

ROWING TRAINING SYSTEM FOR ON-THE-WATER REHABILITATION AND SPORT

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ABSTRACT

Quantitative and continuous performance assessment enhances effective physical training in sports and rehabilitation. Rowing uses the large muscles of the body in an aerobic and strength building manner. Rowing has utilization as a competitive sport, an aerobic exercise, or a rehabilitation exercise, such as related to spinal cord injury, stroke, trauma, old age, obesity, chronic obstructive pulmonary disease or osteoporosis. Guidance from a physically present coach or therapists has high cost and time requirements that limit accessibility. A computerized system that gives instructions to the rower, monitors rowing performance, and transmits the data to a computer for analysis, storage, and communication would increase accessibility of quality feedback and guidance. Ergometers are stationary rowing stations with automatic instructions and monitoring of performance. Sensors have been developed for on-the-water monitoring of rowing, but these devices typically have disadvantages of affecting the oar, difficult mounting procedures, and high cost. This project developed modules of a system integrated with the oar, which then wirelessly transmitted the recorded force and rotational data to computer. The computer could analyze, store and communicate the data to the rowers, coach or therapist, medical staff and other appropriate family members or associates.

Categories and Subject Descriptors

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General Terms

Measurement, Human Factors.

Keywords

therapy, exercise, health, endurance, strength, spinal cord injury, strain gage, accelerometer, oar, force, power, wireless.

1. INTRODUCTION

Competitive training or sessions of physical therapy may be effectively guided by a present and observant human coach or therapist. However, for rowing activities, having such a human guide physically near a boat during training sessions has disadvantages of human cost and time. These limit accessibility of the potential training assistance to the rowers. Moreover, even though the guide is physically close by the boat and observing the

rowers closely, the complete profile of force and power data of individual rowers is not observable. The guide may be able to give even better feedback and advice to a rower by having more complete information. A computerized system that provides instructions and goals to the rowers, monitors force and rotational information, transmits the data to a computer for analysis, storage and display, would enable summary feedback directly to the rowers or to a remote or off-line coach who would give feedback and further instructions to the rowers.

Competitive rowing teams would benefit from such a system for better coordination and balancing of the different rowers in the boat [13], detection of changes in rowing pattern during a rowing session [19], and longitudinal comparison of individual force and power performance over weeks of training. Measures of the biomechanical and physiological aspects of rowing have been developed [18, 20, 24-25].

Besides being a competitive sport, rowing has many health benefits when done on a regular basis. Rowing improves cardiac health, with improved left ventricle function and morphology [8], and increases arterial compliance [6]. Rowing by people who were obese also improved their cardiac health, as indicated by lower resting heart rate, and increased stroke volume, end diastolic volume, and ejection fraction [26]. Rowing in old age improves physical fitness and arterial compliance [16], and also increases muscle force and cross-sectional area [4]. Rowing has helped individuals with chronic obstructive pulmonary disease improve respiratory function [7]. Physical exercise such as rowing is recommended for people with osteoporosis [1].

Spinal cord injury (SCI) limits motor function, often resulting in a more sedentary lifestyle and less aerobic exercise. Individuals with SCI generally have a higher risk for diabetes mellitus type 2, hypertension and a lipid profile associated with atherogenesis [14]. Cardiovascular exercise is limited without utilization of muscles for the lower extremities. Functional electrical stimulation (FES) for cycling activities has been shown to improve power and work output, lean muscle mass, and blood glucose and insulin levels [10, 17]. Such health benefits have also been shown by FES for rowing, including improved strength and endurance [11, 14, 23], oxygen consumption [11-12], anaerobic power [23], weight ratio and body fat content [23]. FES generated cycling for SCI individuals has enabled increased mobility, such as leg-cycling propelled wheelchairs [15] and tricycles [21]. Such increases in the quality of life may be extended to rowing activity if the rowing were able take place on-the-water in a boat, and not just on a stationary ergometer.

Stationary ergometers for rowing have been developed [18], used extensively for competitive sport training [5, 19-20], health [4, 6-7, 16, 23] and rehabilitation [11, 14, 23]. On-the-water systems with sensors to monitor rowing performance have been developed

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for competitive sport training applications [3, 9, 22]. Individuals with SCI or other mobility impairments would also benefit from on-the-water rowing systems that monitor rowing performance. Such a system could function as a coaching or therapist guide, to give exercise instructions prior to or during the session, monitor and record the rowing performance, and post session analysis and feedback. Simultaneous wireless transmission of the data to a computer would enable storage, analysis, display of the results, and cloud-based access to the information.

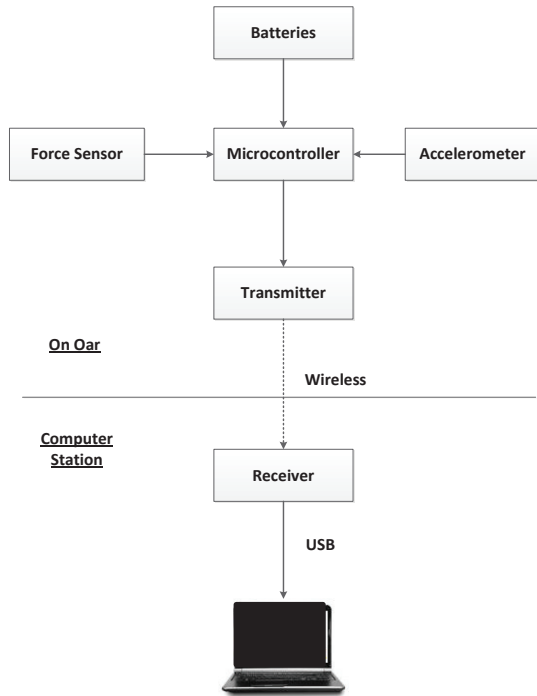


Figure 1: Strength Trainer Design Block Diagram.

The purpose of this project was to develop prototypes of modules of an on-the-water rowing guidance and monitoring system. The modules were designed to be compatible with a wide variety of oars and boats. The on-oar system included force sensors, accelerometer, microcontroller, wireless transmitter and batteries. The mobile computer that functioned as the wireless receiver could be on the same boat, another boat or on land, as long as the location remains within the transmission range. Rowing measurements were made and continuously transmitted to the remote computer for storage, analysis and display.

2. MATERIALS AND METHODS

The system has two main subsystems, one on the oar to gather and transmit the data, and the other at a remote computer to receive, analyze, display, store and communicate the data (Figure 1).

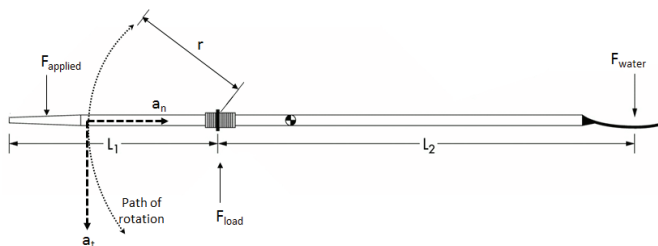


Figure 2: A free body diagram of the oar with sensors.

The on-oar subsystem was designed to be adapted to standard oars, without compromising their function or mechanical

integrity. The force sensors were positioned on the oar where the oar sleeve and oar lock meet (Figure 2). The sleeve makes contact in two spots with the oar lock. As the rower begins the stroke, the oar sleeve exerts mechanical stress onto the oar lock at these two locations, inducing strain within the oar. Two Flexi force sensors (Tekscan, Boston, MA) were aligned with the long axis of the oar and attached at these two locations near the oar lock.

An accelerometer was also positioned on the oar. The accelerometer was within a circuit box on the oar between the oar lock and the handle as shown in Figure 3.

Estimates of power output over time were made from calculations of torque (τ) and angular velocity (ω). Torque was derived from the force value (F_{applied}) and the radius (r). The radius was the distance of the observed force from the centroid of rotation (radius) [2]. Radius, r , was determined as the ratio of $L_2 / (L_1 + L_2)$, as diagrammed in Figure 2.

$$\tau = F \times r$$

Estimates of angular rotation were derived from values of acceleration along the oar shaft (a_n), with gravity (g) and angle (θ) [2].

$$a_n = \omega^2 r - g \cos \theta$$

$$\omega = \sqrt{\frac{a_n + g \cos \theta}{r}}$$

Since Power is the product of τ and ω , the full equation for estimates of power was

$$\text{Power} = r \left(\frac{F_{\text{applied}} \times L_2}{L_1 + L_2} \right) \sqrt{\frac{a_n + g \cos \theta}{r}}$$

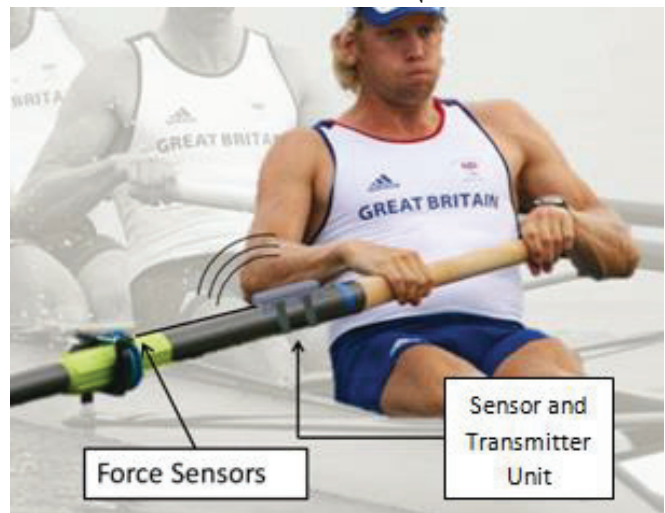


Figure 3: Example of an on-oar measurement system with module locations similar to the one developed in this project. Image adapted from "FAQ: Physics of Rowing", Dudhia, Anu, Department Atmospheric Physics, Oxford University.

The on-oar subsystem (Figure 1) determined values of F_{applied} and acceleration, a_n . These time-domain values were transmitted to the remote computer subsystem for analysis (Figure 1). The on-oar module contained the two force sensors and a circuit inside a protective plastic case on the oar. The circuit included a microcontroller (Arduino Pro Mini) board, accelerometer (2g Dual Axis, Dimension Engineering, Akron, OH), operational

amplifier to amplify the signal from the force sensor, Xbee wireless transmitter (SFE, MaxStream, Minnetonka, MN), and battery pack. The microcontroller sampled sensor from the force sensors and the accelerometer. The microcontroller then sent this data to the Xbee transmitter that transmitted the information wirelessly to an Xbee receiver on the computer station (Figure 1).

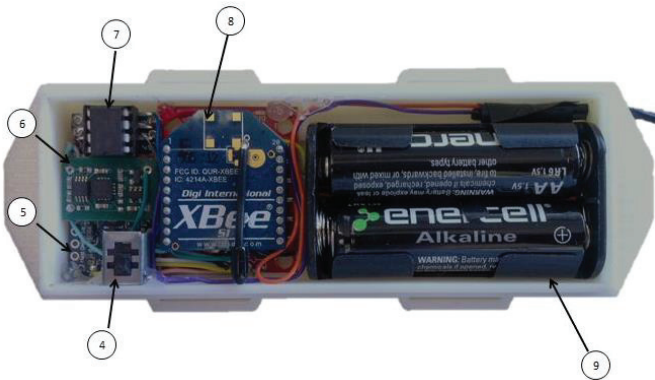


Figure 4: Arrangement of circuitry and components inside the case of the power switch (4), on-oar prototype controller (5), accelerometer (6), transmitter (8), op amp (7), and batteries (9).

Figure 5 shows a case to hold and protect the on-oar electronic system. The case was placed as close to the oar handle as possible without interfering with the grip and motion of the rower (Figure 3). Such a location allowed for a relatively large radius of rotation to obtain a more accurate value for angular velocity. The bottom of the casing was inwardly rounded to better lie adjacent to the oar. The straps held the case to the oar straps (Figure 5).

On the computer station subsystem, the Xbee receiver was connected to the computer through a USB port. The computer ran a custom LabVIEW (National Instruments, Austin, TX) program. This program analyzed the force and acceleration data from the receiver, and computed an estimate of the power of the rower. The results were plotted and stored.

3. RESULTS

The system was tested under conditions similar to those that would be used in practice. The assessment device was attached to an oar used by a rower on the Wentworth Institute of Technology Rowing Club. The computer station was located in a motorboat that followed the rower, as would typically be done by a coach or trainer. Figure 6 shows a plot of the estimates of power versus time. From a baseline of having the rower at rest, the values of power increased by 7 or 14 fold. A greater effort by the rower to pull on the oar and make a stroke resulted in greater values for force and estimated power (Figure 6).

The rowing athlete who used the system thought that the system did not interfere with rowing activity. However, the size and weight of the device did slightly impede rotation of the oar while “feathering”.

4. FUTURE DIRECTIONS

Further testing and calibration are necessary to check accuracy of force, torque, angular velocity and power. A gyroscope could be added for measurement of angular rotation, supplementing the accelerometer data. A smaller and lighter module for the on-oar system would lessen any physical effect on the rowing stroke or

movement. Multiple on-oar systems would enable a rowing monitoring system for each rower in a boat. Software for the computer station could be developed to further analyze, store and communicate the data. Analysis could include comparisons of rowers, changes in stroke or power profile over time during a training session, or from one training session to the next. Summary data could be determined and provided to the rowers, coach or therapist, and other appropriate people using a cloud based database and communication system.

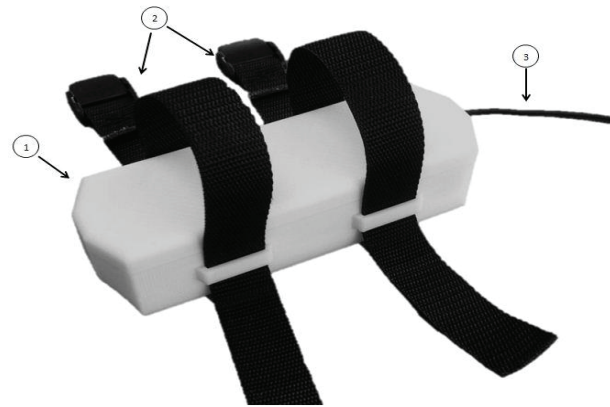


Figure 5: Case (1) and straps to hold the on-oar circuitry. The straps (2) secured the case to the oar between the oar lock and the handle. Wires (3) extended out of the case to connect with the force sensors.

The system shows promise as modules of a guidance and monitoring system. Not only would this help competitive sport rowers train without their coach being continuously present, but would also enable rehabilitation and physical therapy applications, where individuals and caregivers could undertake rowing therapy and training. Such training on-the-water would support improvements in health and the quality of living.

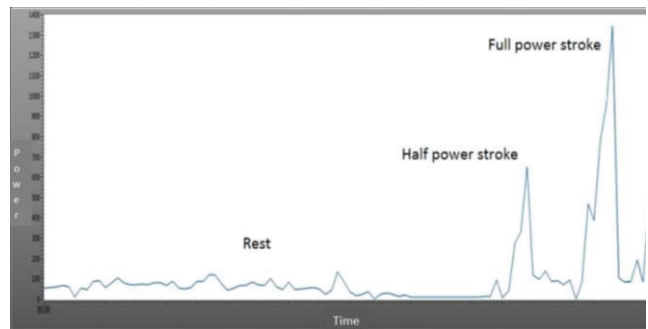


Figure 6: Power Assessment of a Rower’s Stroke During Strength Trainer Testing. The waveform labeled “Rest” was recorded while the rower was not moving the oar to make a stroke. A moderately forceful stroke by the rower resulted in the power profile labeled “Half power stroke”. A strong stroke by the rower resulted in the profile labeled “Full power stroke”.

5. ACKNOWLEDGMENTS

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