An Instrumented Glove for Swimming Performance Monitoring

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Keywords: Glove, Performance Monitoring, Embedeed Electronics, Swimming, Wearable Device.

Abstract: This paper presents a project of wearable motion capture system for motion analysis in swimming. Two versions of this system have already been designed, one with a wired structure, based on a microcontroller and an inertial measurement unit (IMU), and the other with a distributed architecture, based on a wireless communication and another IMU. This system has been initially designed to target tri-athletes population, but this study only presents the considerations concerning the swimming application.

1 INTRODUCTION

Movement efficiency is a challenge in the training of swimmers in order to increase their performances (Callaway, 2015; Psycharakis and Sanders, 2010; Ohgi et al., 1998). A coach can easily measure stroke frequencies or split times but currently, it is difficult to evaluate the swimming technique. Indeed, underwater, 2D or 3D cameras (Samson et al., 2012) have been traditionally used in order to collect swimming kinematics, but they are cumbersome and expensive, and they require an heavy post-processing and a correct brightness.

This study presents a part of a project which consists on developing a smart electronic measuring system, supposed to be wearable and composed of multi-sensors areas communicating with a central station and a computer. The main application is the quantification of swimming kinematics. In order to improve its wearability, we have chosen to integrate it into a glove which can be used by the swimmers.

The purpose of this study was to validate different parts of the future system (accuracy of the system, waterproofness, wireless communication) and to collect preliminary hand kinematics from both elite and recreational swimmers.

2 ARCHITECTURE DESIGN

2.1 Wired Approach

Our first approach was based on a previous study (Hernandez et al., 2014) which presented an instrumented glove used for the capture of hand gestures for a surgical application. We propose another application in sports by firstly developing a wired system monitoring the hand positions of a swimmer. We used an inertial measurement unit *(IMU MPU9150, InvenSense)*, which uses Inter-Integrated Circuit (I2C) communication standard. The *MPU9150* includes a 3-axis gyroscope with a full-scale range of ±250, ±500, ±1000, and ±2000 °/sec, a 3-axis accelerometer with a full-scale range of ±2, ±4, ±8, and ±16 g, and a 3-axis magnetometer with a full scale range of ±1200 µT. The gyroscope and the accelerometer are in 16-bit resolution, and the magnetometer is in 13-bit resolution.

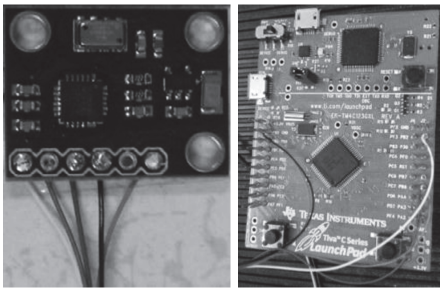

Figure 1: MPU9150 (left) and TIVA launchpad (right).

Mangin, M., Valade, A., Costes, A., Bouillod, A., Acco, P. and Soto-Romero, G..
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In *Proceedings of the 3rd International Congress on Sport Sciences Research and Technology Support (icSPORTS 2015)*, pages 53-58
ISBN: 978-989-758-159-5

This IMU was connected via wires to a microcontroller on a *Tiva C Series EK-TM4C123GXL launchpad* (Figure 1) which sent the data at 50Hz. The microcontroller was programmed to handle the data processing, which means reading the raw data from the IMU, computing the sensor orientation and sending the results to the computer via USB data link.

2.2 Distributed Approach

Our second approach was to propose a distributed processing (called *AREM Gateway*, or *Gateway*) (Figure 2), where a sensor is connected to a microcontroller (with embedded computing algorithms) and equipped with a battery and a wireless communication module. We made our study with only one sensor, but our aim was to use additional sensors. Thanks to this wireless architecture, the *Gateway* would give two feedback possibilities:

- a feedback at the end of a series of laps, with a data post-processing,
- a direct feedback, as the data can be processed in real-time by an algorithm embedded into the microcontroller.

We used another IMU, a *ST iNemo-M1*, which includes a 6-axis IMU (consisting on a 3-axis accelerometer and a 3-axis magnetometer), a 3-axis gyroscope and an *ARM STM32* microcontroller. The wireless transmission of the processed data is done using an *ESP8266 WiFi module* working in a station mode and connecting to a standard WiFi Access-Point. We also added a USB connector for the microcontroller, in order to communicate with a computer and to charge the battery, and a Serial-ATA connector connected to a Serial Peripheral Interface (SPI) bus to enable extension capabilities (with a SD card for example). Finally, the *Gateway* is 31 mm wide, 44 mm long, 13 mm high (with the battery and connectors), and weights 15 g with a 300 mAh battery, which has been tested and supply power for 2h30 in normal operation mode.

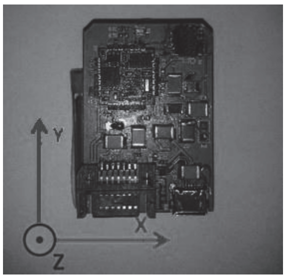

Figure 2: Second version of the system (*Gateway*).

3 VALIDATION

3.1 Laboratory Tests

During the development of our systems, our first aim was to validate the hand swimming kinematics thanks to the IMU. In view of this, we compared pitch, roll and yaw angles provided both by the IMU of the wired system and the *Gateway* and a Vicon system (using *Nexus 1.7.1* software), a marker-based motion capture system acknowledged as a reference. This motion capture system carries 12 *MX3+ cameras* with a frequency of 200 Hz, a millimeter accuracy and a resolution of 659 × 494 pixels each.

We set up two trials in order to compare the IMU with the Vicon system. Each trial was filmed and recorded with both systems (wired and distributed). For the first, the IMU was surrounded with three reflective passive markers (Figure 3) and controlled by software (sample code from *Texas Instruments*, and *TeraTerm* for the *TIVA* and a *Python* script for the *Gateway* as computer softwares). We put it on a table at the center of a room equipped with the Vicon system, and we collected data with the IMU and the Vicon system simultaneously during a rotation about a spatial axis. We made these rotations successively around the three axes in order to obtain the roll, pitch and yaw movements. For the second trial, we put the IMU on the hand of a swimmer (Figure 4) and we asked him to simulate a crawl movement while collecting data with both the IMU and the Vicon system.

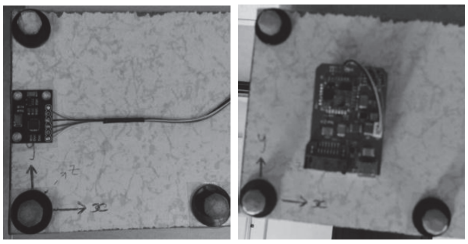

Figure 3: Settings for the first experiment (left: wired, right: distributed).

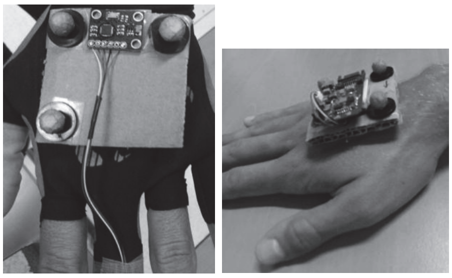

Figure 4: Settings for the second experiment (left: wired, right: distributed).

To compare the data collected with the IMU and the Vicon system, we first had to convert the coordinates provided by the Vicon cameras into angles. To do so, we used an algorithm with a simple angular projection leading to a coherent result for simple rotations around X, Y or Z axis. Finally, we were able to compare the data collected by both systems (Figure 5).

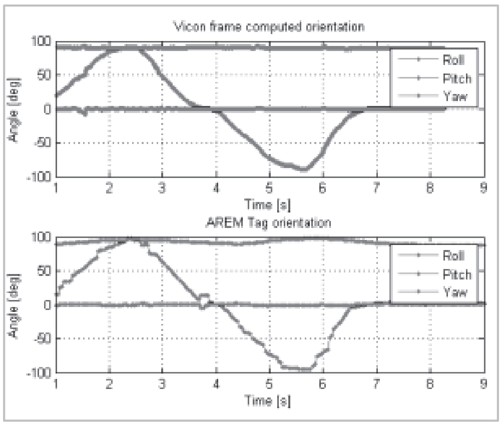

Figure 5: Comparison between IMU and Vicon for the roll, pitch and yaw angles (defined with respect to the sensor's orientation).

Moreover, we are currently working on an algorithm based on the method described by Arun, Huang and Blostein (Arun, Huang and Blostein, 1987), to determine rotation matrixes and translation vectors with Vicon coordinates as inputs to deduce Euler's angles. Knowing the rotation matrix, we will be able to determine the sensor's attitude. This will allow us to compare two methods of conversion, and to determine which one is the most accurate.

3.2 Preliminary Field Tests

After the lab tests, we wanted to carry out field validation tests. Ensuring waterproofness appeared more difficult with the wired version, because we hadn't any glove prototype available yet. Consequently, we decided to do the trials in pool only with the *Gateway*.

Firstly, we tested the WiFi communication provided by the *ESP8266 WiFi module* (2,4 GHz) in a swimming pool in order to establish if the communication was possible in such an environment (water surrounding, metallic structure), and if it was possible under water. To do so, we attached the *Gateway* to the hand of a swimmer and we asked her to put gradually her hand in the water until the loss of the communication (Figure 6). The orientation of the IMU is presented in Figure 7.

Figure 6: First tests of the WiFi communication.

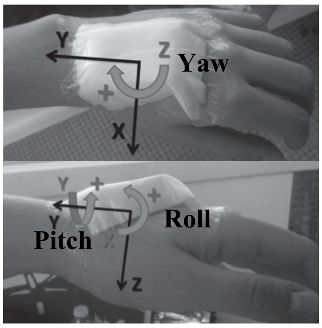

Figure 7: IMU's orientation during the field preliminary tests.

We noted that the depth limit was about one centimeter (under this depth, the WiFi signal was lost), but that the communication was very good on the surface of the water despite the environment quite unfavorable to the correct travel of electromagnetic waves.

Secondly, we decided to test the range of the WiFi signal next to and in the swimming pool. We noticed that the distance between the *Gateway* and the surface of the water didn't change the range of the signal, and we determined it at about sixty meters.

Thirdly, we tested data recording with the *Gateway* during a fifty meters swim by two swimmers. Because of the impossibility to communicate underwater, we chose to record the data when the WiFi signal was lost and to send them at the end of each lap (at the communication restoration). We managed to retrieve the data corresponding to five crawl movements of each swimmer.

4 RESULTS AND DISCUSSION

As the present study is a work in progress, the following part will present results based on preliminary field tests, introduce test protocols and analyses we want to realize with athletes, before talking about the design we have proposed for the glove.

4.1 WiFi Communication Tests

We draw out two options from this experiment: 1) we had to change the frequency of the wireless signal (in order to limit the absorption of the signal by the water) or 2) to reconsider the wireless communication strategy. In fact, we would have to adapt our system to record the data and transmit them to a computer when the *Gateway* is out of the water (at the end of a swim lap). This improvement would enable us to propose a real-time feedback, or at least a faster feedback.

4.2 Swimming Evaluation

In order to get preliminary data related to the hand movement of a swimmer, we will work in collaboration with recreational and elite athletes.

We supposed that elite swimmers would have a hand trajectory which permit them to be more effective, that's why it could be interesting to compare hand kinematics of both groups in order to assess differences between elite and recreational swimmers.

Athletes will be asked to do a self-determined warm-up before being equipped with the *Gateway* on the left hand. Then they will have to perform crawl during fifty meters, without a diving start, in a fifty meters swimming pool. In order to standardize the measurements, the swimmers will be asked to put their hand at the surface of the water, in the direction of the pool, before beginning to swim. Data will be recorded in an external memory (SD card) and collected on a computer at the end of each lap.

4.3 Parameters Extraction

From the variations of pitch, roll and yaw angles provided by the *Gateway*, the challenge was to interpret the collected data. First, it is necessary to correlate the curves obtained with hand positions, and then to determine what is the most effective trajectory. Moreover, it would be interesting to evaluate if the hand acceleration (Hagema et al., 2013) could be associated with swimming effectiveness.

Our approach is the following: we are comparing hand angles between different swimmers in order to distinguish both elite and recreational swimmers. Preliminary data comparing a recreational and an elite swimmers are presented in Figure 8.

With the current state of the study, we can make the following preliminary interpretations. A decrease of the roll angle can be interpreted as the beginning of the crawl movement, when the swimmer draws water. In this part of the movement, the yaw angle represents the hand's direction. Indeed, if it decreases, the hand is pulling from the left to the right, and if it increases, the hand is pulling from the right to the left. Afterwards, an increase of the roll and yaw angles can correspond to a hand's lateral displacement, which is an example of a movement to avoid.

A perspective of analysis is a comparison of two crawl movements: a "correct" movement and a movement where the arms are stretched (Figure 9).

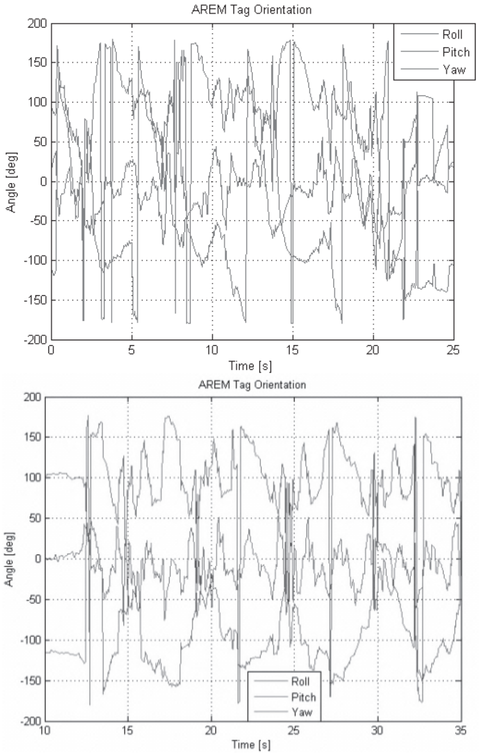

Figure 8: Comparison between a recreational (top) and an elite (bottom) swimmers.

Because of dealing with raw data in these figures, we can emphasize the need of a fast filtering algorithm to correct some unattended points like "gimbal lock" and also compute useful data for real time retrieval. Some recent works (Janota et al., 2015) explain how to perform the Euler angles computing, and we expect to include that correction on IMU chips.

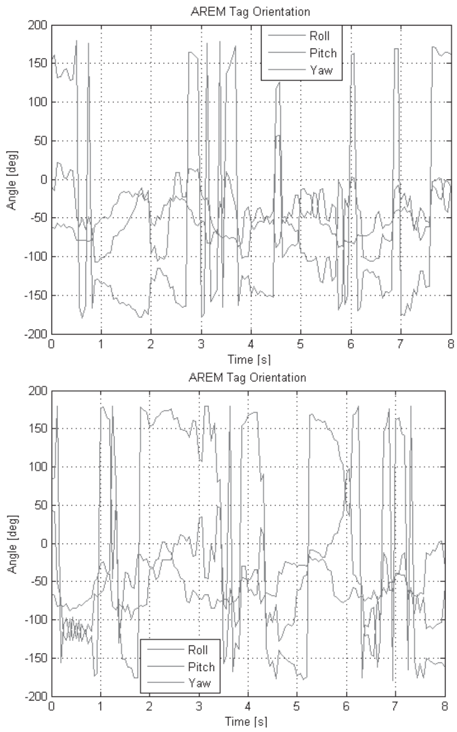

Figure 9: Two different crawl movements (top: incorrect, bottom: correct).

However, our system also measures the 3-axis accelerations, angular velocities (and magnetic field which will not be detailed in this paper). A first comparison between elite and recreational swimmers showed a difference in acceleration amplitude on different styles (Figures 10 and 11).

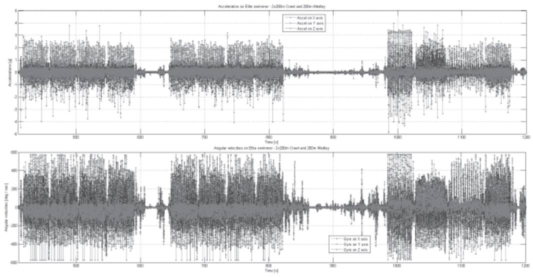

Figure 10: Acceleration (top, in g) and angular velocities (bottom, in deg.s^{-1}) during an elite swimmer test: 2x200m frontcrawl and 200m Medley (red: X, green: Y and blue: Z axis).

A more fine analysis showed differences on patterns and amplitudes/frequencies for each style. That suggests the interest of establishing a “quality factor” qualifying the swim, based on pattern analysis, to evaluate swimmer stroke and give a real time feedback.

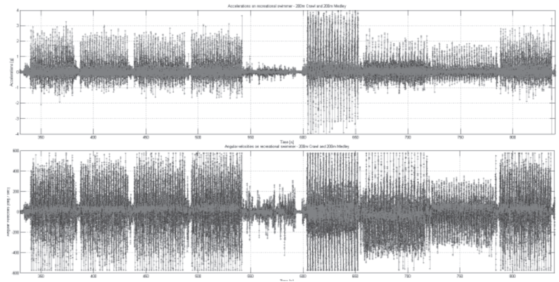

Figure 11: Acceleration (top, in g) and angular velocities (bottom, in deg.s^{-1}) during a recreational swimmer test: 200m frontcrawl and 200m Medley (red: X, green: Y and blue: Z axis).

We show on next figure (Figure 12) the front crawl pattern, being the most analyzed (Dadashi, Crettenand and Millet, 2012). But that pattern will be studied for other swimming styles, like backstroke. We expect to be able to perform the analysis of fatigue impact on swimmer stroke, by storing data from long distance tests.

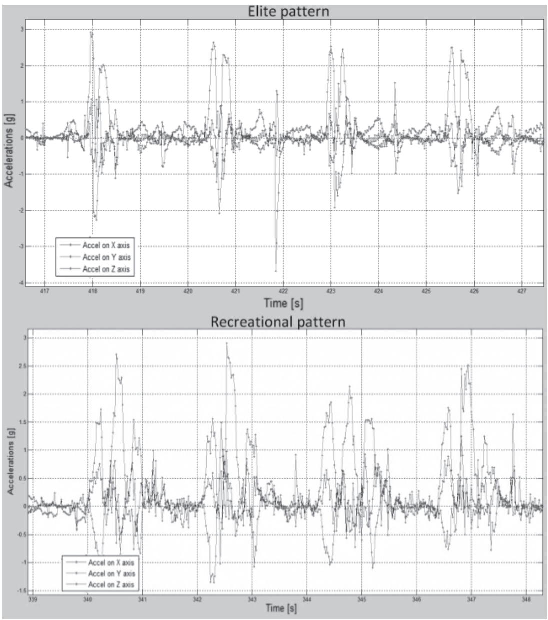

Figure 12: Comparison between elite (top) and recreational (bottom) front crawl stroke pattern.

4.4 Glove Design

In parallel of the development of the electronic part, we proposed different kinds of shapes for the glove. For the prototype, we decided to develop a glove without fabric on the palm and the fingertips. The lengths of fabric on the fingers have been chosen in order to permit the addition of pressure sensors (Figure 13).

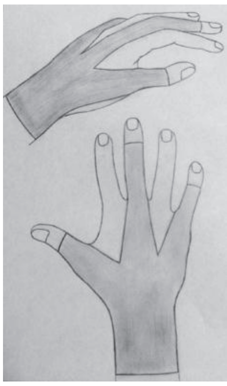

Figure 13: Drawings of the first design of the glove.

The glove has been proposed to two swimmers to collect their perceptions and their opinions. They appreciated the fact that the palm and the fingers tips were free, and didn't feel disturbed by the glove. But they underlined the need to adjust correctly the size in order to prevent the passage of water at the back of the hand, and the slight difficulty of putting the glove on.

5 CONCLUSIONS

The preliminary interpretation seems to show that the Euler's angles variation would be a first interesting parameter to quantify the swimming technique. Indeed, the correlation between the curves and the movements would enable to provide to the swimmer certain necessary adjustments without a video recording or the observation of his coach. But the understanding of the curves obtained implies a correction of the data collected, because the curves seem to contain some aberrant points.

A more common analysis, according to literature, shows a difference in patterns between elite and recreational swimmers. More than recognizing the swimming style, the next step will be to extract a quality stroke index by style and perform fatigue analysis on swimmers.

This study represents a step forward in the development of a wearable motion capture system to monitor swimming performances. It also underlines the fact that the wireless communication must be re-engineered in order to transmit data underwater.

In a further study, we would like to add several pressure sensors in order to provide information relative to the force exerted by the athlete on the water. This would be another parameter to assess swimming kinetics, in addition to the kinematics provided by the sensors presented in this study.

ACKNOWLEDGEMENTS

This research project is partially supported by TE Connectivity and Compressport International. The authors would like to thank Mrs. Marie Percebois, Mr. Manuel Roux, Mr. Louis Cupillard, and others coaches and athletes from Besançon Triathlon and Toulouse Université Club (TUC Triathlon), for their assistance in swimming tests.

The authors would also like to gratefully acknowledge Mrs. Kris Martinez, Mr. Xavi Carabi and Mr. Sylvain Laur, from Compressport Int, for their help in glove design and first prototypes of wearable devices.

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