ARCS AUTONOMY RESEARCH CENTER FOR STEAHM

NASA

CSUN CALIFORNIA STATE UNIVERSITY NORTHRIDGE

Boracle (the oracle for your Body)

An Open-Source Platform for Streamlining Wearable Data Access

Presenters:

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ARCS
AUTONOMY RESEARCH CENTER FOR STEAHM

Interdisciplinary Student and Faculty Team

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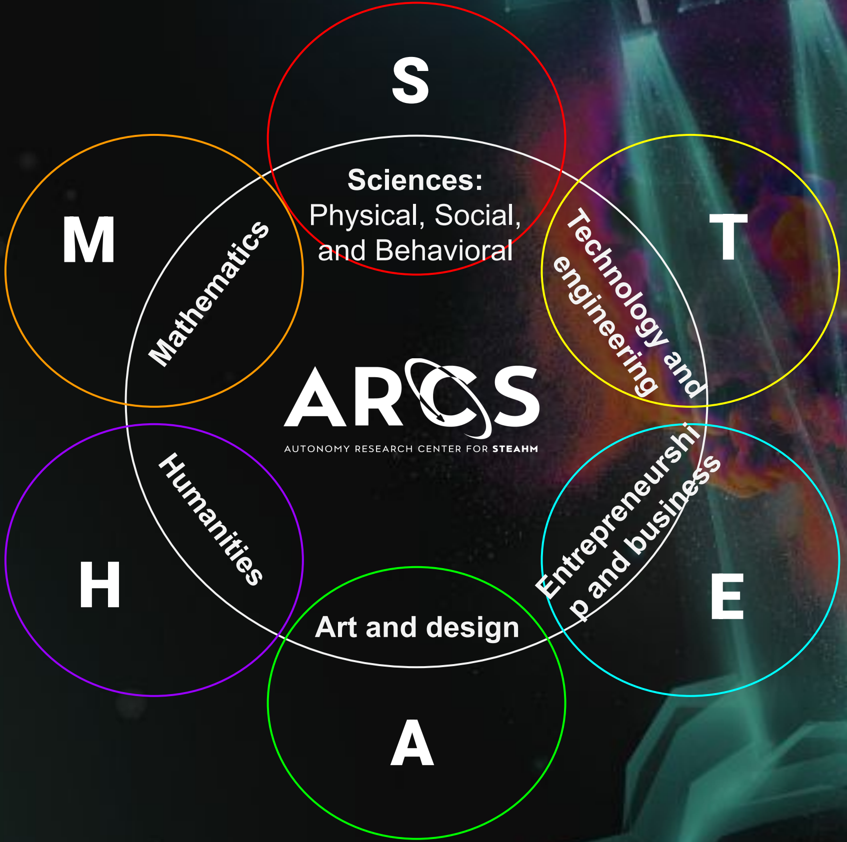
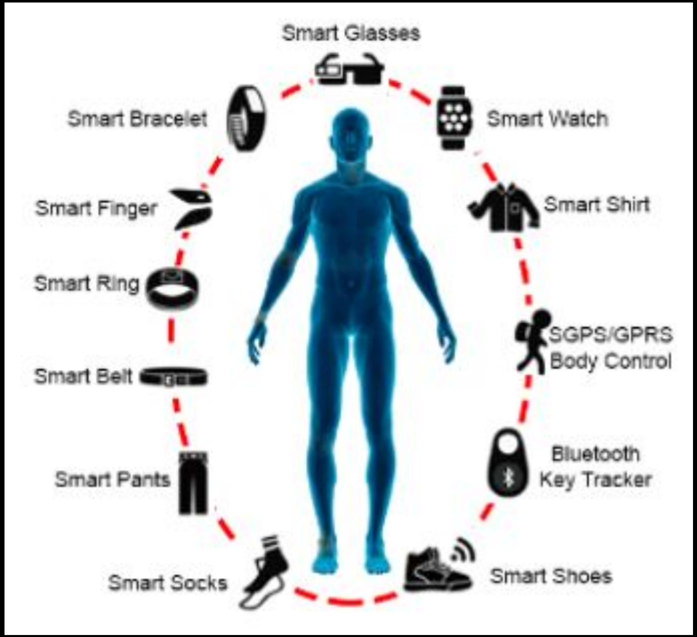


Introduction to Wearable Technology

- **Health Monitoring**
  - Devices collect sensor data
    - Heart rate, blood oxygen, sleep
    - GPS, foot placement, eye movements

- **Rapid Growth**
  - New types of devices
    - Smart rings
    - Smart shirts
    - Smart socks

  - Devices equipped with many sensors
    - Sensors are cheaper and more effective
    - Huge quantities of health data generated



Source: https://www.researchgate.net/figure/Different-types-of-wearable-technology_fig5_322261039

Problem Statement - Consumers

- **Hard to access/share wearable data**
  - In their own ecosystems
  - different data formats
- **Pairing Apps**
  - Mobile pairing app
    - Collects and stores device data
  - Multiple devices → multiple apps
- **Choice Overload**
  - Many smart devices on the market:
    - Too many choices
    - No one place to access product info

Image Source:
https://www.linkedin.com/pulse/consumer-smart-wearables-market-size/

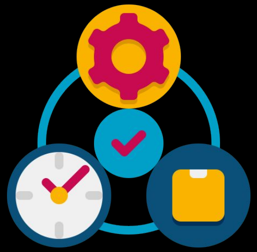
Problem Statement - Device Manufacturers

- **Creating Pairing Applications**
  - Why? Data moves: device → phone → storage
  - Forces manufacturers to spend resources on making apps
- **Inefficiency in Device Creation:**
  - Shifts resources: device production → app development
  - Time/money could be spent improving devices

Problem Statement - Algorithm Developers

- **Limited Data Access:**
  - How we obtain data is specific to each device
    - Download into a file?
    - Data through an API?
    - Through a pairing app?
    - Through an OS?
    - Through Bluetooth/Wi-Fi?
    - Too impractical to obtain?

- **Lack of Data Standardization:**
  - If we can obtain sensor data:
    - Different devices have different data formats
      - Algorithms require a singular format to run
    - Requires developers to do extra work

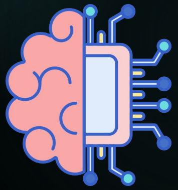


- **Inefficiency in Development:**
  - Hurdles in accessing and processing wearable data

Three Teams on Boracle Project

- **Boracle Platform**
  - Solve problems with algorithm development
  - Fix multiple pairing app problem
    - For consumers and device manufacturers

- **Boracle Marketplace**
  - Reduce choice overload for consumers
  - Promote access to reliable information for smart wearables

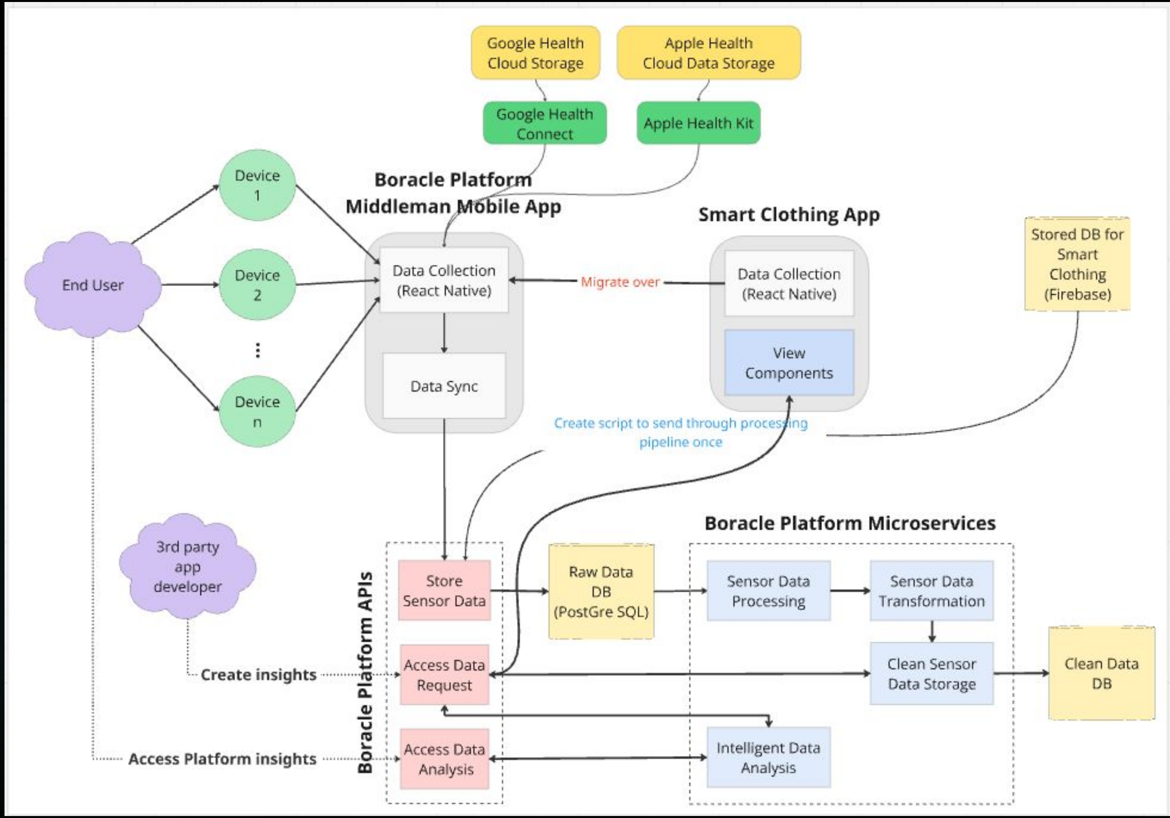


- **Intelligent Algorithms**
  - Better understand needs of algorithm developers
  - Create our own health detection algorithms

Boracle Platform - Solve Technical Issues

- **Centralized Data Collection:**
  - Introduce the Boracle pairing app:
    - Collects data from **any** smart device on market
    - Eliminates need for multiple pairing apps
- **Standardization, Storage, and Easy Access:**
  - Data is converted into a standard format
  - Data is stored securely, ready for developer use
- **Free, Open-Source Model:**
  - Encourages contribution from device manufacturers, academia, and medical experts
  - More contributions → more capable platform

Boracle Ecosystem - Architecture Diagram



Boracle Platform - Work from 2023-2024

- **Created documentation:**
  - System requirements
  - System design
- **Starting implementation:**
  - Pairing (middleman) application
    - Collection access for smart device data
    - Using: React Native, Firebase Authentication
  - Boracle Platform backend:
    - Public facing APIs
    - Microservices: data processing, storage, and sharing
    - Using: Spring Boot, Firestore

Boracle Platform - Progress backend

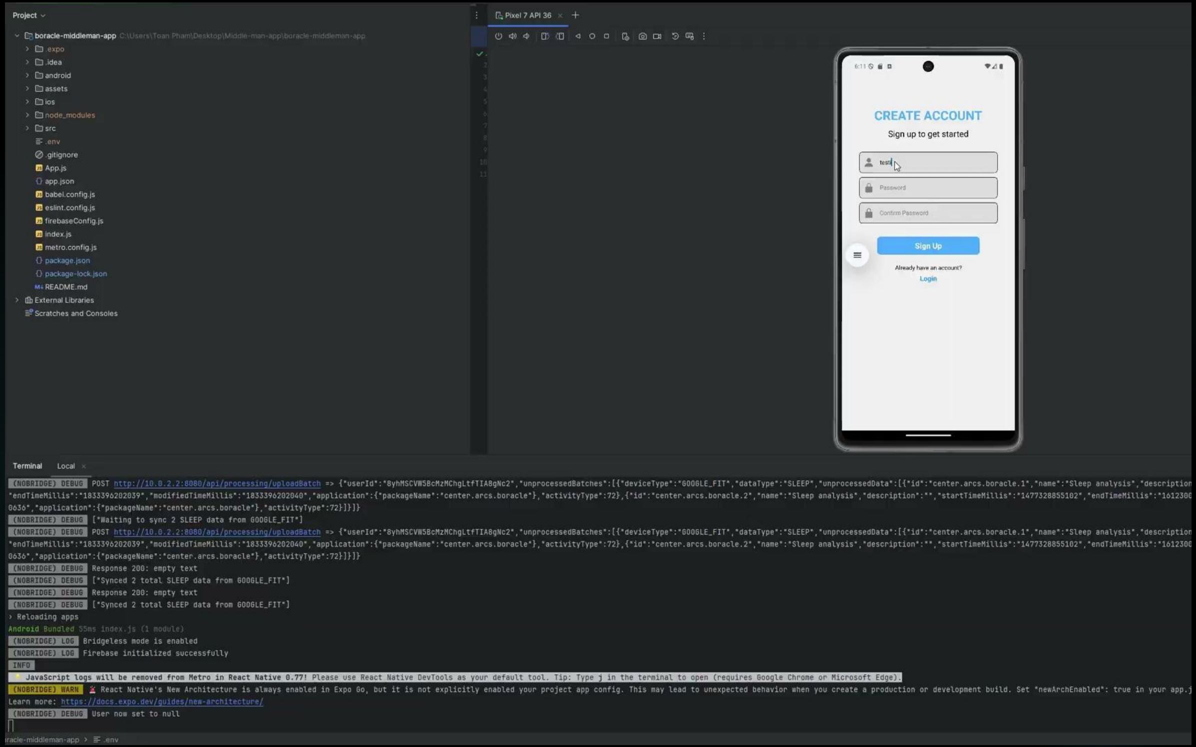
- **Microservice progress:**
  - Migration from using firebase to postgreSQL for storage
  - Security and authentication : Firebase
  - testing (mock, integration), 94% coverage
  - Data standardization:
    - sleep data
    - heart rate data

Boracle Platform - Progress Middleman application

- **Middleman application:**
  - UI for user sign up
    - uses firebase authentication
    - can sign up as normal user or app developer
  - Data collection from Apple health kit and health connect
  - Data collection using BLE

Boracle Platform - Demo

- Android Version Middleman App Demo



Boracle Platform - Demo

- BLE Demo:
  -

Boracle Platform - Next step

- **Boracle Platform**
  - Integrate more smart wearable into the system
  - Testing data collection pipeline for Android, iOS, and through Bluetooth
  - Integrate data analysis intelligent algorithms
  - Allow 3rd party app developers to read users data
  - Add in transformation service

Boracle Marketplace

- **Solve Consumer Issues**
  - **Centralized Catalog:**
    - A web platform offering a comprehensive list of:
      - Smart devices
      - Health-related applications
  - **Centralized Community Feedback:**
    - Incorporates a review system
    - Promoting informed decision-making
  - **Discovery and Verification:**
    - Users can explore verified products
    - Verification process ensuring device and app integrity

Boracle Marketplace (Web Application)

new features:

- Personalized app & device recommendations
- Explanation tool tips for recommendation reasoning
- Automatic recalculation when bookmarks change
- Weighted similarity to prioritize important features
- User-friendly visual presentation

Intelligent Algorithms (IA)

- IA team members:
  - Undergrad: Patrick, Brandon, Maxwell, Ridham, Mishek, Miles
  - Grad: Spencer, Abhinav, Bhumil, Neha, Pranati
- Deploying machine learning for big data analysis

Develop explainable AI with transparent data collection and interpretable algorithms

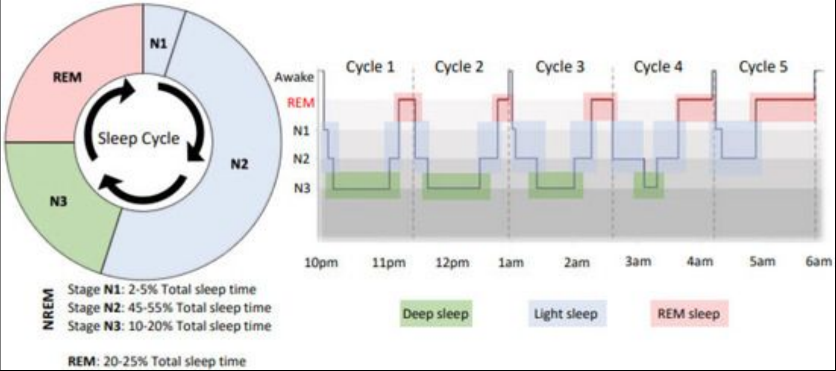
Build ML models to provide personalized health insights and prognosis

Enhance athletic performance and increase accessibility with minimized intrusiveness and reduced costs

Intelligent Algorithms

Sleep Stage Classification

- Humans typically go through 5 stages of sleep in a night
- Awake, 2 types of light sleep, deep sleep, REM
- Cycle through these 5 stages 4-6 times per night



- Sleep deprivation can cut athletic endurance by up to 10%
- Sleeping < 8.1 hrs. on average makes athletes 1.7x more likely to get injured

DREAMT Dataset:

- 100 individuals @ Duke University Sleep Lab
- Data collected with **Empatica E4**
- **Signals @ 64 Hz include:** Blood volume pulse, Accel., Electrodermal activity, Temp., HR, IBI
- Includes sleep technician-annotated sleep stage labels

Image Source: https://www.mdpi.com/2075-4663/11/1/14; https://box.empatica.com/documentation/20141119_E4_TechSpecs.pdf

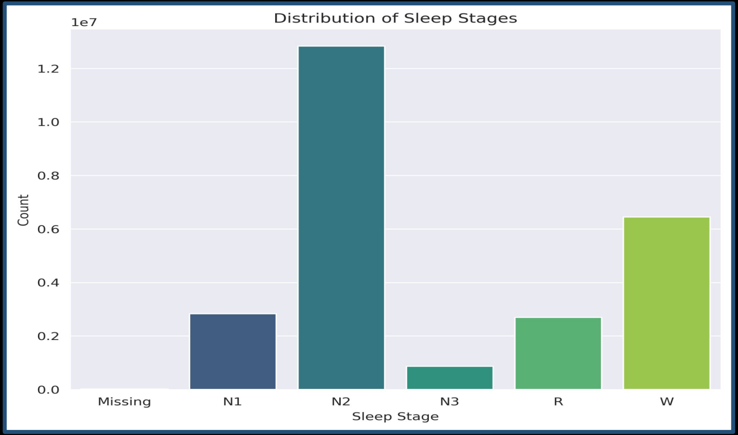
Intelligent Algorithms

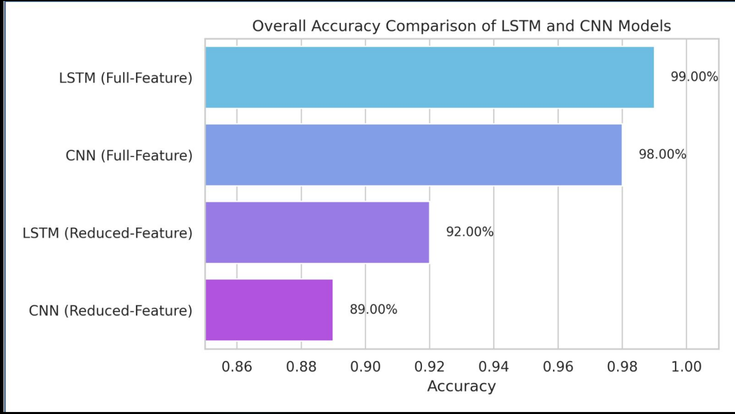
Sleep Stage Classification Data Preprocessing:

- Data downsampled from 64 HZ to 10 HZ & 1 HZ
- Full Feature: All features from original dataset
- Reduced Feature: Most common to consumer-grade wearables

Neural Network Training:

- Focal loss & class weighting to mitigate class imbalance
- LSTM & CNN trained both on:
  - Full feature set
  - Reduced feature set
- LSTM achieves highest performance for both full and reduced set



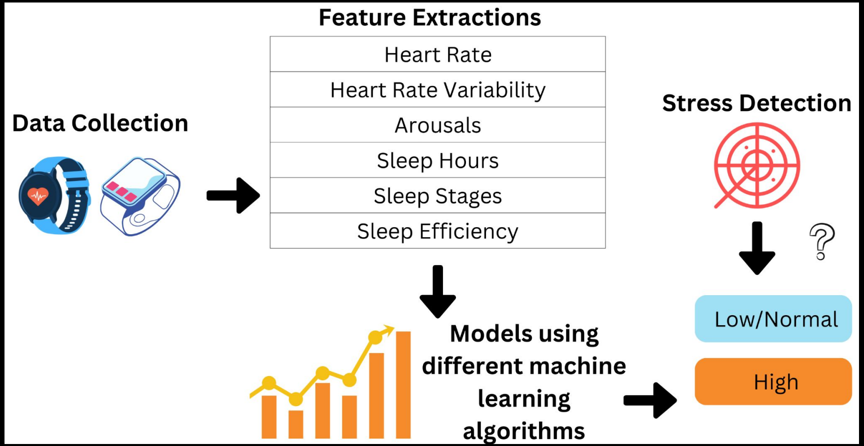


Intelligent Algorithms

Stress Detection

- High stress can cycle into poor sleep, poor sleep can lead to higher stress levels
- Sleep patterns can reveal insights on stress level

- **Machine learning models trained** on data from **Sleep Heart Health Study (SHHS)**
  - **Best performing model achieves 99% accuracy** in detecting stress based on sleep patterns
  - Higher instantaneous HR (IHR) and low heart rate variability (HRV) during sleep correlated with stress



Sleep (hrs)	Heart Rate (bpm	Heart Rate Variability (ms)	Sleep Efficiency (percentage)	Arousals (count)	Stress State
7-9	46-89	30-144	47-98	3-55	Low/Normal (Healthy)
2-6	68-99	24-102	59-79	7-52	High (Unhealthy)

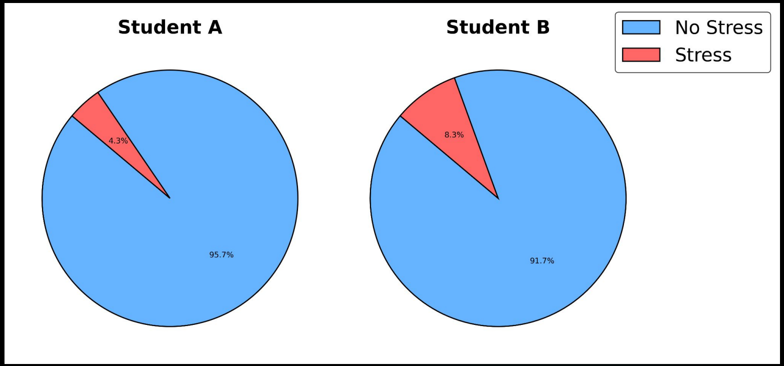
Intelligent Algorithms

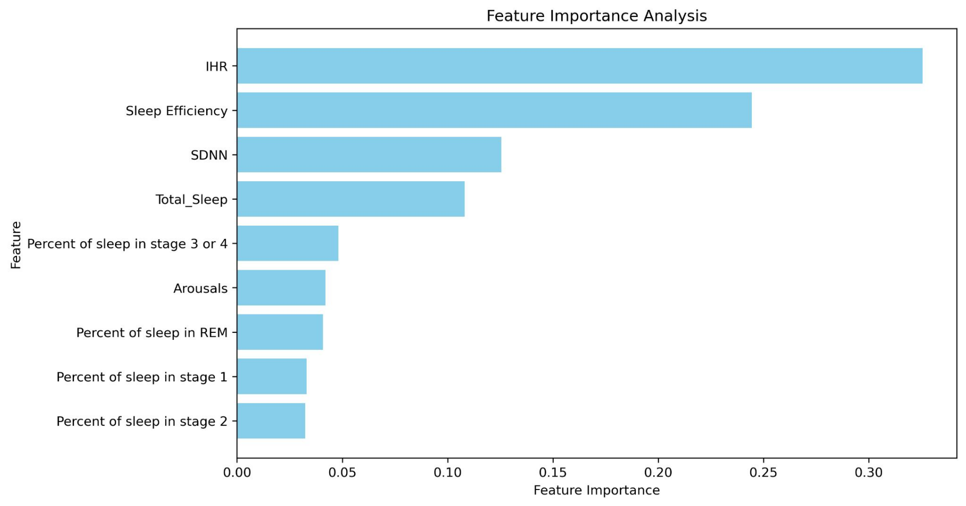
Stress Detection – Apple Watch Data Integration

- To explore the usage of our stress detection algorithm
- 2 IA team members wore **Apple Watch Series 9** watches
- Our novel algorithm does objectively detect stress based on physiological metrics

Importance of Physiological Metrics in Detecting Stress

- Sleep Efficiency & Total Sleep Time are factors humans have more control over





Intelligent Algorithms

- **Soccer Injury Prediction**
  - Lack of restful sleep combined with excessive stress can make athletes more likely to be injured
  - Addressing risk injury factors early on, can help avoid future injury likelihood

- Injuries in Europe's top five soccer leagues resulted **$800m in financial losses** for one season [5]
  - An injury occured every 92 mins. on average

- **SoccerMon Dataset:**
  - Largest soccer athlete dataset available
  - **Data collected with:** STATSports APEX Athlete Series Soccer Tracker
  - 10, 075 objective reports
    - > 6 billion GPS position measurements
  - HR, GPS, Accelerometry, Gyroscope

Image Source:
https://www.nature.com/articles/s41597-024-03386-x/figur

Intelligent Algorithms

- **Machine learning models trained** on **SoccerMon** dataset:
  - XGBoost, Rocket, Decision Tree, LightGBM, CatBoost
- Issue of class imbalance (injury / no injury)
  - Mitigated with data augmentation using SHAP

- LightGBM achieves
  - F1 Score = 87%
  - ROC AUC = 0.9821

- **Factors found to contribute to injuries**
  - Too high/Too low amount of time in HR zone 4
  - Too high/Too low average HR
  - Sudden changes in distance traveled
  - Lack of load variation

Zone	Training Effort	Rate of Perceived Exertion (RPE)	Fitness Goal
Zone 1	50-60% Max Heart Rate	2-3/10	Warm Up, Recovery (including active), Cool Down
Zone 2	60-70% Max Heart Rate	4-5/10	Building an Aerobic base, Fat-burning, Sustainable for long periods
Zone 3	70-80% Max Heart Rate	6-7/10	Improving Aerobic capacity and muscle strength
Zone 4	80-90% Max Heart Rate	8-9/10	Increasing the anaerobic threshold; helps improve performance in short-duration activities.
Zone 5	90-100% Max Heart Rate	9-10/10	Develop fast twitch muscle fibers for sprinting and power. Not good for long periods.

Image Source: https://endurancetraining.ca/understanding-heart-rate-zones-in-strength-training/

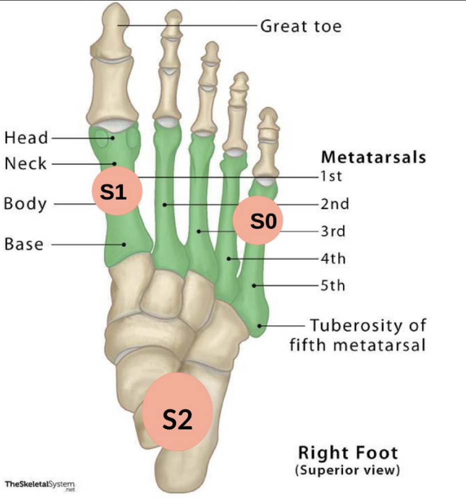
Intelligent Algorithms

Sensoria Smart Sock Data Analysis

- Sensoria Sock captures **pressure, accelerometry, and gyroscopic** data over time
- Sensor placements are at **3 locations over the foot**

- **Analysis** can reveal insights on **fatigue, potential injury risk, pressure imbalances** between feet, and inconsistencies in foot behavior over time - offering valuable indicators of athletic performance and biomechanical efficiency.

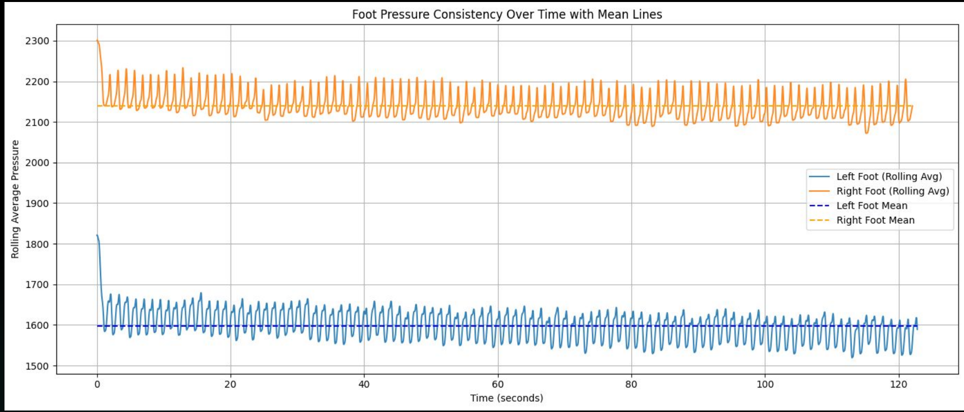
Sensoria Sock



Sensor Sock approximate sensor placement; Aligned leftmost toe, rightmost toe, and heel

Sensor Placement

Intelligent Algorithms

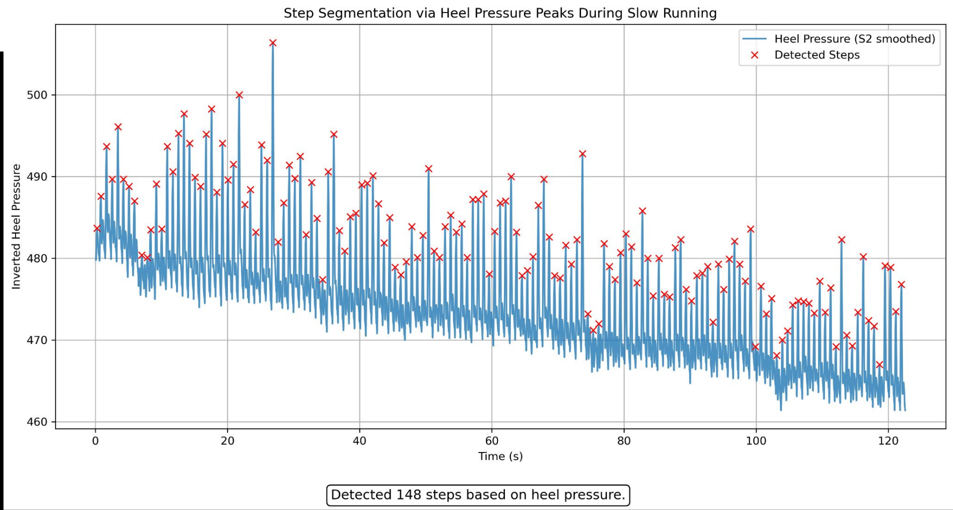


Total Foot Pressure over an Inclined Treadmill Walking Session

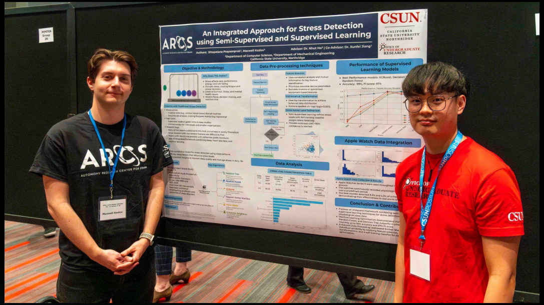
- Foot pressure decreases over time
- Could be a natural plateau
- If pressure remains inconsistent:
  - Can signal fatigue
  - **Could potentially forecast an injury**

Heel Pressure Measured per Step During Slow Running

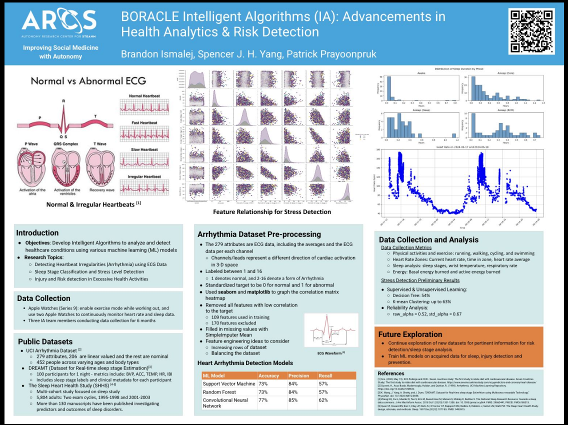
- Detected 148 steps over 123 seconds via heel pressure peaks
- Heel strikes indicate stable/non-stable cadence
- Can **provide actionable insights** to avoid
  - Plantar Fasciitis
  - Heel Spurs



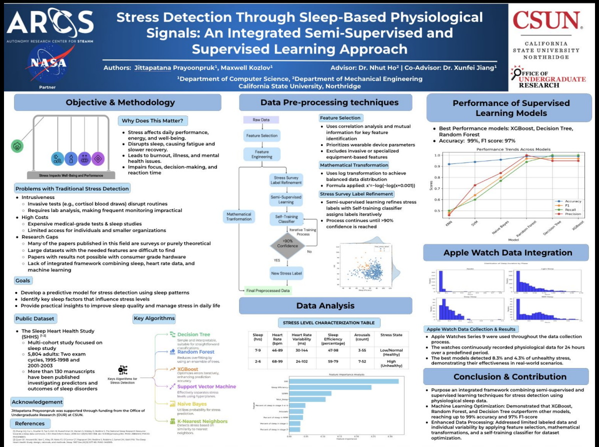
Intelligent Algorithms

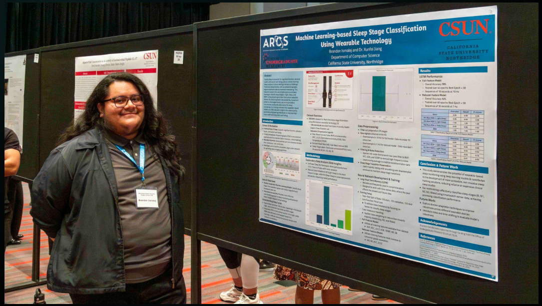


2025 CSUNPosium (Max, Patrick) - won first place in poster session group 26

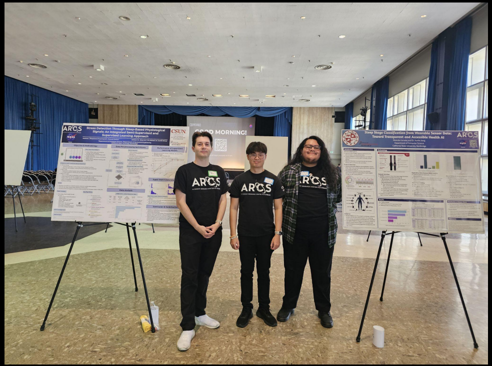


2024 CSUN REU Workshop Poster

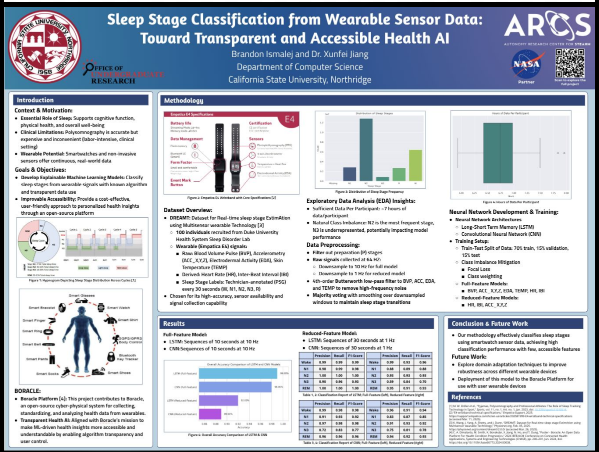




2025 CSUNPosium (Brandon Ismalej)



2025 SoCal AI Research Summit @ UCLA



Intelligent Algorithms

- **Plan for data collection from the athletes**
  - Technical trainings will be offered to the athletes students
    - Trainings for data collection using Apple Watches
    - Trainings for how to view/understand their data using a smart wearable application
  - Approach to follow for the data collection
    - Two Apple Watches are given to each student athlete
    - One Apple Watch worn continuously, swapped when the battery dies
  - Duration of data will be collected
    - 4 week data collection period
  - Any communication needed during the data collection
    - Weekly meetings with the student athletes and coaching staff
    - Online surveys to measure satisfaction over course of study

Intelligent Algorithms

- **Next Steps:**
  - Work toward analyzing more data to examine factors related to increase athletic performance and efficient training
  - Examine physiological factors that can contribute to increased likelihood of injury
  - Build models to forecast injury risk in future training/performance sessions
  - Examine HR metrics to analyze performance of athletes over time

- **GOAL:** To provide actionable insights to increase athletic performance and reduce injury risk

References

- [1] S. Scataglini, A. Moorhead, and F. Feletti, "A Systematic Review of Smart Clothing in Sports: possible Applications to Extreme Sports," *Muscle Ligaments and Tendons Journal*, vol. 10, no. 02, p. 333, Jun. 2020. [Online]. Available: http://www.mltj.online/a-systematic-review-of-smart-clothing-in-sports-possible-applications-to-extreme-sports/

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- [3] J. M. Bumgarner et al., "Smartwatch Algorithm for Automated Detection of Atrial Fibrillation," *Journal of the American College of Cardiology*, vol. 71, no. 21, pp. 2381–2388, May 2018, doi: 10.1016/j.jacc.2018.03.003.

- [4] Fuller, Daniel, Javad Rahimipour Anaraki, Bongai Simango, Machel Rayner, Faramarz Dorani, Arastoo Bozorgi, Hui Luan, and Fabien A. Basset. "Predicting lying, sitting, walking and running using Apple Watch and Fitbit data." BMJ Open Sport & Exercise Medicine 7, no. 1 (2021): e001004.

- [5]https://apnews.com/article/football-injuries-rodri-club-world-cup-ad6d9dc6a5c2e79e5995285381e52ee2

Ways to Contribute

- **Boracle Platform:**
  - Research existing devices, sensor information
  - Help design format for health data
  - Write software:
    - Middleman app: collect data, UA management
    - Platform: enterprise software

- **Boracle Marketplace:**
  - System testing
  - Enhance the Rating Feature

- **Intelligent Algorithms:**
  - Analyze sensor data
  - Health condition prognostics:
    - Using ML models
    - Designing traditional algorithms

Interested in joining? Scan me!

Questions?

Thank you!