SwiMe: A Single-Camera Markerless System for Swimming Biomechanics Analysis

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Summary

This study presents and evaluates a single-camera markerless system for the analysis of swimming biomechanics. A computer vision model based on deep learning was used for system development. We customized models for sagittal and transverse views of swimmers, and the models achieved an average precision (AP) score of 92.5% in detecting joint positions. Next, algorithms using these outputs automatically extracted key biomechanical parameters, including stroke rate, kick rate, projected joint angles, and stroke phase timings. The results of the system were compared to manual annotations. The comparison showed strong agreement, with a mean absolute percentage error (MAPE) of 0.33% for stroke rate and 0.26% for kick rate and a root mean square error (RMSE) of 4.1–13.0° for projected joint angles. The results indicate that our system can enable automated analysis of swimming techniques without requiring manual annotations or complex motion capture equipment, thus potentially allowing for larger-scale swimming biomechanical studies.

Introduction

Current methods of swimming analysis often rely on time-intensive manual video analysis or complex motion capture systems, which limits the scale of underwater biomechanical studies [1]. Human pose estimation (HPE) is a computer vision method based on deep learning that enables the localization of joint positions. This method shows promise in biomechanical analysis across various sports [2], but current models of HPE do not work on underwater videos of swimmers [3]. Thus, this study developed and evaluated an automated system for extracting key biomechanical parameters from single-camera swimming videos.

Methods

We developed two customized HPE models for sagittal (side) and transverse (front) views of swimmers by fine-tuning the YOLO-V8 Pose model by Ultralytics followed by customized algorithms that use the HPE outputs to automatically extract key biomechanical parameters. The system results were evaluated with a test dataset containing 24 videos (12 per view) of different swimmers performing the front crawl. Videos were captured at 60 fps using stationary cameras. The system automatically processed the videos to extract joint positions, projected angles, stroke phases [4], and key performance parameters, including stroke rate, kick rate, and elbow angles at push. The system outputs were compared with manual annotations from an experienced swimming coach.

Results and Discussion

The customized HPE models achieved average precision scores of 93.4% (sagittal) and 91.6% (transverse), thus significantly outperforming the standard (out-of-the-box) HPE models(<1%).

Projected joint angle accuracy showed RMSE values ranging from 4.1° (knee) to 13.03° (ankle) for the sagittal view and 6.73° (shoulder) to 7.19° (elbow) for the transverse view. Phase detection accuracy for push start, entry, and recovery events was 1.54, 3.35, and 1.5 frames (RMSE), respectively. Key performance parameters showed strong agreement with manual annotations, with MAPE values of 0.33% and 0.26% for stroke rate and kick rate, respectively, and an RMSE of 4.84° for elbow angle at push start.

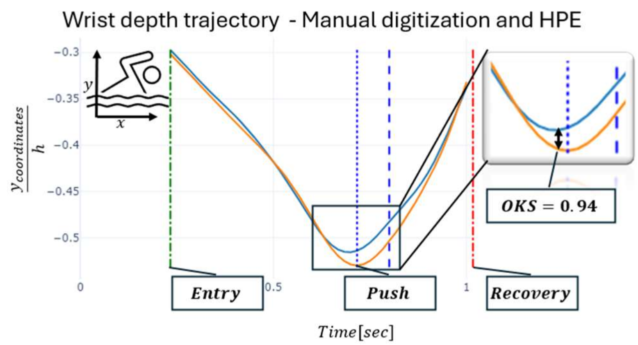

Figure 1: Example for comparison of wrist depth (vertical) trajectory in a single participant side view video, as obtained by manual joints digitization (blue) and HPE (orange). Events (**entry**, **push**, and **recovery**) were obtained by manual event annotations (dots) and by the system (lines).

Conclusions

The evaluated system demonstrated sufficient accuracy for automated swimming biomechanical analysis across multiple parameters. The results suggest that HPE-based analysis can provide reliable quantitative data for swimming research without requiring specialized equipment. This approach could enable larger-scale studies and more accessible technical analysis in swimming biomechanics.

Acknowledgments

This study was partially supported by the Israel Innovation Authority, the Sylvan Adams fund, and the Helmsley Charitable Trust through the Agricultural, Biological and Cognitive Robotics Initiative of Ben-Gurion University of the Negev.

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