HUMAN MOTION CAPTURE VIA INERTIAL SENSORS FOR CLINICAL AND SPORTS APPLICATIONS

Felipe Marrese Bersotti, University of São Paulo, USP, Brazil. felipe@mocapbrasil.com
Anderson Alves Oliveira, Mocap Brasil, Brazil. anderson@mocapbrasil.com
Lucas Ortega Venzel, ABC Federal University, UFABC, Brazil. lucas@mocapbrasil.com
Carlos Souto Ande, Mocap Brasil, Brazil. carlos@mocapbrasil.com
Mário Sandro Francisco da Rocha, Mocap Brasil, Brazil. mario@mocapbrasil.com

Abstract: Human Motion Capture (Mocap) systems can be built with different technologies, which depend on requirements such as: accuracy, number of tracked points, real time data view, multi person capture and capture volume. Mocap systems based on inertial sensors, including accelerometers, gyroscopes and magnetometers, are considered the most promising, because they don't depend on external reference, and thus can be used in unstructured environments. In this paper we show the development of a commercial inertial Mocap system, including wireless sensors and a software interface dedicated to rehabilitation applications. In the section 'future work' it is pointed the next steps the company is taking toward the establishment of partnerships with researchers in Brazil, in projects with objectives such as carry out a quicker and precise evaluation protocols reports; use of the sensors in a virtual reality system to represent the limbs movements by a 3D avatar in a novel biofeedback therapy technique.

***Key Words**: Biomechanics. Inertial Sensors. MEMS. Rehabilitation. Sport.*

1. INTRODUCTION

Precise measurements of spatial orientation plays a critical role in many fields, such as aerospace, robotics, navigation, human motion analysis, and human-machine interaction (Madgwick, *et al.*, 2011).

With the advancement of the technologies applicable to motion capture (Mocap) systems, it is notable that there is a growing number of Mocap applications in physiotherapy, biomechanics, rehabilitation, sports, ergonomics, movies, games, etc.

In the market, there are several types of Mocap systems, built with different technologies, each one having its specific precision level (Ricci and Formica, 2014). Currently, there is not a technology that can be identified as the best one. However, the use of SoC (System on Chip) that includes accelerometers and gyroscopes of MEMS type and magnetometers (wearable system) is considered the most promising one, because of its independence from external references (Welch and Foxlin, 2002).

With this technology, Anderson Oliveira developed a sensor module for Mocap based on the results of his Master's thesis, able to capture data and send it to a PC (Oliveira, 2014). Now, with the support of PIPE/FAPESP Fase I, the Mocap Brasil company are developing an innovative human motion capture system, including hardware and software, for biomechanical applications. The graphical user interface and its functionalities have been developed in Blender, a free and open source 3D creation suite integrated with the script language python, and has been based on the field research results obtained by a specialist professional in biomechanics, from both rehabilitation centers and universities. Currently, we are using the unity game engine to develop the interactive functionalities of the interface, and the Blender 3D creation suite for motion capture, data export and other non interactive tasks.

Our goal was divided in two objectives:

I. Develop an embedded system for transmitting data in appropriate physical means, with up to 16 inertial/magnetic modules providing spatial orientation at the points of the body where they will be placed. To accomplish this, the Mocap Brasil team need to fulfill the following technical or research sub-objectives:

a) Analyze the quality of the IMUs (Inertial Measurement units) sold in the market together with the data fusion tools provided by the manufacturers;

b) Develop the module with the best sensor/algorithm set;

c) Develop a wireless communication network with Bluetooth Low Energy technology between the inertial modules and a data center gateway;

d) Implement in this gateway a communication for sending real-time encoded data to the PC.

II. Develop a PC application with a graphical user interface designed to the area of biomechanics, which basically reads and processes motion capture data and outputs the results on the screen in real time. And, to accomplish this, the Mocap Brasil team need:

a) Develop code that can read and decode the data received in real time;

b) Search, implement, and evaluate algorithms based on biomechanical models;

c) Develop the efficient graphical user interface for users of the rehabilitation area;

d) Implement report generation with spatiotemporal information used in rehabilitation and physical training.

2. MATERIAL AND METHODS

The requirements description for the foregoing technical or research sub-objectives are shown in Table 1.

Table 1. Requirements description of our technical or research sub-objectives

Sub-objective	Requirements Description
i.a	For the choice of the sensors to be used in the manufacture of our Mocap system we looked to meet the best relationship between the requirements of lowest cost; smallest dimension; lower internal noise (RMS and PSD); minor misalignment between internal axes; lower cross-axis sensitivity; and lower non-linearity.
i.b	This step is composed of the fusion algorithm implementation based on the results of (Oliveira, 2014) and (Madgwick, *et al.*, 2011); and of the development of the board that will receive the sensor together with the auxiliary circuits for power and wireless communication through Bluetooth Low Energy, as a server module in a network.
i.c	The gateway will be developed with the same Bluetooth Low Energy module, but as a client in a network. The module is able to be connected to PC via USB communication in a very high transmission rate. For outdoor applications this module is able to record the data in a Micro SD Card for posteriori data analysis.
i.d	The data packet of the sensors will be set and tested using a serial port emulated over USB, optimizing it to real time applications.
ii.a	Implement this communication through Python scripts into the open source Blender suite.
ii.b	Develop a self-calibration algorithm, by using biomechanical models, for the basic change compensations between the soft tissue of the body, where the sensor is fixed, and the movements of the bones or joints in study. The patent of the company Xsens (Luinge *et al.*, 2012) is considered the state of the art in this challenge.
ii.c	With the contribution of professionals from physiotherapy, physical education, and related areas, through personal interviews and/or possible partnerships, we aim to adapt our graphical interface in order to present data of interest for those professionals, such as data of gait analysis and motion amplitude.
ii.d	Currently, the data, or variables that are important for rehabilitation and physical training are spatiotemporal information: 1. Cadence (s/min); 2. Velocity (m/s); 3. Total gait cycle (s); 4. Gait cycle length (m); 5. Stride cycle length (%); 6. Total stance phase (%); 7. Swing phase (%); 8. Double support phase (%); 9. Single support phase (%); 10. Stride total; 11. Inclination, obliquity and rotation in degrees 12. Center of Gravity Shift (cm) * These values are presented with symmetry index, normality values (according to the literature).

3. RESULTS

In the current phase of the Project there is a prototype of the sensor modules using IMUs 9-axis in a single-40x40mm package, as shown in Fig. 1.

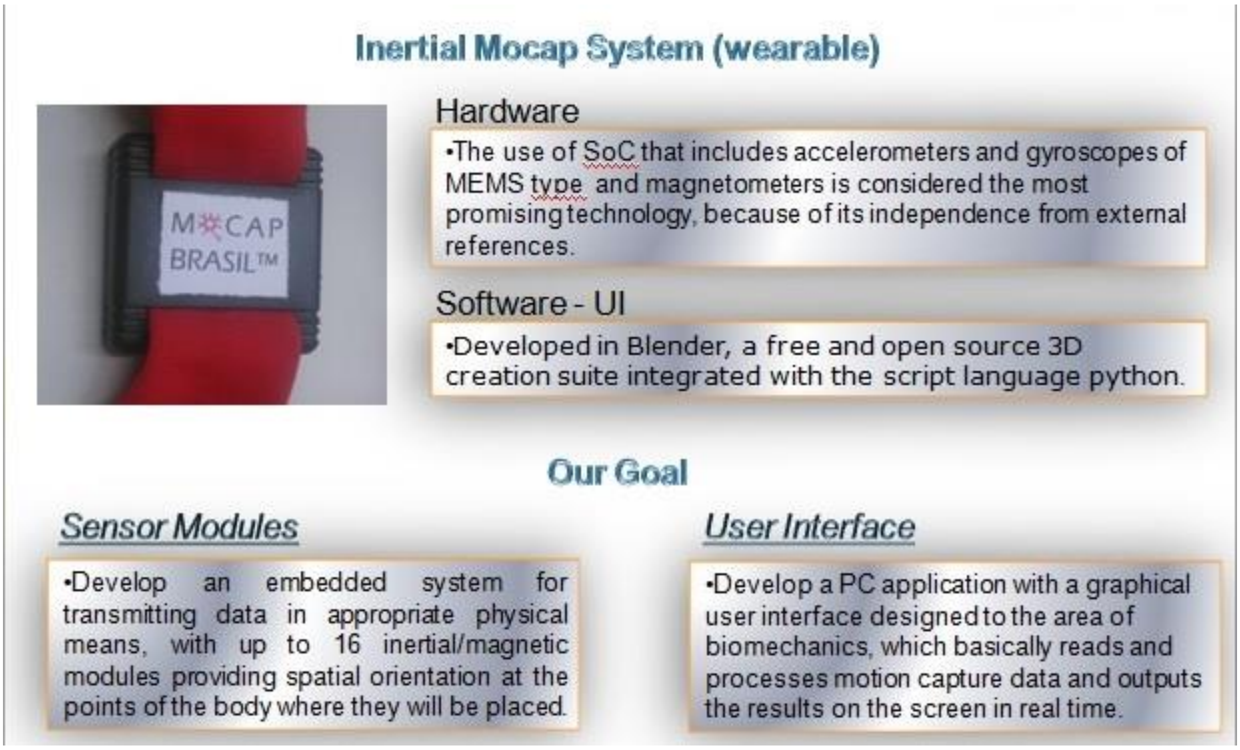

Fig.1. Inercial Module MocapBR

This module is a server node that outputs the angular orientation data in quaternions and Euler angles. The measurement accuracy of our system will be evaluated by comparing it with that provided by an optical system.

The gateway prototype in development is going to read data from up to 16 modules as a client node. The sending of the data to the PC is accomplished with a USB to Serial converter transceiver. A Micro SD Card Slot allows the offline recording of data.

The graphical interface has been developed using Blender, open source software for 3d computing, which allows running a script codified in Python that imports the serial module to open the serial ports and then reads the streamings with the information sent by the sensors. Still in this interface, it is possible to make the association between each sensor module and its respective bone in the 3d model, as shown in Fig. 2. Currently, we are using the cross-platform and multipurpose unity game engine to develop the interactive functionalities of the interface, and the Blender 3D creation suite for motion capture, data export and other non interactive tasks. We expect that by taking advantage of the large community of users of these platforms we will certainly improve the use of our interface.

Fig.2. GUI (in Blender) + data read module

4. DISCUSSION AND CONCLUSION

According to (Oliveira, 2014) and (Madgwick, *et al.*, 2011), an error (RMSE) is expected between 1 and 2 degrees for the inertial module. Thus, the feasibility of the use of the system needs to be discussed in accordance with the application. Regardless of this outcome, it is considered important to develop a MOCAP system in Brazil, and, in view of the rapid evolution of MEMS technology in the last decade, it is hoped that the quality of the sensors will be improved to meet a greater number of Applications.

The results of the preliminary tests conducted with our GUI show that Blender is a suitable tool to continue with the development of our interface as we planned, especially by enabling the construction of biomechanical models, and having the physics modules and graphics embedded in it. In addition, the use of the unity game engine for developing interactive content aims to strengthen our interactions with other developers and to increase the number of users of our system.

In parallel with the development of items ii.b, ii.c and ii.d, and with the development of a commercial product from this prototype, the Mocap Brasil team seek partnerships with researchers from the areas of physiotherapy, physical education and ergonomics to collaborate in the specification of the functionalities and design of the interface according to the user needs in these areas.

5. FUTURE WORK

It should be noted that this paper only describes the development of this new tool and its first evaluation. Future work should investigate the use of inertial sensors for the application of protocols for the functional evaluation of human movement, such as: Time Up and Go, Sit-To-Stand test, 6-minute walk, jump research, among others already established in the literature, these protocols can be performed capturing data through these sensors and applying it into a biomechanical model using individual anthropometric measurements. We also plan to carry out tests for the application in certain pathologies, such as: Parkinson's disease, neurological and neuromuscular diseases, by comparing our motion capture data with those obtained in other scientific works published in the literature.

Another future research is related to "virtual rehabilitation". By attaching inertial sensors to the patient, it will be possible an accurate interaction of his movements inside virtual reality games. The sensors can assist in the evaluation process to provide a novel therapeutic alternative to restore mobility in severely paralyzed patients or to treat other sensory and motor disorders. It also can assist in therapies where biomechanics and motor control are important factors to be analyzed, since sensors can be an excellent complement to immersive virtual reality, where a human 3D avatar can be simulated. It has been observed that patients have the most accelerated learning when sensory feedback is provided (vision, proprioception and other senses responsible for providing information for the running motion command) (Donati, et al., 2016; Shokur, et al., 2016).

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