DESIGN, VALIDATION AND APPLICATION OF AN UNOBTRUSIVE OAR FORCE-ANGLE MEASUREMENT SYSTEM

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Feedback is necessary for the improvement of motor performance. Elite level athletes in particular require accurate and detailed kinematic and kinetic information for improvement. The purpose of this study was to design, build, validate and apply an unobtrusive oar force-angle measurement system for the evaluation of on-water rowing performance. Performance measurement systems must also meet the criteria of accuracy, unobtrusiveness, reliability, quality visualisation and affordability. Using high quality IMU and force measurement technology a system (RowIMU) was designed and built that met these criteria. Results for horizontal, vertical and feather angle of the oar and the normal handle force were obtained and reported. The system provided innovative and useful information for coaches and rowers.

KEY WORDS: rowing, performance, on-water.

INTRODUCTION: When learning motor skills, it is essential that the learner obtain appropriate feedback at each stage of development (Schmidt, 1988). Further, Newel, and Walter (1981), maintain that the provision of kinetic information feedback is preferable to mere knowledge of results and that feedback should occur as soon after performance as possible. More recently (Sigrist, Rauter, Riener, & Wolf, 2013) have shown that terminal visual feedback is the most effective because there was a focus on the internalization of relevant aspects of the task. However, concurrent feedback encouraged the correction of errors that were irrelevant to the task and thus hindered learning. Performance was much better in a concurrent visual and haptic feedback group during training with the feedback compared with nonfeedback trials. Training the three-dimensional movement using auditory feedback of the movement error was not practical for for most participants. The authors suggest that concurrent multimodal feedback in combination with terminal feedback may be most effective. The learning would be enhanced if the feedback strategy is adapted to individual skill level and preferences.
The systems developed by Smith and Loschner (2002) and Pilgeram and Delwiche (2006) are examples of many on-water systems for the provision of feedback to rowers. The advance of technology has facilitated increases in accuracy, unobtrusiveness, reliability, quality of visualisation and affordability and has the potential to provide the most effective feedback mode.
The aim of this project was to design and evaluate a rowing performance measurement system (RowIMU) that met these criteria.

METHODS: The RowIMU system consists of a narrow circuit board mounted in a water proofed enclosure which in turn is mounted inside a strain gauge equipped oar (Figure 1).
The circuit board contains an Invensense MPU-9050 tri-axial combined accelerometer, gyroscope and magnetometer as well as a TI LMP8358 precision strain gauge amplifier. The board also has a 32 bit ARM processor and Bluetooth connectivity.
The raw sensor data is acquired and processed to generate a complete dataset every 10 milliseconds. The dataset is composed of: the sample time, oar feather angle, oar elevation angle, oar (or yaw) angle and oar paddle force. This is streamed via the Bluetooth wireless protocol to a waterproof Smartphone attached to the rowing shell (Figure 2). The data from up to two oars can be collected simultaneously.

Sensors in the Smartphone compensate for yaw angle measurement errors due to rowing shell heading drift. The RowIMU application on the Smartphone allows test control and data display (Figure 3) as well as real time force/angle graphical feedback to the rower for technique monitoring (Figure 4). The dataset is saved both in the phone memory and in user online storage, for later detailed analysis.

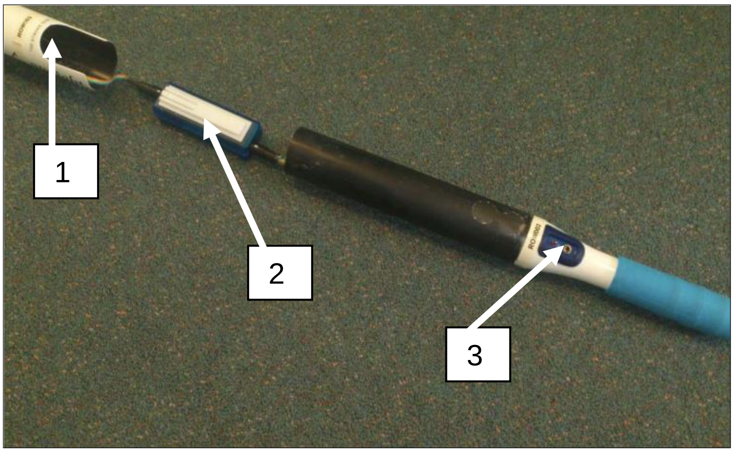

Figure 1. Dismantled Instrumented oar. Paddle with strain gauge force sensor (1). RowIMU module (2). On/Off switch, mode LED and charging port (3).

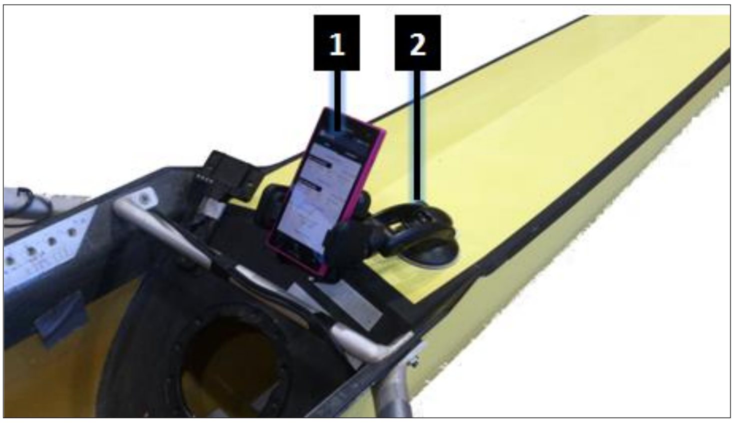

Figure 2. Smartphone (1) mounted on rowing shell (2).

The RowIMU was evaluated at an international rowing course with a sub-elite level female single sculler and two other male scullers. The oar force was pre-calibrated in the laboratory using known masses suspended from the handle (RMS error = 0.14%, r = 0.999, p < .001) and the oar angles gains calibrated against the laboratory motion analysis system (Cortex, Motion Analysis Corporation, USA) (RMS error = 0.03%, r = 0.9997, p = < 0.001) (Figure 11).

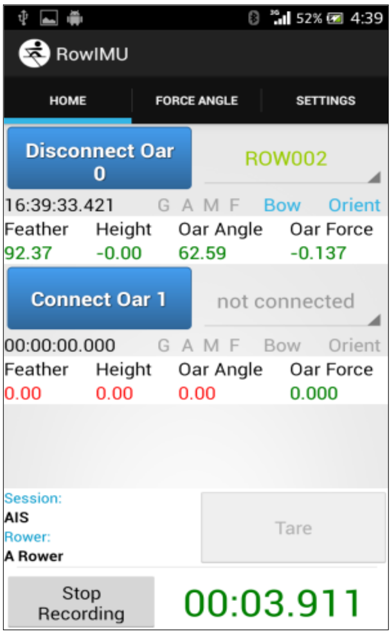

Figure 3. RowIMU application data monitor screen.

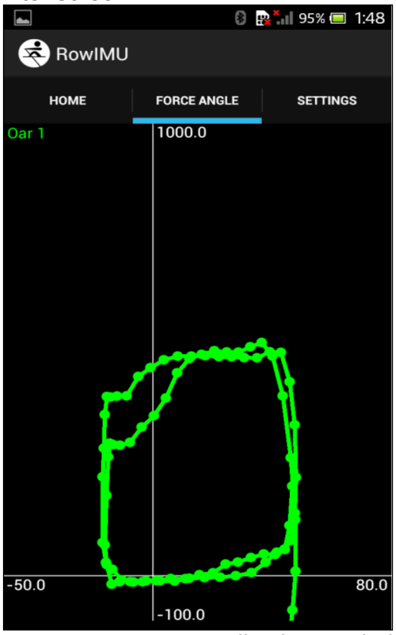

Figure 4. RowIMU application real time oar force angle display screen. (not a real stroke).

On the course the IMU magnetometer was calibrated using a figure-of-eight movement of the oar in three dimensions. At the beginning of the test the oars were held in the square-off position while the IMU accelerometer and gyroscope were zeroed. The sculler then rowed for 500 m at a stroke rate of 26 strokes per minute with the RowIMU measuring and storing oar force, horizontal, vertical and feather angle of the oar. At the conclusion of the piece the data was transmitted to a cloud store. The data was downloaded to a laptop computer where rowing strokes were automatically detected, time normalised and averaged.

RESULTS: The RowIMU system was successful in measuring and storing the force and oar angle data and in providing a real-time display during on-water single sculling. An example of 21 successive strokes for one oar is displayed below for the horizontal oar angle (Figure 5), vertical angle (Figure 6), feather angle (Figure 7) and oar force (Figure 8). The catch is at 0 and 100 % of the stroke and the release or finish is at 40%.

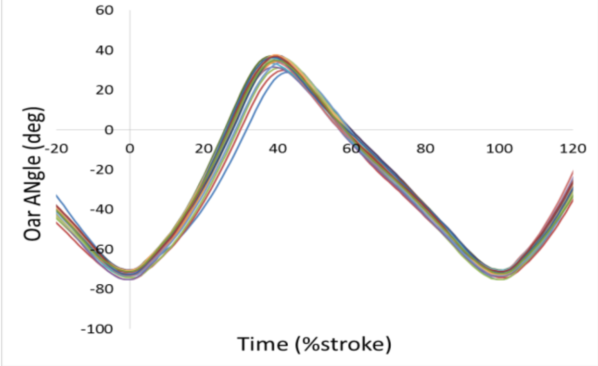

Figure 5: Horizontal oar angle

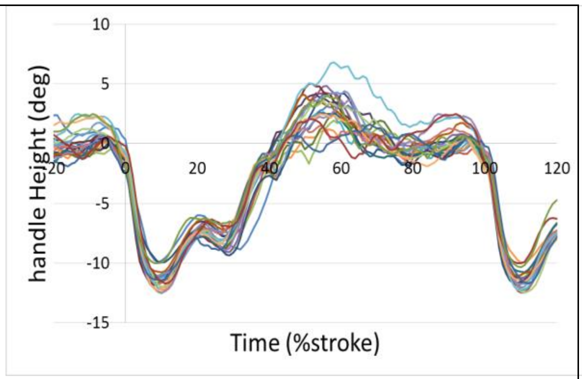

Figure 6: Vertical oar angle

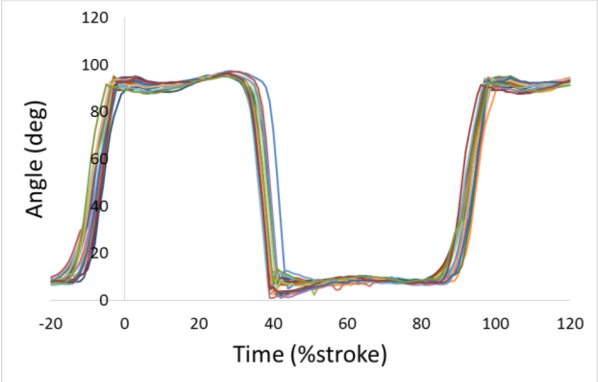

Figure 7: Feather angle

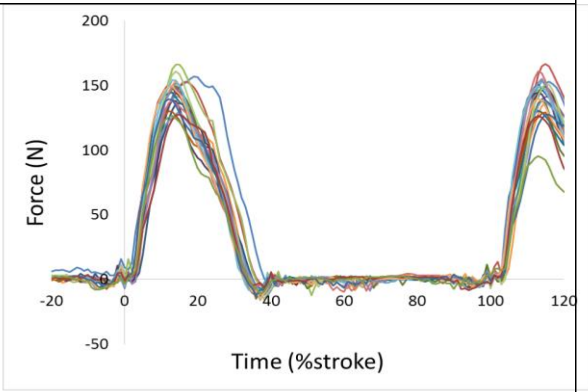

Figure 8: Normal handle force

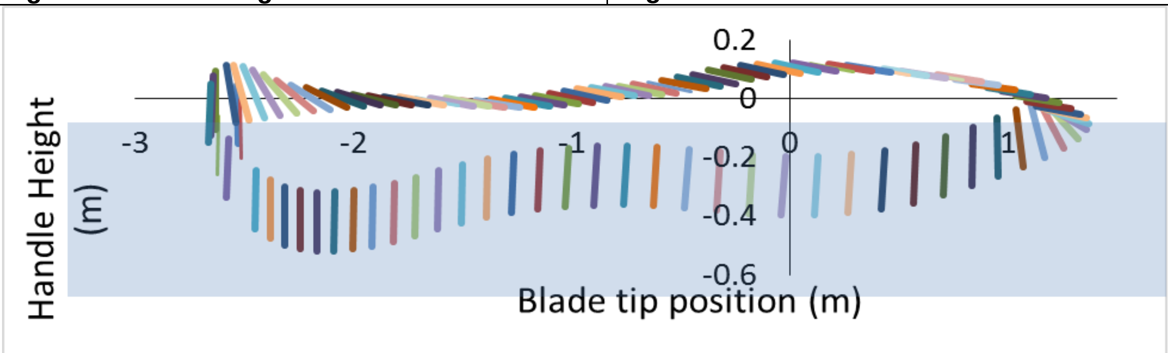

Figure 9: Visualisation of the orientation and position of the blade tip during one stroke. The blue background represents the water.

DISCUSSION: The RowIMU unit was easy and quick to set up on the course and was successful in measuring and storing the three oar angles and oar handle force. Importantly, the method used to calculate the oar angles in the RowIMU reports the true horizontal angle of the oar independently of the vertical and feather angle. Further, there is no need to mount custom gates on the boat pin in order to measure oar force as in other systems.

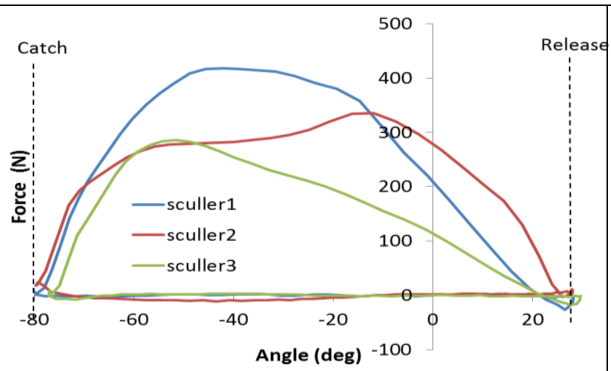

Figure 10: Force – angle profiles from three different scullers showing widely different characteristics.

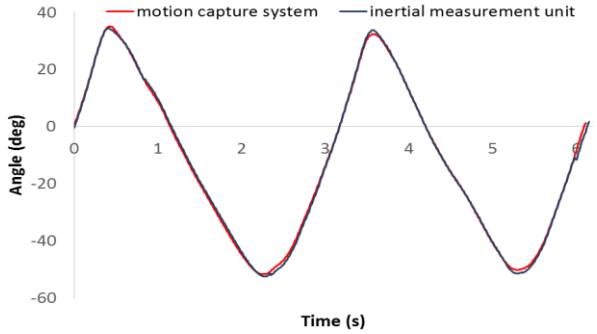

Figure 11: Two cycles of horizontal oar angle comparing the measurement from the motion capture system with the RowIMU unit.

This is important for coaches who often mention the horizontal oar angle and its catch and release position as the most desired variables from a rowing performance measurement system. Differences in force angle profile are obvious when comparing force-angle profiles of different scullers (Figure 10).

An innovation in the visualisation of the data is the graph in Figure 9. This figure is a representation of the lateral view of the end of the blade every 10 ms as it would appear to the coach from their boat moving parallel to the scull. The horizontal and vertical position is calculated from the horizontal oar angle and the outboard length of the oar. From this graph the coach can discern the rower's technique in getting the blade into and out of the water, the path of the blade in the water and the feathering during the recovery.

Obvious other visualisations are force-angle (Figure 10) and power-angle graphs. Performance variables available after data collection are average power and blade movement without force at the catch and finish.

CONCLUSION: The RowIMU system met the criteria set for its performance. It is unobtrusive, accurate, reliable and easy to use and provides useful information to coaches and rowers for the improvement of rowing performance. Work is also being done to characterise performance through the analysis of the force and angle data using functional data analysis to provide a more evidence based process for improving rowing performance.

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