

Using IMUs to monitor body kinematics while cycling in different in-field conditions

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Abstract – Wearable sensors and system can profitably be used in bicycle riding to help evaluating the performance and provide trainers and athletes with indications about the strategy used to execute the gesture. In this paper a set of commercial Inertial Measurement Units (IMUs) was used to assess body segment accelerations while pedalling outdoor in different conditions, obtained combining tracks with different slopes and different positions on the saddle. Results show an evident variation on data recorded by the IMUs placed in the upper body segments, as a function of both slope and saddle position, that can be interpreted as a different inertial contribution of the trunk to the gesture. This information can be used to both evaluate different strategies and monitor the evolution of a functional recovery while using cycling in rehabilitation contexts.

Keywords – *IMU, cycling, sport gesture evaluation, road condition, acceleration, measurement*

I. INTRODUCTION

Elite athletes are increasingly using smart and wearable devices to monitor the performances [1], and this practice is widening also to amateurs and recreational athletes. The market of commercial devices to monitor physical activity is full of solutions to evaluate physiological parameters, as well as parameters associated with movement: to name a few, the heart rate or the amount of steps of a runner are two very common variables that can be easily captured by smart bracelets or body-worn devices [2]; in the specific field of bicycle riding monitoring, innovative devices and techniques in the last years have been developed to evaluate both kinematic and dynamics [3-6].

In clinical contexts, sports equipment and related devices are increasingly being used to help rehabilitation from injuries or from surgery procedures. Among different sports, cycling is one of the most used in these situations, to assess both the motor performance and the level of functional recovery [7, 8].

In cycling, the use of many instruments on the bike

has been very popular for more than 30 years, even if only recently athletes started using wearable sensors to monitor their performances. Among possible monitoring means, Inertial Measurement Units (IMUs) have been introduced in this context, as valid alternatives for human motion analysis (e.g. instead of systems like stereophotogrammetry [9] or to supplement dynamic measurements from other devices like force platforms [10]) both in clinical contexts and in the comprehension of neuromuscular mechanisms for planning and executing physical activities [11-12]. In this study, the possibility of using IMUs to evaluate in-field human body kinematics was tested, with the final aim of evaluating the adopted strategy of controlling the body equilibrium while cycling in different conditions.

II. RELATED RESULTS IN THE LITERATURE

Several studies have been carried out focusing on different aspects of the interaction between the rider and the bicycle: starting from the analysis of handling and manoeuvrability to the modelling of the bicycle-rider system, Doyle [14] examined the mechanisms to control the bicycle, by analysing the balancing strategies; in a different study, the effect of the upper body in the control mechanisms was evaluated to better assess the strategy adopted during cycling [15]; Koijman and Schwab [16] presented an exhaustive review, which embraces all the motor control hypotheses and studies performed on the rider and the bicycles focusing on the modelling techniques of both the elements. Furthermore, strategies of cycling have been examined also by considering the implications associated with human motor control and planning [17, 18].

The kinematics associated with the interaction between the rider and the bicycle has been often analysed inside laboratories using video capture systems, but the use of inertial measurement units allowed to perform these analyses outdoor: Zhang et al. [19-20] presented a computational scheme to estimate the whole-body pose of the rider-bicycle system, while in a successive work the study was extended by using 11 wireless inertial sensors on prolonged recordings on different road conditions

[21]. In these in-field conditions, it may be of help to understand how different terrain conditions (level, slope), and how different bicycle posture styles (e.g. seated or standing on pedals) influence the kinematics, and as a result, the performance: this will be object of the present study.

III. DESCRIPTION OF THE METHOD

In the present study, accelerations were measured using a set of 7 Shimmer3 IMU units (ShimmerSensing). These IMUs present the features needed to be easily worn, given their rather low weight (23.6g each) and size (51x34x14mm). The sensors are controlled by a central unit, connected via Bluetooth that allows the synchronous start of data acquisition. Moreover, each unit is equipped with an on-board memory that allows independent and synchronous acquisitions when the central unit cannot be reached.

In order to evaluate the accelerations of the different human body segments, the IMUs were placed in 6 different points of the subject's body, as showed in Fig.1, using housing and belts provided with the system to reduce the errors introduced by the fixing methods [22-23].

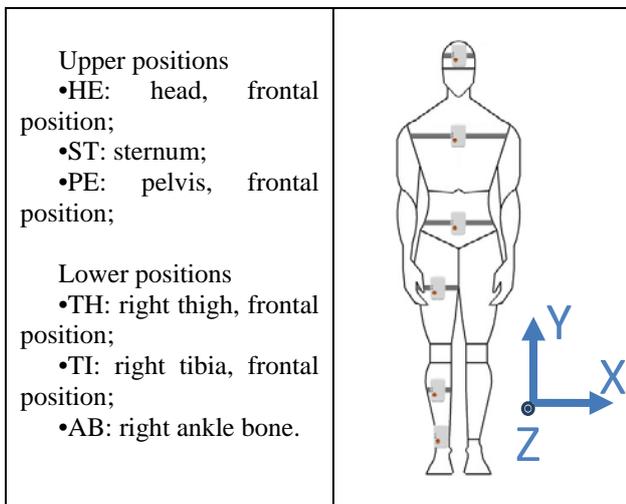


Fig. 1. IMUs positioned on the body.

Sensor placement was chosen in such a way to evaluate the accelerations of different body segment, involved directly or indirectly in the gesture, to finally determine their dynamic behaviour in different road and pedalling conditions: in particular, the IMUs positioned on the lower limb provides information about the movement for the propulsive power, while the ones positioned on the head-trunk complex gives information about the body posture and dynamics while pedalling. If the upper body is hypothesized as a rigid body, which is integral with the bicycle frame, information coming from the upper section of the IMU should be just a bias coming from the different orientation of each sensor from the

bicycle frame; if this does not occur, the hypothesis is that the behaviour of the trunk could be different, also based on different conditions, and can reflect a different strategy for each pedalling condition. A further IMU was positioned on the bicycle frame (BF-IMU).

The axis orientations were chosen uniform for each IMU while the subject stood barefoot, according to the reference system showed in Fig.1.

The tests were performed on a population of 8 male subjects (age 23 ± 2 yrs, height 180 ± 10 cm), that pedalled in 4 different conditions, combining 2 different positions – seated (Se) and standing (Sg) on pedals – and 2 different tracks– level riding (Pl) for 400m and uphill riding (Uh) for 200m. The bike seat was regulated according to the KOPS method [1] and subjects were asked to pedal at a fixed frequency of 75RPM, following an audio beat. A familiarization test on a level track was executed with the IMUs fitted on the body to let the subject adapt to the trial condition, without considering the correspondent acquired data.

Signals were recorded using a 102.4Hz sampling frequency, $\pm 8g$ amplitude range, using a Labview panel (National Instruments) that was designed to continuously store data once the trial started. The IMUs were connected to PC using their custom wireless adapter and the Labview panel was developed using the provided Shimmer libraries. When a new acquisition starts, a sync signal is sent to each IMU that starts sampling and stores signals into its on-board memory. At the end of the recording, all data are downloaded to the PC and signals are time aligned using the common sync.

For each IMU i , the acquired signals were processed to obtain the total acceleration vector $\mathbf{a}_{tot}^{body_i}$ as vector sum of the 3 components. Then, the dynamic acceleration vector of each body segment $\mathbf{a}_{dyn}^{body_i}$ was calculated for each IMU placed on the subject's body, according to the following equation (1):

$$\mathbf{a}_{dyn}^{body_i} = \mathbf{a}_{tot}^{body_i} - \mathbf{a}_{tot}^{BF-IMU} \quad (1)$$

where $\mathbf{a}_{tot}^{BF-IMU}$ represents the acceleration vector of the bike frame. The dynamic component is free of the gravity component nor the inertial components coming from the bike frame dynamics, thus maintaining the information related to the athlete movement relative to the bike.

The time series of each body-referenced IMU were then segmented and averaged, by using the minimum peak locations of the TH Y component as trigger, as they correspond to the top dead point of the crank, to obtain an acceleration template profile for each pedalling cycle. For each averaged profile, the magnitude and the mean value along the cycle was calculated: this procedure was repeated for every individual, along all the 4 pedalling conditions.

IV. RESULTS AND DISCUSSIONS

A visible difference between the two conditions – seated and standing on pedals – appeared both for the plain track (Se-Pl and Sg-Pl) that for the uphill one (Se-Uh and Sg-Uh), in all the upper IMUs (HE, ST and PE), while the differences are not as evident for the lower ones (TH, TI and AB).

The mean values and RMS of the average profiles of accelerations of the PE, ST and HE IMUs result appreciably higher than zero, thus showing that the upper part of the body is not steady with respect to the bicycle frame: this is in agreement with the initial hypothesis of a direct inertial contribute of the upper body to the gesture, that helps maintaining equilibrium in the different conditions. In Fig.2 these values (mean and RMS) show a remarkable variation while passing from a seated position to a standing position: in both cases of level and uphill track, the mean value of each IMU increases, thus showing a greater movement of the trunk that may be associated with finding the correct position.

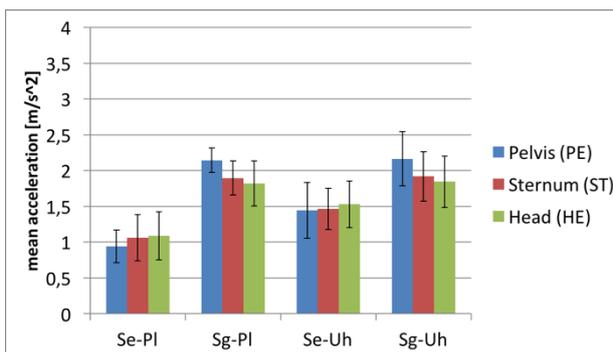


Fig. 2. Group mean values and standard deviations for the acceleration magnitude of the upper IMUs in different conditions.

On the other hand, the mean values and RMS of the average profiles of dynamic accelerations of the AB, TI and TH IMUs are very similar in the 4 conditions, thus showing that the pedalling kinematic strategy doesn't change if the pedalling cadence is maintained constant during different trials. In general, as it is shown in Fig.3, the mean values are higher than the ones of the upper part of the body, as expected given the placement of these IMUs on the cycling focal limbs.

From the obtained results, it is possible to observe that the behaviour of the upper limbs contributes to the different modes of performing the sports gesture associated with the different conditions, probably with an important role in maintaining the balance; the lower limbs have a limited role in this, having the main function of producing the propulsive power instead. Maintaining balance needs different strategies when different internal forces are applied: with the subject standing on the pedals, the upper limbs counteract perturbations to balance coming from the lower limb; in the seated

position, this compensating effect appears instead rather limited, maybe as a result of a less threatening perturbation to balance.

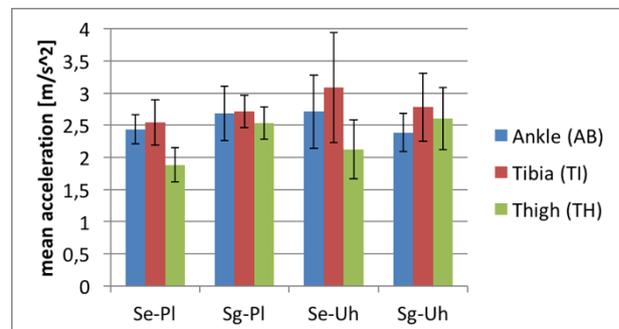


Fig. 3. Group mean values and standard deviations for the acceleration magnitude of the lower IMUs in different conditions.

V. CONCLUSIONS

In this work, body segment accelerations were measured by means of body-worn IMUs placed at different body parts during bike riding conditions, thus assessing the possibility to use these sensors in in-field conditions. The obtained results can be useful to implement a technique to characterize the body kinematics during bike riding in a simple and fast way, with applications in sport and clinical contexts, where the use of complex instruments on patient is not easy if at all possible.

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