AN INSTRUMENTED ROWING MACHINE TO EVALUATE PERFORMANCE AND FORM

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BACKGROUND

Since increased boat speed is the major objective of the sport, rowing is driven by efficiency and output. Rowers are especially concerned with body form as it affects output. The most generally accepted measure of output is power generated.

While rowing machines can be simply exercise machines, they may be able to serve other functions more closely related to actual rowing. For example, some available rowing machines provide users with the energy expended in the exercise period and an estimate of the time it would have taken for a boat to traverse a given distance as a result of the rower's effort. However, there appears to be no exercise machine-based measurements of form that correspond to even the rudimentary performance measurements available.

To make rowing machines more useful for improving rowers' performance, for use in prescribed exercise and for interested recreational exercisers, extended performance and form measurement capabilities and conversions from measured rowing machine outputs to predicted boat speed are needed. The project described below was aimed at producing such a rowing machine system.

PROBLEMS ADDRESSED AND APPROACH

All of the types of rowing machine improvements listed above were addressed in this project. The overarching problem addressed was the generation of rowing machine performance and form information and presenting results in an easy-to-interpret way directly related to actual rowing.

The goal of the project was to make performance and form information continuously available. Specifically, performance was based on direct measurements of power generated, rower momentum, stretcher (foot support) forces and calculated resulting boat speed. Form was characterized using optical measurements and image analysis of video display of the rower.

The approach to producing the rowing machine system was to combine advanced, but readily available, instrumentation, engineering science concepts and models, and the information processing and display capabilities of computers. A commercially available rowing was machine was used as the base for the form and performance monitoring system developed.

The system components and overall system operation are described in the following sections.

PERFORMANCE MEASUREMENT

Power

Power is the most widely used quantity in describing rower performance, but direct, continuous measurement and display of it is not a feature of available rowing machines.

On the instrumented rowing machine power is calculated as the product of rowing handle force and velocity. The force is measured using a strain gage-based load cell placed in-line with the machine chain linked to the flywheel that produces the resistance load. Handle speed is measured using the video system that is used to characterize form. The handle position is tracked and the measured change in position and frame rate of the video system are used to calculate speed.

The power profile can be observed by the user during the stroke. Power profile, boat speed plots and form images are displayed simultaneously and continuously so the power-boat speed-form interactions are easily seen.

Stretcher Forces

At some as yet not quantified level forces exerted on boat stretchers by individual rowers affect other rowers and overall boat performance. More directly, rower stretcher force imbalance causes a loss of efficiency because of boat roll.

The forces applied by the rower's feet to the machine foot rests are measured using specially constructed instrumented load platforms. The load platforms are separate components that mount on the machine stretchers. They are designed to measure force normal to the stretcher and to be insensitive to variations in the location of load application. The distributed load from the rower's foot is converted to a point load on a simply supported beam that rests on a load cell at midspan. The 380 mm long by 130 mm wide by 50 mm high package contains the flexures and the tension/compression strain gage load cell.

Stretcher forces are displayed graphically as side-by-side bar charts to provide measures of forces and force balance.

Momentum

Rower motion with respect to the boat affects boat speed through individual rower effects and interactions with other rowers. Crew synchronization, similar timing and speed of rowers in the boat, can be quantified using individual rower momentum.

Momentum of the rower on the machine is calculated using the rower's mass, center of mass position and center of mass velocity. The center of mass position is estimated using the measured body joint locations and general rules specifying the percentage of total mass that makes up body segments.

Calculated momentum can be plotted continuously as a display option.

Boat Speed

Typical boat speed models use the force-acceleration relation of Newton's Third Law. Acceleration, and hence velocity, is calculated from the sum of the forces acting and the total mass of the boat-rower system. Forces include oar force and drag forces. These models are usually used in theoretical studies of the effects of rowing forces on boat speed, not to provide performance output on a rowing machine.

Rowing machine performance is extended to estimating boat speed using an extension of the typical model and a direct measurements of force and power. The boat speed calculation model includes momentum transfer of the rower as well as power output. Published drag force models are used. Calculated boat speed and changes in speed with changing handle force correspond to commonly quoted values.

Boat speed is continuously displayed so that the average boat speed and the generally sinusoidal variation around the average can be used as training aids in evaluating performance. A grand average boat speed is displayed at the end of an exercise session.

ROWING FORM MEASUREMENT

While rowing machines do not produce an exact simulation of actual rowing form, many important aspects of form can be obtained from a two-dimensional, side view of the rower on the rowing machine. Rowing form is visually displayed as a combination of body configuration of the rower during the rowing stroke and model forms. To provide an easily observed form display a stick figure of the rower is overlaid on the video display of the rower.

Tracking Body Movements

An optical camera operating at the standard frame rate of 30 Hz is used to capture gray scale images of the rower. The video display is to a computer monitor and projecting the image results in a larger-than-life display. Light emitting diodes are used as motion tracking targets. Targets are mounted on the rowing machine stretcher, seat and handle and on the rower's shoulder and elbow. Search windows are placed over the targets and a centroid location algorithm is used to find the location of the brightest pixel in the search windows. Tracking programs include algorithms taking into account target position, velocity and acceleration so predictive target following is implemented. An error checking method is used to verify continuous target tracking.

The targets mounted on the machine are powered from the instrumentation system. The rower-mounted targets are electrically connected and powered by one battery.

Stick Figure Abstraction of Form

A stick figure is created and overlaid on the display of the rower. Hip position is calculated from the known target to top of seat distance and an experimentally determined factor specifying seat-hip joint distance. The ankle-knee and knee-hip components of the figure are created from the hip position, the machine stretcher location and known body proportion ratio. The shoulder, elbow and hand (machine handle) positions are established by direct measurements of the corresponding target positions. These joint positions are linked to form a stick figure that is displayed on the full video display of the rower.

Rowing Form Evaluation

Form is evaluated by comparing the orientation of the rower stick figure to one of several widely-accepted form models. The orientation of the rower's limbs and back are compared to a set of angle and position specifications for a particular model for each phase of the rowing stroke. Deviations from the form model are calculated at the video system frame rate. The extent of the differences between the rower stick figure and the model form are called out by changing the color of limbs of the stick figure from green to yellow to red based on the severity of form error. In addition, a summary window displays errors and the number of times each was committed. This helps the user identify form errors that may happen over very short times and so are hard to detect as a color change in the stick figure.

A coach or experienced rower can modify the form model used since several slight variations exist as to ideal form among serious rowers. Or, form models for rowers with specific needs or problems may be needed. To implement such model form changes default constraints can be adjusted and a form model generated for the individual user.

SYSTEM OUTPUT DISPLAY

Rowing performance and form are continuously displayed on the system computer monitor and can be projected to give life-size, or larger, displays. The display is composed of three window areas. The video display of the rower with overlaid stick figure is continuously displayed in one window. The other two windows are used to display user selectable performance outputs. One of these two windows is used to display continuous plots of power and estimated boat speed. Other performance measures can be displayed at the user's option. The third window is used to display the typical measures displayed on available rowing machines, e.g., time duration of exercise, energy expended.