Smart Dance Shoes with Machine Learning Powered Light and Motion Synchronization

Project Report

Course Name & Code: CSC 317 1.5 - Human Computer Interaction

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Introduction

In the era of rapidly advancing technology, the fusion of wearable devices and machine learning has opened new frontiers in interactive experiences. Motion-responsive systems, particularly in smart wearables, enable dynamic interactions that enhance performance and creativity. This project, "Smart Dance Shoes with Machine Learning-Powered Light and Motion Synchronization," leverages motion data to create a visually immersive experience, seamlessly synchronizing RGB lights with the user's movements.

The project utilizes the ESP32-S3 microcontroller, known for its robust processing capabilities, and the MPU-6050 sensor, which captures accelerometer and gyroscope data. Machine learning algorithms process this motion data in real-time, triggering RGB light patterns based on movement intensity, direction, and rhythm. The system is designed to be cost-effective, portable, and user-friendly, making it an ideal solution for performers, dancers, and fitness enthusiasts.

The motivation behind this project stems from the growing demand for interactive and immersive wearable technology, particularly in performing arts and entertainment. By integrating motion analysis with smart lighting control, this project not only enhances user experience but also demonstrates the potential of AI-driven innovation in wearables.

Objectives

- To develop a real-time motion recognition system that synchronizes RGB lights with movement using the ESP32-S3 and MPU-6050 sensor.
- To implement machine learning algorithms that classify dance movements and adjust lighting effects dynamically.
- To ensure the system is lightweight, efficient, and responsive, with minimal setup and seamless integration into dance performances.

Tools and Technologies

- ESP32-S3 microcontroller
- MPU-6050 motion sensor (Accelerometer & Gyroscope)
- LED Neon Light Strip RGB
- Machine Learning Model
- 3.7 V batteries (LiPo Battery)

Figure 1: ESP32-S3 microcontroller

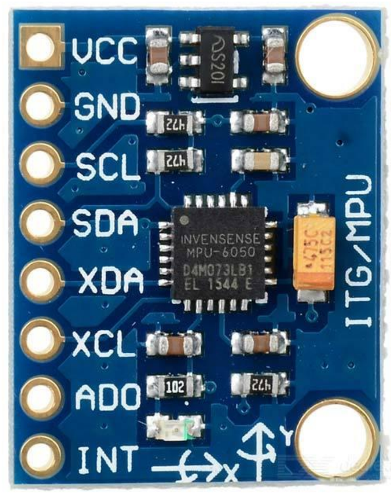


Figure 2: MPU-6050 motion sensor

Figure 3: 3.7 V batteries (LiPo Battery)

Figure 4: LED Neon Light Strip RGB

Here's a concise breakdown of why each component is used:

- ESP32-S3 Dual-Core: Acts as the brain, processing motion data and controlling RGB lights. Offers WiFi, Bluetooth, dual-core processing, and low power consumption.
- MPU-6050 Sensor: Detects movement using 3-axis accelerometer & gyroscope, enabling motion-based lighting effects.
- RGB LED Strip: Provides dynamic, customizable lighting controlled by ESP32 based on motion input.
- 3.7V LiPo Battery: Lightweight, rechargeable, and high energy density, supplying stable power to all components.

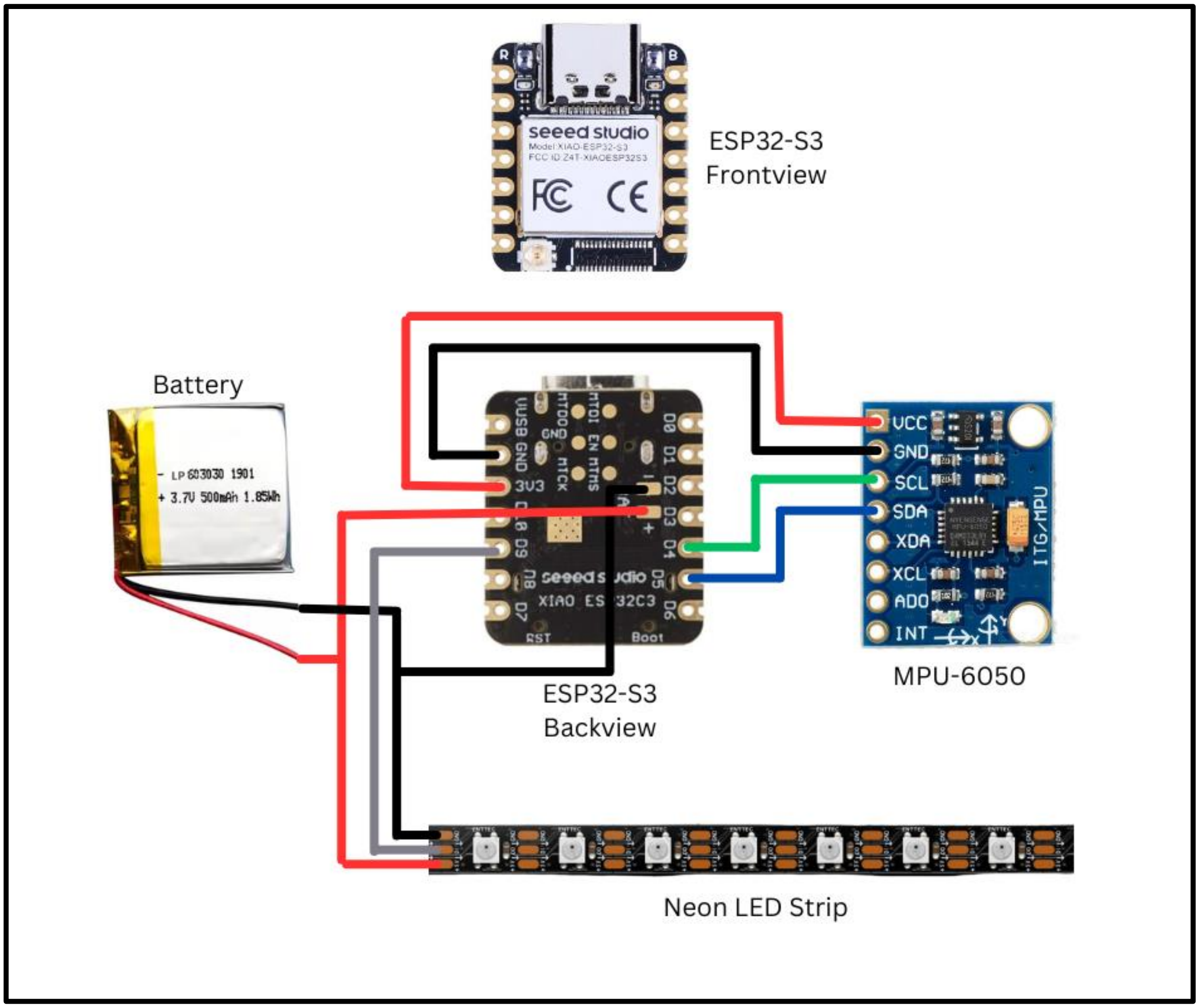


Figure 4: Circuit Diagram

Methodology

Hardware Setup:

- Assembled the hardware components, including the ESP32-S3, MPU-6050 sensor, RGB LED strips, and power supply.
- Established connections between the ESP32-S3 and RGB LEDs to ensure seamless light synchronization with movement.
- Mounted the MPU-6050 sensor onto the shoes to capture real-time motion data.

Data Collection for Motion Recognition:

- Used a professional dancer to generate training data by performing a variety of dance movements.
- Captured real-time accelerometer and gyroscope data from the MPU-6050 during different movements, such as jumps, spins, and steps.
- Collected a diverse dataset to ensure robust training, covering different speeds and movement intensities.

Machine Learning Model Development:

- Utilized Edge Impulse, a machine learning platform, to train a motion recognition model.
- Uploaded the collected motion data to Edge Impulse for preprocessing and feature extraction.
- Trained a convolutional neural network (CNN) model to classify dance movements and trigger appropriate RGB light patterns.
- Evaluated the model’s performance using test data and optimized it for better accuracy, efficiency, and real-time responsiveness.

Model Deployment:

- Exported the trained motion recognition model from Edge Impulse.
- Uploaded the model to the ESP32-S3 using the Edge Impulse SDK.
- Verified the model's functionality on the ESP32-S3 by testing real-time motion recognition with the collected dance movements.

Integration with RGB LED System:

- Programmed the ESP32-S3 to interpret motion outputs from the trained model.
- Mapped specific dance movements to corresponding RGB light patterns (e.g., rapid footwork = flashing lights, spins = color transitions).
- Established a Bluetooth connection between the ESP32-S3 and a web application for wireless customization of lighting effects.

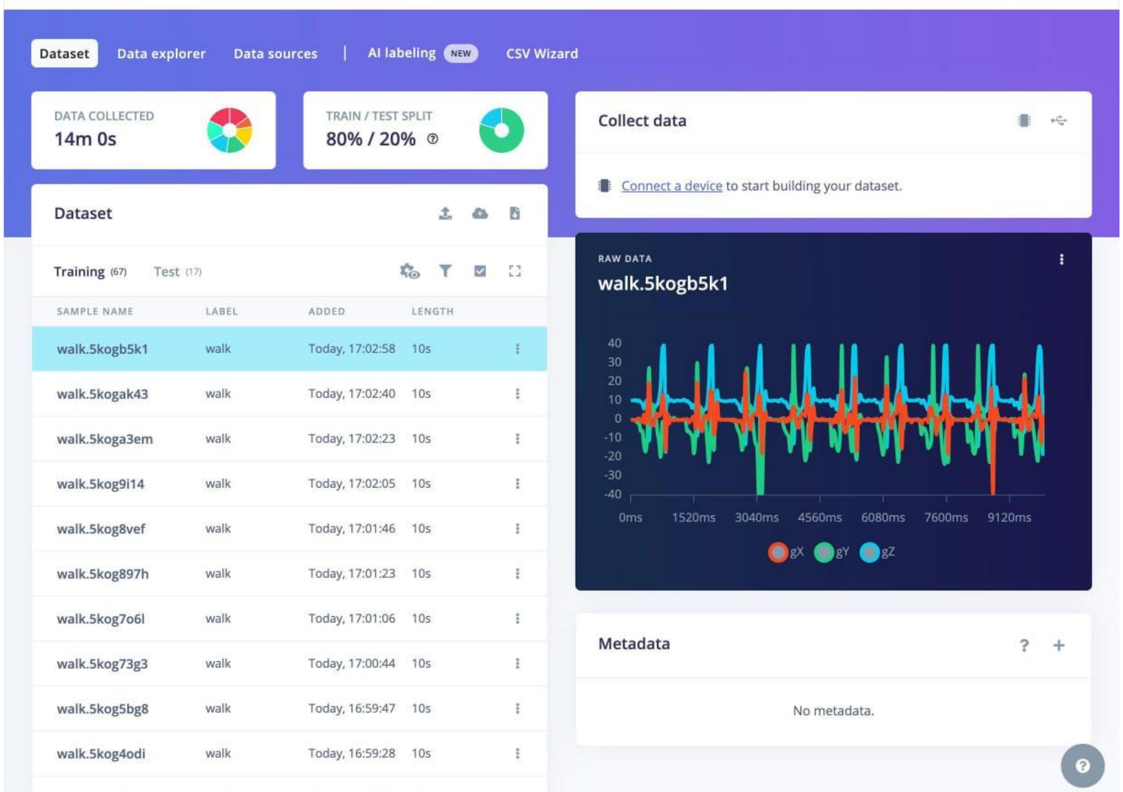


Figure 6: Anomaly Detection Settings and Data Clustering

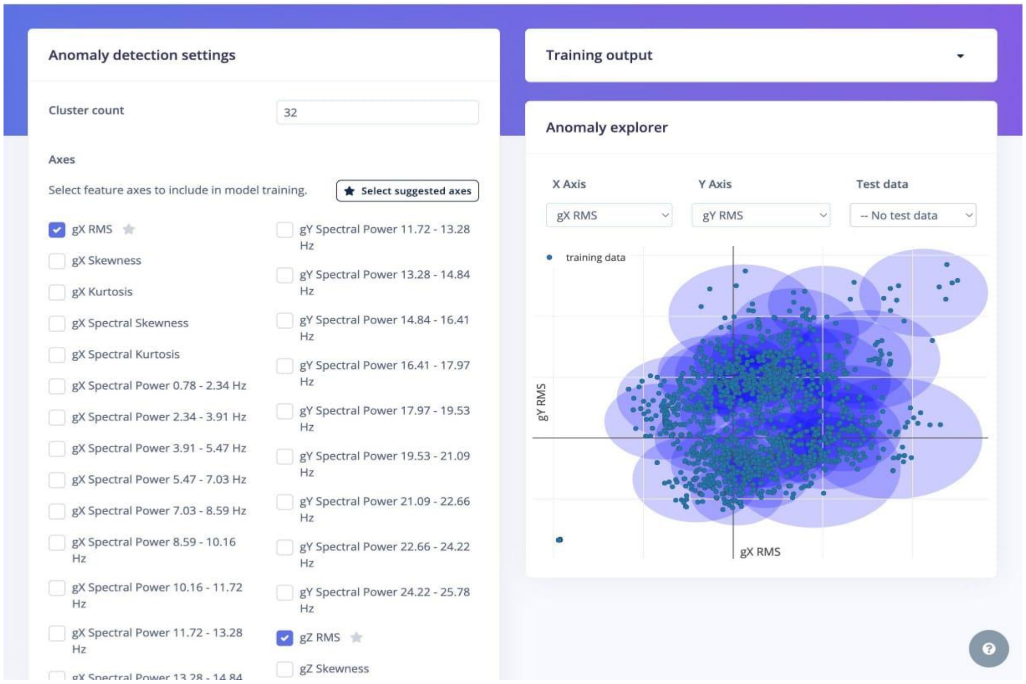
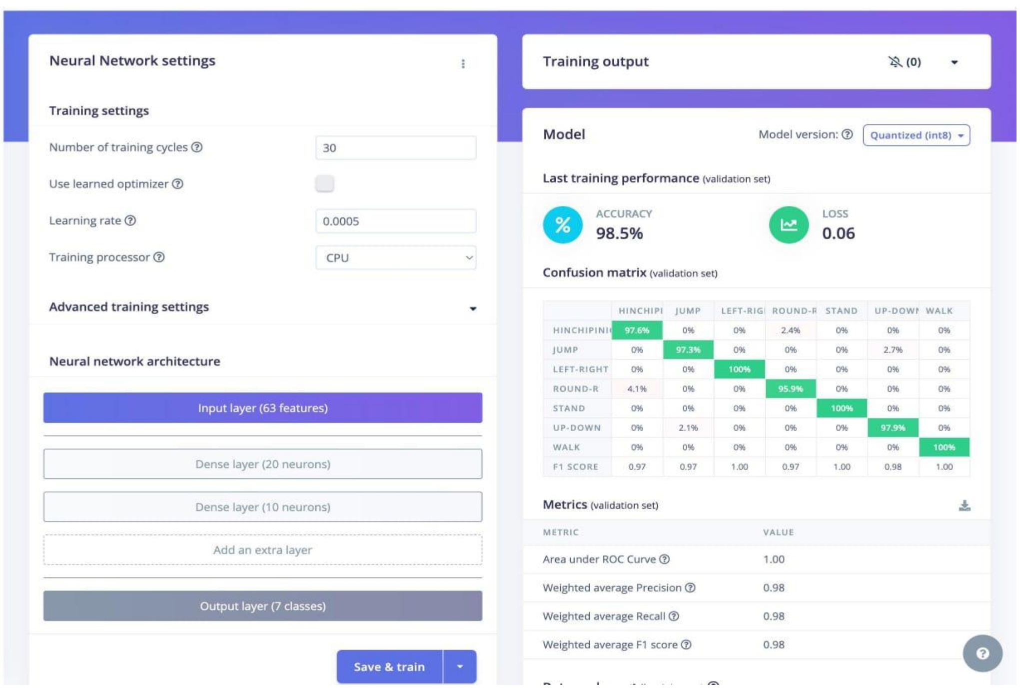


Figure 7: Dataset Collection and Exploration



	HINCHIPI	JUMP	LEFT-RIG	ROUND-R	STAND	UP-DOWN	WALK
HINCHIPINI	97.6%	0%	0%	2.4%	0%	0%	0%
JUMP	0%	97.3%	0%	0%	0%	2.7%	0%
LEFT-RIGHT	0%	0%	100%	0%	0%	0%	0%
ROUND-R	4.1%	0%	0%	95.9%	0%	0%	0%
STAND	0%	0%	0%	0%	100%	0%	0%
UP-DOWN	0%	2.1%	0%	0%	0%	97.9%	0%
WALK	0%	0%	0%	0%	0%	0%	100%
F1 SCORE	0.97	0.97	1.00	0.97	1.00	0.98	1.00

METRIC	VALUE
Area under ROC Curve	1.00
Weighted average Precision	0.98
Weighted average Recall	0.98
Weighted average F1 score	0.98

Figure 8: Neural Network Training Settings and Performance

System Testing and Optimization (Essentials)

System Testing:

- Unit Testing – Verifying individual components like ESP32, sensors, and LEDs.
- Integration Testing – Ensuring smooth interaction between hardware and software.
- Performance Testing – Checking speed, accuracy, and real-time responsiveness.
- Real-World Testing – Validating the system with actual user movements.
- Error Handling – Testing failure scenarios and system recovery.

Optimization:

- Model Compression – Reducing model size for better execution on ESP32.
- Power Optimization – Minimizing energy consumption using sleep modes.
- Latency Reduction – Enhancing response speed between detection and LED activation.
- Wireless Stability – Improving Bluetooth connection reliability.

Results

The Smart Dance Shoes successfully achieved real-time synchronization of RGB lights with dance movements using machine learning. The system accurately classified various dance movements based on motion sensor data and responded with dynamic light patterns.

Key outcomes include:

- Accurate Motion Recognition: The Edge Impulse-trained model effectively classified dance movements with high accuracy, ensuring responsive light effects.
- Seamless Integration: The ESP32-S3 microcontroller and MPU-6050 sensor worked efficiently together, enabling real-time motion detection.
- Dynamic Light Synchronization: The RGB LEDs displayed visually appealing lighting effects that enhanced the performance experience.
- User Experience: Dancers found the system intuitive and engaging, adding an extra layer of creativity to their routines.
- Wireless Customization: The Bluetooth-enabled web application allowed performers to customize lighting effects, increasing flexibility.

Figure 9: Final product

Future Improvements

While the project achieved its primary objectives, several enhancements could improve performance and usability:

1. Advanced Machine Learning Models: Implementing more complex models, such as LSTMs or Transformers, could improve motion classification accuracy.
2. Extended Gesture Recognition: Expanding the dataset to include more dance styles and gestures would make the system more versatile.
3. Improved Hardware Design: Creating a compact, wearable, and wireless module with a built-in power source to enhance comfort and portability.
4. Multi-Shoe Synchronization: Enabling communication between multiple pairs of shoes to synchronize lighting effects for group performances.
5. Music-Driven Lighting: Integrating audio analysis to allow lights to react dynamically to music beats and rhythm.
6. Cloud-Based Learning: Utilizing cloud computing for continuous model training and improvement based on real-world usage data.

Group Members

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Thank You!.