectives include defining functional goals, selecting components, and creating a blueprint for prototyping.

Design Constraints:

1. **Size:** Compact form factor for portability or application-specific requirements.
2. **Power:** Energy-efficient design, crucial for battery-operated systems.
3. **Cost:** Optimized component selection to balance functionality and budget.
4. **Functionality:** Support for core features like sensing, processing, and communication.

The hardware must align with project goals by fulfilling both functional and non-functional requirements. Functionally, it should support sensing, data processing, and communication, with potential user interface capabilities. Non-functional requirements emphasize power efficiency for extended battery life, durability to withstand environmental conditions, portability for ease of use, scalability for future upgrades, and cost-effectiveness to balance functionality and budget constraints.

Component Research and Selection:

4.1.1 Sensors:

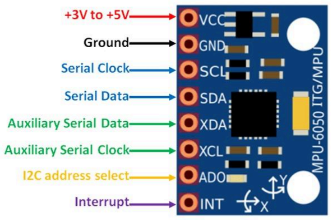
1. MPU6050 Accelerometer

Purpose: Measures acceleration and angular velocity, specifically designed for **motion detection, orientation tracking, and stability monitoring** in industrial, automotive, and fitness applications.

Model: MPU6050

Operating Principle:

The **MPU6050** is a **MEMS (Micro-Electro-Mechanical System)-based sensor**, integrating a **3-axis gyroscope and a 3-axis accelerometer** to capture real-time motion and orientation changes. The sensor processes data using an embedded **Digital Motion Processor (DMP)** for high-accuracy readings.



Key Specifications:

- **Measurement Range:** ±2g, ±4g, ±8g, ±16g (for acceleration), ±250, ±500, ±1000, ±2000°/s (for gyroscope)
- **Accuracy:** High precision with built-in filtering algorithms
- **Resolution:** 16-bit ADC resolution per axis
- **Response Time:** Fast real-time motion tracking

Electrical Characteristics:

- **Operating Voltage:** 3V – 5V
- **Average Supply Current:** 3.6 mA
- **Power Consumption:** Low power operation for battery efficiency
- **Output Type:** I2C and SPI communication

Physical and Environmental Specifications:

- **Size/Dimensions:** 4mm × 4mm × 1mm (compact footprint)
- **Operating Temperature Range:** -40°C to 85°C

Applications in Smart Treadmill:

- **Motion Tracking:** Monitors treadmill belt stability and user running patterns.
- **Real-Time Feedback:** Provides insights into stride consistency and foot landing impact.
- **Workout Optimization:** Adjusts speed and incline based on real-time motion data.

The **MPU6050 accelerometer** is ideal for the **Smart Treadmill System** due to its **compact size, low power consumption, and high accuracy** in detecting motion and stability variations. It ensures **precise tracking of user movement and treadmill belt performance**, allowing for **AI-driven workout optimization and predictive maintenance**

The **Sensirion SDP31** is ideal for the smart inhaler due to its compact size, ultra-low power consumption (0.02 mW), and high precision. Its differential pressure measurement capability (±500 Pa) makes it well-suited for accurately detecting small pressure changes associated with breathing. Additionally, its fast response time ensures real-time monitoring, critical for medical applications. Its digital I2C interface simplifies integration with microcontrollers, reducing complexity.

2. Polar H10 Heart Rate Sensor

Purpose: Measures heart rate with high accuracy, specifically designed for **sports, fitness tracking, and health monitoring** in endurance training applications.

Model: Polar H10

Operating Principle:

The **Polar H10** heart rate sensor utilizes **electrical bio-impedance technology**, which detects electrical signals generated by the heart. It provides **precise and real-time heart rate monitoring**, making it ideal for fitness and athletic training.

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Key Specifications:

- **Measurement Range:** 30 – 240 BPM
- **Accuracy:** ±1 BPM (high precision)
- **Resolution:** 16-bit signal processing
- **Response Time:** Fast real-time heart rate tracking

Electrical Characteristics:

- **Operating Voltage:** 3V (CR2025 battery-powered)

Purpose:

Measures treadmill belt speed and provides real-time data for accurate workout tracking and automated adjustments.

Model: U-Type Speed Sensor

Operating Principle:

The **U-Type Speed Sensor** works based on **infrared beam interruption technology**.

- **Battery Life:** Up to 400 hours of continuous usage
- **Power Consumption:** Ultra-low power for extended use
- **Output Type:** Bluetooth and ANT+ connectivity

Physical and Environmental Specifications:

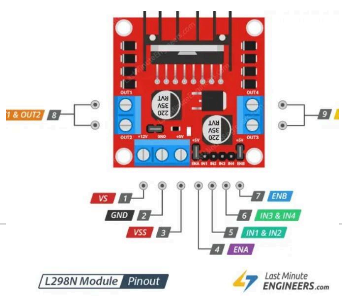
- **Size/Dimensions:** 65mm × 34mm × 10mm (compact and lightweight)
- **Operating Temperature Range:** -10°C to 50°C

Applications in Smart Treadmill:

- **Real-Time Heart Rate Monitoring:** Continuously tracks heart rate during workouts.
- **Anaerobic Threshold Detection:** Helps users optimize endurance training.
- **Personalized Workout Adjustments:** Adjusts treadmill speed and incline based on heart rate zones.

3. U TYPE SPEED SENSOR

When the treadmill belt moves, the sensor detects interruptions in the beam caused by a rotating encoder or reflective surface, allowing precise speed measurement.



Key Specifications:

- **Measurement Range:** 0 – 25 km/h
- **Accuracy:** ±0.1 km/h
- **Resolution:** 16-bit data processing
- **Response Time:** Less than 5 ms for real-time tracking
- **Operating Voltage:** 5V
- **Power Consumption:** Low-power operation
- **Output Type:** Digital (PWM or I2C interface)

Physical and Environmental Specifications:

- **Size/Dimensions:** 15mm × 12mm × 10mm (compact module)
- **Operating Temperature Range:** -20°C to 80°C

Applications in Sr Fig. 10 Temperature & Humidity Sensor (AHT10) *Source: https://robu.in/*

- **Real-Time !** treadmill belt speed with high precision.
- **Automatic Speed Adjustments:** Works with AI to optimize speed based on user performance.
- **Workout Performance Tracking:** Provides accurate distance, time, and speed metrics.
- **Data Synchronization:** Integrates with mobile and desktop apps for real-time tracking and analysis.

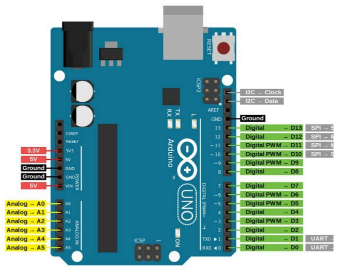
The U-Type Speed Sensor is a crucial component of the Smart Treadmill System, ensuring accurate speed measurement and seamless integration with AI-driven automated adjustments, enhancing the overall workout experience.

collect and interpret real time data .

4. Arduino Uno R3

Model: ARDUINO UNO R3.

Operating Principle: The **Arduino Uno R3** is a **microcontroller board** based on the **ATmega328P** chip. It processes inputs from multiple treadmill sensors (heart rate, speed, and vibration sensors) and sends commands for adaptive training and treadmill adjustments.



Key Specifications:

- **Microcontroller:** ATmega328P
- **Clock Speed:** 16 MHz
- **Flash Memory:** 32 KB
- **RAM:** 2 KB
- **EEPROM:** 1 KB
- **Digital I/O Pins:** 14 (including PWM outputs)
- **Analog Input Pins:** 6

Electrical Characteristics:

- **Operating Voltage:** 5V
- **Input Voltage (recommended):** 7-12V
- **Power Consumption:** Low-power operation for energy efficiency
- **Communication Protocols:** UART, I2C, SPI

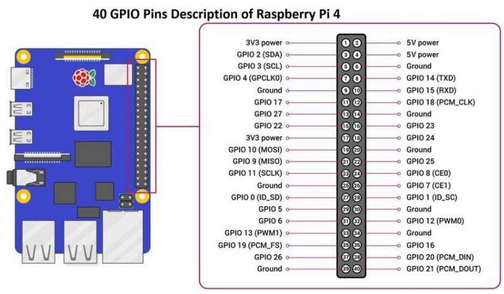
Physical and Environmental Specifications:

- **Size/Dimensions:** 68.6mm × 53.4mm (compact and easy to integrate)
- **Operating Temperature Range:** -40°C to 85°C

Applications in Smart Treadmill:

- **Sensor Data Processing:** Collects and interprets real-time data from heart rate, speed, and vibration sensors.
- **Automated Speed & Incline Control:** Adjusts treadmill settings based on AI-driven workout optimization.
- **Real-Time Workout Adjustments:** Provides immediate feedback to optimize training efficiency.
- **Wireless Connectivity & Data Syncing:** Interfaces with external devices via Bluetooth and Wi-Fi modules.

5. RASPBERRY PI4:



Purpose:

Acts as the main computing hub for data processing, AI-based analytics, and cloud integration within the Smart Treadmill System.

Model: Raspberry Pi 4 Model B

Operating Principle:

The Raspberry Pi 4 is a high-performance single-board computer (SBC) that manages real-time data collection from sensors, processes AI-driven workout adjustments, and connects with mobile and cloud applications for enhanced tracking.

Key Specifications:

Processor: Quad-core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz

RAM: 2GB, 4GB, or 8GB LPDDR4-3200 SDRAM

Storage: MicroSD card slot (expandable storage)

GPU: Broadcom VideoCore VI @ 500MHz

Connectivity: 2x USB 3.0, 2x USB 2.0, Gigabit Ethernet, Bluetooth 5.0, Dual-band Wi-Fi

Electrical Characteristics:

Operating Voltage: 5V via USB-C power supply

Power Consumption: 3W - 7W (depending on workload)

Interfaces: GPIO, I2C, SPI, UART, HDMI, CSI, DSI

Physical and Environmental Specifications:

Size/Dimensions: 85.6mm × 56.5mm × 17mm

Operating Temperature Range: 0°C to 85°C Applications in Smart Treadmill:

Cloud Connectivity & Data Storage: Stores user workout history and syncs data with cloud platforms for detailed analysis.

Real-Time Sensor Fusion: Processes multiple sensor inputs (heart rate, speed, and vibration) for accurate training feedback.

Remote Access & Mobile App Integration: Enables users and trainers to monitor performance from anywhere.

The Raspberry Pi 4 is an essential component of the Smart Treadmill System, providing high-speed processing, cloud integration, and AI-driven performance optimization.

6. DC Winch Motor

Purpose:

Drives the treadmill belt, providing variable speed control and torque adjustments for a smooth and efficient workout experience.

Model: DC Winch Motor

Operating Principle:

The **DC winch motor** operates based on **electromagnetic principles**, converting electrical energy into mechanical motion. It provides **precise speed control** through **Pulse Width Modulation (PWM)**, ensuring seamless treadmill operation.

Key Specifications:

- **Voltage Rating:** 24V DC
- **Power Output:** 250W
- **Torque:** High torque for efficient treadmill belt movement
- **Speed Range:** 0 – 5000 RPM
- **Efficiency:** >85%

Electrical Characteristics:

- **Operating Voltage:** 24V DC
- **Current Consumption:** 5A – 15A (depending on load)
- **Control Interface:** PWM for variable speed control
- **Protection Features:** Overcurrent and overheating protection

Physical and Environmental Specifications:

- **Size/Dimensions:** Compact motor casing for easy treadmill integration
- **Weight:** 3-5 kg (varies based on specifications)
- **Operating Temperature Range:** -10°C to 50°C

Applications in Smart Treadmill:

- **Treadmill Belt Drive System:** Ensures smooth and reliable treadmill operation.
- **Speed Control & Adjustment:** Works with AI algorithms to regulate belt speed based on user performance.
- **Energy Efficiency & Durability:** Provides long operational life with minimal maintenance.
- **Safety Features:** Integrated protection against overheating and excessive load.

The **DC Winch Motor** is a critical component of the **Smart Treadmill System**, enabling **smooth speed transitions, controlled resistance, and AI-driven optimization for a seamless workout experience**.

Manufacturing Drawings & CAD Model:

4.1.7 Manufacturing Drawing:

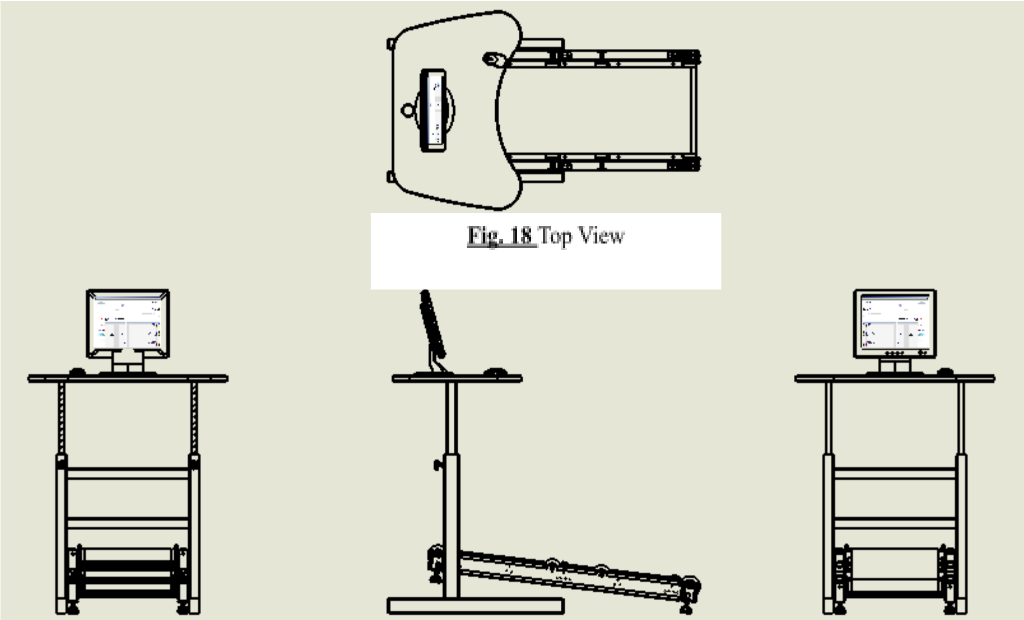


Fig. 18 Top View

Fig. 17 Rear View   Fig. 16 Side View   Fig. 15 Front View

4.1.9 CAD Model:

1. Smart Treadmill

Fig. 22 Smart Treadmill CAD Model

2. Spur Gear

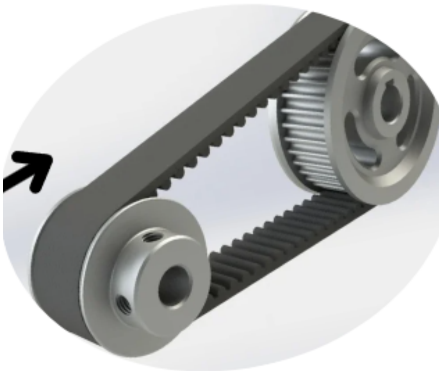


Fig. 22 Spur Gearl CAD Model

For **3D printing the frame and protective casing of key treadmill components**, the **Fused Deposition Modelling (FDM) process** was chosen due to its **cost-effectiveness, material versatility, and ability to create durable and functional parts**.

Material Selection:

- **PLA (Polylactic Acid):** Selected for the outer casing and static parts due to its rigidity, lightweight properties, and ease of printing.
- **TPU (Thermoplastic Polyurethane):** Used for treadmill belt-related attachments and footpad coverings to provide **flexibility, grip, and shock absorption**.
- **ABS (Acrylonitrile Butadiene Styrene):** Utilized for structural reinforcement components due to its **high impact resistance and heat tolerance**.

Design Optimization:

- **Layer adhesion and infill patterns** were adjusted to enhance **strength and durability**.
- **Support structures** were minimized to **reduce material wastage** and printing time.
- **Ergonomic considerations** were made to ensure **comfort and usability**.

Post-Processing Techniques:

- **Sanding and smoothing** were applied to improve **surface finish and user comfort**.
- **Annealing and heat treatment** were performed on load-bearing parts to **enhance durability and impact resistance**.
- **Protective coatings** were added to **improve water resistance and longevity**.

By leveraging **FDM 3D printing**, the **Smart Treadmill System** ensures a **lightweight, durable, and customizable design**, making it **adaptable to user preferences while maintaining high performance and reliability**

4.2 Software Design:

4.2.1 System Architecture:

Overview: The system architecture is divided into three main layers:

1. **Device Layer**:The **smart treadmill** is equipped with sensors to **monitor training performance and mechanical health**:
    - **Polar S10** for **heart rate monitoring** (anaerobic threshold estimation).
    - **MPU6050** for **vibration analysis** (gear fault detection).
    - **U-type speed sensor** for **real-time speed tracking**.

*AI-driven **speed and incline adjustment** ensures optimal endurance training.

2. **Cloud Layer**:
   ->**AWS IoT Core / Azure IoT Hub** stores and processes treadmill data.

   ->**Digital Twin-based predictive maintenance** models track **gear degradation** and mechanical failures.

   ->**AI-powered anaerobic threshold estimation** predicts optimal training intensity based on real-time heart rate.

3. **Application Layer**:
   ->**React Native-based mobile application** provides **training insights, gear fault alerts, and real-time recommendations**.

   ->Coaches and athletes can **track endurance progress, receive notifications, and adjust training settings remotely**.

Data Pipeline:

1. **Sensor Data Collection:**
   ->Heart rate, vibration, speed, and incline data are collected in real time.

   ->Data is transmitted via **Bluetooth/Wi-Fi to the cloud**.

2. **Data Processing & Storage:**
   ->AWS/Azure Storage stores sensor data for further analysis.

   ->AI-based fault detection processes vibration and speed sensor data to predict **gear failures**.

   ->Anaerobic threshold analysis optimizes **training intensity** based on HRDP.

3. **AI Analysis & Predictive Modeling:**
   ->**Machine learning algorithms** analyze heart rate trends to **detect anaerobic threshold** and suggest optimal speed/incline.
   ->**Digital twin simulation** predicts **gear wear and failures** based on vibration data.

4. **User Interface & Alerts:**
   ->The mobile app displays real-time treadmill analytics, heart rate trends, and predictive maintenance alerts.
   ->Athletes receive training optimization suggestions, while maintenance teams get gear failure warning.

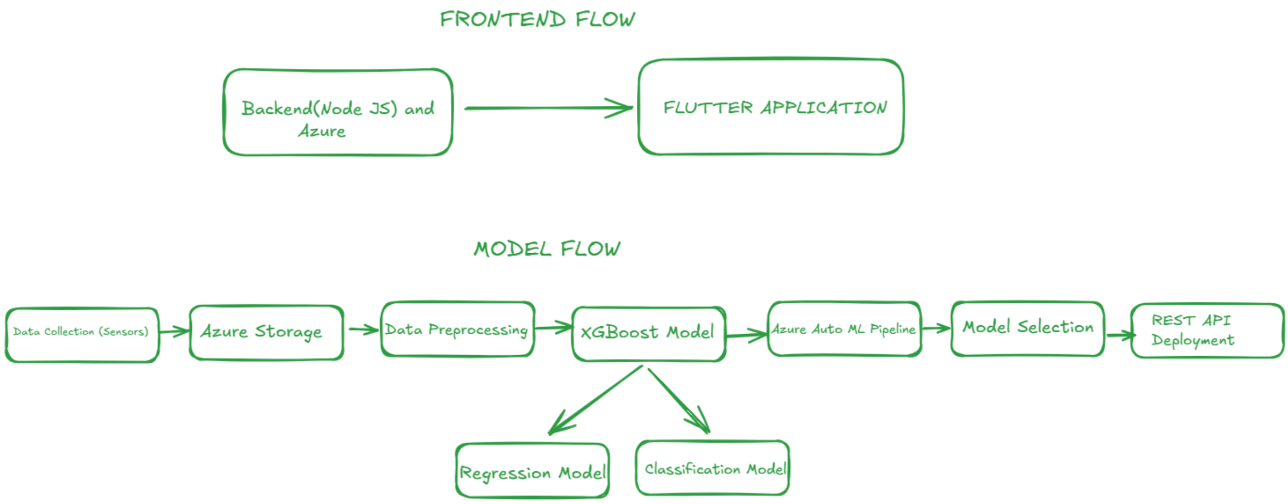


Fig. 15 Data Flow of Device (a)Cloud to App(b)Sensor to App

4.2.2 AI Model Design:

1. Type of Model:

Supervised Learning:

- **Gear Fault Detection (Classification):**
  - Binary classification: "Normal" (0) vs. "Faulty" (1).
  - Algorithm: **XGBoost** (Gradient Boosting) for its high performance and robustness in structured data.
- **Fitness Analysis (Regression):**
  - Predict optimal training parameters (e.g., speed, slope) based on the anaerobic threshold.
  - Algorithm: **XGBoost Regression** for accurate numerical predictions.

2. Dataset Requirements:

o <u>Gear Fault Detection:</u>

- MPU6050 vibration data (frequency, amplitude).
- Speed sensor data (irregularities in speed changes).

o <u>Fitness Analysis:</u>

- Polar S10: Heart rate, real-time monitoring.
- Speed sensor: User pace, treadmill incline.

o <u>User-Specific Data (Fitness Analysis):</u>

- Age, gender, weight.
- Maximum and resting heart rate.
- Training history and current intensity.

3. Data Preprocessing:

->Gear Fault Detection:

- Extract features from vibration data (e.g., FFT for frequency domain).
- Label training data (manually or from logs).

->Fitness Analysis:

o Normalize heart rate and speed data for regression.

- o Extract time-series features (e.g., heart rate trends during exercise).
- o Handle missing data with imputation techniques.

- Apply **feature scaling** (e.g., MinMaxScaler for XGBoost compatibility).
- Balancing the Dataset: Use **SMOTE** or similar methods if faulty gear data is underrepresented.

4. Model Evaluation Metrics:

Gear Fault Detection (Classification):

- Precision and Recall: Minimize false negatives (missed faults).
- F1 Score: Balance false positives and negatives.
- ROC-AUC Score: Ensure good separation of normal vs. faulty gear.

Fitness Analysis (Regression):

** Mean Absolute Error (MAE): To minimize the prediction error.

** R^2 Score: Evaluate overall fit of the model.

5. Implementation:

- Feature Selection Tools**:**Use SHAP values or Recursive Feature Elimination (RFE) to identify critical features.
- Model Selection: Perform hyperparameter tuning using GridSearchCV or Optuna.

Example XGBoost parameters:

- `max_depth`: Depth of trees for overfitting/underfitting control.
- `learning_rate`: Trade-off between model update speed and accuracy.
- `n_estimators`: Number of trees for training.

- Frameworks and Tools: TensorFlow, Pytorch, Scikit-Learn.

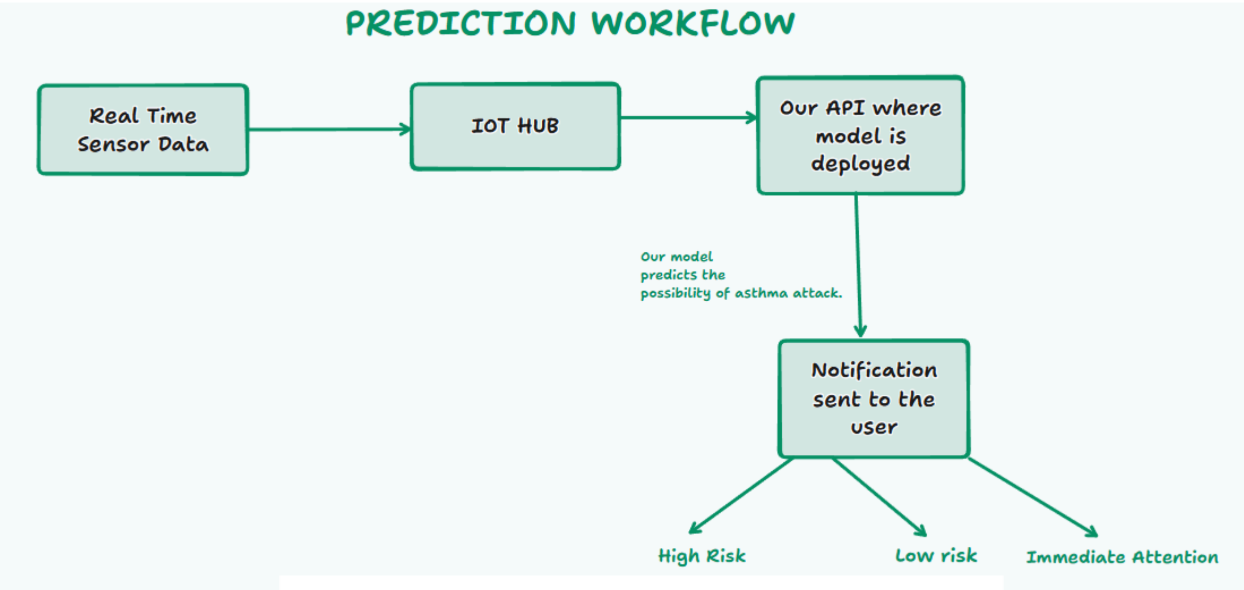


Fig. 16 Prediction Workflow of Heart attack

1. **Capturing Real-Time Data**: The treadmill is equipped with sensors that monitor key parameters, including vibration patterns (using the MPU6050), speed (using the U-type speed sensor), incline, and user heart rate (via the Polar S10). This ensures that critical operational and fitness data is captured in real time as the treadmill is in use.
2. **Processing Through the IoT Hub**: Once the sensors collect data, it is transmitted to an IoT hub. The IoT hub

acts as an intermediary, ensuring the data is securely aggregated and formatted for advanced analysis. This ensures a seamless transfer of data for predictive maintenance and fitness monitoring.

3. **Analyzing with a Predictive Model**:
   The collected data is processed by predictive models hosted on an API. These models use advanced machine learning algorithms like **XGBoost** to:
   - Detect potential faults in the treadmill's gear system by analyzing vibration patterns.
   - Provide real-time fitness insights based on speed, heart rate, and incline data.
     The models are trained on historical sensor data to ensure high accuracy and reliability in predictions.

4. **Sending Personalized Notifications**:
   Based on the analysis, the system sends notifications through a connected mobile app. These alerts are tailored to ensure user safety and optimize performance:

   For Fault Detection:

   - **Green Notification:** "Treadmill operating normally."
   - **Yellow Notification:** "Maintenance recommended soon."
   - **Red Notification:** "Critical issue detected – Stop using the treadmill immediately."

   For Fitness Monitoring:
   - **Low Intensity (Green):** "Good pace – keep it up!"
   - **Moderate Intensity (Yellow):** "Optimal training zone achieved."
   - **High Intensity (Red):** "Reduce speed or incline – Heart rate too high!"

4.2.3 App Design:

The companion app for the Smart Treadmill is designed to provide a seamless and intuitive user experience while ensuring effective_athletic endurance training. Below is an overview of the app's design and functionality:

Features

1.Real-Time Performance Tracking

What It Does:

- Tracks the user's real-time speed, heart rate, and treadmill vibration data during workouts. Provides instant feedback if the treadmill detects anomalies, like gear issues or incorrect running posture.

Why It's Useful:

- **Enhanced Training:** Ensures users maintain optimal performance and avoid inefficiencies.
- **Preventive Maintenance:** Detects gear faults early to prevent breakdowns.
- **Motivation Boost:** Real-time stats keep users motivated to push their limits.

How It Works:

- Firmware: Sensors such as the MPU6050 for vibration and the U-type speed sensor feed real-time data into the app.
- IoT Integration:
  - o A cloud platform stores and processes sensor data for live analytics.
  - o The app visualizes this data in user-friendly charts and graphs.

- Mobile App: Built with React Native for cross-platform compatibility.
  - o Provides live metrics like speed, heart rate, and calories burned.

2. Customized Workout Plans and Goals

What It Does:

- Allows users to set personalized training goals (e.g., distance, time, or calories). Suggests workouts based on the user's fitness level and progress.

Why It's Useful:

- **Targeted Training:** Tailored plans improve efficiency and help users reach specific goals.
- **Motivation:** Regular updates and goal tracking inspire consistent effort
- **Convenience:** Users can adjust plans based on their schedule or energy levels.

How It Works:

- **Mobile App:**
  - Users input fitness levels, goals, and preferences.
  - React Native UI offers an intuitive setup process.
- **Backend:**
  - A cloud-based algorithm recommends workouts based on user data.
  - Goals and progress are stored securely in a SQL database.

3. Fault Diagnosis and Alerts

What It Does:

- Monitors the treadmill's vibration and gear system for abnormalities. Sends alerts if issues are detected, reducing the risk of equipment failures take preventive actions.

Why It's Useful:

- **Safety First:** Alerts users to potential dangers like unstable vibrations.
- **Reduced Downtime:** Early detection minimizes disruptions to training.
- **Cost Efficiency:** Prevents expensive repairs by addressing small faults early.

How It Works:

- **Sensors:** The MPU6050 detects vibration anomalies.
- **IoT Integration**:
  - o Fault data is analyzed in the cloud using predictive maintenance models.
- **Mobile App**:
  - o Displays fault alerts and provides maintenance tips.

4. Workout History and Insights

What It Does:

- Displays past performance data, including speed, heart rate, and calories burned, in easy-to-read graphs. Analyzes trends to help users improve over time.

Why It's Useful:

- **Performance Tracking:** Users can monitor progress and set new benchmarks.
- **Data-Driven Training:** Trends reveal strengths and areas for improvement.
- **Goal Achievement:** Clear insights keep users on track

How It Works:

->Backend:

- Stores historical data in a SQL database.
- Azure AutoML analyzes trends and provides actionable insights.

->**Mobile App:**

o Interactive charts display data by day, week, or month.

o Users can filter metrics for a detailed view.

5. Find My Treadmill:

A. What It Does:
Helps users locate their treadmill by activating a buzzer when the app loses connection with the device.

B. Why It's Useful:
->Prevents Misplacement: Useful in gyms or shared spaces.
->Time-Saving: Quickly locate the treadmill during workouts.

How it works:

- ***Hardware***:
  - A Bluetooth module and buzzer are integrated into the treadmill.
  - Buzzer activates on disconnection or manual trigger.

- ***Mobile App:***

  ->A "Find My Treadmill" button in the app uses Bluetooth Low Energy (BLE) APIs to locate the device..

6. User Support Features

What It Does:

Includes a "Help" section with user guides, FAQs, video tutorials, and feedback forms.

Why It's Useful:

- **Enhanced Usability:** Helps users navigate features and resolve issues.
- **Improved Engagement:** Allows users to provide feedback and suggest improvement.

How it works:

->Mobile App:

- Displays guides and FAQs in a dedicated section.
- Integrates video tutorials using React Native Video.
- Feedback responses are stored in a SQL database for analysis.

5 Bill of Material:

Component Name	Specification	Cost (₹)	Quantity
Polar H10 Heart Rate chest sensor	monitors heart rate with high accuracy.	8999	1
U-Type Speed Sensor	Treadmill Speed Monitoring.	400	1
MPU6050 ACCELEROMETER	Used for faulty gear detection.	111	1
RASPBERRY PI 4	Use for ML Model.	5800	1
ARDUINO UNO R3	Real tme sensor data collection	2500	1
DC Winch Motor	Drive the treadmill belt.	2250	1
Aluminium Alloy	Aluminium Frame.	2500	10kg
Emergency Stop Bu□on	NA	100	1
Treadmill PVC belt	Aluminium Frame.	300	1
Motor Mount	Hold the motor in place .	320	1
Motor Driver	Motor Controller (48v 10A)	300	1
Spur Gear	Aluminium Frame.	400	2
MISELLANOUS	NA	2500	NA