Altius
Climbing Performance Evaluation System

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Introduction

Wearable Sensor Integration

Altius uses Arduino Nano 33 BLE Rev2-based sensors mounted on each limb to track full body motion during climbing sessions, ensuring detailed data collection

Real-Time analysis and Scoring

Captured data is streamed live to a central device, where it is analysed to produce a performance score at the end of each session

Objective Metrics for Evaluation

Key metrics are fall detection, rhythm and flow, smoothness, arm vs leg usage, stability and grip count, offering a robust and data-driven assessment of climbing performance

System Overview & Components Used

System Overview:

- 4 wearable units (1 per limb)
- Each unit captures **9-axis motion data** (accelerometer, gyroscope, magnetometer)
- Data streamed via **Bluetooth** to a Python-based central
- Performance evaluated via **algorithmic metrics**
- Scores are displayed in **GUI**

Hardware:

- Arduino Nano 33 BLE Rev2
- 7.4V LiPo batteries
- 3D printed cases
- Velcro straps

Software:

- Arduino Firmware (IMU & BLE Communication)
- Python (Data Acquisition & Processing)
- CSV Data Format for Logging Sensor Data

Arduino setup

- Each Arduino was programmed to send data to the central device using Bluetooth Low Energy (BLE) connection
- Data was sent as a single 36 byte string (9 values, 4 bytes each)
- Data was collected by the central device using bleak and asyncio python libraries
- Data was then logged to 4 .csv files, corresponding to each limb

Scoring System Overview

Metrics:

- Rhythm and Fall Detection
- Arm vs Leg Usage
- Smoothness
- Stability
- Grip Count

Each metric scores 0–100

Fall Detection and Rhythm

Goal: Evaluate control, coordination, and timing by detecting falls and assessing movement rhythm throughout the climb

***Fall Detection* – How it works:**

- Acceleration magnitude is calculated for each limb
- Partial fall: only some limbs exceed 10 m/s²
- Full fall: all limbs exceed threshold within 0.5 s
- Identifies moments of lost control

***Rhythm & Flow* – How it works:**

- Smoothed signals → detect motion vs rest
- Analyze intervals between movements
- "In rhythm" = 1.0–3.0 s between motions

Algorithm 1 Fall & Rhythm Detection in *ClimbSense*

Input: acceleration data for limbs $\mathcal{L}$; thresholds t_{fall}, t_{move}; sync window δ; pause p

Output: partial falls $\mathcal{P}$, full falls $\mathcal{F}$, rhythm score $\mathcal{R}$

procedure AnalyzeClimb($\mathcal{L}, t_{fall}, t_{move}, \delta, p$)
  $\mathcal{P} \leftarrow \emptyset$, $\mathcal{F} \leftarrow \emptyset$, movementTimes $\leftarrow \emptyset$
  for all limbs $\ell \in \mathcal{L}$ **do**
    for all frames f **do**
      compute magnitude $m = \sqrt{a_x^2 + a_y^2 + a_z^2}$
      if $m > t_{fall}$ **then**
        add $(f.timestamp, \ell)$ to $\mathcal{P}$
      if $m > t_{move}$ **and** $f.timestamp - lastMoveTime > p$ **then**
        add $f.timestamp$ to $movementTimes$
        $lastMoveTime \leftarrow f.timestamp$
  Group $\mathcal{P}$ events within window δ
  if all limbs triggered within δ **then**
    add full fall time to $\mathcal{F}$
  sort $movementTimes$
  compute intervals Δ between moves
  $\mathcal{R} \leftarrow \frac{\text{std}(\Delta)}{\text{mean}(\Delta)}$
  return $\mathcal{P}, \mathcal{F}, \mathcal{R}$

Arm vs Leg Usage

Goal: Evaluate how evenly the climber distributes movement between arms and legs, as an indicator of technique and efficiency

How it works:

- For each limb, we compute acceleration magnitude from IMU data
- A movement is counted if the change in magnitude exceeds a threshold ($\theta = 0.8\ m/s^2$)
- Total motion events are grouped: Arms vs. Legs
- Ratios are calculated to measure usage balance:

$$\text{Arm Usage Ratio} = \frac{M_{\text{arms}}}{M_{\text{arms}} + M_{\text{legs}}}, \quad \text{Leg Usage Ratio} = \frac{M_{\text{legs}}}{M_{\text{arms}} + M_{\text{legs}}}$$

Threshold Interpretation:

< 0.3 — Indicates excessive reliance on upper limbs

0.3–0.6 — Suggests balanced limb usage

> 0.6 — Reflects effective use of lower limbs, associated with improved endurance

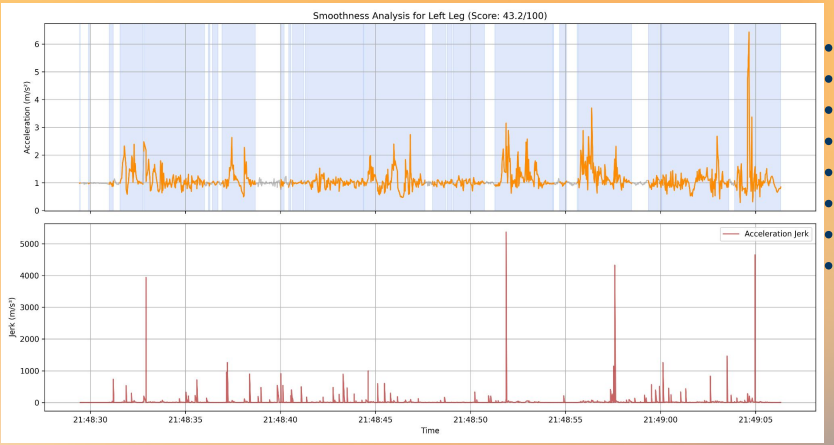
Smoothness

Goal: Measure how calm and steady the climber's movements are
We look at how much acceleration and rotation change - fewer sudden spikes = smoother movement

How it works:

- Compute magnitude of acceleration and gyroscope:
- A rolling standard deviation detects movement vs. stillness.
- Compute jerk: the rate of change of acceleration and rotation.
- Score Normalization:

$$smoothness\ score = \left(1 - \frac{median\ jerk}{\max expected\ jerk}\right) \cdot 100$$



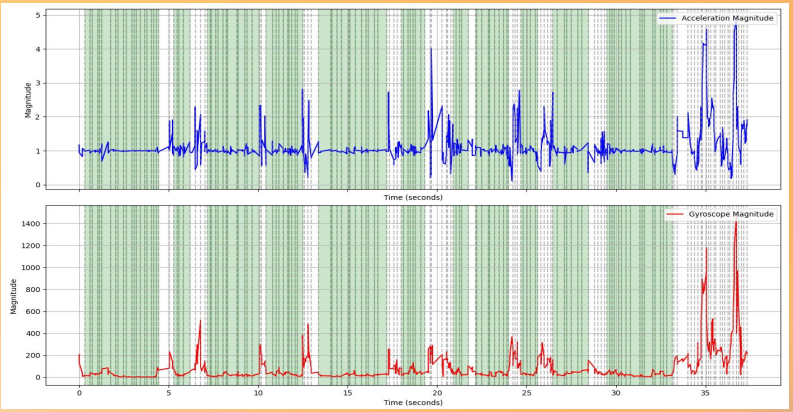
Score range: ***0 (jerky)*** *to* ***100 (very smooth)***

Stability

Goal: Evaluate how steady the climber is during static positions (holds), based on sensor stability

How it works:

- Sensor data is split into short time windows (0.25s)
- A window is "still" if values stay near resting levels
- Sequences of still windows (≥ 0.75s) are marked as holds
- Each hold is checked for signal stability (low standard deviation)
- A hold is stable if variation remains below threshold



Stability Score = proportion of hold windows classified as stable

High score → good control and precise movement

Low score → unstable holds, possible hesitation or grip issues

Grip Count

Goal: Count how often the climber holds a grip with each arm — to analyze symmetry and arm usage

How it works:

- Based on the same “still window” detection as in the Stability metric
- A grip is detected when a still period occurs between two motion phases
- Each arm is tracked independently
- The number of grips per arm is counted across the full climb

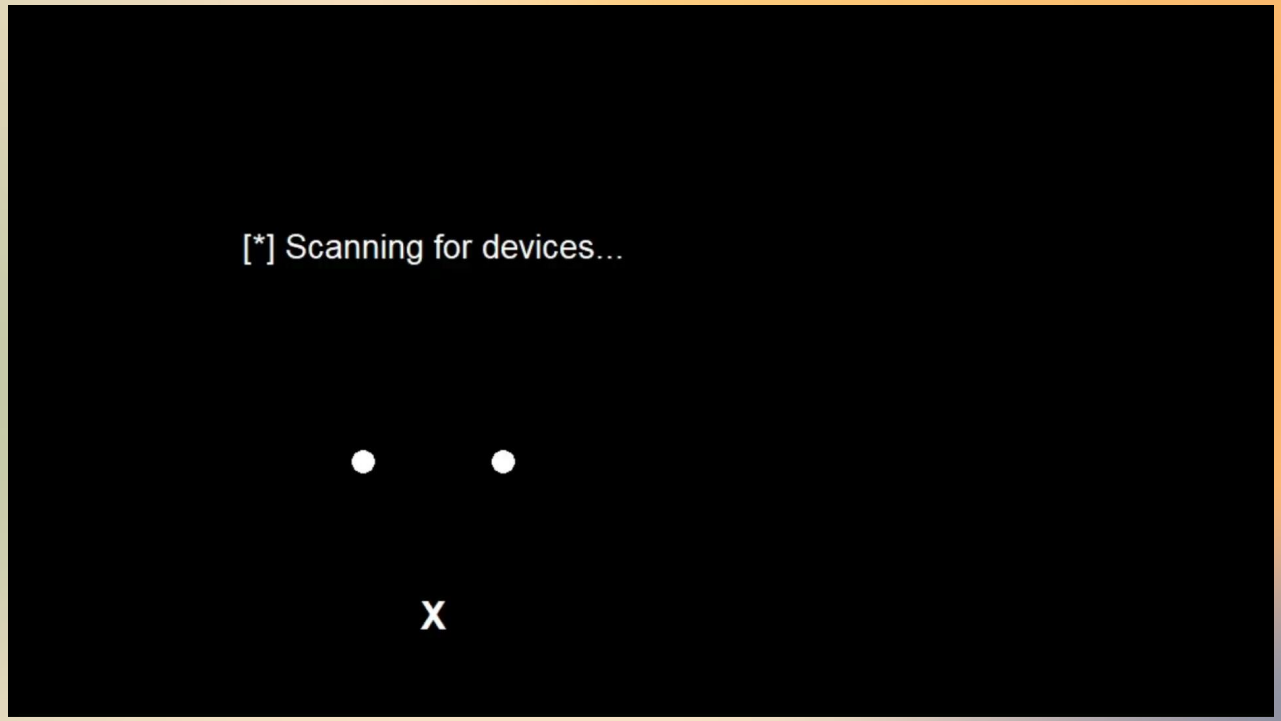
→ ***Helps identify arm dominance***

→ ***Shows if the climber uses both arms symmetrically***

→ ***Useful for technique assessment and movement balance***

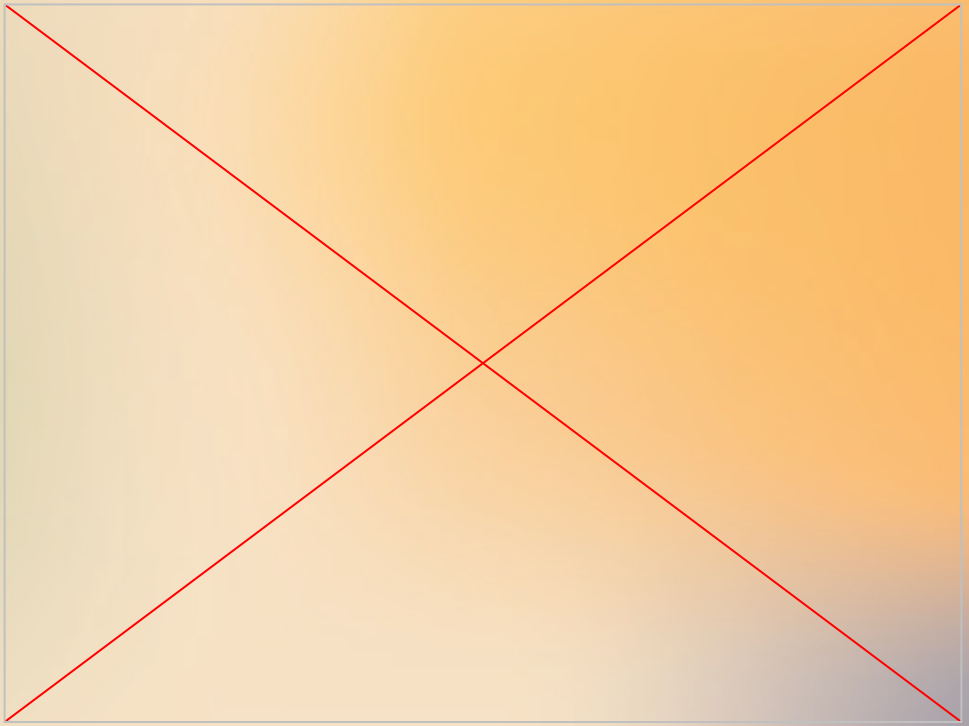
Not Smooth Climb

https://github.com/flaferty/altius/tree/main/videos



Arms vs Legs

https://github.com/flaferty/altius/tree/main/videos



Technical Challenges

1. Low data transmission rate
2. A lot of data for threshold tuning
3. Issues with concurrent connection

Challenges

1. Finding the project idea
2. Choosing the right materials
3. Time management

Thank you!

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