BIOMECHANICS OF SURFING: DEVELOPMENT AND VALIDATION OF AN INSTRUMENTED SURFBOARD TO MEASURE SURFBOARD KINETICS

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The purpose of this study was to investigate the different relations between the actions of a surfer and the kinematic behaviour of his surfboard. An instrumented surfboard has been designed with a force platform synchronized with an inertial measurement unit and acquisition system. An experimental campaign has been carried out *in situ*, where different waves have been surfed to validate the device. Results revealed that measured efforts of the surfer and kinematics of his surfboard are consistent regarding the expected behaviour. Instrumented surfboards will help coaches by giving them a new performance analysis tool. It will also provide an experimental database for the development of numerical models about interactions Surfer/Surfboard/Wave.
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KEY WORDS: Motion analysis, Dynamic solicitation, Instrumented Surfboard.

INTRODUCTION: In surfing, a system allowing for the quantitative analysis of the movements of an athlete to execute a given figure doesn't exist at the present time. A lot of sports use simulation and scientific approaches to understand interactions between a sportsman and his equipment. Recently, in some sports like tennis, baseball or golf, on-board instrumentation has been used to assess precisely the material performance and the athlete's training (Nathan & Faber, 2011; Andrew, Chow & Knudson, 2003). In order to develop a surf simulator to study the relations between a given figure and the biomechanical response of the surfer, interindividual variability to execute a given movement and to optimise actions of the person aiming at better performances, surfing trajectories have to be reproduced in controlled environment. In 2011, as part of the SurfSens project (now abandoned), Tecnalia initiated instrumentation of a surfboard using sensors with the main objectives of improving the characteristics of a surfboard (Letamendia, 2011) but they didn't identify direct interactions with the surfer.
The purpose of this study was to provide an instrumented surfboard to identify, record and analyse *in situ* the interactions Surfer/Surfboard/Wave. First, we identified all the experimental devices to measure all the data defining the interactions Surfer/Surfboard/Wave. Secondly, the complex and indefinite oceanic environment to design a reliable experimental surfboard and to instrument it with all the necessary measuring tools has been taken into account. Finally, an experimental campaign was organized *in situ* whose results will be presented.

METHODS:

1. Identification of measuring tools.

The interactions between the surfer and the surfboard can be measured with a 6-component force platform. Such a force sensor gives access to the six components of resulting force and moment applied on the platform. The force platform (02-A1, Sensix, Poitiers, France) has been designed from specifications defined by preliminary tests about dimensions and measuring ranges on each axis. Specific behaviour of this platform, based on the results of Boucher (2005) allows large measuring ranges with small volume: respectively (5000N, 5400N, 14500N, 560Nm, 650Nm, 750Nm) for (Fx, Fy, Fz, Mx, My, Mz). The conditioner is located inside the platform in order to facilitate and reduce the acquisition system. Interactions between the surfboard and the wave can be identified by analysing the dynamic behaviour of the surfboard: angular velocities and longitudinal accelerations of the surfboard using a 3-axis gyroscope (ITG3200, InvensSense, San Jose, California) and a 3-axis accelerometer (ADXL345, Analog Devices, Norwood, USA). An acquisition system equipped with an analog-digital converter (Arduino Mega2560 card, Arduino, Torino, Italy) and a microSD shield (microSD Shield, SparkFun Electronics, Niwot, USA) have been used to synchronize the three measurement devices: force platform, accelerometer, and gyroscope.

2. Complex environment to implement an instrumented surfboard
Design of the surfboard was the subject of a specific work in collaboration with a professional surfer and surfboard shaper. A board has been created to accommodate all measurement tools without losing manoeuvrability and reactivity. The force platform has been placed in the surfboard (Figure 1) under the front foot of the rider which corresponds, in surfing, to the predominant foot and is directly correlated to the behaviour of the surfboard. To obtain a reliable measurement of the mechanical actions, it was necessary to have quasi-direct contact between foot and sensor. As the latter is not waterproof, some experiments have been done in laboratory conditions to find a sufficiently tight and resistant fabric (Seaguard Flex 5400, Dickson, Wasquehal, France) to protect the sensor from the marine environment without degrading the measurements.
All the electronic components (accelerometer, gyroscope, acquisition system, battery) have been placed on top of the surfboard in a waterproof case connected to the force sensor (Figure 1). It was designed with a switch for triggering and activating the manual stop at the beginning and the end of the wave. *In situ* data acquisition was started (manual activation by the surfer) when the surfer was lying down and could see a wave coming. The acquisition ended when the surfer finished surfing the wave and was no longer on the surfboard (manual stop). Frequency of the acquisition was chosen at 50Hz. The 12 measuring tensions were stored on an SD card associated to a time measurement. Moreover, a video camera was placed on the beach filming the surfer on the wave: it was used to analyse the behaviour of the surfer, his surfboard and some characteristics about the wave (size and direction). Another on-board video camera (GoPro Hero3, GoPro, California, USA) was on the top of the board (Figure 1b), filming front foot positions on the force platform.

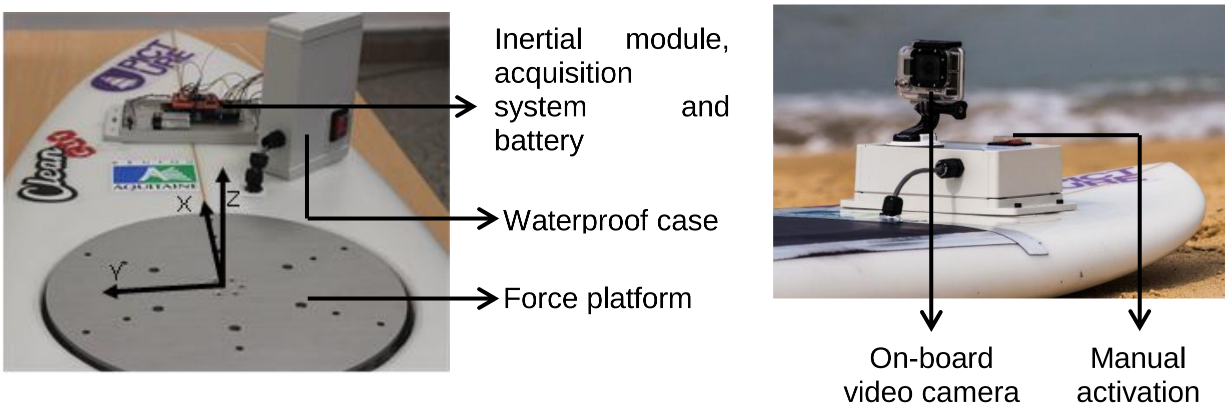

Figure 1: Photos of the instrumented surfboard

3. Data Processing
Data processing was done in several steps. First, all the stored tensions were converted into physical values ([N], [Nm], [m.s^{-1}], [m.s^{-2}]) and reduced to the basis ($\vec{X},\vec{Y},\vec{Z}$). Vertical force Fz was analysed numerically to identify the four main actions of the surfer once the acquisition is triggered: the first one is to wait for the wave sitting on the board: Fz = 0. The second is the paddling to catch the wave: the surfer is lying on his surfboard, only his chest is in contact with part of the sensor, therefore the range of Fz corresponds to 40 to 60% of bodyweight.

Then there is the surfing phase beginning with a take-off corresponding to a significant Fz-peak linked to the first contact between the foot and the sensor. The last phase corresponds to the surfer when he gets off the surfboard (end of the wave or fall): Fz = 0.

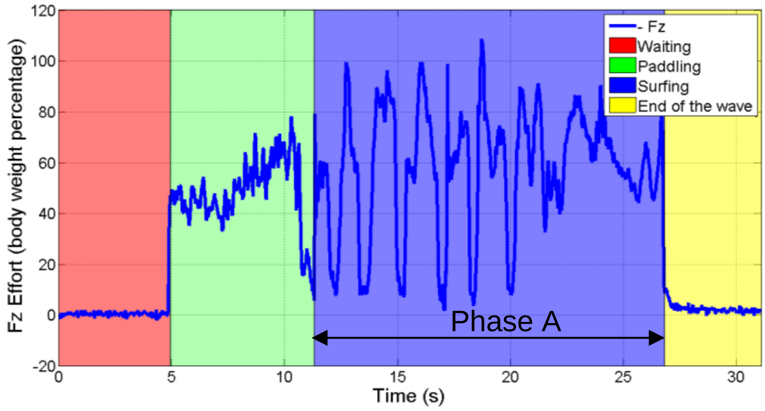

Figure 2: Example of Fz raw efforts saved on a wave with a 50Hz frequency.

The most interesting part is the "Surfing" phase (referred as phase A in Figure 2) where the surfer is generating an action with his body to point his surfboard on the wave. Instantaneous position of the centre of pressure (COP) was calculated considering that the resulting free moments along the X and Y axes are equal to zero (Besser, Kowalk & Vaughan, 1993). Finally, video cameras were synchronized manually during post processing to keep only parts corresponding to phase A using the time of contact between the foot and force sensor.

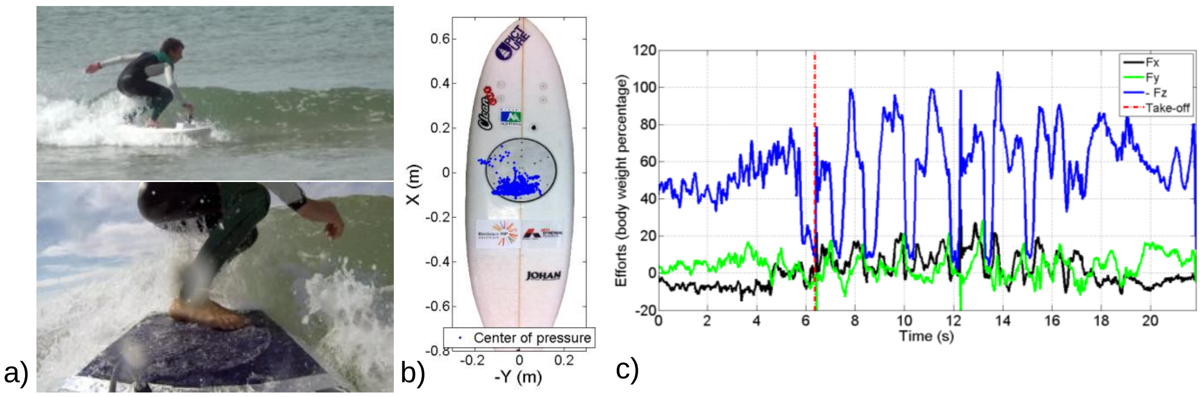

Figure 3: Synchronized experiment data on one wave: a) onshore and in-board videos, b) COP and c) forces on each axis.

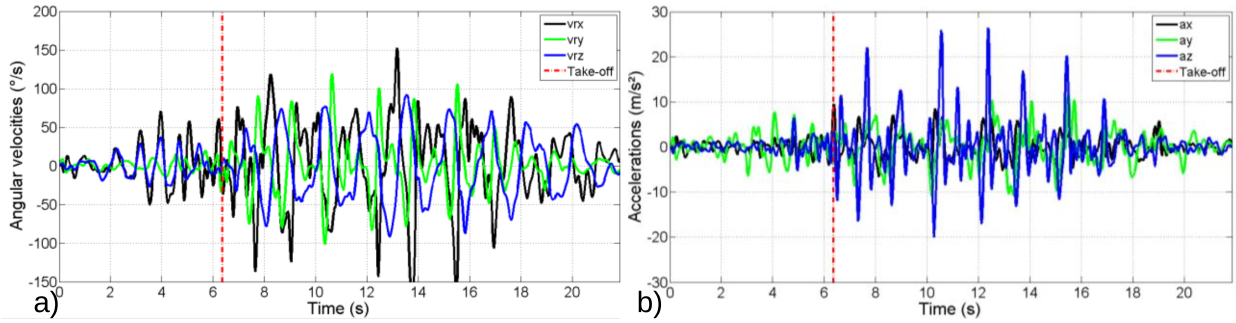

Figure 4: Example of synchronized experiment data on one wave: angular velocities (a) and longitudinal accelerations (b) on each axis.

RESULTS: The objective of this project was to develop an experimental device to evaluate interactions Surfer/Surfboard/Wave during the progression of a surfer on a wave. The easiest way to show that such a system is successful is to present the results of a test with a professional surfer. Figures 3 & 4 are an example of raw data analysed to check the validity of the device. Firstly, instantaneous positions of the COP during «Surfing» phase (Figure 3.a) are consistent with the real front foot position recorded with the on-board camera. In this example, the athlete performed a "Speed generation" on the wave, which corresponds to several flexion-extension movements of the surfer. During the "Speed generation" phase, a professional surfer should put almost all of his body weight on his front foot during the flexion-extension phase. Conversely, he must have almost no support during the reduction phase. On figure 3c, the graph shows as a function of time the evolution of efforts between the rider and his surfboard expressed in percentage of body weight of the surfer. It perfectly illustrates this concept of « speed generation ». Figure 4 presents the evolution of angular velocities (Figure 4a) and longitudinal accelerations (Figure 4b) along the three axes ($\vec{X}, \vec{Y}, \vec{Z}$). To check their validity, high frequencies of these signals have been filtered. After integration, instantaneous surfboard movements on the wave have been directly analysed. For example, after filtering and integration of data from Figure 4, the evolution of instantaneous positions on the vertical axis Z is a sinusoid of amplitude 45cm. This is consistent with the behaviour of the surfboard noticed with the onshore camera on this wave of 50cm, which oscillated between the top and bottom of the wave due to the « speed generation » action of the surfer.

DISCUSSION: As part of a surfing simulator project with a hexapod, equipped with multi-axis force plates, a database is built up for the development of a numerical model characterizing connections between actions of a surfer and the dynamic behaviour of the surfboard. The development of the simulator based on the hexapod will require a control of the trajectory of the moving platform from the forces generated by the user. From a biomechanical point of view, the associated technologic and scientific challenges are numerous: the study of training, practice and balance rehabilitation. Several studies in the literature have been done to evaluate the physiological properties of the human body and their dependencies to experimental protocol (Knuesel, Geyer & Seyfarth, 1983). However, for all the used protocols, movements carried out by the subjects were elementary (one solicitation direction and one level of solicitation). The use of the hexapod and its instrumentation could allow to find the links between the parameters of a complex disturbance (degree of freedom, range of movement, speed, acceleration) and the biomechanical response of the human body.

CONCLUSION: There is a real demand from coaches and athletes to have technical tools allowing them to analyse their actions and their equipment's behaviour. This instrumented surfboard is the first complete interactions Surfer/Surfboard/Wave analysis tool and potentially offers surfers and coaches a way of improving their level of performance and their way of training.

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