smartSHELL: Measuring and Motivating Human Performance in an Outdoor Rowing Environment

Gwelleh Rachelle Hsu

Bachelor of Science, Natural Sciences Area
University of Pittsburgh, Pittsburgh, Pennsylvania, 1992

Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
in partial fulfillment of the requirements for the degree of
Master of Science in Media Technology
at the Massachusetts Institute of Technology

June 1998

Author
Gwelleh Rachelle Hsu
Program in Media Arts and Sciences
May 8, 1998

Certified by
Michael Hawley
Assistant Professor of Media Arts and Sciences
Alex Dreyfoos Jr. Career Development Professor of Media Arts and Sciences
Thesis Advisor

Certified by
Rosalind Picard
Associate Professor of Media Technology
NEC Career Development Professor of Computers and Communications

Accepted by
Stephen A. Benton
Chair, Department Committee on Graduate Students
Program in Media Arts and Sciences

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Abstract

A system was built that has the capability to determine the state of a person's performance level and then uses this information to help encourage the person. The underlying hypothesis being that motivation is critical for performance, and that if it is administered properly, it can boost performance.

The setting of the study took place in the sport of rowing, during normal training sessions of crew season. A real-time feedback system was developed to detect how tired a person is, and how well they are rowing. Every time a rower performs the rowing motions, data on fatigue and pressure are collected. The coxswain, who sits in the stern of the boat to help motivate the rowers, has periodic feedback on how the rowers are doing and what effect his/her commands have on the crew. While many of the mechanisms which mediate motivational responses are not yet understood, we are presently able to quantify them with the aid of recording and measuring devices.

There are several goals of this research. One is to gain empirical information regarding the measurement of motivation in terms of human functioning factors: physiological and psychological data. This is of interest to the field of psychology in general, as it adds in a unique manner to knowledge about what occurs during human motivational response. Additionally, this project is designed to provide information to aid in the production of a monitoring device which has far reaching implications for sport enthusiasts, psychology professionals, educators, and many other disciplines.

Thesis Advisors:
Michael Hawley
Assistant Professor, Program in Media Arts and Sciences

Rosalind Picard
Associate Professor, Program in Media Arts and Sciences

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The following people served as readers for this dissertation:

Thesis Reader
Michael Hawley
Assistant Professor of Media Arts and Sciences
Alex Dreyfoos Jr. Career Development Professor of Media Arts and Sciences
MIT Media Laboratory

Thesis Reader
Rosalind Picard
Associate Professor of Media Technology
NEC Career Development Professor of Computers and Communications
MIT Media Laboratory

Thesis Reader
Stuart Schmill
Director of Crew
MIT Athletic Department

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Chapter 1 Introduction: Rowing into the Future

Imagine yourself in a boat on the water. You're rowing. There are people in front of you and people in back of you. You're pulling as ***hard*** as you can on an oar that seems to be much heavier now than when you left the dock 10 minutes ago. **"5 seat, you're early at the catch! 6 seat, watch your slide!"**

You're 6 seat. You think, *"Should I slow down or speed up?"* I'll slow down. I'm following the person in front of me...

"Stand on those footstretchers! Harder! Another boat's coming up to us! Don't let them get near us! Don't let them have it so ea-zee! Give me a Power 10!"

You can't even feel your legs. You're breathing hard. Your heart is racing. How did you get tired so soon?

Life without a lot of feedback is difficult no matter what situation you're in. Let's look at this scenario in a different way:

Imagine yourself in a boat on the water. You're rowing. There are people in front of you and people in back of you. You're pulling as *hard* as you can on an oar that seems to be much heavier now than when you left the dock 10 minutes ago. "5 seat, you're early at the catch! 6 seat, watch your slide!"

You're 6 seat. You think, "*Should I slow down or speed up?*" You glance at your personal feedback module screen. *I'm not going as slow as the others.* There. Perfect.

"Stand on those footstretchers! Harder! Another boat's coming up to us! Don't let them get near us! Don't let them have it so ea-zee! Give me a Power 10!"

A glance at your screen indicates that you're giving about 70% the effort that you normally give. Got to pull harder. My legs are getting...

"6 seat! Give me a little more: Let me see 75%. I'd rather see you steady to the finish!"

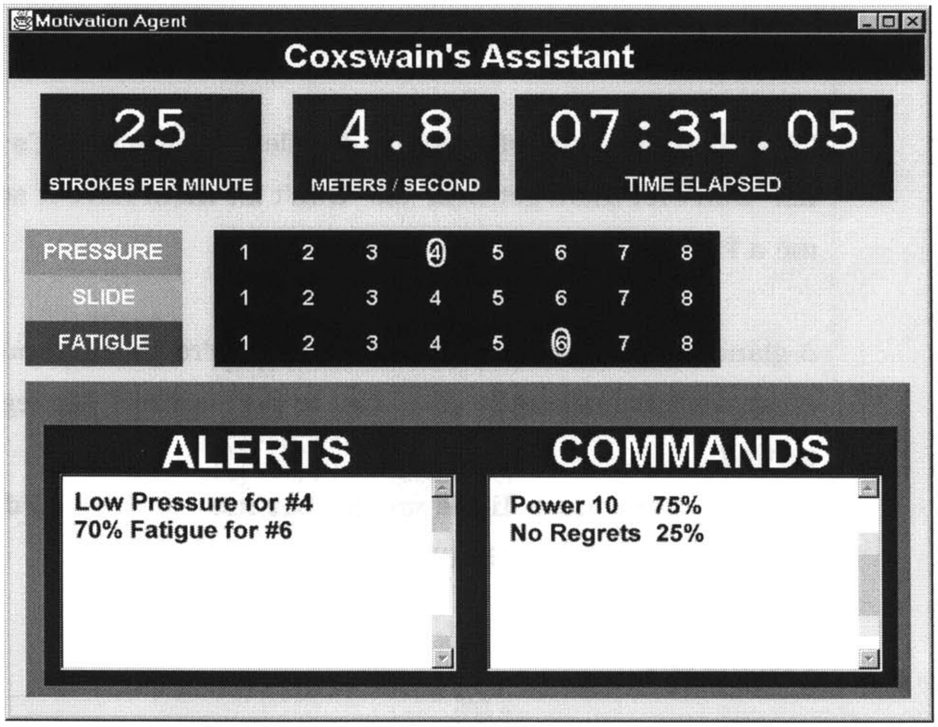
Yes, ma'am!

What are sports without instant replays? Let's see those last few seconds again:

A glance at your screen indicates that you're giving about 70% the effort that you normally give. Got to pull harder. My legs are getting...

(Cutting to the coxswain's thoughts) OK, looks like we're going to clear the bridge just fine. We seem smooth, but let me check.)

(She glances at her coxswain module)



(Hey, That Power 10 worked pretty well. Man, No Regrets is pretty overused, I guess)

"4 seat! Lean on that Oar! 6 seat! Give me a little more: Let me see 75%. I'd rather see you steady to the finish!"

Yes, ma'am!

1.1 Background: Rowing, Sports, and Motivation

1.1.1 Rowing

Rowing is a unique sport in that rowers are people who are supposed to be doing the same movement extrinsically motivated in a short-term manner by a coxswain in addition to the coach and environment. Because each person is unique yet performing the same motion in unity with the rest of the team, issues involving individual and team motivation apply. Also, the coxswain acts as a team leader and motivator.

There are many topics of research which can be examined within a rowing environment where sensors are providing real-time physiological and motor skill feedback: flow/peak performance, social loafing, motivation using feedback analysis of fatigue overexertion points, performance/skill analysis and coxswain language augmentation. In this study, a sensing system was developed that can be used in this environment, allowing researchers to explore ideas based on the Motivation Systems Theory (MST) described in section 1.1.3.

1.1.2 Sports as an Experimental Environment

The use of sports as a testbed of studies has provided an endless subject pool. It is ideal for studies of motivation and human response, since people in sports are goal oriented individuals or teams, and goals are achieved within a reasonable time period over a specified amount of time, such as a season.

1.1.3 Motivation and Related Theory Derived from a Sports Context

Research in motivation has been studied in sports psychology and has far reaching implications in other areas. There are many studies on intrinsic and extrinsic motivation (Deci, 1975, Roberts, 1986) to explain what drives an individual as well as studies on what drives a team. Team performance is positively impacted by team motivation (Zander, 1975), team cohesion (Carron, 1982) and team leadership (Chelladurai, 1984), and negatively impacted by social loafing (Hardy, 1989; Kerr & Bruun, 1983; Stroope, 1992), and fatigue (Ford, 1992).

One theory on motivation is developed by Ford (1992), who at that time was the Chair of the Committee on Psychological studies at Stanford. He conceptualizes motivation in a simplistic way using similarities in past motivation theories. He describes it by a motivation equation, called the Motivation Systems Theory (MST) Formula for Effective Functioning:

Achievement=Motivation x Skill x Biology in a responsive environment.

He describes a fundamental concept of motivation in terms of facilitation:

> All of the MST principles for motivating humans must be understood in terms of the general conception that *facilitation*, not control, should be the guiding idea in attempts to motivate humans. Even when one is in a position of power or authority, the strategy of trying to motivate people through direct control of a person's actions – as opposed to indirect facilitation of their goals, emotions, and personal agency beliefs – should be reserved for situations which swift attainment of a goal is urgent and no other means are available. In addition, because short-term motivational gains often come at the expense of longer-term motivational patterns, one should always carefully consider whether efforts to

> promote a particular *achievement* will also facilitate the development of an individual's competence to deal with similar situations in the future.

Ford's theory is particularly interesting because it suggests that we can measure motivation indirectly, as a function of achievement, skill, and biology. The system developed in this thesis uses sensors to measure a person's achievement, fatigue level, and response to motivating factors in an outdoor rowing environment.

Social loafing describes a phenomena where a person's individual effort diminishes as a group's size increases. It was first researched by Ringelmann, with results published in 1913. His research was significant because he also generated a linear model to predict individual effort as a function of group size. (Kravitz, 1986) Social loafing has serious consequences for the efficiency of any group whether it be for business, athletics, politics, or education.

Stroope (1992) found no support for social loafing in an intact rowing team, but all the testing was done inside on rowing ergometers, and there is reason to believe that her study would not apply to a team rowing on actual water, because of extra variables involved in outdoor vs. indoor rowing (See Chapter 4). Social loafing has not been studied in a competitive vs. practice environment. Although not in the scope of this study, it is possible to use a lighter weight version of the system developed during the course of this thesis to study this phenomena.

1.1.4 EMG, Fatigue, and Motivation

Electromyography is a method for measuring the muscular activities of individual muscles or muscle groups. In ergonomics, surface electromyography is most often used since it allows the subjects to perform their activities in an unobtrusive manner. There are basically two areas in which electromyography is used in ergonomics: "finding the level of muscle strain within a complex work sequence and the examination of whether an activity is associated with the occurrence of muscle fatigue."

The development of muscle fatigue can be inferred from the change in EMG amplitude in the time domain or through changes in the spectral response in the frequency domain. With spectral response, the muscles must be performing a task that causes isometric contractions at regular intervals. The rowing motion provides the right conditions for sensing fatigue.

"A fatiguing activity can only be performed for a limited time. It should therefore be interrupted by regular breaks." (Kumar, 1996)

Ford(1992) cites fatigue as one of the nonemotional affective states that can serve a motivational function. A study by Raymond Compton (1973) presented the motivational effects of four variables on the performance of subjects using a "fatigable handgrip." Subjects were exposed to an attractive girl, monetary reward, verbal encouragement, and control (basic instructions) while performing a repetitive handgrip exercise. The conclusions he derived from the study were

(a) Motivation does not affect an individual's maximum initial strength or his relative muscular endurance;
(b) Verbal encouragement is as effective as monetary reward and basic instructions in its effect on strength and exercise;
(c) The presence of an attractive girl is approximately as effective as verbal encouragement or basic instructions as a motivating factor; and

(d) Verbal encouragement is the most effective means of reducing the fatigue experienced in repetitive handgrip exercise.

The study keeps each motivational effect (the attractive girl, monetary reward, and verbal encouragement) a constant throughout each experimental session. With the developed system, it may be possible to vary an emotional effect over time to facilitate better performance.

1.1.5 Connections in the Media Lab

This work is a significant extension of the work being done in the Media Lab's Personal Information Architecture and Affective Computing Groups. Prior work of Professor Hawley, Maria Redin, and Brad Geilfuss in the Personal Information Architecture Group demonstrated the use of capturing data relating to one's personal state in the Marathon Man and Black Boxes projects (PIA, 1997). My work extends this, using the context of the rowing shell to collect data on a person's physiological and skill state while he/she is rowing on the water.

The Affective Computing Group focuses on computing that relates to, arises from, or deliberately influences emotions (Picard, 1997). Current applications include better learning systems. My work provides the foundation for the proposed learning interface derived from the captured training data to help a coxswain motivate his/her rowers.

1.2 Research Overview

In this thesis, I provide a framework for further research in quantifying the behavior involved in motivation by developing real-time feedback systems and a response system.

Although this work is presented in a linear form, the research method is an iterative design process where one part of the system is always affecting the some other part of the system. One just has to troubleshoot and determine where improvements can be made in small steps.

1.3 Organization

The next chapter shows the exploration of different response systems tested in a rowing environment. The explanation includes four different configurations. Chapter 3 discusses the motivation and implementation of a sports response agent. Chapter 4 takes a look at issues and findings with the current system. Chapter 5 concludes with a summary of the current system with comments from the crew and a summary of contributions. Chapter 6 recommends future work. This is followed by a bibliography and an appendix.

Chapter 2 The Search for a Good Feedback System

An on-board real-time feedback data collection system was developed and tested. The following is a list of design goals considered important in the design of an effective on-water data collection system.

2.1 Design Goals

1. The system can not interfere with the normal operation of the rowing shell.
2. The system should be portable from shell to shell and generally easy-to-use.
3. The system should weigh less than 10 pounds, in order to not add excessive weight to the shell.
4. Each person should have their own "Personal Module" so that they can choose what kind of feedback they want to capture for themselves. Each personal module would have a description of a personal profile or goal that they want to achieve.
5. There should be a way for each Personal Module to connect with each other. If two or more people want to compare each other's goals or work as a team, they should be able to connect their Personal Modules with the others.
6. At least two sensors of each kind should be mounted on the boat in order to make comparisons among the rowers.
7. The System A/D board should sample at least 1024 samples/s if EMG sensors are used, or at least 20 samples/s for other types of sensors measuring force or acceleration.
8. All data should be processed on the on-board computer for greater speed of rower and coxswain feedback.

9 Some of the data that is processed should be sent out of the boat via a modem to another location so that it is known that the system is working while on the water.

10 The system should be waterproof. Parts of the system should have a heat-sinking capability.

11 There should be rower feedback so that the rower can automatically monitor his/her performance.

12 There should be coxswain feedback about the rower's physiological and psychological state.

13 There should be coxswain feedback in terms of how he/she is affecting the rower by his/her commands.

14 There should be an on-board GPS system to monitor where the boat is in order to compare previous performance at that location.

15 The general public should be able to track the boat's location through the Internet.

16 The system should be usable over a long period of time; an average crew practice is 1.5 hours long.

2.1.1 Current Design

The current design meets Design Goals 1, 2, 6, 7, 8, 9, 10, 12, 13, 15, 16. Other goals can be attained with recommendations (See Chapter 6 Future Work).

2.2 *The Tactile Feedback System*

The following system was developed for the requirements of a class project during MAS 837: Collaboration Between People, Computer, and Things:

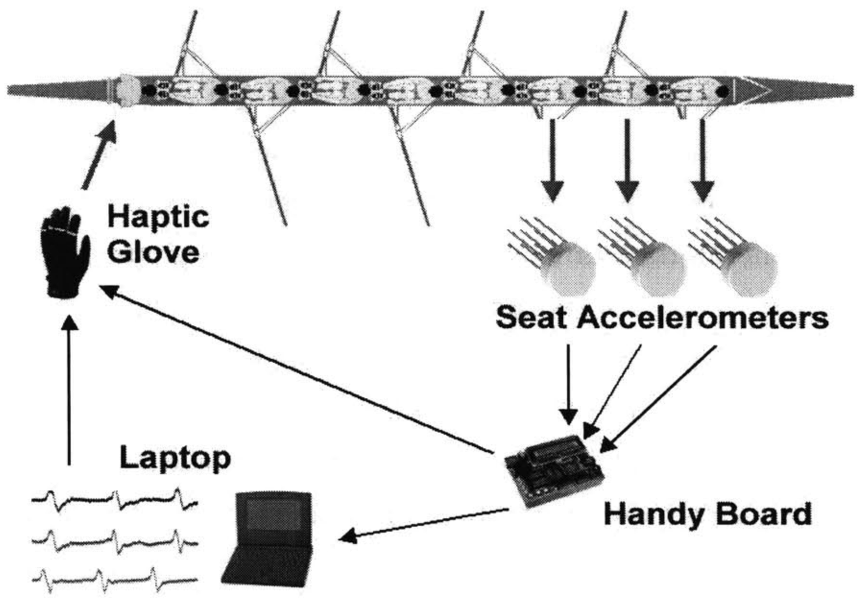


Figure 1: Handy Board System with Tactile Feedback Glove

The system consists of a Handy Board, which takes analog sensors, which is attached to a laptop computer. The computer processes the sensor data (in this case accelerometers to measure the slide motion of a rower) and a range is defined based on the rower's average slide ratio. The coxswain wears a haptic glove which is part of the sytem. The haptic glove has a motor on each of the fingers (not including the thumb) to correspond to one of the eight rowers. When a rower is out of range relative to how fast other people are rowing, a signal is sent via a vibration of the motor on the haptic glove.

This system worked well in terms of fast response from aggregate data of one type in a real-time situation.

The same seat accelerometers were retained for systems 2, 3, and 4.

Several problems with this system were:

- The motors used were very bulky; other vibrating motors, such as the one used in pagers may be better in terms of user comfort.
- It is not clear how many types of signaling devices (i.e. vibrating motors) can be put on a haptic glove to signal the user about different types of sensors. A user can get very confused if there are too many signaling devices in a small area, such as a glove. The coxswain also has to use his/her hands to steer the boat. In general, the number of different types of signaling devices limits the number of sensors that can be used at one time.
- The Handy Board may be overkill as a personal module. It can handle up to eight analog sensors, and has many more controlling chips for use with other devices not needed in this study. It also requires more power than other alternatives of a similar kind like the irX board.
- Although adequate for classroom demonstration, the personal computer used was too bulky and weighed too much. It is possible to get the same computing power and storage capability from a wearable computer such as the PC104.

2.3 SmartSHELL System

A real-time feedback system was developed and tested with the MIT lightweight crew team:

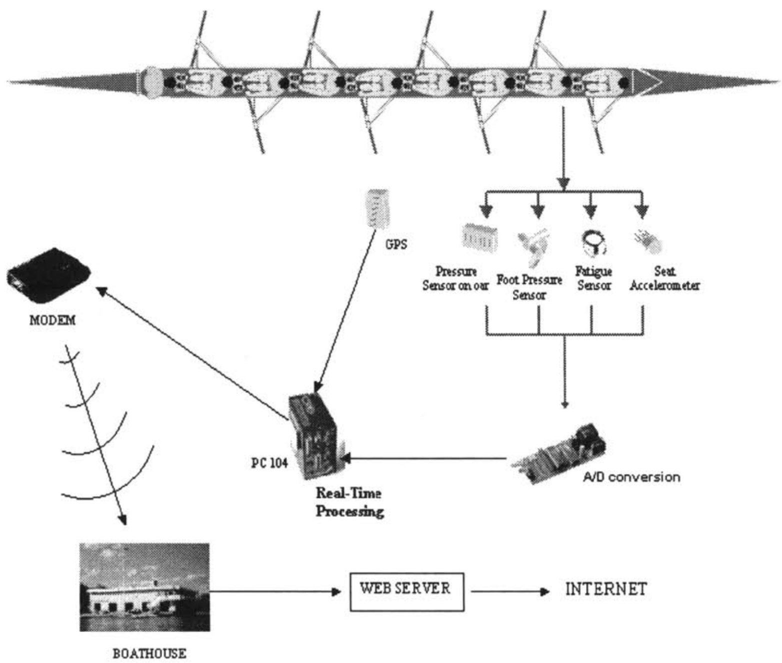


Figure 2: Original System with PC104 and irX Sampling Boards

On October 19, 1997, this system raced in the International Annual Rowing Event, the Head of the Charles. Over 4500 male and female rowers from all over the world competed in 16 events over a 3 mile course. The course begins at the Boston University Bridge and ends at Herter Park. The system was placed on an eight-oared shell and used by the MIT lightweight men's varsity team. We had waterproofing problems (See Section 2.5.1). Although the program controlling the board and computer worked, the data gathered during the Head of the Charles was unusable. Problems from this version provided valuable insights for versions 2 and 3.

A PC was used inside the shell, to avoid an "outside the boat processing" latency. The system consists of a PC104 wearable computer as its main processing component connected to a personal module for each rower. The PC 104 used a Linux system with a 80486-50 MHz processor and a 2Gb hard drive. An SSP card is used to add extra serial ports to the unit. The personal module consists of an irX board where sensors are attached to capture physiological and skill information.

Part of the information was sent to a multicast webserver (Boissière, Dreilinger, Hsu, 1998) so that the outside world could monitor what was going on in the boat. The Garmin GPS II+ satellite receiver and modem were both connected via serial ports to the host computer. The GPS uses signals emitted by the 24 GPS satellites administered by the U.S. Department of Defense to triangulate a latitude/longitude position accuracy of around 30 meters [This can be improved to 1-5 Meters if differential corrections are used]. The particular unit we used takes about 45 seconds to get an initial position fix from powering up the unit, then sends out the current position over the serial line using NMEA protocol every two seconds. Because the device was located in the boat, satellite reception was particularly good as there were virtually no obstacles to interfere. The five bridges on the Charles course did not pose any problem as the shell transversed below quickly enough to keep a fixed signal. The PC104 host computer parses the NMEA position information as it is received and converts the latitude/longitude position to an abbreviated format, which is then transmitted via the wireless modem every fifteen seconds to the land based multi-cast subsystem.

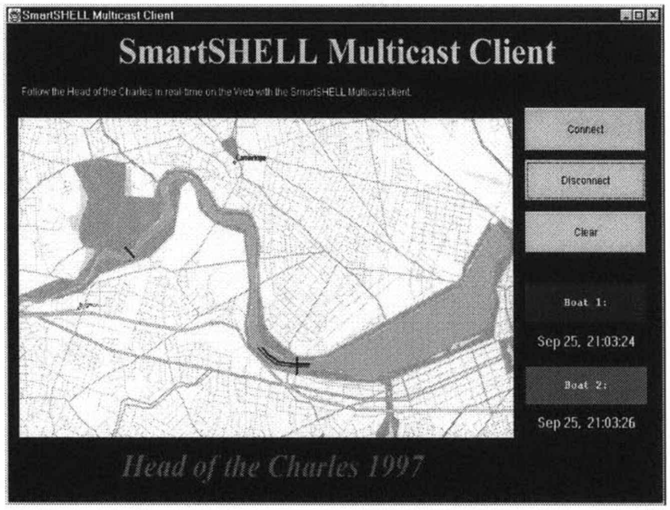


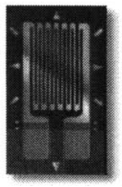
Figure 3: Screenshot of the Multicast Racing Interface

The irX boards were used in the third system. The GPS with webserver and all the other sensors were retained for the second and third version. The control program was retained for the second version. There was no feedback to the coxswain at this point; this was tested for the purpose of data collection

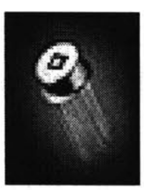
Several problems with this system:

- Low sampling rate of the irX boards when chained together. The sample rate for single irX board is high, but when multiplexed together, it takes 1 second to change channels. This is acceptable for sensors such as those that measure heartrate or temperature in certain conditions, but it is too low for EMG or pressure sensors.
- Inability to receive feedback from the PC104 once it is in the boat. One has to wait till the boat gets back to find out what was data was actually recorded. There is no capability of recording what the coxswain is saying. The PC104 was limited in the number of ports that could be outfitted.
- Lack of Good Waterproofing from layers of plastic bags and duct tape. See section 2.5.1 Course 101: Waterproofing your computer.

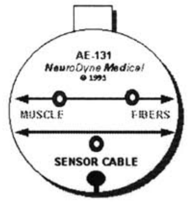
2.3.1 Sensors



Rowing power is measured in the on-board system, using oars and footstretchers instrumented with strain gauges to assess force. The strain Gauges come from Measurements Group and are a general purpose type (CEA-06-125UW-350) widely used for experimental stress applications like force measurements on oars or strain on helicopter blades. After applying the strain gauges to the oars, a special epoxy is applied to the gauge, and then covered with a general purpose epoxy to make it waterproof. The amplifier for the strain gauges comes from Transducer Technique, requiring a 12V power source. These were used with smartSHELL 1 and 2.



Accelerometers are placed on the rower's seat to determine whether he/she is rushing the slide and also as an indicator of what part of the stroke correlates with the force measurement. The accelerometers resolve minute changes in acceleration (from 0 g to ±5 g full scale) with 0.005 g resolution. It uses a 5V power supply. These types of accelerometers have been used in virtual reality headsets, machine health monitors, seismic instruments, medical and applications involving movement. These were used with the haptic system and smartSHELL 1 and 2.



Muscle fatigue development is measured through an electromyography signal (EMG). The EMG sensors are from Neurodyne Medical, Inc. The following is taken from their website information (www.neumed.com) about their EMG sensors: the sensors house a preamplifier with high common mode rejection. The signal is boosted by 60 dB (1000x) before being sent down a cable, thereby eliminating a major source of artifact. This configuration, in conjunction with high impedance inputs allows scanning of various muscles without necessary use of gels. It features full power bandwidth measurement of the EMG signal to prevent false readings as a result of spectral shifts induced by fatigue. It also contains a power detection circuit which produces estimates of force over a 80 dB dynamic range. Immediate amplification of EMG signals also means that they can use long wires without distortion. The signal then requires minimal filtering). These were used with smartSHELL 1, 2, and 3.

As described earlier, a Garmin GPS II+ relays location data of the boat to the webserver. This was used with smartSHELL 1.

Heartrate sensors were considered but are not in the scope of this project; they can easily be added to the system. These sensors are the same ones used throughout all the smartSHELL systems.

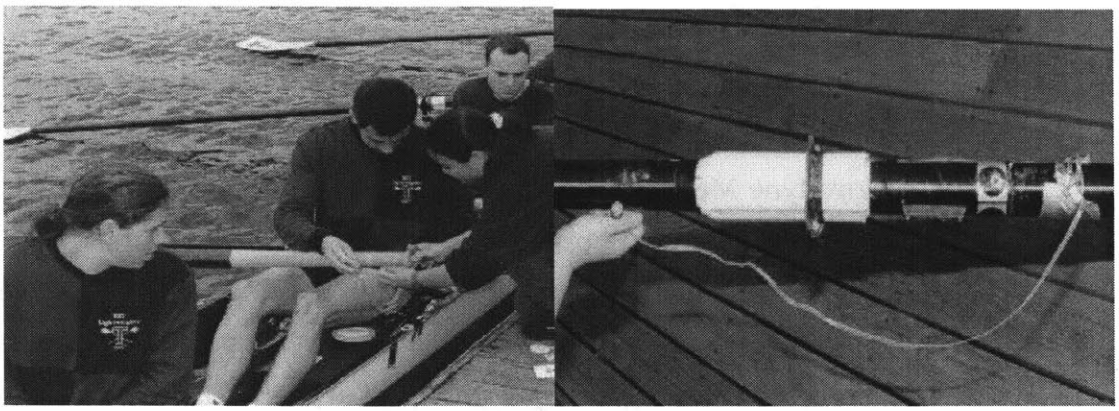


Figure 4: (left) Putting EMGs on the Rower's Leg; (right) Strain Gauges on the Oars

2.4 SmartSHELL System version 2

A problem with the sampling rate of the irX board led to other configurations, this time with a RS-485 device.

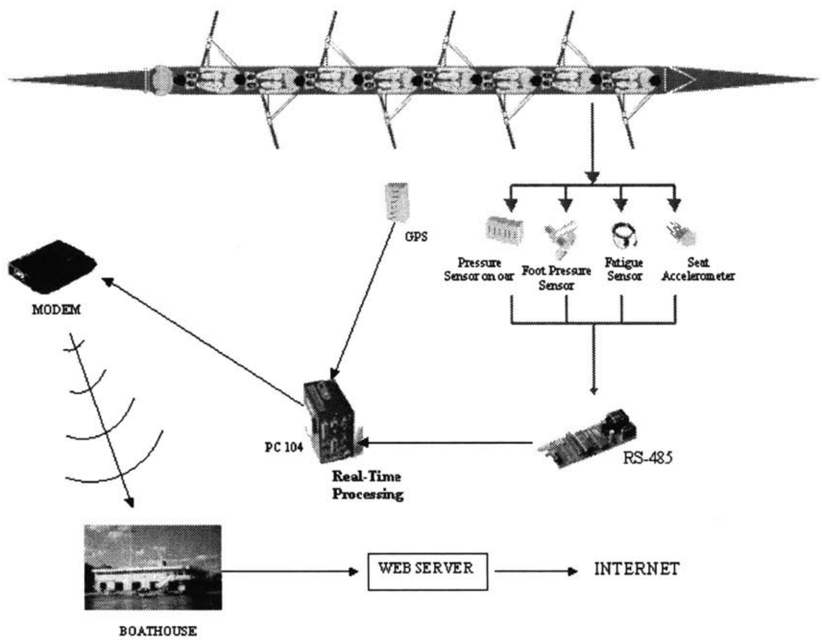


Figure 5: Second system with RS485 Hub Connected to irX Board

Each of the irX boards held one sensor and was connected to an RS485 hub with a RS232 output port. This acted as a multiplexer for the irX board, since it has a higher sampling rate when it is by itself. In a way, the RS485 acted as a "bandaid" rather than a robust solution for the irX sampling rate when the use of more than one sensor was needed for tests. The RS485 hub also works better for long distances and is a differential data line, which is supposed to be superior to RS232 communications. Yet, still several problems remained with this configuration:

- RS485 hub is another extra bulk –It is 3 pounds and needs another pound of batteries to run. The real problem was that the irX board needed to be replaced with a board with faster multiplexing capabilities.

- The lack of feedback problem while using the PC104 was still an issue, and other systems seemed to be better, more flexible solutions as the reader will see next.

There was no feedback to the coxswain at this point either. The sensors and GPS webserver were retained for the future version.

2.5 S^3 (SmartSHELL System Version 3)

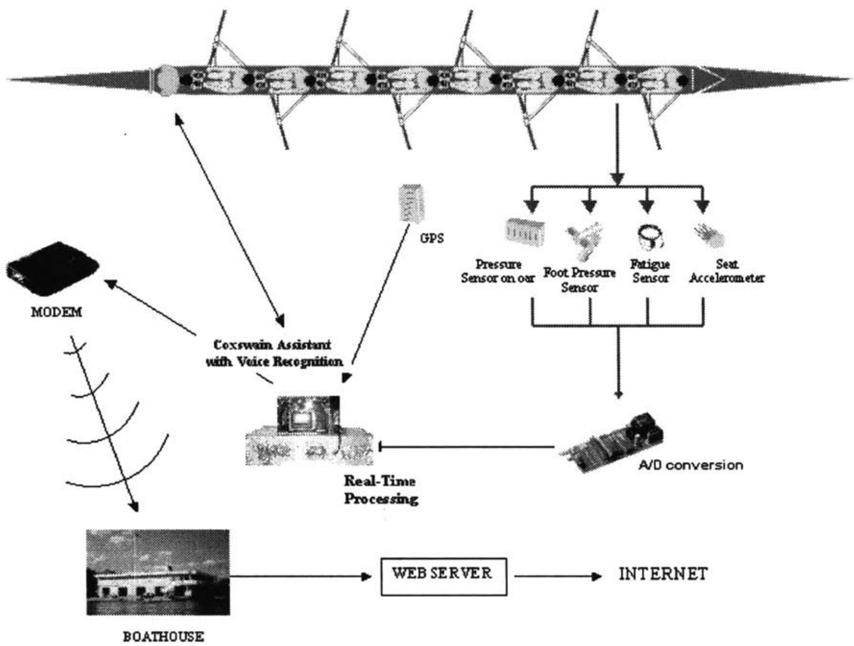


Figure 6: Current Version of the System Featuring Voice Recognition

The newest, improved system at first appears to be similar to the previous systems, but many of the units are very different. A Compaq Armada 7730MT laptop serves as the main processing component connected to an A/D board by Computer Boards, Inc. through its PCMCIA slot. There is another slot where a wireless LAN by AMP transmits information to a remote computer with the same LAN module. The Compaq notebook runs at 166MHz with 148M of RAM. It is running a software agent written in Java called the Coxswain's Assistant, which is explained in more detail in Chapter 3. The Coxswain's Assistant has a voice recognition module made using Watson (AT&T) with input through the same coxswain microphone used for a CoxBox. Because of the voice recognition capability, any main processing component for this system needs a minimum of 65M of RAM.

Currently, problems are:

- Weight of the system: The system is too heavy and too bulky to be put in the shell during a race; however, the software is transferable to any computer running Windows 95 or NT. In the future, it is hopeful that PC104 or some smaller system can handle the large RAM constraint. If we owned the notebook, then it could be taken apart so that the screen is not available, since there is an additional display. A better possibility is to have dedicated boards built right into the shell.
- A/D board too bulky. It samples fast enough, but it is too big for a personal module. Different lengths of wire are needed to tie the oars into the sampling board and cause ununiformity of signals.
- Bigger but petite display for the Coxswain's Assistant (See Displays). The TV is a usable option, but a higher resolution and wider screen TV or waterproof display would be better. Four inch diameter seems to be a good size.

2.5.1 Course 101: Waterproofing Your Computer

Waterproofing became an important issue after the Head of the Charles. Although previous experiments were successful using layers of plastic bags secured with duct tape, the water at the Head of the Charles was extremely choppy, causing the boat to be filled with water. Plastic layers were not enough.

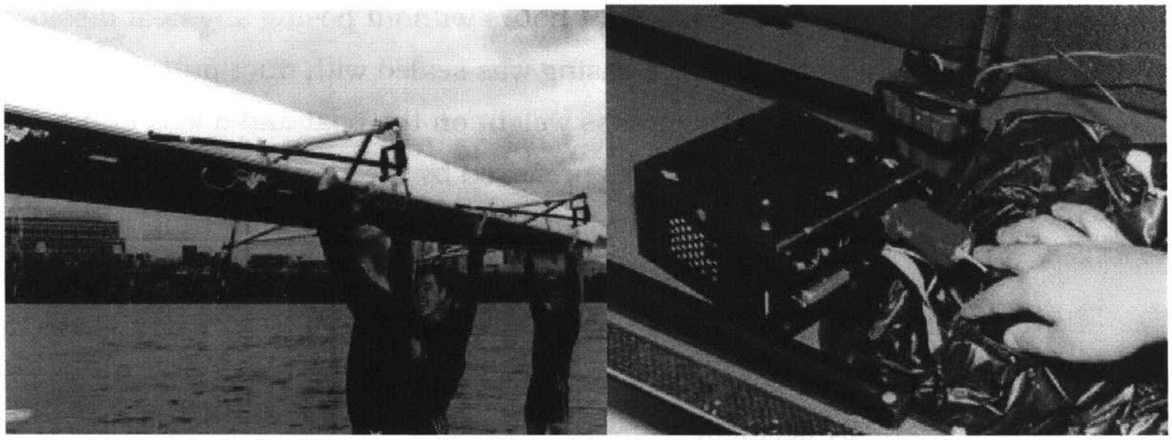


Figure 7: (left) Crew Emptying the Boat Full of Water; (right) PC104 Barely Surviving the Boat

Experiments to determine temperature variables were performed, and a final waterproofing system was made. The computer was placed in boxes of different materials with a thermometer. Aluminum was recommended by a professor in mechanical engineering at MIT, a physicist at University of Pittsburgh, and a CMU machine shop supervisor as the lightest and best heat dissipating material for this purpose. The temperature was checked every 10 minutes for an hour. The box made of aluminum helped heat dissipate the best, while boxes made out of plastic increased the temperature 12 degrees, making it necessary to reboot the computer.

The aluminum box was outfitted with null adaptor connectors so that all connections could be made from the outside of the box. All the connections on the outside of the box are enclosed in home-made encasings and sealed with duct putty and tape. The box corners are sealed with RTV or duct putty. Another way to deal with the outside connections is to use hermetically-sealed connectors, but for certain shapes of connectors (like the parallel port), it is difficult to find.

Another casing was made for the computer using GoreTex material. Previous testing with GoreTex proved that the computer would stay on for at least eight hours without posing any heat dissipation problems. The casing was sealed with duct putty with an overlay of duct tape. For less weight on the boat and a less bulky package, the GoreTex case was preferred by the Coxswain. With this casing, the computer survived and did not shut down during the worst rainy day of the season. Extra padding is required when using a GoreTex casing, since it is integrated into a thin material, and the docks are slippery when wet causing coxswains to occasionally drop equipment by accident.

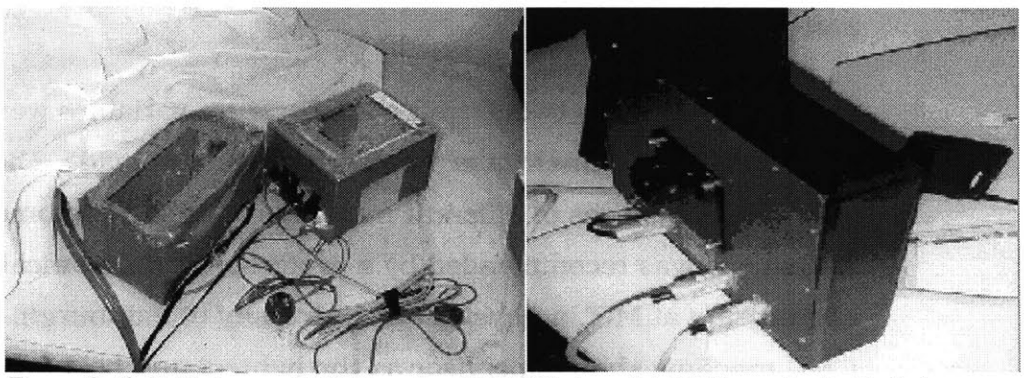


Figure 8: (left) Waterproof A/D Board and EMG System; (right) Hermetically Sealed Connectors

2.5.2 Displays

The S3 system utilizes a graphical user interface like the ones shown on the screens of the following displays. The graphical user interface is actually the window to a response agent that will be described in Chapter 3. Initially, a Pilot interface was going to be used, but to display a monochrome version of the same output, it needed an extra serial port and hardware. Color output was more visible and preferred by the coxswain. Five display configurations were investigated for the system using a coxswains' opinion for input. They are presented in chronological order:

♦ **Waterproof LCD Flat Panel**

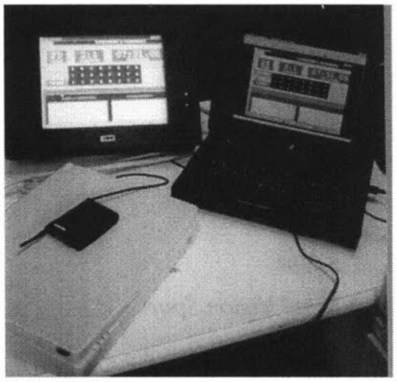


Figure 9: Waterproof LCD Flat Panel Display by Advanced Engineering Incorporated

This display was the coxswain's second choice. It features a High Bright Backlight that is 10 times brighter than a typical laptop display. There is a touch screen capability that was convenient for the coxswain to switch between the sensor screens. The image quality matched that of the laptop. Unfortunately, it weighs more than 10 pounds, making it extremely heavy for race capabilities.

♦ **M1 Personal Viewer by Liquid Image Corporation (not pictured)**

This unit is designed to be a field of view display for applications that require hands-free operation. It offers exceptional image quality in black and white. It is designed so that a little screen is situated 4 inches in front of your eyes. It is less obtrusive than the Virtual Vision Sport Visor below, and it was preferred over this one because of its less obtrusive quality.

♦ **Visor with display**

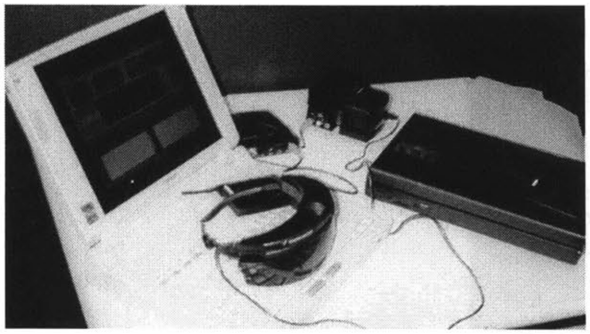


Figure 10: Visor with Eyepiece Television by Virtual Vision Sport

This visor houses a mini screen about 1.5 inches below your normal field of view. The image quality is not as good as the M1, as it is designed for NTSC. The screen is also not as large as the M1, making it more difficult to read text in this format. Coxswains were not as comfortable with this as the M1 as it is too close to the normal field of view, and they feared it may interfere with their ability to see other boats in their line of sight.

♦ **Television with External Antenna Input**

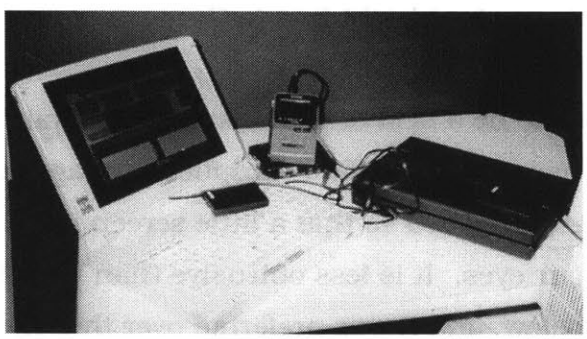


Figure 11: Casio Pocket Television as display

This configuration features a VGA-to-Video Modulator connected to an RF Modulator connected to an external antenna input of a pocket television. This is a good option as the screen is text-readable at certain sizes. The screen is 2.5", and it is big enough for a coxswain to glance at, but not as obtrusive as a large display. This screen was acceptable by the coxswain, and it was preferred over the first display because of it compact size.

♦ **Pocket Television with Video Input**

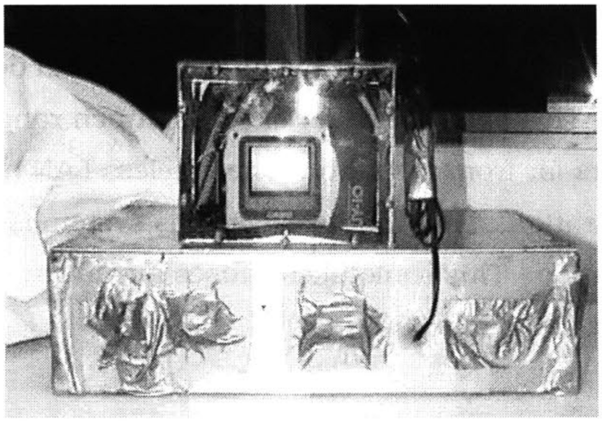


Figure 12: Casio Pocket Television encased in Waterproof Housing on top of Laptop Box

This configuration is similar to the previous one, and is the one used in the final version. This model has a video/audio jack, so an RF modulator was not needed, reducing bulk. The screen is 2.5" and text can be read at a certain size. The display is shown with its waterproof casing.

2.5.3 The CoachBox: A Coach's Aid

During practice, a rowing coach will follow his/her crew in a separate boat called a launch. From a small distance, he/she can monitor the crew from a different perspective than the coxswain. The coach orders drills and offers advice to the coxswain and rowers while on the water. With a system on the shell, a coach can monitor what the coxswain sees on the on-board computer with a separate computer the author calls the CoachBox. The CoachBox consists of a laptop with a wireless network. With the help of a program that connects the two computers, the coach can monitor conditions in the boat. The program acts as a remote control for the computer that is in the shell. The coach can compare what he/she sees with his eye to what the computer reports about the sensor information. The coach said that this is helpful as it gives extra information to the coach to make decisions as to what the crew should do next.

The wireless LAN used works in a range of 1000 feet and does not need a main hub. This is adequate for shell to launch range, as neither boat lingers far from the other. The wireless LAN hardware is a PCMCIA configuration. The A/D board on this system is also a PCMCIA configuration. This sometimes causes a conflict, depending on the computer it is installed on.

Chapter 3 Sports Assistants and other Responsive Agents

Imagine that you're riding your bicycle. After 8 miles, it's that hill you hate. You can't see the top of it. Flashbacks to the last time you and THE HILL met only conjure the memory of the sting of sweat in your eyes with salt on your lips. *Well, I did it last time, maybe this time I'll make it up the hill.*

The Sports Assistant is on. Good, GO FOR IT!!

The first tenth is always easy. Like starting a new project, everything is new and full of promise. Then reality sets in. You're tired from the last three hills 2.5 miles ago. Your legs are like logs. It's like you have asthma. You're not in high school anymore. Everything is bothering you, and you still have that 9/10 of a hill.

Suddenly, your favorite music kicks in. It's just the right tempo for how fast you could pedal at the moment. There is no change in the angle of the hill. A second favorite song kicks in and it's a little bit faster.

Before you know it, you're pedaling down the other side of the hill, and things are GREAT!

Now what should I do with that car loan?

The Sports Assistant. This is just one scenario of how a sensitive, adaptive system in conjunction with a variety of sensors can be used to try to help an individual perform his/her best. The S3 system uses an agent which responds to physical and physiological behavior and tries to help an individual become more motivated. In addition to rowing, this type of system can be used in other endurance sports. One difference between a person riding a bicycle, running, or swimming vs. a person who is rowing competitively is that in addition to your own intrinsic motivation, there is a person called the coxswain who helps motivate you and your team.

3.1 Coxswain's Motivational Techniques

Coxswain

In the sport of competitive rowing, an eight-person boat requires a coxswain. The coxswain sits at the stern of the boat and works with the rowers and the coach. He/she has the following responsibilities:

- Steering
- Motivator of the crew
- Feedback to improve oarsmen's technique

The coxswain has a key role in the boat because he/she is the one who help the rowers to collaborate together and to make the boat go as fast as possible.

Coxswains use different techniques to motivate their teams. Eight coxswains at MIT, some of whom had Olympic-hopeful experience, some of whom were varsity-level, and some who had years of intramural experience, were polled to find out what they used to motivate in the boat.

- **Words to emphasize parts of the stroke**

Lean (for the swing), drive, go, jump, stand on it (for the legs), away (hands out of bow), catch/release

More technique phrases:

quick/sharp catches
fast turn around at the catch/front end
fast hands on the finish
catching on the recovery
seat/blade timing
rolling off the feather
skying at the catch
going deep
washing out
rowing it in
holding the knees down
early body angle out of bow
high hands at the finish
leaning through the stroke
relaxed shoulders
staying long/length
low hands during the first part of the recovery
bringing the hands up to make the catch
relax on the slide/slowing the slide/controlling the slide

- **Random phrases used spontaneously**

Going through the wall, Bringing out the kodiak, No Regrets, walking/dancing right through 'em, Pull it Home

- **Different voices**

"I also have many different voices. I only use my "race voice" during races. If it is a race piece (race piece means it is a practice piece as if it were a real race], it's usually not quite intense as during a real race. A friend of mine didn't know which boat I was in because she thought I was a guy. The voice I use for racing is very deep and gutteral.

When I'm trying to calm them down, it is, of course much more smoothing. If I want things precise, it's short and quick, but not hard, because that just makes their technique go to hell."

"Voice intonation. Deep, uplifting voice that is in synch with the pace of the boat. Slow for long pieces. Sharp commands in faster pieces. Tell them to go faster in various ways. 'More on the drive! Get up! Flow at the catch!" "Swing! Swing!'"

- **Yelling to the Rhythm**

"Saying ' PUll it in' to the same rhythm of the stroke helps the rower with synchronization. I like to synchronize my voice with the rhythm of the stroke. That seems to help the rowers."

- **Sense of Urgency**

"Tell them where other boats are. Tell them that they are moving on them. If they aren't, tell them they have to move. "Two seats down on the other boat. Confidence now. Open it up and drive, drive. Stand up...yeah!! We made a seat, now let's go for another!"

"All Right, I'm on their 6 man. I want their 5 man in 5 strokes."

"[I tell them] Time/distance to go.:"

- **Positive or Constructive Criticism**

"Tell them what they are doing well, and what they are not. "Catch timing is good, but we can do better with our slide control. In two, down one [stroke per minute] on the slides, up one on the drive..'"

3.2 The Coxswain Assistant

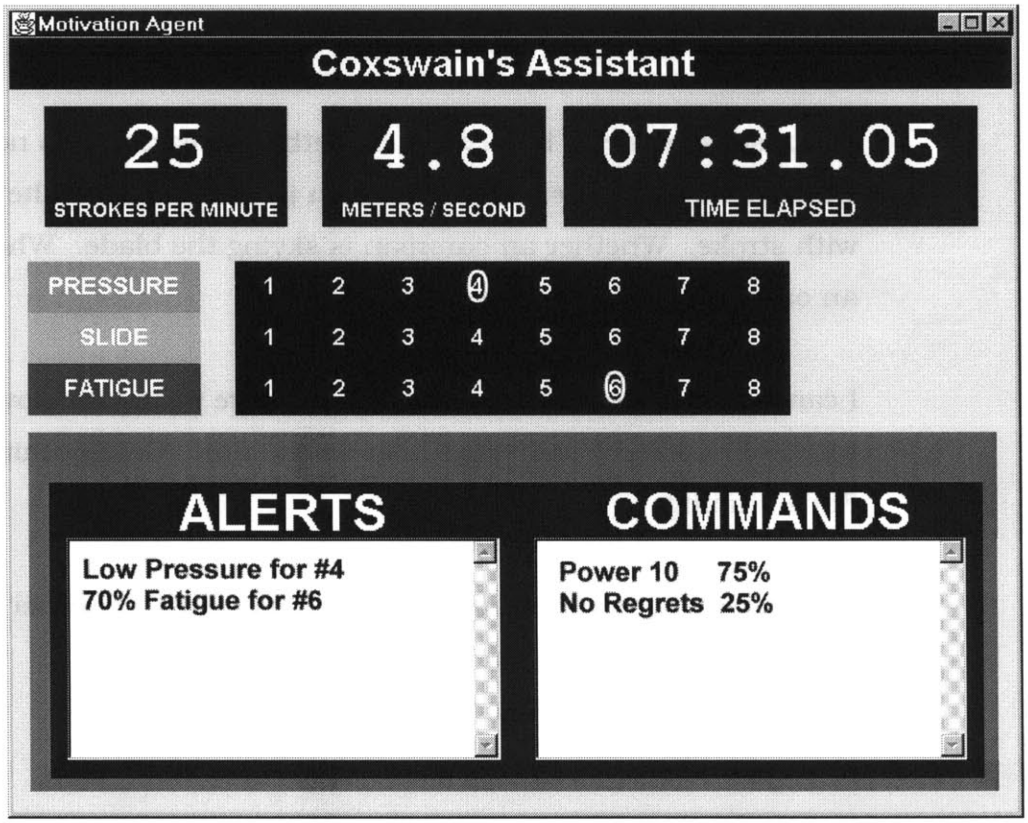


Figure 13: Interface that the Coxswain Sees on His/Her Display

As the coxswain sits in the front of the boat, without electronic equipment, he/she is aware of:

- whether the boat is balanced or not
- whether one or more of the oarsmen are not in synchronisation with the others

Current electronic equipment helps the coxswain with average speed of the boat, and strokes per minute. The problem with all this information is that it gives a coxswain a general idea of where problems may occur, but it takes a very experienced coxswain with a coach to figure out exactly which rower and what specifically the rower is doing wrong. This is in part because, he/she can only see the rowers in front and the oars on the side: the visual cues are very limited.

"I can see oarsmen's bladework. Whether an oarsman is not catching with the stroke. Whether an oarsman is not feathering the blade with stroke. Whether an oarsman is skying the blade. Whether an oarsman is rushing the slide.

I can feel boat run, whether the oarsmen are plying the power together and accelerating the boat as one unit. Catch timing. Finish timing.

I can hear whether the catches are in general off. Whether the finishes are in general off. Whether water is being thrown up at the catch or finish..."

The above figure is the graphical interface that a coxswain would see on his/her display as part of the S3 system's augmented coxswain interface. This interface was designed with the input of several coxswains at MIT. Currently, the Time Elapsed, Alerts, and Commands functions work with the Coxswain Assistant. Speed, Slide Rating (strokes per minute), and the Pressure/Slide/Fatigue bars are left open for future work. The ALERTS and COMMANDS functions are really windows for a response system the author calls a motivation agent.

3.2.1 Coxswain's Motivational Assistant

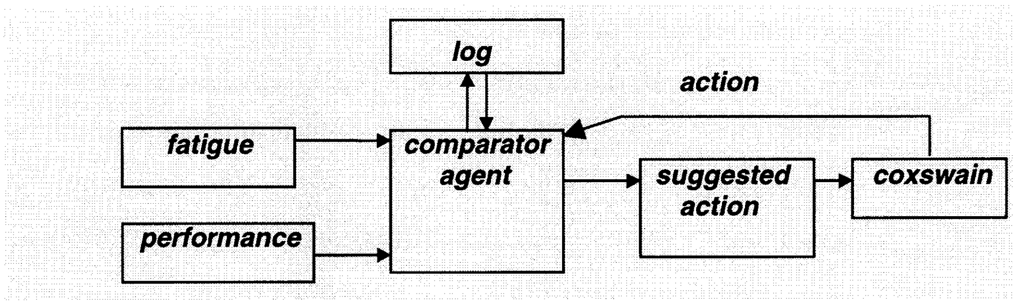


Figure 14: Diagram of the Mechanism of the Agent in the Coxswain's Assistant

The Coxswain's Motivational Assistant is an agent that uses a standard reinforcement-learning model: on each step, the comparator agent in Figure 14 receives as input some indication of the current state of the environment; the agent chooses an action to generate output (Kaelbling, 1996). Fatigue and performance data are measured over time and sent to an agent that check how they compare to previous performance. From the different measurements, an action is taken under the form of a signal sent to the coxswain. Thus, at any time, the coxswain is given an indication of which rower is acting outside the specified boundaries. A coxswain will act in one of the preprogrammed states (i.e. do nothing, or decide to motivate the person using a certain command or phrase). The coxswain action or nonaction is logged. If performance and fatigue data gets better as a result of the action, a "reward" will be assigned to that action given the status of the global parameters of the race. If the action has negative results, the action will be given a punishment corrective value. Overall, the action taken that will be taken by the agent will be the most promising one as calculated by previous rewards and punishments.

When the system is first turned on, original EMG and force data are obtained and compared to preprogrammed results from individual indoor experimental data. Accelerometer data is saved for future work. In terms of EMG, the agent tracks the maximum of amplitude during the rowing motion. If the maximum amplitude decreases for five consecutive strokes to 30% of its initial value, the coxswain is alerted. To calculate this amplitude, a window based on a rowing motion and a half, which is approximately 3.3 seconds, is applied to the signal. The coxswain responds as he/she normally would in terms of coxswain language and a voice recognition module understands certain phrases a coxswain would train it to recognize (See 3.2.4 Commands and Effects).

Referring back to the MST Formula for Effective Functioning (Section 1.1.3) where *Achievement = Motivation x Skill x Biology in a responsive environment*, motivation is being measured indirectly by this system as a function of achievement, skill, and biology. Achievement refers to "the attainment of a personally or socially valued goal in a particular context" (Ford, 1992), and in this case refers to how close to maximum power the person is rowing. For skill, since we are looking at specific set within the MIT lightweight varsity crew, we say the skill set is constant. For future implementation, use of the accelerometers vs. pressure sensors can determine a person's skill level to see if the greatest force is occurring at the catch, whether he/she is applying constant force through the drive, etc. Biology refers to measurement of fatigue in terms of EMG response. Other sensors can be used such as those that measure heart rate or respiration.

3.2.2 The Time Elapse function

The Time Elapse function is essentially a stop watch. When start is pressed, it queries the computer system time and stores it in memory. Every few milliseconds, the program queries the computer time and calculates the difference with the recorded computer time. This difference corresponds to the number of seconds since the watch was started.

3.2.3 Alerts

When a rower performs the rowing motion, information about the rower is captured through EMG or foot or oar pressure sensors. By the method explained above, if a rower is below the expected performance level, then the coxswain will be notified through the Alerts window. The expected performance level is determined through the individual's indoor data. The slope of the EMG signal helps determine how far from maximum the rower is performing. The maximum pressure indoor is compared to maximum pressure outdoor, and it can be adjusted for trials outdoors if maximum pressure outdoors exceeds the indoor maximum. All these values can also be adjusted with consensus between the coach and athlete. The symptom and rower are identified.

3.2.4 Commands and Effects

When the coxswain sends a command to the rower or rowers, this command is input to the speech recognition system and transmitted to the agent. The agent has a list of predetermined commands that are personalized for each coxswain. When a command from the list is received, the program monitors the performance of the rowers during a specified period of time until the next command is recognized. If the command has a positive effect on the rower's performance in terms of the nature of the command vs. the amplitude of the pressure or maximum muscle exertion amplitude of EMG envelope, a positive reinforcement value is given to that particular command. Over time, for each command, a success percentage (percentage of time the desired outcome occurs) is calculated. For example, if a coxswain says "Power 10", which denotes that all rowers have to row at maximum pressure for ten strokes, then if 6 rowers have max pressure and 2 rowers are under max the success percentage will be 75%. This helps the coxswain to make more informed decisions about what kinds of phrases are having what kind of effect on the rower. In essence, the agent enables the coxswain to measure his/her ability to motivate the crew.

Chapter 4 Issues

"Why bother taking data outdoors when you can get data indoors?" "
The author admits that since every time she wants to take the system outdoors --besides the long preparation before a daily setup routine, the daily setup routine requires 2.5 hours before setting the system on the boat, and another 2 hours to recover the system to get it back to a state for use the next day, not to mention the additional 3 hours to process the data that night to see what has happened –the work is very tenuous and that is a very resounding question. Since the context is rowing, the rephrased questions are

Why bother taking rowing data outdoors when you can get rowing data inside? Isn't it very similar, since rowers perform the same motion indoors and outdoors?

When a rower does work indoors on an ergometer, many outdoor factors are not present:

- There is no coxswain to motivate the person the same way as outside.
- There is feedback on the ergometer screen telling you how fast you are pulling, what your stroke rating is, and the time elapsed.
- The rower does not have to worry about keeping the boat set, or balanced.
- The rower does not have to worry about blade placement in choppy waters or other technical factors.

Additionally, the indoor rower can tell how hard he/she is pulling the handle based on the amount of wind that he/she generates with the flywheel attached to the ergometer. For all these and other reasons, a person rows differently outdoors than indoors.

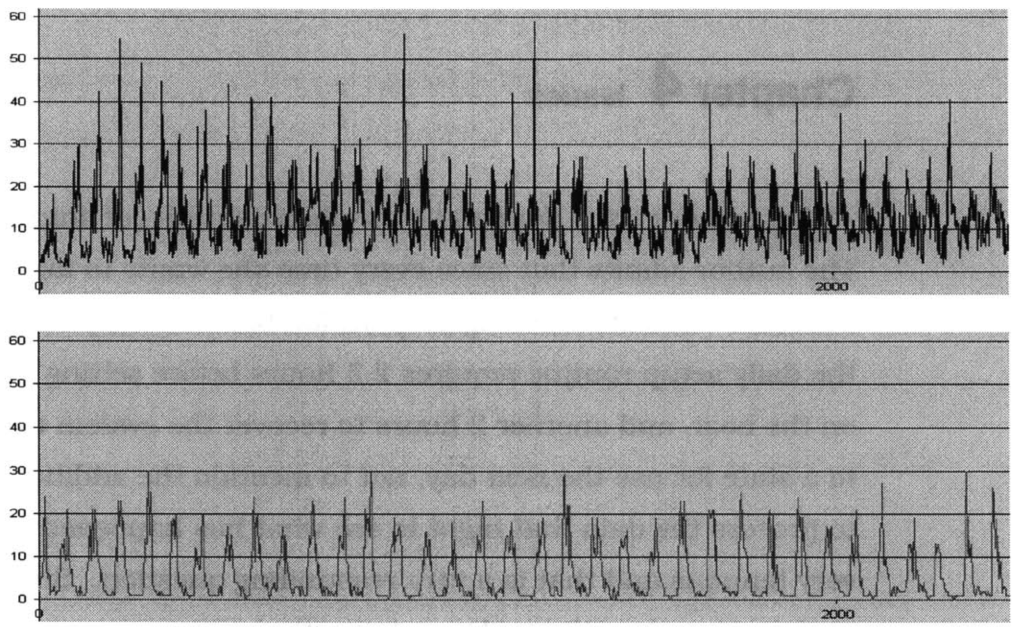


Figure 15: Indoor Rowing Test , Subject 1 at the beginning of two successive trials

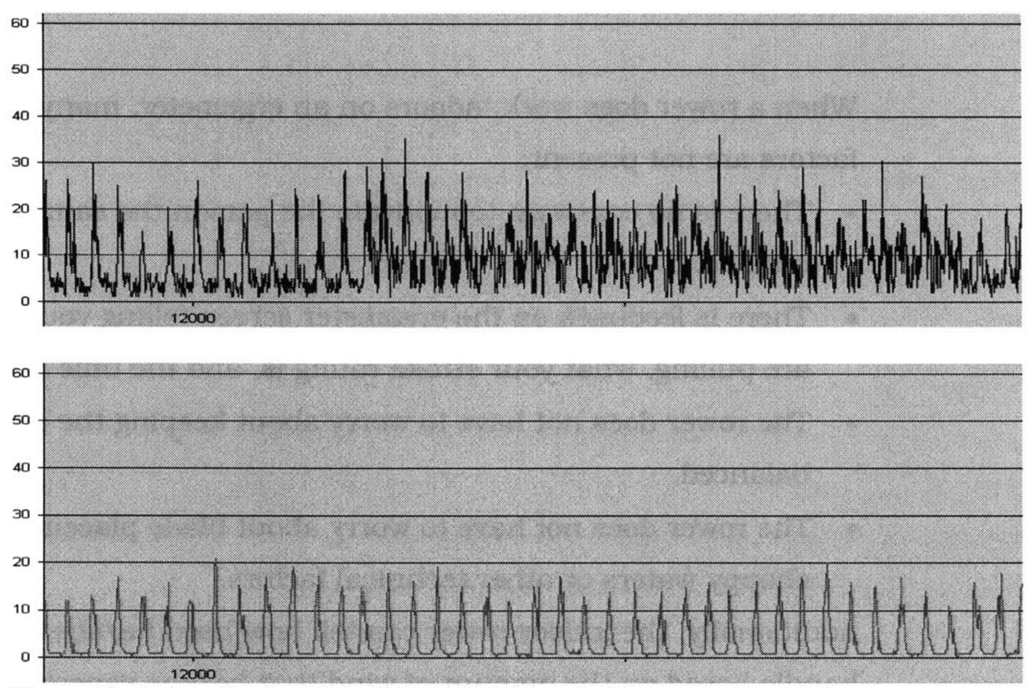


Figure 16: Indoor Rowing Test , Subject 1 at the end of two successive trials

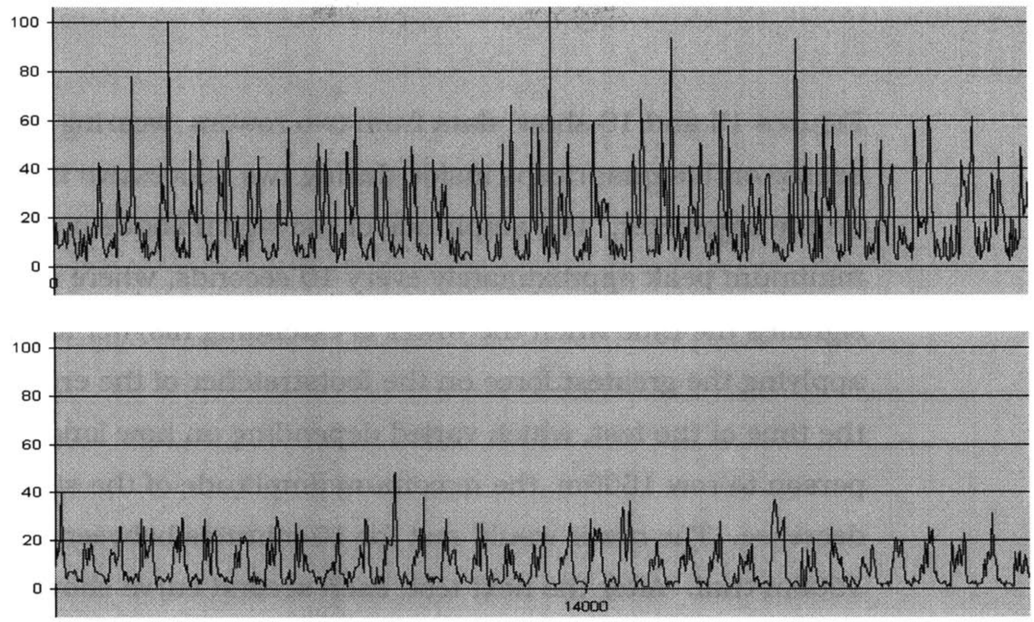


Figure 17: Indoor Rowing Test , Subject 2 at the beginning of two successive trials

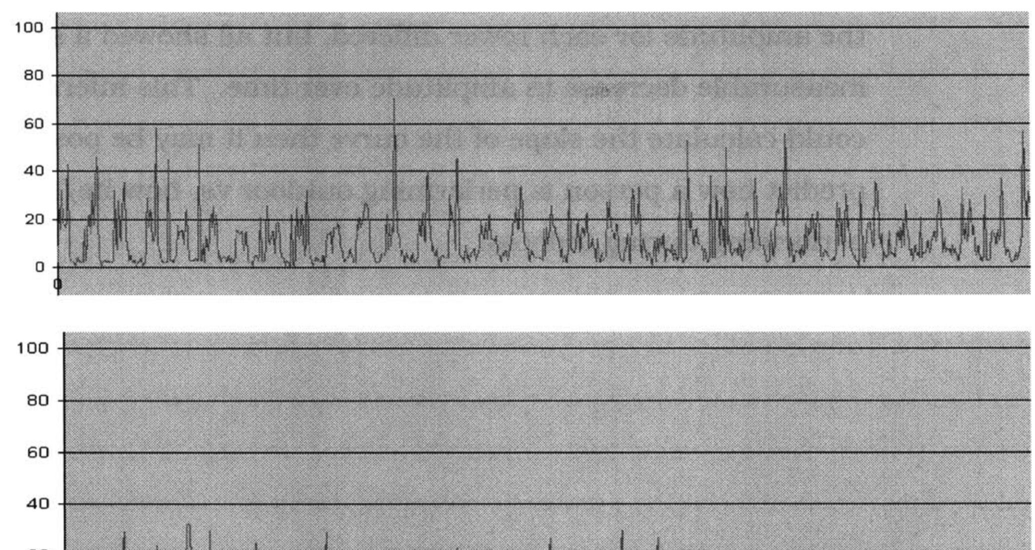


Figure 18: Indoor Rowing Test , Subject 2 at the end of two successive trials

Figures 15 and 16 show data from two rowers wearing an EMG sensor on his quadriceps inside during two successive trials of 1500m on the ergometer. The amplitude of the signal shows a maximum or minimum peak approximately every 10 seconds, where each peak signifies the time when the rower is extending his/her legs and applying the greatest force on the footstretcher of the ergometer. Over the time of the test, which varied depending on how long it takes each person to row 1500m, the maximum amplitude of the signal would decrease. The rower would rest for 10 minutes between their next 1500m trial. After the next test, each second curve shows that the maximum amplitude is lower over the same time period. Comparing the two curves over time show a decrease in the maximum amplitude as the rower would become more tired. In all the indoor rowing tests, the amplitude for each rower differed, but all showed a steady measurable decrease in amplitude over time. This inferred that if one could calculate the slope of the curve then it may be possible to predict how a person is performing outdoor vs. how he/she was performing during indoors.

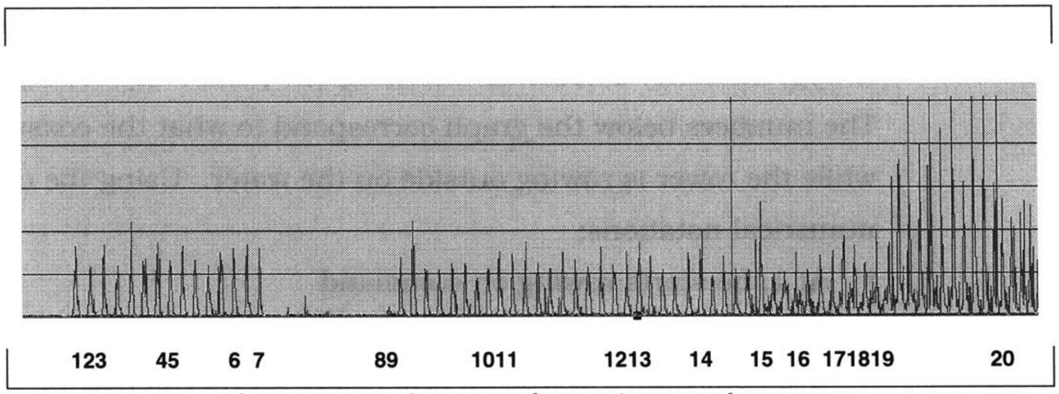


Figure 19: Rower 6 transitioning from normal to maximum stroke pressure

No.	Coxswain Transcript	What it means 3 = rower 3
1	Stern 6 from the finish	Rowers 8-3 start rowing
2	On the feather	while turning your oars
3	Blade off the water drill	blade stands still drill
4	What we'll do is we'll switch pairs	
5	In two, 3, 4 out That was one, two: 3, 4 **weigh enough** ; bow pair take over	In 2 counts, 3 and 4 stop rowing, 1 and 2 start
6	In two, 5, 6 out; 3, 4 back in	in 2counts, 3, 4 back in
7	5, 6 out; 3, 4 back in; blades up and over the waves now	5,6 stop; 3, 4 back in
8	In two, 5, 6 in; stern pair out	in 2 counts, 5,6 back in; 7,8 out
9	One, two: stern pair out; 5, 6 back in	7, 8 out; 5,6 in
10	In two, hold on?	in 2 counts, hold on?
11	OK, we're OK? In two, stern pair in: oh, we're not ready? Alright	OK… in 2 counts, 7,8 in not ready
12	Let's lock it down,	
13	In two, stern pair in two	in 2 counts, 7, 8 in 2 counts
14	That's one	counting 1
15	two, stern pair on this one	counting 2; 7,8 on this count
16	**OK Get focused** now. Alright. We have 10 minutes to get a warmup in. We'll improvise. We'll do 10 stroke	Getting ready to do 10 strokes at maximum pressure
17	pieces. First 10.	
18	At 30 strokes a minute, 3 and 10	Talking about stroke rating
19	We'll start in two; That's one, two up and over on this one We're at 22, 1! **Power 10;** That's it, **2! 3! 4! 5! 6! 7, Good Posture now! 8! 9! 10!**	Power 10= maximum pressure 10
20	Hold, be in **good focus**; Ready to go; Let's go to half pressure on this one	Reduce to half pressure

Figure 20: Table that corresponds with Figure 17; Speech recognition denoted in bold italic.

In Fig. 19, the graph denotes EMG over time on Rower 6. Each peak is approximately 2 seconds, denoting one peak every rowing motion. The numbers below the graph correspond to what the coxswain says while the rower is rowing outside on the water. Using the coxswain numerical notations:

- At 1, he starts rowing on command
  The coxswain gives a command for the first six rowers to start rowing during a warm-up drill where two of the rowers sit out and set (keep it balanced) the boat. He does steady strokes here.

- At 7, he stops rowing on command
  The coxswain gives a command to stop rowing, since he's rower 6 and rower 5 also stops rowing. The little peaks are small movements by a resting muscle.

- At 9, he starts rowing on command again
  It is the same drill as before.

- At 16-19, he's getting ready for a Power 10
  The coxswain starts gearing the rowers up and motivating them for a Power 10; which means each rower should row at 100% pressure for 10 strokes. At this point, he tells them to focus, and he tells them at what stroke rate he wants them to perform. On the actual taped transcript, his voice changes to a sterner, higher pitch telling them to get ready. At the transition, you note that the peaks become higher. At 16, he starts a mental transition for the rowers by telling them to "get focused" for their next drill. It is not clear whether the noise in the peaks correspond to the rower's response to having to perform in the next drill or whether the rain was starting to affect the position of the EMG sensor.

- At 19, he's performing a Power 10
  The coxswain gives the signal, "Power 10", and starts counting. Each time the coxswain counts, he has a sharp, authoritative voice that goes with each stroke. Note that the peaks of the rower are considerably higher than before.

- At 20, he's at half pressure
  The coxswain told them to stay focused and go down to half pressure. His voice is a little bit more relaxed, but even. The peaks of the rower are down to approximately 50%.

In Figure 20, the words that are denoted in **bold type** under the "Coxswain Transcript" column are the commands that in this case are recognized using the Coxswain's Assistant speech recognition module (See section 3.2.4).

4.1 Useful Findings

Several issues were discovered:

- EMG as an indicator of fatigue development

As illustrated in Figures 15 -18, the amplitude of the signal lowers over time, illustrating the previous statement that the development of muscle fatigue can be inferred from the change in EMG amplitude in the time domain as well as through changes of spectral response in the frequency domain.

- EMG as an indicator of performance and motivation level

As noted from Figure 19, the peaks from the EMG signal are considerably higher when the coxswain tells them to do a Power 10. This is caused by an extra effort on muscle activity performed by the rower. Even when the coxswain is in the transition point from the

"Blades Off the Water Drill", the peaks change to a higher amplitude indicating some positive response to the coxswain's motivation commands. This indicates the signal as a measure of performance vs. motivation. If it is an indicator of pressure exuded during the rowing stroke, it is difficult to tell which part of the stroke has the most pressure exerted. It is important to the rower to know that he/she is exerting more pressure at the catch and even pressure during the drive.

- Difference between rowers

Indoor experiments showed that two rowers rowing at the same pace on an ergometer did not produce the same amplitude in EMG. The layer of fat between a surface electrode and the actual muscle can cause a change in amplitude of the signal. Coordination and crosstalk of muscles also has an effect on amplitude, as well as the location of the electrode with respect to the innervation zone (De Luca, 1997)

- Same rower, differences before and after exercise

Experiments have shown that the response of the same individual at the beginning of a training session and at the end of the same training session varies. A ergometer test was conducted over a period of 20 minutes: every rower had an amplitude significantly greater at the beginning of the session than at the end.

- For the same individual, indoor and outdoor

In both cases, amplitude can be quite different. In general, indoor data is much more regular than outdoor data. It seems that the force exerted between two strokes outdoor can be much greater than indoor, or in other words, the variance of the maximum amplitudes is much larger.

- Watson performed better than other speech recognition packages

Overall, Watson by AT&T had a better performance than ViaVoice by IBM, and Dragon's Naturally Speaking. ViaVoice and Naturally Speaking are both continuous recognition packages, and confused all the commands, recognition was about 5% for each case. They work even worse if the tone of voice changes. Watson works well with phrases that are simple, such as Power 10, Weigh Enough, and Get Focused (average recognition 80%). Phrases like Number 2, Pull Harder work 60% of the time. The tone of voice does not seem to matter as much as how much space of silence you give before the command. The command can be reprogrammed depending on the personal preferences of the coxswain.

4.2 Open Issues and Problems

It is difficult to determine burnout point from the current system. During races, a rower exerts more pressure and force than during other times. Fatigue is the failure point of a muscle that occurs when a contraction can no longer be maintained. Although indicating fatigue development, the data collected so far does not indicate a person reaching the burnout point. The pattern of fatigue can be assessed, but it does not imply what the person can or cannot do next.

Chapter 5 Conclusion

"One sentence summary: I think [the S3] can be a very useful training tool with improvements to size/weight and durability."
-MIT Lightweight Coxswain

"Yes, I feel that the S3 has a great deal of potential in its ability to develop faster crews. The best (and most available) way to measure a rower's strength right now is the rowing ergometer. It is widely recognized, however, that erg times alone do not always give an accurate measure of how he performs in the boat. With the S3, oarsmen could get objective measurements of their individual performances, the way they do when doing a land workout, while keeping the benefits of practicing on the water, in the conditions that they race in."
-6-year oarsman for the MIT Lightweight Crew

"The idea and concept of the S3 system would be useful as a practice tool. At this time, the execution leaves something to be desired but the data [gathered is] useful. I for one would be curious to see how my personal performance responds under race conditions."
-4-year oarsman for the MIT Lightweight Crew

"The entire system needs to be much lighter because any gained performance could be negated by a heavy system, which causes greater water resistance. Also, the system needs to be designed so that there is no way it could impede the motion of the rowers, oars or seats. Equipment failure during a race inevitably causes the boat to lose."

"I think your biggest concern for putting this idea into a racing shell is weight and design. Our coxswain drinks a gallon of water before weigh-ins just so he doesn't have to carry an extra 5 or 6 pounds of weight in the boat. The 10 pound limit is still too high to race with. Realistically speaking, to get it into a serious race it would have to be less than 3. (Based upon my opinion as the guy who has to pull it around) I've lost races by 0.1 seconds, and if I'd had a 10 pound computer in the boat, I would have been really mad. The other thing is that the elements should be custom fit for a racing shell. There isn't a lot of space in a shell to start with, so the system must be size-economical."

More on weight:
"Make it SMALLER! It gets violent in a crew shell and space is limited. 10 pounds is TOO MUCH. At most SIX pounds for this to be a durable and feasible training tool. And at this higher end, it must be as reliable as a cox-box to replace it.[...] Must be able to drop the unit on a hard surface. It will happen."
-Coxswain

Can you comment on how the S3 system can help personal performance?
"When rowing a long, hard practice, rowers can lose concentration and stop rowing well. If the cox gets feedback on individual performances in the boat he can remind the individuals to stay focused on rowing well. Also, if the oarsmen know that every stroke is being recorded, for the coach and team can see, they might be more concientious about rowing well for the entire practice."

"The system would give oarsmen an idea of what phases of the race they were most effective in, and where they needed work. It's tough to say how an individual performs by watching an 8 row, so this system could help nail down trouble spots."

What the Coxswain and the Rowers think

- The S3 system can be a useful performance feedback tool with improvements

For the crew, even if data is stored and shown at a later date, it is more valuable than having no feedback.

- The current system is too large and bulky.

The computer weighs 7 lbs. (13"x 3"x 10") , The A/D board is 13 oz. (4" x 4" x 10"), and the EMG case is 3 lbs. (5" x 3" x 8"). Each oar amplification module is 2" x 2" x 4". Because of all the features, a system with large RAM capabilities is needed. The system is too difficult to put on the boat everyday without a separate full-time person (like a researcher) dedicated to the task.

- The system needs to be as robust as the CoxBox.

The CoxBox is the standard feedback system containing speed and stroke rating information. It is possible to incorporate its features into the Coxswain's Assistant, but it is not in the scope of this project.

- The system needs feedback to the rowers.

If the rower could see how hard he/she was rowing, he could tailor his stroke to gain maximum pressure. And the coxswain assistant will help with keeping him at a sustained level.

Contributions

- In Chapter 2, we see the development of four performance feedback systems leading to the the latest final version. This version has many more improvements in terms of speed of the sampling module, ease of use, and feedback to the coxswain as well as coach.

- In Chapter 3, we see the development of the Coxswain's Assistant which houses a motivation agent that compares the physiological and performance signals to what the coxswain says.

- In Chapter 4, we see that the EMG signal used in the system can be an indicator of motivation and pressure as well as fatigue level.

Overall,

- With a more compact and robust version of the system, rowers could use this tool themselves on a daily basis to help improve and monitor their performance.

- The design of the system could be successfully applied to other endurance sports to generalize the relationship between motivation and fatigue.

Chapter 6 Future Work

For the system, several improvements can be made:

- Smaller is Better – The computer used in the final system was very large, but it could handle the Coxswain Assistant with the voice recognition module with its large RAM capability and high-speed processor. For now, we are limited by current technology. Small improvements can be made to the current system. Perhaps a similar speed PC104 can be used with large RAM capability.

- Continuous Speech Capabilities – The current system employs a voice recognition module with a limited vocabulary. Depending on the command, how much noise occurs at the time of the command, and the spacing before and during the command, commands work 5- 80% of the time. Performance varies greatly. It would be better if the computer could recognize commands that are specific to each individual coxswain in addition to the more formal commands.

- Incorporation of current CoxBox capabilities into Coxswain Assistant – The CoxBox by Neilsen Kellerman provides information to the coxswain such as speed of the boat, stroke rating, and stop watch. All of these features can be easily incorporated so that the coxswain can get the same information and more.

- The Assistant is Expandable -- Parts of the Coxswain Assistant, such as the motivation agent, alert window, and stopwatch can be used for other endurance sports to use as a biofeedback device.

Experimentation in other contexts can help reveal different motivation and technique information natural to those situations.

❖ Integration of the System into natural environment -- It would be more natural for the oars to be able to display their own information. Perhaps use of a dedicated board to be integrated into the oar itself can sample its own strain gauges or other sensors. If the footstretcher displayed information on the back of a rower, it would give the rower additional feedback in an unobtrusive manner.

❖ Obtain more data with latest system

More analysis of patterns of success of different commands and motivational strategies as well as burnout/fatigue development needs to be done. Placing EMGs on different muscles to obtain a better picture of fatigue development can be a next step.

❖ Vocal Affective Patterns as a study

The vocal affective quality of the coxswain's commands along with the effect on the output of the team can be studied. In this study, we look at some of the commands issued, but not *how* they are issued. Different stresses of the voice at different times may influence the response of the individual.

Appendix A

Equipment Used in Final Version

Hardware

Compaq Armada 7730 MT

Black Box VGA to Video Portable II

Casio JY-10 LCD Color Television

Computer Boards Inc. PCM-DAS16S/16 and CIOEXP-16

Actiview Dual Channel Portable EMG Trainer by NeuroDyne Medical

Strain Gauges by Measurement Group

Strain Gauge Amplifiers by Transducer Techniques

Homemade Waterproof Boxes (aluminum boxes, duct putty, duct tape, RTV)

Software

Windows 95

Visual Basic

Symantec Visual Café

Watson 2.1 by AT&T

RangeLAN2 by AMP

Laplink for Windows

Equipment Used in Previous Versions (and not in Final)

Hardware

Tactile Feedback

Haptic Glove – Regular Sports Glove with Pager Motors

Accelerometers from Digikey

HandyBoard

smartSHELL 1

PC104 486 50MHz

Garmin GPS II+

irX 2.0

Sierra Wireless Modem

smartSHELL 2

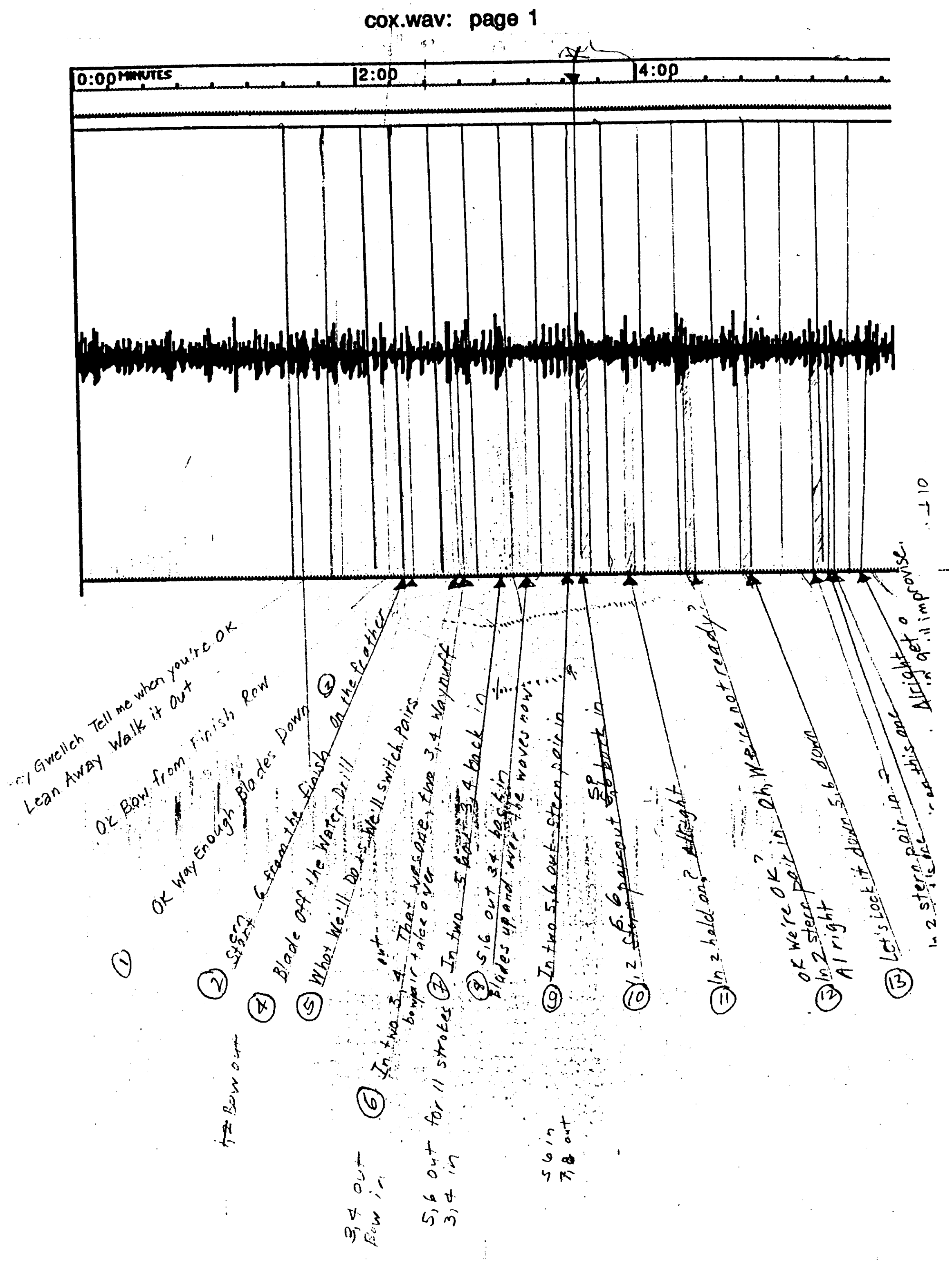
PC104 486 50MHz

RS485HUB

irX 2.0

Appendix B

Coxswain Transcript



Glossary

Basic Rowing Terms

Coxswain	Person who sits in the front or back of the shell to steer and motivate the rowers to make the boat go fast. In an Eight-oared shell, the coxswain usually sits at the stern.
Shell	This refers to the boat that the rower or crew rows in. They use different shells for different weights of crews.
CoxBox	Electronic device used by coxswains to measure speed of the boat and stroke rating. There is also a timer.

The Rowing Stroke

Catch	This refers to the part of the stroke where the blade is first put into or catches the water. The rower begins pulling the oar handle back. It ends when the blade is submerged in the water.
Release	This refers to when the blade of the oar comes out or is released from the water. It ends when the blade is completely out of the water.
Drive	This refers to the time that the oarblade remains in the water, and it is the time which the rower propells the boat by pulling on the oar handle. This occurs between the Catch and the Release.
Recovery	This is the part when the rower is preparing for the next stroke. This happens between where the Release ends and the Catch begins.
Stroke Rate	This is measuring in strokes per minute and tells how quickly a rower or crew is rowing but is not the speed of the boat.

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