9-DOF Inertial Measurement Unit Data for Swimming Stroke Classification and Hand Position Estimation

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Background

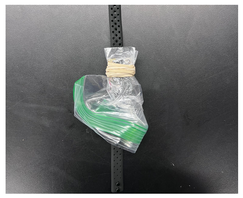
Many high-level athletes benefit from using wearable technology to analyze training details, however there is a noticeable lack of such technology in the world of competitive swimming, due to the complexity of body movements and the challenges induced by the aquatic environment. The goal of this project was to investigate the effectiveness of utilizing wearable technology, specifically wrist mounted inertial measurement units, to gather useful data so that analysis could be conducted on different aspects of a swimmer's stroke.

This project built upon stroke classification work done by Connor Morikawa, and hand displacement estimation based on the work of Baker & Graham (2025).

Additionally, many existing technologies perform data analysis in the cloud, posing privacy concerns around the ownership and usage of athletes' data without their explicit consent. Additionally, a goal of this project was also to assess the feasibility of having data analysis occur on the wearable device itself, eliminating the privacy concerns of uploading the data.

Methods

To collect IMU data for processing, I used a Seeed Studio nRF82540 Sense board, coupled with BNO085 9-DOF IMU. Data was logged at an interval of 20 Hz using custom FreeRTOS-based software, and was written to the onboard QSPI flash memory using an SPI connection and the Adafruit SPIFlash library, with custom persistence and wear-leveling features to ensure data was stored safely. The chip used can be seen on the right, as well as the waterproofed unit used for testing.



After successful data collection, the data was ran through two pipelines, overviews of which are shown below. One of the pipelines classified the data into stroke categories, while the other attempted to calculate approximate hand position.

Stroke Classification Pipeline

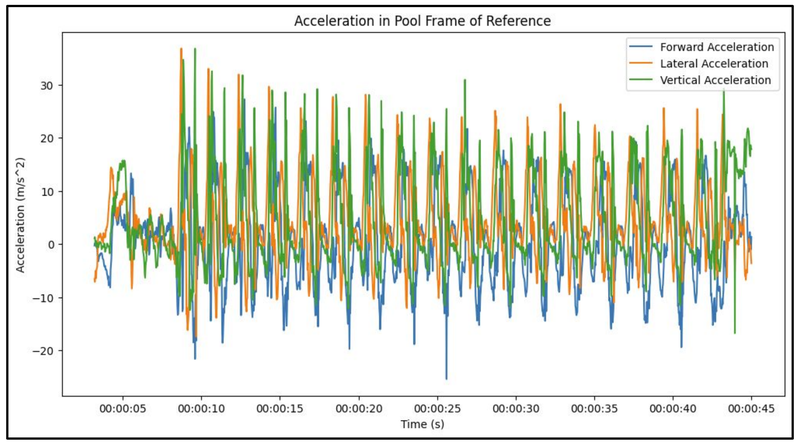
Data Import & Cleaning → LSTM Model Training → LSTM Model Performance Evaluation

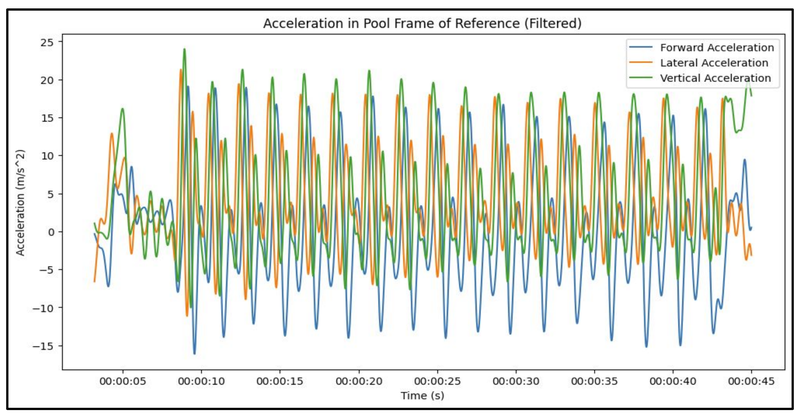
Wrist Position Pipeline

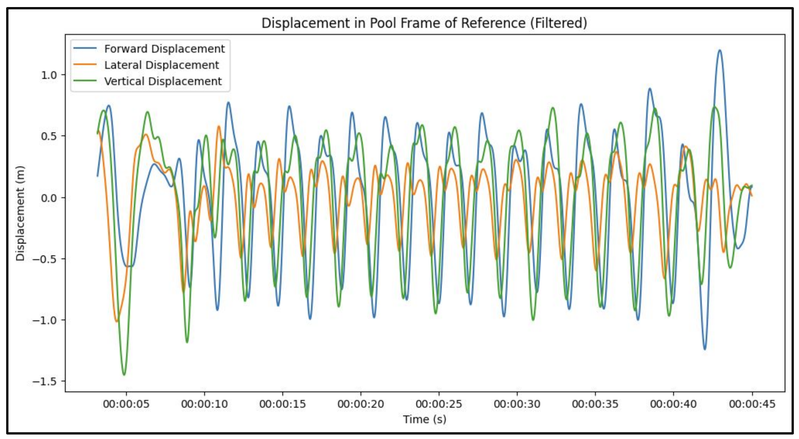
Rotate Acceleration to Pool Frame → Low Pass Filter → Numerical Integration & High Pass Filter → Numerical Integration & High Pass Filter

Position Estimation Results

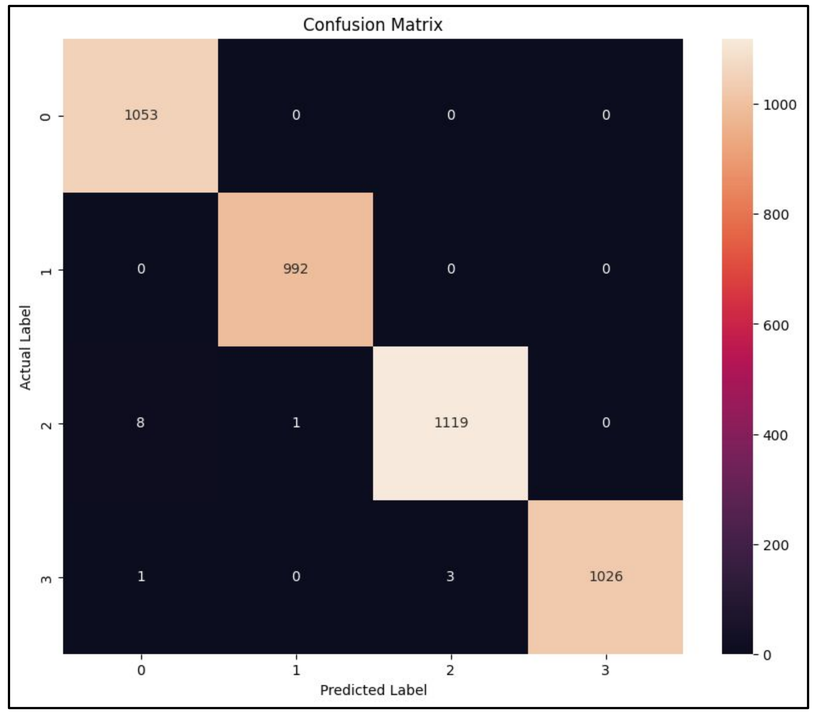
The following graphs show a few of the steps through the wrist position pipeline describes in the methods section. The first graph shows the acceleration data recorded from the nRF82540 Chip, rotated to the pool frame of reference. The second graph shows the acceleration data once the low pass filter has been applied, and the final graph shows the displacement after two numerical integration steps and high pass filters.







Classification Results



0 - Freestyle 1 - Backstroke 2 - Breaststroke 3 - Butterfly

Above is a confusion matrix showing the high level of accuracy the model was able to achieve on the test dataset. Nearly all stroke categories achieved a high level of accuracy, showing that LSTM models excel when classifying time series movement data such as swimming movement.

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- Thank you to Connor Morikawa for his work done on stroke classification using an LSTM model, which served as the basis for the classification model that I trained and evaluated.

- Baker, N., & Graham, K. (2025). *IMU Assessment on eo SwimBETTER – Pilot*. Eolab. (PDF)

All code & data can be found on GitHub: