Stroke Classification for Integrated AI Coaching Business Report

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Executive Summary

This report explores the effectiveness of inertial measurement units in classifying the different stroke types and phases of swimming which can then be used by AI to provide personalized feedback to users. Early adoption of this technology will provide a competitive advantage in the AI space and further acquire customers in the growing fitness and health industry.

Introduction

Swimming as a competitive sport and recreational activity has been exploding in popularity worldwide with notorious events such as record-breaking attendance and funding behind the US Olympic Trials (USA Swimming, 2024), collegiate dual meets, and the Olympics gathered head-turns from the public. When it comes to exercising, swimming is hands down the best full-body workout (BBC, 2023) and doubles as a necessary life skill. Fitness and health trackers and smartwatches available in the market are no strangers to the swimming market, as many have differentiated their products by catering toward waterproof applications and even provide built-in apps that specialize in tracking swimming workouts and stats. Despite a surprisingly saturated market, various issues plague even the best tools and prevent accurate measurements. While general issues such as distance swam accuracy, waterproof effectiveness, or submerged heart rate monitoring have been consistently improved, very few have invested in technology that differentiates the stroke one is swimming or if someone was doing drills or kicking with/without a board.

Improving stroke classification capabilities through an inertial measurement unit (IMU) would improve the accuracy of swimmers using fitness watches and apps and enhance the analytics provided to inform their health goals better. In addition, data from the IMU would be efficient and effective in giving immediate feedback through AI for swimming performance improvement. Thus, it would provide another incentive for swimmers to use these products, as they would then be able to track their improvement after making adjustments and allow them to train efficiently.

This report will explore how various swim-tech or fitness-tracking companies can utilize IMUs to accurately classify swimming workouts and translate the microdata into analysis that beginners and professional swimmers alike can use through AI.

Context

The proposed inertial measurement unit, or IMU, uses a combination of accelerometers, gyroscopes, and magnetometers to track one's angular velocity, acceleration, and orientation/direction as movement data. Data from the IMU would allow performance to be quantified and translated as an IMU parameter that can then be correlated to a goal metric. Currently, the most common setup professionals use is a speedometer and setup cameras (CAM) to capture the velocity and displacement of a swimmer. A CAM system was used as the validation system for the IMU data but in some instances, the CAM system was used alongside the IMU to allow for a comprehensive analysis (Hamidi Rad et al., 2021, b). One advantage IMU has over CAM is that it is less time-consuming to analyze numbers reported from the IMU than a video. Additionally, capturing the entire length of a pool would require maintaining and syncing multiple expensive cameras.

Four major swim strokes are classified based on the micro variables from the IMU: butterfly, backstroke, breaststroke, and freestyle. A swimmer swimming different strokes would not be burning the same calories if they were doing freestyle compared to swimming butterfly, nor would their heart rate be equal for different strokes, which would impact the accuracy of health tracking devices, hence the need to differentiate. Additionally, various swimming phases such as open turns, flip turns, and dives would also need to be differentiated as those are separate skills that swimmers could improve upon. This would serve as additional personalization for users and allow for more accurate feedback depending on the stroke swam.

During the swim, various phases must be accounted for to thoroughly examine the swimmers' technique and efficiency at each phase. The push phase proceeds when there is forward movement in the body and ends when the feet leave the wall. This phase is similar to all the strokes except that it happens in the supine position for the backstroke. Following the push, the glide phase occurs as long as there is no underwater upper or lower limb movement. When a dolphin kick action happens, this phase ends and proceeds to the stroke preparation phase until the first stroke cycle. The swimmer will be in the swim phase for the majority of the swim until the swimmer approaches the wall for a flip turn where the head rolls downward or when the swimmer touches the wall for an open turn. Finally, the turn phase ends on the next push phase (Hamidi Rad et al., 2021, a).

Nowadays, all competitive smartwatches are equipped with state-of-the-art technology that checks as many of the needs of users looking to integrate technology into their swims. This benefits experienced swimmers and coaches as performance monitoring at the highest level becomes essential to gain a competitive advantage, and normalizing the integration of IMUs would alleviate the technological disparity between athletes (Hamidi Rad et al., 2021, c). Numerous research and studies have explored the effectiveness and reliability of IMU for data collection in allowing for micro-analysis progress measurement in elite swimmers. More casual audiences may not have access to a private coach who may give corrections that align with their swimming goals, so being able to receive feedback generated by an AI supported by their personal IMU swimming data provides an alternative way to train.

Business Potential

Available and qualified swim coaches are difficult to come by, not to mention the exorbitant prices that come with receiving one-on-one lessons. For the majority of swimmers, improvement stems from the consistent repetition of laps, where they will build strength and become comfortable in the water. While resources are readily available online to reference for improving swimming, they are only personalized if there is a price tag attached, and it is also difficult for swimmers to gauge whether they have implemented the technique and changes adequately mentioned in the guide without a third-party expert. Precise stroke analytics based on the stroke of the swimmer allows for segmented analysis that would better reliably inform the swimmer. For example, it would be more valuable to compare backstroke times to backstroke times from previous weeks and not compare holistically, as other strokes have different time standards.

By improving the swimming tracking and analysis capabilities of current smartwatches, swimmers who have yet to be convinced of tracking their workouts will now have the opportunity to receive actionable feedback on their swims, which could influence their decision to purchase a device. Furthermore, additional premium features such as pro-swimming technique recommendations could be advertised to casual swimmers transitioning to avid swimmers and serve as an extra source of revenue for companies. Additionally, advanced features would open opportunities for collaborations with elite-level swimmers who would be sponsored to bring awareness of the company's product in exchange for detailed IMU data analysis, which could give them a competitive advantage internationally.

According to market.us, 24.31 million users worldwide have smartwatches as an essential part of their daily life. The global smartwatch market is expected to grow at a compound annual growth rate of 13.5% from 2024 to 2033, growing to 138.7 billion from its current worth of 39.1 billion in 2023. Tied with the fact that swimming as a sport has been quickly gaining traction, as seen from record attendance numbers from the US Olympic Trials and collegiate dual meets, the wearable market, driven by technological advancements and increased health awareness, is posed to introduce AI integration backed by IMU microanalysis to the general public. (market trend analysis?)

Classification Results

RandomForest classifier with RandomizedSearchCV and hyperparameter tuning that selected the best model based on cross validation achieved 0.9310 test accuracy compared to the deep learning model of a hybrid CNN-LSTM model, which reported a test accuracy of 0.8448. After evaluating all the models using AUC-ROC, the logistic regression model had the highest AUC at 0.979 compared to RandomForest 0.978 and CNN-LSTM 0.962. For binary classification tasks (e.g. is it freestyle or not), Random Forest with a higher accuracy might be better but if the task requires probability estimates, then logistic regression might be better as it has the highest AUC. Evaluating on AOC is preferable when evaluating classification problems as it is more robust to class imbalance compared to just evaluating on accuracy. However, the difference between logistic regression and random forest AUC is small coming in at 0.1% so both models perform extremely well but the random forest model would be the best performing model overall when considering precision, recall, f1-score, accuracy, and confusion matrix as well as AUC.

Both models performed exceptionally well in recognizing the majority freestyle class and the dive class, which aligns with our expectations because there was the most data available for freestyle. In contrast, other classes that ran into sparsity and dives from a block are not impeded by water resistance, so fundamentally, the results reported from the IMU should significantly vary. Overfitting was prevalent during the training test for all models due to limited data available for each class and class imbalance. An oversampling technique was attempted using the Synthetic Minority Oversampling Technique (SMOTE) to address class imbalance, but this led to models further overfitting the training data. LSTM was also attempted as the temporal model but had poorer performance than the hybrid model. Deep learning models could have performed worse due to a lack of an extensive database despite the temporally presented data.

Recommendations

It is recommended that companies interested in the capabilities of IMU data and AI adapted for swimming feedback should do the following:

1. Invest in data expansion to develop the AI system to give accurate and personable feedback to all user types. The current dataset is limited in model training capabilities, so gathering IMU data from swimmers of all ages and skill levels would enhance the recommendations provided by the AI.
2. Build partnerships and sponsorships with well-established athletes, clubs, and brands to build credibility and spread awareness of the product. Bringing awareness to the product would drive up interest and funding and also provide us with additional data to improve our models.
3. Provide affordable features of swimming AI feedback for users to cater to the general population that may not have access to coaching.

Conclusion

Integrating IMU-based stroke classification into health-tracking devices for AI-driven performance improvement presents a business opportunity catering to the broad market appeal of the growing interest in swimming. Early adoption of AI technology for smartwatches and fitness trackers will allow companies to tap into an untapped market and drive user acquisition and retention for their products.

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Appendix

Dataset: https://www.kaggle.com/datasets/ruslanbredun/swimming-styles-imu-data