Adaptive smartphone-based sensor fusion for estimating competitive rowing kinematic metrics

Bryn Cloud[1], Britt Tarien[1], Ada Liu[1], Thomas Shedd[1], Xinfan Lin[1], Mont Hubbard[1],
R. Paul Crawford[2], Seth Weil[2], **Jason K. Moore**[1]
[1]Mechanical and Aerospace Engineering, University of California, Davis, California, USA
[2]Hegemony Technologies LLC, Davis, California, USA
Email: jkm@ucdavis.edu

Summary

Competitive rowing highly values boat position and velocity data for real-time feedback during training, racing and post-training analysis. The ubiquity of smartphones with embedded position (GPS) and motion (accelerometer) sensors motivates their possible use in these tasks. In this work, we present the use of two real-time digital filters to achieve highly accurate yet reasonably priced measurements of boat speed and distance traveled per stroke. Both filters combine acceleration and location data to estimate boat distance and speed; the first using a complementary frequency response-based filter technique, the second with a Kalman filter formalism that includes adaptive, real-time estimates of effective accelerometer bias.

Methods

Experiments were performed two days apart to validate the effectiveness of the proposed sensor fusion methods using a different rower-boat combination on each day: an experienced club-level rower sculling a 2 person boat alone and an elite rower sculling a single person boat. In each experiment, the rower performed a series of trials over a range of assigned stroke rates (target= 16, 20, 22, 24, 26, 28, max) in opposing directions (NW and SE) on the same 300 m course.

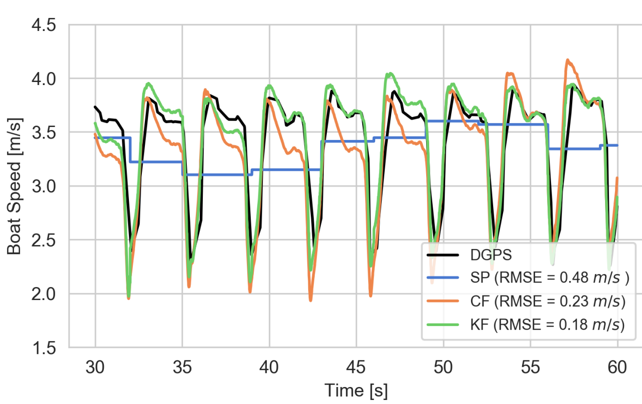

Figure 1: Example boat speed estimates. The figure indicates the speed as a function of time for the last 30 s of the elite 16NW trial as estimated by the smartphone SP, complementary filter CF, and Kalman filter KF. The reported RMSE values are relative to the DGPS computed speed shown in black.

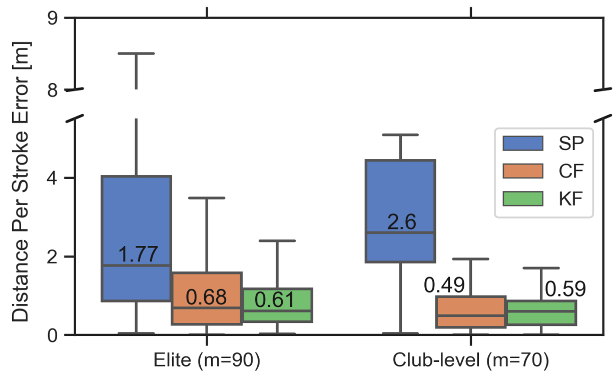

Figure 2: Summary of the distance per stroke error for the last 10 strokes of each trial. Comparison of the distance per stroke error relative to the DGPS-derived value for all trials for the elite and club-level rowers, respectively. The numbers indicate the median values.

Results

The estimates of distance and speed from both filters were validated and compared with accurate reference data from a 10 Hz differential GPS (DGPS) system with better than 1 cm precision. (Figure 1) shows an example of the two filter boat speed estimates for a portion of a single trial. (Figure 2) shows the overall distance per stroke estimation error improvements relative to the smartphone estimate. Compared with single channel (smartphone GPS only) measures of distance and speed, the complementary filter improved the accuracy and precision of boat speed, boat distance traveled, and distance per stroke by 44%, 42%, and 73%, respectively, while the Kalman filter improved the accuracy and precision of boat speed and distance per stroke by 51% and 72%, respectively. Both filters demonstrate promise as general purpose methods to substantially improve estimates of important rowing performance metrics.

Conclusion

We have presented two methods to estimate the distance, speed, and distance per stroke along a rowing boat's path in real time that provide improved accuracy and precision results from the relatively low accuracy sensors in a single smartphone attached to the boat. This work demonstrates the capability that carefully crafted, activity-specific sensor fusion algorithms can have even with low accuracy sensors.