

SMARTPHONE-BASED SENSOR FUSION FOR ESTIMATING ROWING KINEMATIC METRICS

Key Requirements

We desire highly accurate estimates of the distance the boat travels along its path during each individual stroke using readily available and easy to use consumer products, i.e., smartphones. High accuracy allows for inter-rower, -race, and -day repeatable comparisons in both distance traveled and boat speed. Our ultimate goal is to:

- Improve distance per stroke estimates to approach 1cm of accuracy.
- Use estimation techniques in real-time for easy to use training feedback to rowers and coaches.

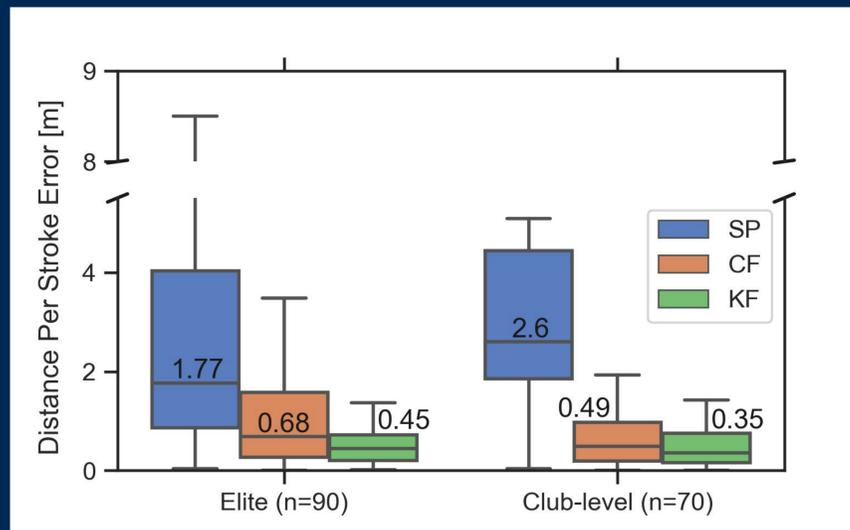
Design Selected

Two methods are presented for fusing the smartphone position and motion data to generate more accurate estimates of the rowing metrics.

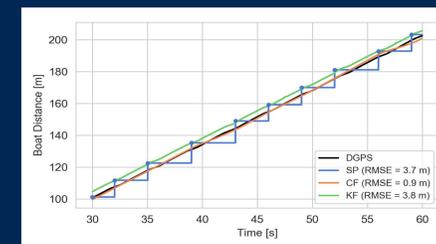
- Complementary Filter (CF): Low frequency information from the GPS sensor is combined with the high frequency accelerometer to retain information about an entire stroke.
- Kalman Filter (KF): A real-time Bayesian statistics based algorithm fuses data collected from different sensors with a predictive dynamic physical model to estimate the time-varying variables. In our case, the body-fixed longitudinal acceleration is used as an input to a kinematic model to predict the displacement and speed of the boat along its path.

Project Description

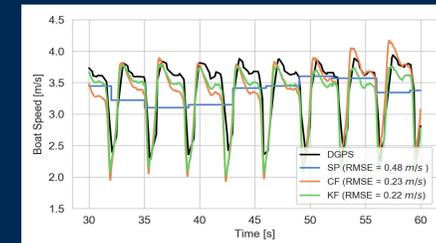
Competitive rowing highly values boat position and velocity data for real-time feedback during training, racing and post-training analysis. The ubiquity of smartphones (SP) with embedded position (GPS) and motion (accelerometer) sensors motivates their possible use. We investigate the use of two real-time digital filters to combine acceleration and location data. The first uses a complementary filter (CF) technique, the second with a Kalman filter (KF) formalism that includes adaptive, real-time estimates of effective accelerometer bias. The estimates of distance and speed from both filters were validated and compared with accurate reference data from a 10Hz differential GPS (DGPS) system with better than 1cm precision.



Summary of distance per stroke error for last ten strokes of each trial



Example trial total boat distance estimates



Example trial total speed estimates

Implementation and Testing

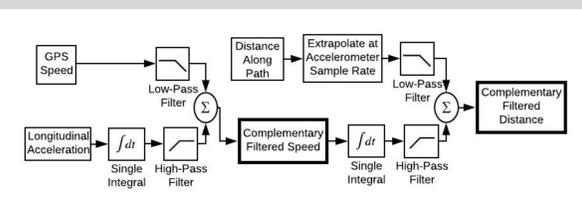
A smartphone was rigidly attached to a boat and used to collect GPS data at an average sampling rate of 0.3Hz and accelerometer data at approximately 100Hz. A high-precision differential GPS (DGPS) was also attached to the boat to measure boat position at 10Hz to serve as validation data. Experiments 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 sculling a 2 person boat alone, and an elite rower sculling a single person boat. Each 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.



Sensor location during elite trials



Satellite image showing a typical trial path



Block diagram depicting the complementary filter algorithm

PROJECT TEAM

Student Researchers:

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Sponsor:

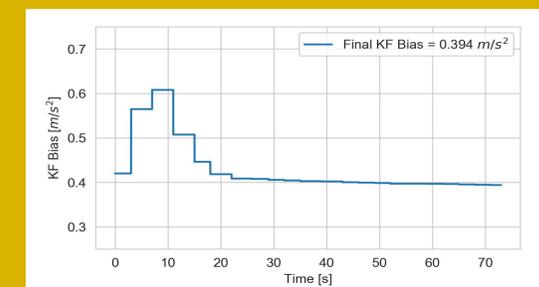
Paul Crawford, Hegemony Technologies

Results

Both filters require the compensation for the pitch of the boat in the smartphone mounted coordinate system to the translated boat in the horizontal coordinate system.

- The complementary filter requires a cutoff frequency to minimize the bias term and maximize the desired signal. If the bias term has significant frequency content, it is difficult to separate them.
- The Kalman filter includes a bias state that will effectively count for the error accumulation and does not have the limitations that the complementary filter does.

Overall, this research demonstrates the capability that carefully crafted, activity-specific sensor fusion algorithms can work even with low accuracy sensors.



Kalman Filter bias convergence over a single trial