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Integration of Multimodal Technologies for a Rowing Platform

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Abstract— **This paper presents the integration of multimodal technologies to measure and transmit different variables and stimuli involved in the human motion analysis, both for the training and for the transfer of users skills achieved by means of a mechatronic rowing platform. Although the mechanical design is the core of this project, this paper describes the integration and interaction of two multimodal systems (the human being and the rowing platform). These systems works together using different sensors and methodologies directly integrated to the human body to obtain detailed information related to the synchronization and correlation among the trajectories, Proximal distance coupling, velocities, muscular activation and muscular force, transversal force in the oars and head position acquired through digital image processing and machine learning techniques. This information is evaluated and used in the rendering section through audio-tactile stimuli for the acceleration learning process.**

Keywords-component; Rowing platform, Multimodal systems, EMG analysis, Vibration training, Image processing, Skills transmition.

I. INTRODUCTION

In the traditional concept of learning, the teacher is the ideal link and feed-back in the transfer of knowledge to perform one action to the student. Normally, the teacher is the responsible to supervise, analyze, correct and motivate the user to carry out a specific task in the best possible way. Therefore, during the repetition and comprehension of the process, the novice users begin to transfer these skills or knowledge (acquired from the external events) to their brain.

Nowadays, the Human Machine Interfaces (HMI) have transformed the form to communicate, interact and learn of the human being [1][2][3]. These technologies extend the perception level and accelerate the process of learning. However, in order to guarantee the complete integration and naturality in the interaction, the HMI must be as transparent as possible[4][5]. Therefore, the principal motivation of this work is to analyze and integrate important measures and feed-backs that can help us to understand what the user is doing, trying to do and how to help him/her to perform a better movement in order to accelerate the learning process of rowing.

II. STATE OF THE ART

Many rowing simulators are today available for rowing training. The CONCEPT2® rowing ergometer is the most employed simulator for indoor physical training and athletes' performance assessment. It has been used to evaluate injury effects on the rowing technique [6] as well as for rehabilitation [7]. Other simulators are used for physical and technique training. The rowing simulator developed at Sant'Anna School [8] is the platform for a rowing training system. It is important to remark that until now no other rowing platform has proved to be a rowing training system.

In a training process, the correlation between human motion and perception plays an important role. Moreover, the modification in these parameters can help the users to augment their perception and identify performance's mistakes in order to correct them. The visuo-kinesthetic stimulus is one methodology which involves the human-senses in order to augment the human perception.

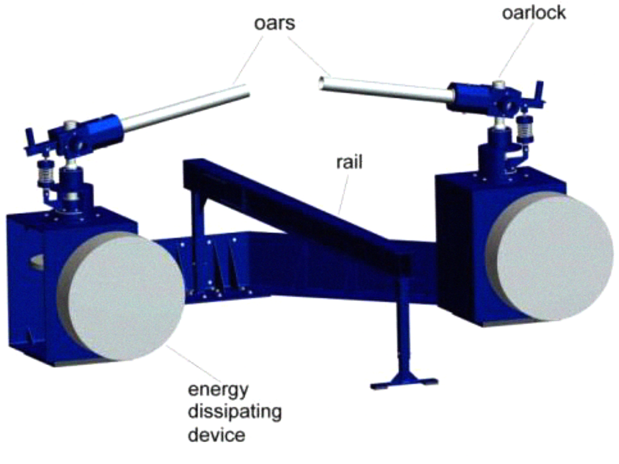

Figure 1. 3D CAD model of the mechanical platform

We suppose a haptic feedback to be useful for rowing training as it provides the user mistakes awareness. For instance the tactile sensation produced on the skin is sensitive to many qualities of touch. Lieberman and Breazeal carried out for first time an experiment in real time with a vibrotactile

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feedback to compensate the movements and accelerate the human motion learning [9]. The results show how the tactile feedback induces a very significant change in performance of the user.

Moreover, the estimation of the muscular force is fundamental in the rowing movement because it is an important parameter which describes the efficiency in the whole movement. Interesting results related to the optimal force application in rowing was obtained by Mallory [10]. In the same line of research Mobasse & Hashtrudi-Zaad [11] analyzed and estimated the rowing stroke force with EMG signals using artificial neural networks.

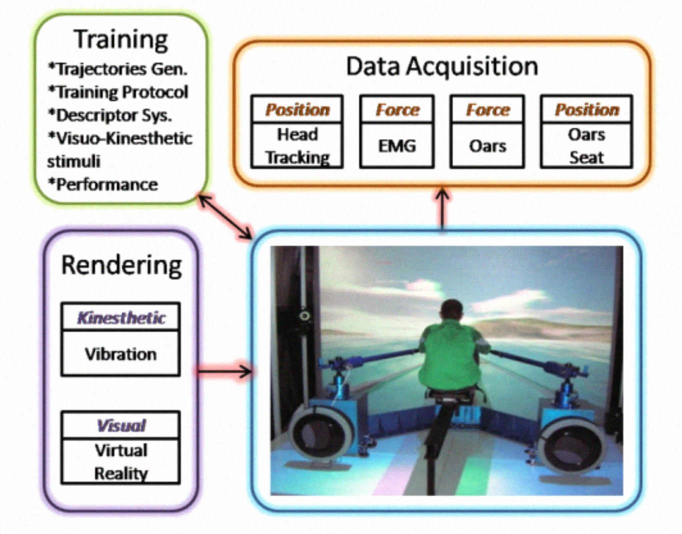

Figure 2. General Description of the System

III. DESCRIPTION OF THE SYSTEM

A. *Mechanical Platform*

The user's interface with the platform (mechanical system Figure 1) has to satisfy some specifications:

1) The kinematics that the user performs with the platform should be the same like the out-door rowing kinematics.

2) Related to a fixed stroke kinematics, the platform has to provide the users with the same resistance they would find in out-door rowing.

3) The platform has to allow the user to perform both sculling and sweep rowing.

4) The platform must provide the conformability to row on the same platform to different user (regarding to anthropometric measures).

By replicating the same elements of a real boat, the sliding seat and the oars, the users row in a similar way like in a real boat. A fluid-dynamic energy dissipating device (EDD) provides the resistance according to the second specification.

The frame which bears such elements is provided with many regulations which permit different users to make use of the same platform for sculling and sweep rowing. The group of the frame parts which support the oar is called oarlock, Figure 2 shows the layout of the system where only the left oarlock is represented.

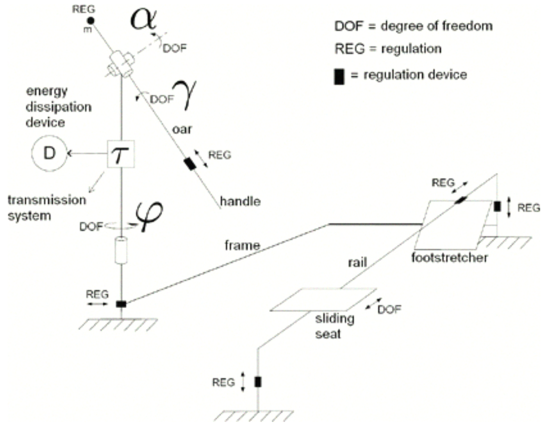

Figure 3. Layout of the system

1) *Energy dissipating device and transmission system*

The CONCEPT2® energy dissipating device has been implemented and analyzed in order to adapt such device to the platform. The EDD is composed of a steel plate (flywheel) where a fan is mounted (Figure 4.).

During the drive phase, the energy furnished by the rower is stored as flywheel and fan kinetic energy, while the fan dissipates such energy during the whole stroke. In the recovery phase the user does not feel any resistance because of the freewheel mounted on the EDD shaft. This device is completely passive: no motors are mounted to regulate the resistance. The regulation is due to a plate which allows the user to vary the air rate, and therefore the resistance. Many measurements gathered from literature as well as years of rowers experience show that such device satisfies the dynamical requirements, therefore, each oarlock has been provided with a dedicated EDD. This solution preserves the oarlock independence and allows the user to disassemble the idle oarlock before a sweep rowing session. Two problems came out from the device analysis:

1) The oarlock axis angular velocity has to be multiplied 64 times to make the EDD work correctly.

2) During a sculling session, rowers distribute their effort on both oars. Since CONCEPT2® device has been designed to make head to the whole rower effort, rowers feel too much resistance while sculling.

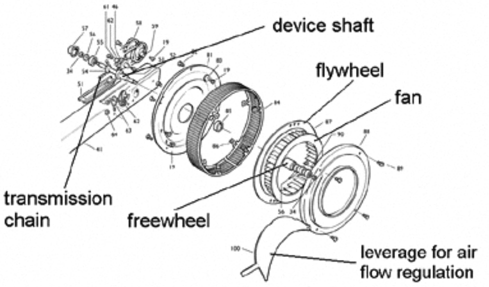

Figure 4. Energy dissipating device

3) Moreover, since the distance between the seat and the oar's pivot is allowed to vary in a determined range, the EDD is assembled with horizontal axis in order to limit the rail height. Therefore, a third problem arises: the direction of the rotation has to be rotated by 90°.

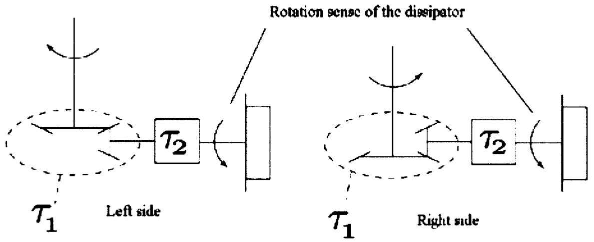

Figure 5. Transmission system

The transmission system provides a solution for the first and the third problem. A first stage, composed of two bevel gears, provides the direction rotation and a transmission ratio τ_1 of four; the second stage, composed of a two stages planetary gearbox, provides a transmission ratio τ_2 of sixteen. The EDD works only in one direction because of the freewheel, since the two oars angular velocities $\dot{\varphi}$ are opposite, the transmission system cannot be the same for both the oarlocks. Figure 5. shows the difference between the two transmission systems in order to make use of the same EDD.

To solve the second problem, the resistance regulation allowed by the EDD has to be assessed. Therefore, a mathematical model of the EDD has been developed in order to figure out how the air rate influences the resistance provided.

2) EDD mathematical model

The EDD model has been developed referring to the CONCEPT2® ergometer, where the rower applies the propelling force on a handle which transmits the effort to the EDD shaft by means of a chain and a pinion (Figure 5.). Since we aim to obtain the exerted force *F*, we consider the EDD rotation velocity $\dot{\theta}$ as input and the resistant torque T_r as output of the model, the EDD components geometry and inertial properties as well as the fluid (air) properties are known. The EDD shaft angular momentum balance is given by

$$Fr_p = T_r \tag{1}$$

where r_p the radius of the pinion which transmits the motion to the EDD. T_r can be expressed by

$$T_r = T_i + T_f \tag{2}$$

where T_i is the inertial contribution due to the flywheel and the fan, and T_f is the fluid-dynamic resistance due to the air flow. The inertial contribution is simply given by

$$T_i = I\ddot{\theta} \tag{3}$$

T_f is tied, for a time unit, to the energy inlet *L* furnished by the athlete:

$$T_f = \frac{L}{\dot{\theta}} \tag{4}$$

L is obtained modeling the EDD as a centrifugal fan with forward-curved blades (Figure 6.) making use of the eulerian theory. Two are the main hypotheses introduced:

1) Monodimensionality: the velocity vector is constant on the blade section.

2) Permanent condition: fluid properties and conditions do not change over time.

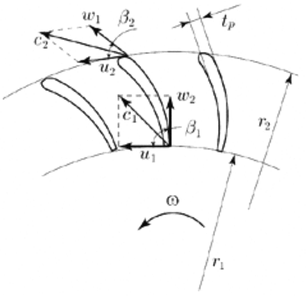

Figure 6. Fan geometry

This section presented a brief part of the mechanical design. The detailed mechanical analysis of this platform is presented in [8].

B. Sensors

a) Encoders

The system measures the angular position in α and φ of both oars using four encoders (both for each oar). In the same way, other two encoders register the speed of the dissipating devices. The information is processed by two microcontrollers (PIC18F4550) which computes the angles and velocities and transmits the information via USB to the computer.

b) Infrared sensors

The position of the seat is another important variable to be measured. The infrared sensors are an economical and effective solution to obtain the distance of the seat. Although the infrared sensors used in the device have a measuring range from 10 to 120 cm, the sensor is extremely sensible in the last 40cm. Therefore, two infrared sensors are located in the first and last part of the rail in order to have a best resolution and precision of the system. One PIC microcontroller acquires the analog input from two infrared sensors and covert them into a digital signal of 12bits resolution. A digital filter is computed inside the microcontroller and the signal is sent it to the computer via USB.

c) Strain Gauges

The EDD model provides indirect measure of the forces. Therefore, it is important to know the direct forces in order to calibrate the system. F is obtained by means of two torque sensors placed on the oarlocks shafts. Each sensor is composed of four strain gauges. The full-bridge Wheastone configuration has been chosen to perform a 4-times amplification of the voltage and to avoid the bending effects. One instrumentation amplifier INA121 provides an amplification of 100 times. Finally, a microcontroller converts the analogical signal into digital one and transmits the information via USB. (Figure 8 a)

C. *Digital Image Processing (Head Tracking).*

In the rowing movement, the posture of the trunk and head are critical in order to maintain the balance and perform an efficient movement. However, one of the challenges in this section was to measure the head in a transparent, efficient and economical way. For this reason, through digital image processing and gesture recognition techniques was designed a system capable to fulfil these three requirements (Figure 9)

The system consists in one webcam (1 MP resolution & 30fps) and 2 infrared sensors. The camera is placed on one side of the user in order to measure the longitudinal displacement of his/her head. The gesture recognition algorithm detects the position the head in the X-Y axis in the image and sends this information via UDP to Simulink.

The recognition of the profile head features are based on an algorithm initially proposed by Paul Viola and improved by Rainer Lienhart. In general terms the idea is to train a classifier (namely a cascade of boosted classifiers working with haar-like features) [12] with a few hundreds of sample views of a particular object, called positive examples, that are scaled to the same size (say, 20x20), and negative examples - arbitrary images of the same size. After a classifier is trained, it can be applied to a region of interest an input image. Finally, the centroid of the head is computed and the XY coordinates are obtained. The code to recognize the head profile and to get the Cartesian coordinates was programmed in C++ using OpenCV libraries.

D. *Vibro-tactile system*

The vibrotactile control system used in these experiments was specially designed to control twelve vibration motors. In general terms the system consists in three PICs microcontrollers (18F4431) capable to control four PWMs (Pulse Width Modulator) in hardware level with a 12-bit resolution. The power control section uses an IC ULN2803 (Darlington transistors array) which modules the power energy applied to the vibration-motors. The communication is based on RS232 protocol that transmits the information given by the computer to a master microcontroller. The master microcontroller transmits the duty-cycle of each PWM via SPI communication to the slave microcontrollers. (Figure 7)

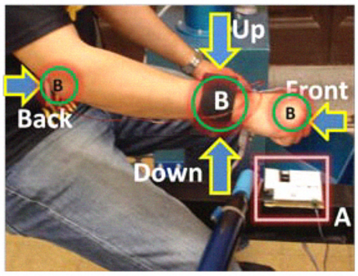

Figure 7. A)Vibrotactile system B) Vibration Motors Location

E. *Electromyography signals (EMG)*

It is known that the control of muscle by the nervous system is accomplished by electrical signals that are sent from motor neurons to muscle. These signals which are known as action potentials can be recorded as they propagate due to a flux of Na+ and K+ ions that are inside of the muscle. Such a recording is referred to as an electromyogram(EMG).

The EMG signals are complex to acquire and process. Normally, a sampling frequency of 2 or 4Khz should be performed in order to obtain a good parameters of the signal. Therefore, a considerable amount of data is obtained during the acquisition process of the raw signal using diverse sensors. This fact produces a waste of computing-time when the desire parameters are estimated. A new embedded system capable to perform diverse calculus in real time in order to save computing-time and avoid saturation in the transmission with the raw signals was designed. The main objective of this device is to process and transmit three important parameters related to muscles: Muscular Time Activation, Force Intensity and Frequency Analysis instead of the raw signal.

The EMG sensors consist in an analogical section which amplifies the difference in voltage of two EMG electrodes using an instrumentation amplifier INA121, the signal pass to an ADC 16-bits resolution and finally the 2 bytes of information are sent to a DSPic via SPI protocol. The DSPic performs all the embedded calculus described before and finally transmits the information via Bluetooth to the computer.

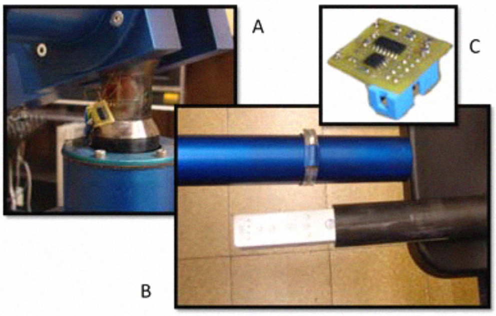

Figure 8. A)Strain Gauge B) Wii Remote C) EMG Sensor

F. *Rotation*

The rotations of the blades are important factors in order to determine the boat dynamics. Therefore, two Nintendo Wii-Remotes were selected because these embedded systems contain three accelerometers which determine the rotation through the gravity and transmit the information via Bluetooth to the computer in an easy way (Figure 8 B).

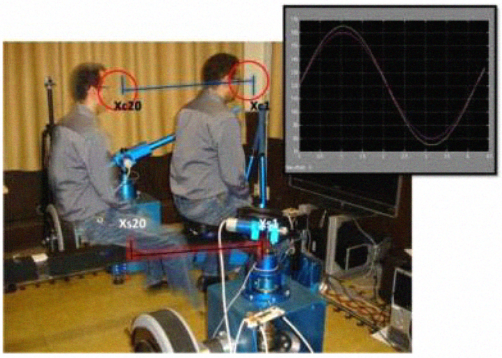

Figure 9. A) Calibration Process B) Real-Time data acquisition, the yellow line is the position of the head and and the pink line is the position of the seat.

IV. EXPERIMENTS

A. *Head Tracking*

The effectiveness of this methodology remains in the calibration process (Figure 9). This calibration is done using the correlation of the distance measured by the infrared sensors (which measure the position of the seat in the platform) and the X position of the head in the webcam obtained by the profile face gesture recognition algorithm. A linear interpolation algorithm was implemented to estimate in real-time the position of the head based on the position in X of the image. A Butterworth low-pass analog filter of 10th order and *Fc* of 100Hz was implemented to reduce small variations around 0.3cm produced principally by the gesture recognition system. The system was tested with 6 persons with different physical characteristics. According to the results it returns the data with a deviate variation of 1.058cm.

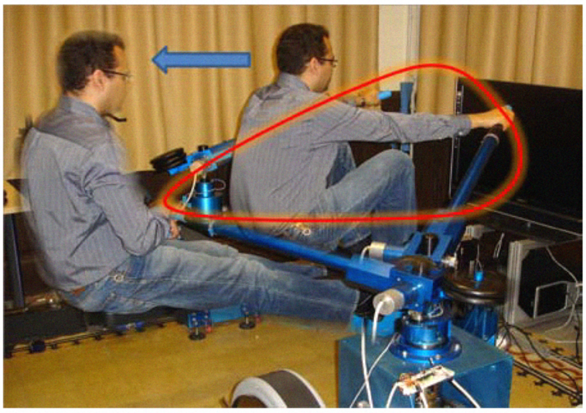

Figure 10. Motion Analysis

B. *Motion Analysis*

Naturally, the body motion is the most important analysis in the rowing. Figure 11 and Figure 12 shows the results of φ and α angle of oars obtained by one professional rower in different cycles of the movement.

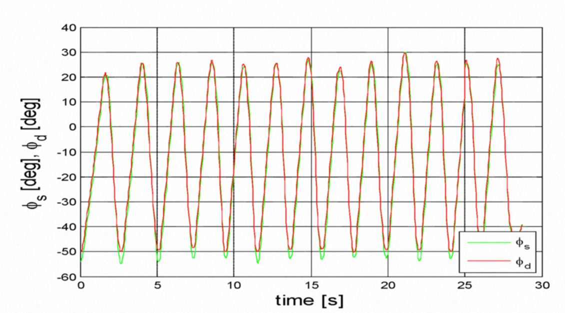

Figure 11. φs is the φ angle of the left oar and φd is the angle of the right oar

C. *Positional Training.*

1) *Perception Experiments with the vibrotactile device*

The aim of this experiment was to know if a person is capable to correct his/her movements only using the kinaesthetic feed-back stimulus. Six participant, five males and one female, aged 25 to 35 were separated in two groups. They are all right handed, one of them was a medium level rower and all of them have at least once experienced haptic devices. The participant sits on a chair between the oarlock and the rail equipped with the vibrotactile device mounted on her/his right arm.

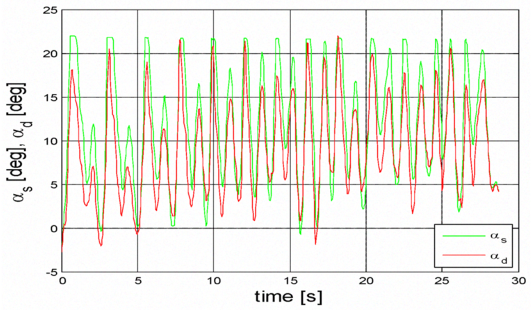

Figure 12. αs is the α angle of the left oar and αd is the angle of the right oar

The experiment was performed using 4 sensors located in the arm of each person. One in the middle finger to simulate the forward constrains, another one in the elbow to simulate the backward movement. The last two vibration motors are located in the up/down side of the wrist to simulate the upwards and downwards constrain. The objective is to perform a square figure of 20 by 20 ° in phi and alpha angles (right oar) during 120 sec like a training process. The vibration motors were activated depending of the state of the gesture to simulate physical constrains and give information to the user in order to perform the movement in the best possible way.

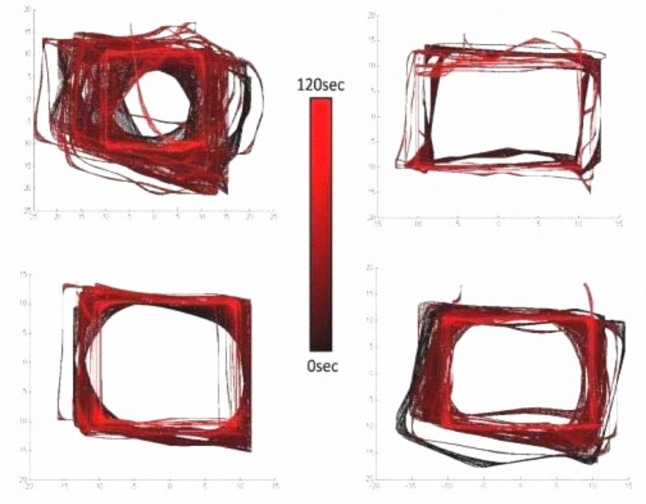

Figure 13. Results of the tactile training performed by 4 users during 120 sec.

The results in Figure 13 show how a person is acquiring the correct movement through the time. The black color corresponds to the initial time and the red color corresponds to the final time in the training. A movement almost perfect is done at the end of 120sec using the vibrotactile feedback.

2) *Gesture Recognition & Data Segmentation*

In the training process is important to remark that an expert has a good grade of flexibility and is capable to arrive at longer distances than a novice user. Therefore, the aim of this part of the system is to contemplate two important points that are not commonly contemplated in the training process. These points are the flexibility and physical dimensions of each user and create an ideal training trajectory for him/her. This methodology analyzes the phi and alpha angles of the professor's movement. This information was segmented through the Gaussian Mixture Distribution Algorithm in order to compute the ideal number of states in which the gesture is divided. The first step in the process calibrates the system according to the physiological characteristics of each person. Therefore the system takes two points: The first one is the initial position of the movement in order to determine the maximum flexion of the legs of the user and the second one determines the dimension of the legs of each user. The system adjusts the trajectories through a linear interpolation algorithm in each state of the gesture according to the initial a final position of the user. Once the system has been calibrated, the algorithm can analyze the error between the user and the professor's movement in a specific state of the gesture in real-time.

D. EMG

A brief experiment was performed to test the EMG data acquisition system. Four sensors were located in 4 muscles (Biceps, Triceps, Tibialis and Quadricep). The DSPIC performs a 4Khz sampling of each sensor and compute the estimation of force and the activation of the muscles. Figure 14 shows the four processes performed by the DSPic. The yellow line show the raw-signal, the pink line shows the absolute value of the signal. The blue line shows the low-pass filter to envelope the signal and finally the red line shows the activation time of the muscle.

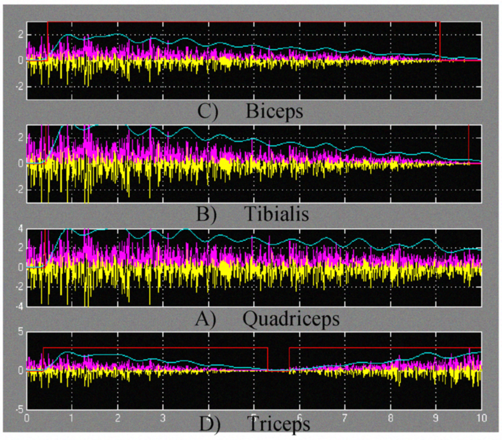

Figure 14. EMG signals A) Biceps B) Triceps C) Quadriceps D) Tibialis

E. Virtual Reality

A virtual reality scenario was developed in XVR in order to simulate a realistic boat in the water and displays different values related to the performance of the user in the movement.

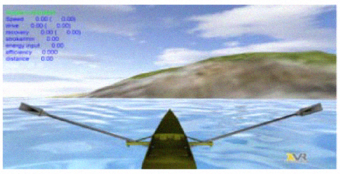

Figure 18. Visual Feed-back

V. CONCLUSIONS AND FUTURE WORK

This paper presented a complete integration of diverse technologies applied in a rowing mechatronic platform used for the acquisition of different variables that are necessary to be known in order to perform several strategies for the future transfer of skills of the rowing movement. Moreover, different technologies were specially designed like the head tracking, vibrotactile and EMG systems to reduce costs and adapt the technology according to the specific requirements of the platform. The experiments have showed interesting results in motion capture and perception of the users which will be applied in future experiments to accelerate the process of learning.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

[1] Cole, R. and Mariani, J.: Multimodality. Survey of the State of the Art of Human Language Technolgy. Carnegie Mellon University, Pittsburgh,PA., (1995).

[2] Sharma, Rajeev, Pavlovic, Vladimir and Huang, Thomas: Toward Multimodal Human-Computer Interface. Proceedings of the IEEE, vol. 86, no.5, pp.853-869, (1998).

[3] Akay, Metin, I. Marsic and A. Medl: A System for Medical Consultation and Education Using Multimodal Human/Machine Communication. IEEE Transactions on information technology in Biomedicine, Vol. 2, (1998).

[4] Hauptmann, A.G. and McAvinney, P.: Gesture with Speech for Graphics Manipulation. Man-Machines Studies, Vol. 38, (1993).

[5] Oviatt, Sharon: User-Centered Modeling and Evaluation of Multimodal Interfaces. Proceedings of the IEEE, Vol. 91, (1993).

[6] F. OSullivan, J. OSullivan, A. Bull, and A. McGregor. Modelling multivariate biomechanical measurements of the spine during a rowing exercise, Clinical Biomechanics, 18(6):488–493, 2003.

[7] R. Davoodi, B. Andrews, G. Wheeler, and R. Lederer. Development of an indoor rowing machine with manual FES controller for total body exercise in paraplegia. Neural Systems and Rehabilitation Engineering, IEEE Transactions on [see also IEEE Trans. On Rehabilitation Engineering], 10(3):197–203, 2002.

[8] A. Frisoli, E. Ruffaldi, L. Bagnoli, A. Filippeschi, C. A. Avizzano, F. Vanni, and M. Bergamasco. Preliminary design of rowing simulator for in-door skill. In Haptic Ambient Systems, 2008.

[9] Lieberman, Jeff and Breazeal, Cynthia.: Development of a wearable Vibrotactile FeedBack Suit for Accelerated Human Motor Learning. IEEE International Conference on Robotics and Automation, (2007).

[10] Mallory, Peter. "Optimal Force Application in Rowing, the Analysis of Rowing Force Graphs and Force Graph Biofeedback". 18th FISA

[11] Mobasser, F. Hashtrudi-Zaad, K. .:Rowing stroke force estimation with EMG signals using artificial neural networks. Proceedings of 2005 IEEE Conference on Control Applications, 2005. CCA 2005.

[12] Paul Viola & Michael Jones. : Rapid Object Detection using a Boosted Cascade of Simple Features. Computer Vision and Patter Recognition, 2001