Machine Learning on Embedded Systems to Assess Correct Form During Weight Training

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Mentor: Dr. Chao Wang, School of Electrical, Computer and Energy Engineering

The research question that this project seeks to address is: How can machine learning classify common weight training exercises in real-time through motion data collected on a strategically placed IMU while also being able to judge correct form and posture?

The research aims to be able to be able to create a system to classify weight training exercises in real-time and generate reliable motion data.
This research advances knowledge in machine learning and motion recognition using Inertial Measurement Units (IMUs) by investigating the role of contemporary machine learning algorithms to identify complex recurring patterns in real-time by relying on motion data collected on a microcontroller, IMU and additional peripheral sensors. The research goals strongly align to the **Fulton Research Theme of Health,** as the work in this project can directly affect the long-term muscle and bone health of athletes. Being able to recognize correct posture and movement during workouts is extremely important for proper muscle growth and to prevent chronic injuries. Dr. Wang's knowledge and experience in machine learning, embedded systems and TinyML will help guide the research.

At completion, the resulting system will be handheld, will be able to **classify exercises in real-time, and collect and train on the data** (on the handheld embedded device or externally). A pipeline will be created to make the data collection and training process faster. Future development will include training/classification with multiple handheld nodes for complex exercises.

Abstract
Machine learning has seen a great increase in popularity in the past few years due to its outstanding pattern recognition within complex systems and even replicating those patterns for generation [1]. When it comes to detecting patterns in body movements during exercises, personal trainers can instinctively recognize patterns in a bad form or a bad movement. Good personal trainers can help an individual prevent injury and help them achieve their goals in fitness [2]. They help with a lot more stuff than form corrections like workout routines and diet. However, **it is hard to find personal trainers** either because there aren't as many to train every individual, or their services are expensive. There is a **need for a device that can help athletes train safely** by monitoring their form and keeping them safe. The device cannot be too heavy or big to influence the movement of the athlete or cause them any discomfort while also being sturdy and have a high computing power.

Current literature and state of the art

1) Detection of Human Body Movement Patterns Using IMU and Barometer [3] : SVM algorithm for motion detection with IMU and Barometer data.
2) Deep-Learning-Based Character Recognition from Handwriting Motion Data Captured Using IMU and Force Sensors [4] : Multiple deep learning algorithms tested to classify handwriting motion data using a system of force sensors combined with IMU data.
3) Improving gait classification in horses by using inertial measurement unit (IMU) generated data and machine learning [5] : Gait classification for Horses from motion data (collected using multiple IMUs) using BLSTM segmentation method.
4) Golf Swing Segmentation from a Single IMU Using Machine Learning [6] : Classification of golf swing phases from motion data using CNN and BLSTM segmentation method.
5) A hierarchical hand motions recognition method based on IMU and EMG sensors [7] : Using data from multiple sensor types to recognize motion patterns with SVM segmentation and classical (non-ML) methods.

Research Plan

Research Method: The research method will begin by analyzing the state of the art. Then a data collection method will be devised followed by collecting the required data. The results will be analyzed through implementation of various ML algorithms.

Materials/Resources:

1) Arduino Nicla Sense ME: Advanced sensor board with Bosch Sensors and Bluetooth
2) Arduino Nano 33 BLE Sense Rev 2: Compact Sensor Board with Wi-Fi and Bluetooth
3) Raspberry Pi 5: Small and powerful single board computer with low power consumption
4) ESP32 : Cheap and powerful microcontroller
5) Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout - BNO055 : External IMU
6) ASU Agave Cluster / Google Collab : Resources for training ML Models

Procedure:

1) **Documentation** will be carried out throughout the research.
2) A comparison will be drawn from **reviewing the state of the art** to determine which microcontrollers, IMUs and algorithms have been used for similar problems. **This part of the process has already been started (October 2023) and is in its early stages.**
3) A complete **research plan** will be devised. Data collection methods will be decided and the hardware to support that data collection will be designed.
    a. Microcontrollers, IMU and additional hardware will be finalized.
    b. Some machine learning algorithms will be narrowed down.
    c. We will narrow down the classes we want to detect. Example: Correct Repetition, Bad Repetition, Fatigue, Incomplete Repetition etc.
    d. A simple exercise will be selected (e.g., Bicep Curls). The appropriate device placement for data collection will be decided.
4) A **data collection plan** will be devised in parallel to step 3 and required parts for the hardware will be ordered. We will collaborate with trained SDFC staff and some students to collect motion data. **ASU IRB** authorization will be requested.
5) **Materials** will be ordered, and a rough 15-day arrival time will be expected.
6) **Hardware synthesis**. A system for our data collection method will be designed and fabricated. It will involve microcontrollers, IMUs, and other sensors that are TBD from the hardware synthesis plan. A pipeline for data collection will be created for the next step.
7) **Data will be collected** from multiple users to reduce bias and have a broad range of observations. The data will be pre-processed to suit the algorithm's architecture.
8) We will then **experiment with different Neural Network architectures** to find the best fit for our use case with the highest accuracy. The following process will be followed:
    a. Process Data
    b. Build a Neural Network architecture
    c. Train
    d. Measure accuracy. If good enough, next step. If not, start again from step a.
9) **Summarize findings**, results and methods into a research paper.

Facilities:

SCAI manufacturing lab 3D printers will be used for any 3D printing related tasks. BYENG 387 will be used for soldering related tasks and for signal analysis using oscilloscopes and signal analyzers.

Expected Outcome:

The built system should be able to classify a performed exercise in one or more of the determined classes in real-time.

Timeline:

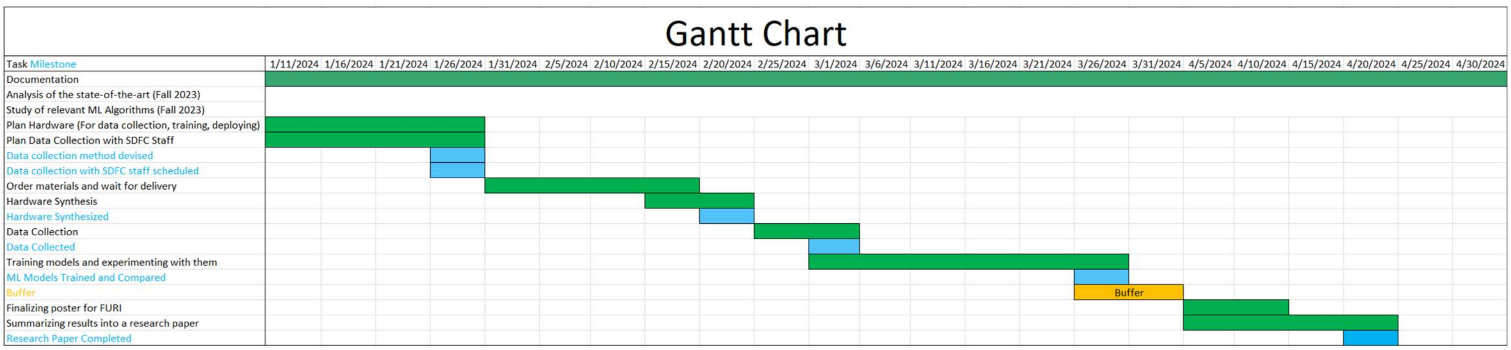
Machine Learning on Embedded Systems to assess correct form during weight training

Milestones

No.	Position	Date	Milestone
1	1	1/30/2024	Data collection method devised
2	2	1/30/2024	Data collection with SDFC staff scheduled
3	3	2/24/2024	Hardware Synthesized
4	4	3/5/2024	Data Collected
5	5	3/25/2024	ML Models trained and compared
6	6	4/25/2024	Research Paper Completed

Tasks

No.	Start Date	End Date	Task	Days
1	1/11/2024	4/30/2024	Documentation	110
2	Fall 2023	Fall 2023	Analysis of the state-of-the-art	NA
3	Fall 2023	1/10/2024	Study of relevant ML Algorithms	NA
4	1/10/2024	1/30/2024	Plan Hardware (For data collection, training, deploying)	20
5	1/10/2024	1/30/2024	Plan Data Collection with SDFC Staff	20
6	1/30/2024	2/14/2024	Order materials and wait for delivery	15
8	2/14/2024	2/24/2024	Hardware Synthesis	10
7	2/24/2024	3/5/2024	Data Collection	10
9	2/29/2024	3/25/2024	Training models and experimenting with them	25
10	3/25/2024	4/4/2024	Buffer	10
11	4/5/2024	4/10/2024	Finalizing poster for FURI	5
12	4/5/2024	4/25/2024	Summarizing results into a research paper	20



References

1) M. Hausknecht, W. -K. Li, M. Mauk and P. Stone, "Machine Learning Capabilities of a Simulated Cerebellum," in IEEE Transactions on Neural Networks and Learning Systems, vol. 28, no. 3, pp. 510-522, March 2017, doi: 10.1109/TNNLS.2015.2512838.
2) Waryasz GR, Daniels AH, Gil JA, Suric V, Eberson CP. Personal Trainer Demographics, Current Practice Trends and Common Trainee Injuries. Orthop Rev (Pavia). 2016 Oct 3;8(3):6600. doi: 10.4081/or.2016.6600. PMID: 27761219; PMCID: PMC5066109.
3) M. Alarfaj, Y. Qian and H. Liu, "Detection of Human Body Movement Patterns Using IMU and Barometer," 2020 International Conference on Communications, Signal Processing, and their Applications (ICCSPA), Sharjah, United Arab Emirates, 2021, pp. 1-6, doi: 10.1109/ICCSPA49915.2021.9385750.
4) Alemayoh TT, Shintani M, Lee JH, Okamoto S. Deep-Learning-Based Character Recognition from Handwriting Motion Data Captured Using IMU and Force Sensors. *Sensors*. 2022; 22(20):7840. https://doi.org/10.3390/s22207840
5) Serra Bragança, F.M., Broomé, S., Rhodin, M. et al. Improving gait classification in horses by using inertial measurement unit (IMU) generated data and machine learning. Sci Rep 10, 17785 (2020). https://doi.org/10.1038/s41598-020-73215-9
6) Kim M, Park S. Golf Swing Segmentation from a Single IMU Using Machine Learning. Sensors. 2020; 20(16):4466. https://doi.org/10.3390/s20164466
7) W. Chang, L. Dai, S. Sheng, J. Too Chuan Tan, C. Zhu and F. Duan, "A hierarchical hand motions recognition method based on IMU and sEMG sensors," *2015 IEEE International Conference on*

robotics and Biomimetics (ROBIO), Zhuhai, China, 2015, pp. 1024-1029, doi: 10.1109/ROBIO.2015.7418906.

Personal statement

My career goal is to be able to design and build smart machines that are perceptive of their surroundings. For the same reason I will be doing my masters in Robotics and Autonomous Systems. This research aims to build a machine that can 'perceive' through IMU's measurements and use that data to intelligently classify it into the required class. This exactly relates to my goal of making smart machines. While working on this, I will also advance the field of machine learning and motion recognition which is always a plus.

Moreover, I go to the gym very often. Many of my friends do too and some of them have suffered from an injury which happened in the gym due to incorrect form. Thankfully, I have never suffered such an injury due to my attention to my form. A personal trainer can prevent such mishaps and help their students work on their posture. However, in my experience, personal trainers can be very expensive for a regular college student or may not be available at the student's schedule. Such a limitation never stopped me from working out safely but may have indirectly led to injuries that my friends have suffered.

I have gained several skills in my time at ASU in Machine Learning and Signal Processing on Embedded Devices. Such skills make me capable of taking on such a project. In the process, I will also make myself a better fit for many career opportunities that involve Machine Learning and Signal Processing.

Summarizing, I want to be able to build a reliable device that can recognize patterns in body movement like that of a personal trainer. Such a goal stems from the need to have a device that is cheap and reliable so that everyone who is working out can access it. I want to be able to help people to prevent injury while making such a goal align to my career interests.

Devesh Nath

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https://github.com/dvsh-n | https://www.linkedin.com/in/deveshnath

EDUCATION

BSE - Arizona State University Aug 2020 – May 2024
Electrical Engineering
- **Cumulative GPA –** 4.00

Masters - Arizona State University Aug 2023 – May 2025
Robotics and Autonomous Systems
- **Relevant Coursework:** Robotic Systems, Computer Controlled Systems, Analog and Digital Circuits

TECHNICAL SKILLS

Programming : Python, C, C++, ROS2, System Verilog, MATLAB and Simulink
Machine Learning: Deep Learning, CNN, RNN, NLP, ML to FPGA, OpenCV
Embedded Microcontrollers/SBC: Arduino Series, STM32, ESP32, Raspberry Pi, Nvidia Jetson
Others: Linux Systems, Github, FPGA, RT Signal Processing, Control Systems, FreeRTOS, CAN, I2S, I2C, UART
Design Software: KiCAD, EasyEDA, Cadence, SolidWorks, Fusion 360

EXPERIENCE

Plant Engineering Intern – Rehrig Pacific Company May 2023 – Aug 2023
- Designed and built an automated test unit for end-of-arm tools with application of Programmable Logic Controllers, Human Machine Interface, Industrial Sensors and Pneumatic Control Valves.
- Saved the company over ~ $30k per annum on Arm Tool related downtime costs.
- Developed several collaborative robot projects and integrated them with vision systems for automation related cost savings.

Fulton Undergraduate Research Initiative (FURI) – Undergraduate Researcher Jan 2022 – May 2022
- Engineered a mobile system for assisting the visually impaired in navigation and text comprehension.
- The research combined the implementation of text to speech and text recognition algorithms, and a LiDAR distance sensor paired with a haptic motor to provide feedback to the user. All deployed on a Raspberry Pi.
- Achieved success by helping an impaired person navigate corridors and ‘hear’ banners.

PROJECTS

ROS2 Based Room Automation System – Motion Sensors, Web GUI, ESP32, Power Savings
Real Time Filtering/Processing of Sound and Images – STM32 implementation
WLED Controller – Custom PCB Design using ESP32 for a LED light system
Microprocessor design – Used System Verilog and DE-10 Lite FPGA
Authentication Key with Fingerprint – ESP32, fingerprint sensor, FreeRTOS, UART
Macro Keypad – ESP32, Custom Keys, Keyboard Emulation, PCB Design, Productivity

LEADERSHIP

President – ASU Sun Devil Robotics Club July 2023 – Present
- Leading 5 sub-teams and designing rover subsystems alongside 75 students to compete in the University Rover Challenge in Spring 2025
- Started the club from barebones: hired an amazing team of students, acquired funding and sustained momentum. Achieved significant progress in a short time by promoting teamwork and collaboration.

Team Lead – Capstone: Drag Racer RC Car with Autonomous Navigation
- Integrating rotating LiDAR, CAN Bus, Computer Vision, ROS2, ESP32, Raspberry Pi, ESCs, Brushless Motors , etc. in a smart RC Car to complete a 20m drag race in record time.

RESEARCH

Aerial Arm Manipulator – ASU RISE Lab August 2023 – Present
- Working with a PhD student on a drone with a 3-Axis Manipulator.
- Implementing Simulink control code on a Raspberry Pi
- Developing system wide ROS2 communication

Arizona State University
Unofficial Transcript

Name: **Devesh Nath**
Student ID: **1219667943**

Print Date: 10/12/2023

Beginning of Undergraduate Record

2020 Fall

Course	Description	Attempted	Earned	Grade	Points
ASU 101-MEE	**The ASU Experience**	1.000	1.000	A	4.000
CHM 114	**General Chemistry for Engrs**	4.000	4.000	A+	17.332
ENG 107	**First-Year Composition**	3.000	3.000	B	9.000
FSE 100	**Introduction to Engineering**	2.000	2.000	A+	8.666
FSE 150	**Grand Challenges for Engrg**	3.000	3.000	A	12.000
MAT 265	**Calculus for Engineers I**	3.000	3.000	A+	12.999

			Attempted	Earned	Points
Term GPA:	4.00	Term Totals	16.000	16.000	63.997
Cum GPA:	4.00	Cum Totals	16.000	16.000	63.997

Academic Standing: Good Standing
Term Honor: Dean's List

2021 Spring

Course	Description	Attempted	Earned	Grade	Points
ECN 212	**Microeconomic Principles**	3.000	3.000	B+	9.999
ENG 108	**First-Year Composition**	3.000	3.000	B	9.000
FSE 104	**EPICS Gold I**	1.000	1.000	B	3.000
MAE 215	**Intro to Programming in MATLAB**	1.000	1.000	B-	2.667
MAT 242	**Elementary Linear Algebra**	2.000	2.000	A	8.000
MAT 266	**Calculus for Engineers II**	3.000	3.000	A+	12.999
PHY 121	**Univ Physics I: Mechanics**	3.000	3.000	A+	12.999
PHY 122	**University Physics Lab I**	1.000	1.000	A-	3.667

			Attempted	Earned	Points
Term GPA:	3.67	Term Totals	17.000	17.000	62.331
Cum GPA:	3.83	Cum Totals	33.000	33.000	126.328

Academic Standing: Good Standing
Term Honor: Dean's List

2021 Fall

Course	Description	Attempted	Earned	Grade	Points
EEE 202	**Circuits I**	4.000	4.000	A+	17.332
FSE 201	**Engineering Undergraduate TA**	1.000	1.000	Y	0.000
MAT 267	**Calculus for Engineers III**	3.000	3.000	A	12.000
MAT 275	**Modern Differential Equations**	3.000	3.000	A	12.000
PHY 131	**Univ Physics II: Elctrc/Magnet**	3.000	3.000	A+	12.999
PHY 132	**University Physics Lab II**	1.000	1.000	A-	3.667

			Attempted	Earned	Points
Term GPA:	4.00	Term Totals	15.000	15.000	57.998
Cum GPA:	3.92	Cum Totals	48.000	48.000	184.326

Academic Standing: Good Standing
Term Honor: Dean's List

2022 Spring

Course	Description	Attempted	Earned	Grade	Points
CSE 110	**Principles of Programming**	3.000	3.000	A	12.000
EEE 120	**Digital Design Fundamentals**	3.000	3.000	A	12.000
EEE 241	**Fundamentals Electromagnetics**	3.000	3.000	A+	12.999
HST 100	**Global History to 1500**	3.000	0.000	W	0.000
PHY 241	**University Physics III**	3.000	3.000	A+	12.999
REL 320	**American Religious Traditions**	3.000	3.000	A+	12.999

			Attempted	Earned	Points
Term GPA:	4.00	Term Totals	15.000	15.000	62.997
Cum GPA:	3.99	Cum Totals	63.000	63.000	247.323

Academic Standing: Good Standing
Term Honor: Dean's List

2022 Fall

Course	Description	Attempted	Earned	Grade	Points
CSE 230	**Computer Org/Assemb Lang Prog**	3.000	3.000	A+	12.999
EEE 203	**Signals and Systems I**	3.000	3.000	B+	9.999
EEE 333	**Hardwre Design Lang/Prog Logic**	4.000	4.000	A+	17.332
EEE 334	**Circuits II**	4.000	4.000	A	16.000
EEE 350	**Random Signal Analysis**	3.000	3.000	A	12.000

			Attempted	Earned	Points
Term GPA:	4.00	Term Totals	17.000	17.000	68.330
Cum GPA:	4.00	Cum Totals	80.000	80.000	315.653

Academic Standing: Good Standing
Term Honor: Dean's List

2023 Spring

Course	Description	Attempted	Earned	Grade	Points
DSC 101	**Design Awareness**	3.000	3.000	A+	12.999
EEE 304	**Signals and Systems II**	4.000	4.000	A+	17.332
EEE 341	**Engineering Electromagnetics**	4.000	4.000	A+	17.332
EEE 404	**Real-Time DSP Systems**	4.000	4.000	A+	17.332

			Attempted	Earned	Points
Term GPA:	4.00	Term Totals	15.000	15.000	64.995
Cum GPA:	4.00	Cum Totals	95.000	95.000	380.648

Arizona State University
Unofficial Transcript

Name: **Devesh Nath**
Student ID: **1219667943**

Academic Standing: Good Standing
Term Honor: Dean's List

2023 Summer

Course	Description		Attempted	Earned	Grade	Points
EEE 484	**Internship**		1.000	1.000	Y	0.000
			Attempted	**Earned**		**Points**
Term GPA:	0.00	Term Totals	1.000	1.000		0.000
Cum GPA:	4.00	Cum Totals	96.000	96.000		380.648

2023 Fall

Course	Description		Attempted	Earned	Grade	Points
EEE 335	**Analog and Digital Circuits**		4.000	0.000	NR	0.000
EEE 405	**Machine Learn w/Deploymnt FPGA**		3.000	0.000	NR	0.000
EEE 488	**Senior Design Laboratory I**		3.000	0.000	NR	0.000
EEE 591	**Seminar**		4.000	0.000	NR	0.000
Course Topic:	Feedback Systems					
EGR 501	**Applied Linear Algebra for EGR**		3.000	0.000	NR	0.000
			Attempted	**Earned**		**Points**
Term GPA:	0.00	Term Totals	0.000	0.000		0.000
Cum GPA:	4.00	Cum Totals	96.000	96.000		380.648

END OF TRANSCRIPT