An Affordable and Accurate GPS Tachometer and Stroke Rate Meter for Rowing

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***Abstract*—I propose a robust and inexpensive device for measuring the speed of a rowing shell and the stroke rate of the rowers. I used a GPS receiver, an accelerometer, and a microcontroller to measure the speed of the shell and the stroke rate of the rowers. The method behind the technology relies on Kalman Filtering to combine the GPS and accelerometer data to produce a more accurate measurement of the shell's speed. The method is accurate and have been thorougly tested by comparing it alongside the industry standard. I used Altium Designer to design the PCB and the microcontroller code is written in C. The total cost of the device is less than $100.**

INTRODUCTION

Rowing is a sport that requires a lot of practice to master. Rowers and coaches use a variety of tools to measure the performance of the rowers and the shell. The most common tools are the speed coach and the stroke coach. The speed coach measures the speed of the shell and the stroke coach measures the stroke rate of the rowers. It is usually a GPS device that measures the speed of the shell. The stroke coach is a device that measures the stroke rate of the rowers. Often, the two are combined as one device. However, the device often is unnafordable for beginner rowers, where the cost of the device often matches a year's worth of rowing fees.

METHODOLOGY

Components

The device integrates the following core components:

- **GPS Receiver:** Provides the foundational data by capturing the shell's real-time location and movement.
- **Accelerometer:** Measures two primary data sets:
  - The stroke rate, identifying the frequency of the rower's strokes.
  - The shell's acceleration, used to deduce its velocity.
- **Microcontroller:** Serves as the processing unit of the device. In the prototype, an Amica NodeMCU ESP8266 was employed, with future designs gravitating towards a custom PCB equipped with an MSP430 microcontroller. The microcontroller's functions include:
  - Reading and interpreting data from both the GPS receiver and the accelerometer.
  - Applying Kalman Filtering to amalgamate the data, enhancing the accuracy of the speed measurements.
  - Displaying the processed data for real-time feedback.

Design and Implementation

The prototype of this device was made on a breadboard using an AMICA NodeMCU ESP8266 microcontroller, a NEO-6M GPS receiver, and an MPU-9250 accelerometer. The microcontroller code was written in C using the Arduino IDE. The accelerometer and screens are connected through the I2C protocol to an I2C multiplexer to enable the use of multiple devices on a single set of bus lines. A similar setup is shown in Figure 2, only for the PCB device. The PCB also incorporates a USB Micro-B charging system for a Li-Po battery, which powers the device.

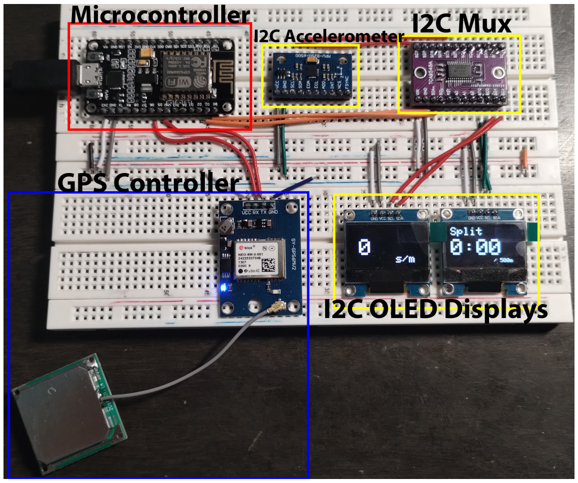


Fig. 1: Prototype Rowelometer on a Breadboard

Shell positioning

A rowing shell changes its orientation in space in the course of a race. In addition the rowelometer may shift over time. This affects the apparent acceleration in the direction of the motion. To deal with this problem I establish a fixed orientation

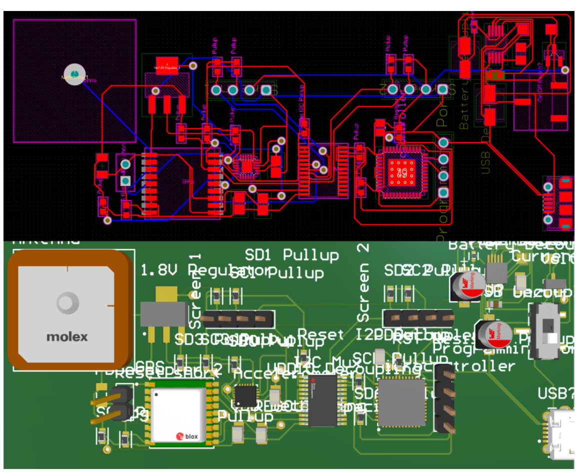
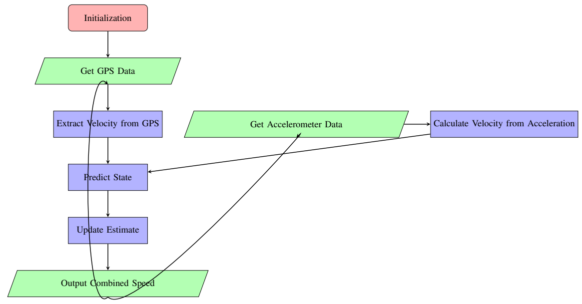


Fig. 2: PCB Design for the Rowelometer



frame and update the frame over time. Borisov and Mamaev [2018] To this end I find the optimal orientation such that z-axis is colinear to the direction of the maximum acceleration. This problem was recast as a search of an optimal orientation that minimizes the difference between predicted direction of the gravity and the measured acceleration. An additional inertial term was added to the target functional to account for tangential acceleration of the boat. Coutsias et al. [2004] Kabsch [1976] The precision can be further improved by adding terms to the cost functional that take into account readings from gyroscope and magnetoscope.

Quaternions offer an efficient and reliable way to represent rotations in three-dimensional space. Unlike other methods, quaternions are less prone to issues such as gimbal lock, making them suitable for accurately tracking orientation in dynamic environments. The target functional, using the quaternion representation for the rotations in the 3D space, is equivalent to an eigenvalue problem that is solved iteratively using the Arduino code I wrote. Extensive testing showed that the rowlmeter correctly detects stroke frequency for a typical training exercise.

Kalman Filtering

A key component in improving the device's accuracy lies in the application of the Kalman Filtering (KF) technique. Kalman filtering is a powerful algorithm used in sensor fusion to provide accurate estimates of variables by combining measurements from various sensors with a predictive model. In the context of my rowing speed meter, the Kalman filter

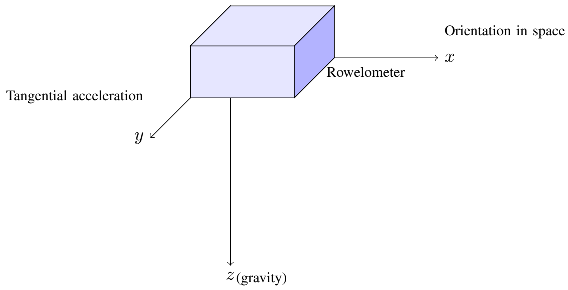


Fig. 3: The rowelometer in 3d space, note that the orientation of the rowelometer is not fixed in space, but gravity is always pointing downwards and has the greatest acceleration.

was employed to fuse data from an accelerometer and GPS to obtain a more precise estimate of the boat's velocity.

The MPU-9250 unit delivers very accurate instantaneous measurements of acceleration; however, there is inevitable drift over time during numerical integration. The GPS unit, while providing absolute reference positions and velocities, does so with relatively lower accuracy. KF merges the data from the GPS and accelerometer, reducing the noise and errors from each sensor to give a much-enhanced speed measurement.

I used the technique outlined in Stengel [1994, Eqs. 4.3-17, 4.3-22, and 4.3-23] to calculate and update the state variable $\hat{\mathbf{x}}$, covariance matrix, and gain matrix. I use the four-dimensional state $\hat{\mathbf{x}} = (v_x, a_x, v_y, a_y)$ and the observation vector $\hat{\mathbf{z}} = (v_x^{GPS}, a_x^A, v_y^{GPS}, a_y^A)$. Only the x- and y- axes are considered, as the shell's motion is defined as being perpendicular to the direction of gravity (z-axis). The Kalman Filtering process is applied to the accelerometer data to obtain the velocity of the shell. The accelerometer data is used to correct the GPS data, ensuring that the velocity measurements are accurate and reliable.

In this case, $\mathbf{H}$ is an identity matrix.

The state transition matrix, ϕ, is derived from the Euler approximation of the kinematic equations of motion: $v_x(t+\tau) \approx v_x(t) + \tau \times a_x(t)$. The same equation is applied for v_y

Special attention has to be paid to the covariance matrix of the process noise. The error is much higher in the direction of the boat's motion than in the lateral direction. I address this problem by rotating the noise matrix by an angle ϕ, applying a 2x2 rotation transformation, $\mathbf{T}(\phi)$, to a diagonal matrix of noise. The same procedure is used to estimate the acceleration covariance matrix. The noise matricies are two differing diagonal matricies that define the noise in the b(oat motion)- and l(ateral)-directions. The noise matrix for a shell rotated by an angle ϕ is given by $\mathbf{Q} = \mathbf{T}(\phi)\mathbf{Q}_0\mathbf{T}^{-1}(\phi)$, where $\mathbf{Q}_0$ is the noise matrix for a shell with no rotation. The noise matricies are given by $\mathbf{Q}_0 = \begin{bmatrix} \sigma_{v_b}^2 & 0 \\ 0 & \sigma_{v_l}^2 \end{bmatrix}$ and $\mathbf{Q}_0 = \begin{bmatrix} \sigma_{a_b}^2 & 0 \\ 0 & \sigma_{a_l}^2 \end{bmatrix}$. Values for $\sigma_{v_b}^2$, $\sigma_{v_l}^2$, $\sigma_{a_b}^2$, and $\sigma_{a_l}^2$ were determined experimentally. There is a measurement uncertainty matrix, $\mathbf{R}$, which is a diagonal matrix with the variances of the measurements. The variances are also determined experimentally.

Features and Benefits

The Rowelometer offers a multitude of features that make it a competitive solution in the realm of rowing metrics:

- **Cost-Effective:** Priced at under $100, it provides a much more affordable solution than many commercial devices.
- **High Accuracy:** The Kalman Filtering technique ensures that the measurements are precise and reliable.
- **Dual Metrics:** Measures both the speed of the rowing shell and the stroke rate of the rowers.
- **Compact and Portable:** Its small size makes it easy to mount on any rowing shell without hindrance.

Results

The Rowelometer, in its current prototype stage, has shown promising potential. While the PCB itself has yet to be printed and assembled, preliminary evaluations of the prototype have been promising. Feedback from the local rowing club, which played a crucial role in the testing phase, indicates that the product is not only feasible but also offers a level of accuracy that meets the standards for real-world applications. This preliminary feedback suggests that once the final PCB is assembled and integrated, the Rowelometer could be a reliable tool for both amateur and professional rowing enthusiasts. Future iterations of the Rowelometer may include a mobile app to display the data from the device.

References

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