POLITECNICO DI TORINO
Repository ISTITUZIONALE

An inertial-based system for golf assessment

Original
An inertial-based system for golf assessment / Lombardo, Luca; Iannucci, Leonardo; Gullino, Alessio. - ELETTRONICO. - (2018), pp. 1-6. (Intervento presentato al convegno 2018 IEEE International Instrumentation and Measurement Technology Conference, I2MTC 2018 tenutosi a Royal Sonesta Hotel, usa nel 2018) [10.1109/I2MTC.2018.8409822].

Availability:
This version is available at: 11583/2712111 since: 2020-02-07T14:55:16Z

Publisher:
Institute of Electrical and Electronics Engineers Inc.

Published
DOI:10.1109/I2MTC.2018.8409822

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright
IEEE postprint/Author's Accepted Manuscript

©2018 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collecting works, for resale or lists, or reuse of any copyrighted component of this work in other works.

(Article begins on next page)

19 April 2024

© 2018 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.

An inertial-based system for golf assessment

Luca Lombardo
Dipartimento di Elettronica e Telecomunicazioni Politecnico di Torino Torino, ITALY

Leonardo Iannucci
Dipartimento di Elettronica e Telecomunicazioni Politecnico di Torino Torino, ITALY

Alessio Gullino
Dipartimento di Elettronica e Telecomunicazioni Politecnico di Torino Torino, ITALY

DOI: 10.1109/I2MTC.2018.8409822

An inertial-based system for golf assessment

Luca Lombardo, Leonardo Iannucci, Alessio Gullino
Dipartimento di Elettronica e Telecomunicazioni
Politecnico di Torino
Torino, ITALY
Email: luca.lombardo@polito.it

***Abstract*—This paper describes a sensor which is designed to help golf players to increase their capabilities by tuning their movements. The proposed solution is characterized by having the sensing unit to be attached to the golf club near to its head so that the sensor placement is easy and the sensor can be moved when the club is changed by the player. The sensor is able to communicate with either a smart-phone or a PC by using the bluetooth LE protocol so that there is no reason to remove the sensor from the club during its use. A GPS unit is used to track the club position so that it is also possible to recreate a golf session including the stroke positions to review the procedure. The system is arranged by using all commercial off-the-shelf components embedded into a 3D printed case. The overall cost is of less than 100$ making it an easy and simple tool for assessing and improving the player skills.**

***Index Terms*—Sport training, Golf, Environmental monitoring, Inertial sensors**

I. INTRODUCTION

Nowadays, the design and employment of smart sensors and new techniques strongly influence the world of sports. In the last ten years, many electronic devices and sensors have been developed to support athletes during their training as well as to help amateurs to play their favorite sport [1,2]. A large number of different devices such as wearable sport computers employed to monitor athlete physiological parameters [3], or smart trackers for ball game, which allow collecting data about each shot, ball speed, swing, ball spin, ball impact spot and so on are now available on the market, in particular for sports such as swimming and tennis which are followed by thousands of people around the world. Often, these devices use wireless communication protocols, like Bluetooth Low Energy (BLE) for short range communication or LoRaWAN [4] for longer range applications and this lets such smart sensors to be employed seamlessly and non-invasively in many different sport fields.

Golf is one of the sports where the precision of any single hit has a high importance and which requires strong discipline and control of the players. In this scenario, a smart sensor which is designed to be used both during training and real matches for a-posteriori analysis of the match would be of great importance.

Such a sensor could be used during training to record and characterize each hit done by the user to let him/her enhance his/her capabilities by immediately reviewing each stroke. During a match, the sensor could be used to record the features of player hits, recording at the same time the environmental conditions (temperature, humidity and pressure) and the path followed during the match. All these values could be reviewed at the end of the match to perform a SWOT analysis (Strengths Weaknesses Opportunities Threats).

In addition, a sensor of this type would give the possibility to let players download, process and share the performance with both friends and other players simply by using their smart-phones, provided that a suitable connection capability would be available.

Few commercial devices offering these types of functionalities are already available on the market [5], ZeppGolf [6], Arccos 360 [7], and they have some disadvantages which limit their use in practical application.

The authors are proposing therefore a system that should achieve better measurement performances due to the position of the sensor on the golf club. In virtually all commercial devices the sensor is placed close to the club grip. With this configuration, only the player hand speed and movement can be directly measured; information about the real head movement must be obtained through post-processing.

The proposed system, instead, is designed to be positioned close to the golf club head, so that its trajectory and speed is directly measured. In order to do this, the sensor has to be extremely light so that it does not alter the club mass and its moment of inertia.

II. THE PROPOSED SYSTEM ARCHITECTURE

The proposed tracking system is intended to be directly fixed on the golf club, close to the club head. Thanks to its very reduced dimensions and the low weight, the system does not interfere significantly with the club balance and does not change the experience of the player. This way it can be a reliable assistant, which provides useful information to the users in order to improve their game experience and enhance their performance.

The proposed system takes advantage of the SensorTile Development Kit, which is produced by STMicroelectronics and is commercially-available at a very low cost. The SensorTile consists of a very small wireless module that integrates most of devices required in this application. The overall size of the module is 13.5 mm x 13.5 mm. Fig. 1 shows the tiny module and highlights the main devices that are used in the system:

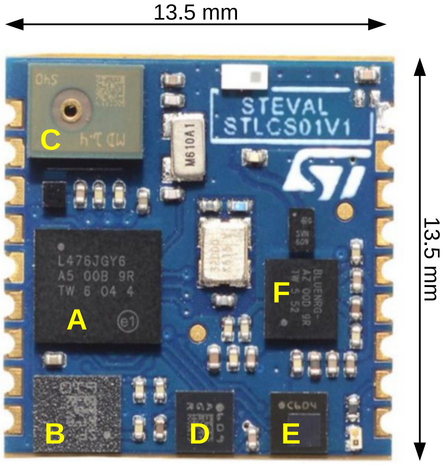

Fig. 1. The SensorTile Wireless module: in the figure the main devices employed in the proposed application are highlighted.

- A The STM32L476 microcotroller. This 32-bit ultra-low-power CortexM4F processor performs all the operations required for the proper operation of the system. It takes care of the interfacing with all the sensors, fetches their measurements, processes such measurements in order to evaluate the key parameters and the information for the player and manages the Bluetooth Low-Energy communication.
- B The LSM6DSM iNEMO inertial module. This chip integrates a 3-axis accelerometer and a 3-axis gyroscope. The device is employed as the main inertial sensor in the application for the acquisition of acceleration and angular velocity which are used for estimating the club head trajectory and the ball velocity after the hit.
- C The MP34DT04 digital microphone. The microphone is used together with the accelerometers to detect the hit time. This way, the club head deceleration can be better identified and used for estimating the ball velocity at hit time. From this information it is also possible to estimate the free ball distance.
- D The LSM303AGR eCompass module. This chip integrates a 3-axis accelerometer and a 3-axis magnetometer. The devices are used to assess the player orientation, which is required to assess the ball direction after the hit. In addition, this information is also used to know the exposition of the player with respect to the sun at the hit time. The accelerometers are also to enhance the accuracy of the iNEMO module, especially during the calibration process.
- E The LPS22HB barometer. This sensor is able to measure the atmospheric pressure and it is employed together with the temperature and humidity sensor for monitoring the environmental conditions during the play.
- F The BlueNRG-MS chip. This chip together with a chip antenna and a balun adapter provides the module with the Bluetooth Low-Energy (BLE) connectivity. This connection is used to transfer in a quasi real-time the acquired data to either the player smart-phone or to a PC.

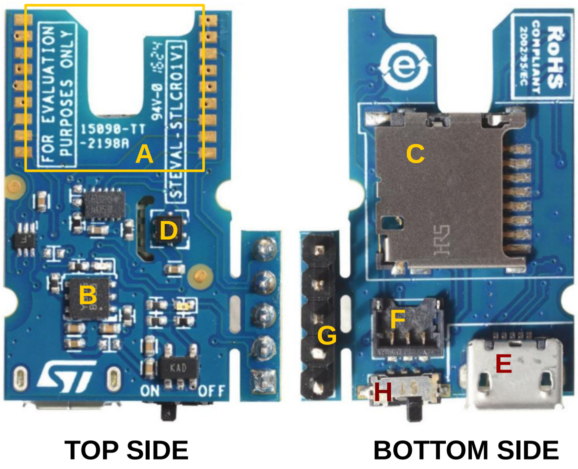

Fig. 2. The SensorTile Cradle module: in the figure the main devices employed in the proposed application are highlighted.

In addition to the SensorTile module also the SensorTile Cradle is used in the application. The SensorTile Cradle is a small board on which the SensorTile module can be soldered and that can be used to expand the functionalities of the basic module. Fig. 2 shows the Cradle board which is designed to host the SensorTile board and provide additional components used by the proposed system:

- A The place where the SensorTile has to be soldered
- B The battery charger which is employed to charge the system battery from a standard source, like a standard USB power adapter.
- C The microSD slot. This slot is connected to the SensorTile and it is used to store permanently the measurements taken by the system. This is a very useful feature because it makes possible to download the acquired data on a PC after a match for analyzing the performance or the errors. Furthermore, having a backup copy of all the data is useful in case a possible wireless link failure occurs.
- D The HTS221 temperature and humidity sensor. This sensor is used to monitor the environmental condition during the play in conjunction with the environment pressure and the player exposition to the sun, already described. Correlating player performance and play results with the environmental conditions can be very useful, being the performance significantly affected by many environmental parameters.
- E The microUSB connector. The USB interface is used primary for charging the battery through a standard 5 V power supply. In addition, the interface can be used for downloading data on a compatible computer running a dedicated application. This can used for analyzing the match performance.
- F The battery connector for the rechargeable battery that power the whole system.

G The programing interface. The programming connector is employed during the system development and the firmware debugging in order to upload the microntroller firmware. In order to reduce the size and the weight of the final system, the connector can be removed from the board after the final firmware version has been uploaded.

H The power switch. The system has a low power sleep mode that is automatically activated when no movement is detected for a given period of time. However, the power switch can be used to turns off the whole system when it is not used for a prolonged period of time.

All the system is allocated inside a 3D printed box whose dimensions are of about $33\ \mathrm{mm}$ x $25\ \mathrm{mm}$ x $21\ \mathrm{mm}$, including both the boards, the GPS receiver module, the battery and the enclosure itself. The reduced size of the system makes easy to attach it to golf clubs without obstructing the player movements.

The total weight is of about $20\ \mathrm{g}$. Considering that the typical weight of a golf club is in the order of $300 \sim 500\ \mathrm{g}$, the addition of the system to the club close to the head (that is the heaviest part a club) has a minimal effect on the balance and on the inertial moment of the club itself. The overall increase of the club inertial moment can be estimated in the range $5 \sim 7\%$. Thus, it can be concluded that the addition of the system does not affect significantly the experience of the player.

III. THE SYSTEM FIRMWARE

All the operations required for the proper working of the system are carried out by the firmware running on the STM32L476 microcontroller available on the SensorTile basic module. The firmware is based on the Free RTOS Operating System [8], which is capable of managing the different tasks running in a system according to a deterministic protocol. This makes it possible to know the response time for each task and simplifies the task synchronization. The RTOS is widely diffused in the embedded field for its robustness and light weight, and allows to reduce the developing time of complex software system keeping low, at the same time, the hardware resource requirements.

In the proposed application the operating system manages all the required tasks and guarantees a synchronization between all the operations. Fig. 3 depicts the basic structure of the system highlighting also all the tasks running and how they operate in order to acquire sensor data and elaborating them. The figure shows on the left all the sensors embedded into the SensorTile and the GPS receiver, which is the only sensor added to the system.

All the embedded sensors and the GPS receiver are connected to the microcontroller using the supported digital interfaces (SPI, I2C and UART). Sensor data are acquired using the dedicated drivers for both the microcontroller digital interfaces (low-level drivers) and the sensor devices (high-level drivers). These drivers, with the exception for the GPS receiver, are provided by STMicroelectronics in a bundle featuring several libraries ready to be added in the application.

The driver for the GPS has been ad-hoc developed for this system and supports all the basic operations required to communicate with the module and to decode the position data. Data reception is managed through specific hardware interrupts in order to minimize the microntroller load.

Several primary tasks are defined in order to acquire, decode and process the sensor data. Each task is responsible for a specific processing, specifically:

- Trajectory and Movement Tracking System. This task is responsible for data acquisition from the embedded inertial sensors (accelerometers and gyroscope) and for their processing. Once data are acquired, the task merges them together and extracts the estimated trajectory of the club head in order to provide information on the movements performed by the golf player during each swing. The same task is responsible to detect the absence of movements and is able to put the whole system in a sleep mode in order to save battery power.
- Ball Hit Detector and Distance Estimator. This task uses the accelerometer data and acquires the microphone digital signals. When the club head hits the ball, there is a small deceleration of the club that is recorded by the accelerometers. At the same time, the microphone records the hit sound. Both the information are merged together in order to achieve a more accurate and reliable timing of the ball hitting. From the estimated club head velocity and deceleration the task estimates the ball velocity at the hit time and, thus, it can get a rough estimation the free-path distance.
- Environmental Condition Logger. This task acquires and decodes the data from the atmospheric pressure sensor and the temperature and relative humidity sensors. These data are used to relate the player performance with the actual environmental conditions he/she is exposed to.
- Global Position and Exposition Logger. This task is responsible to collect data related to the actual position (GPS coordinates) and estimate the player heading. The coordinates as well as the absolute time are provided directly be the GPS receiver, while the player heading is estimated by processing data from the magnetometer, used as a digital compass. This makes possible to estimate the player position and orientation in respect to the global positioning system for checking the direction of each ball hit. All these data are stored and can be useful for analyzing the performance of the player and how these are related with the player position.

The tasks for trajectory estimation and ball hit detection are constrained by severe time requirements. They have to perform a real-time acquisition from the sensors and a real-time pre-processing of the data during all the phases of a golf swing, from the addressing to the impact and finish. Thus, those tasks are granted of the highest priority. Furthermore, it is very important to guarantee the synchronization of the two tasks in order to achieve coherent information of the club trajectory and the ball hit. The other primary tasks have more

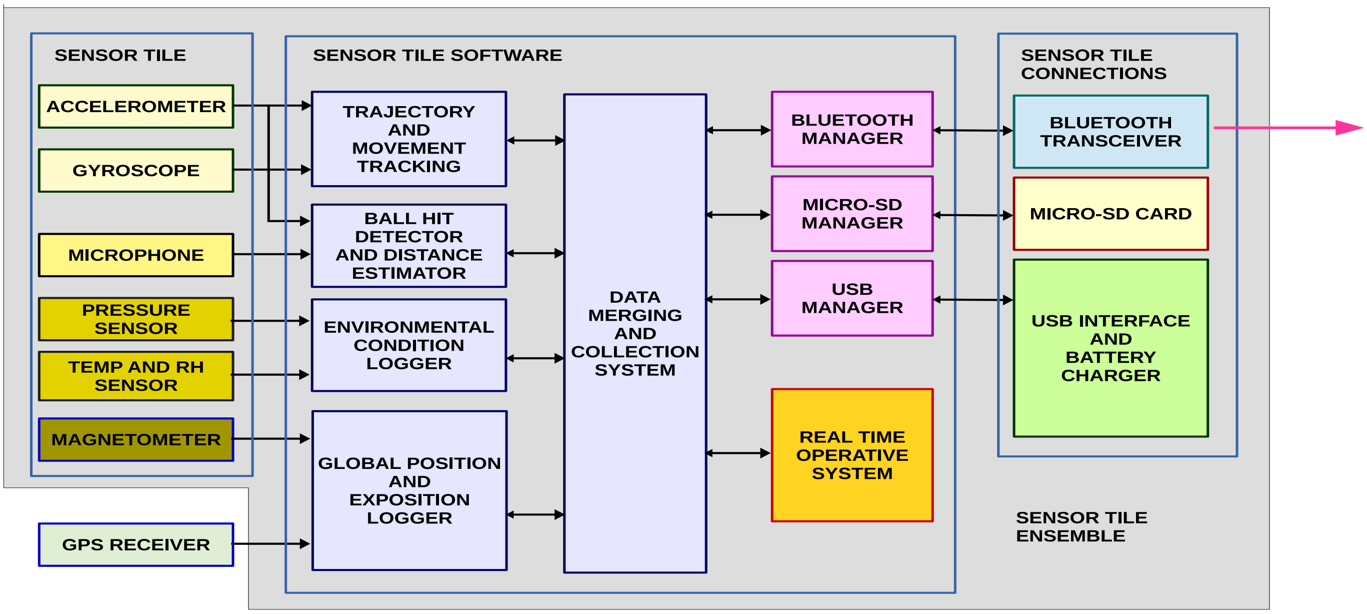

Fig. 3. The structure of the firmware which manages all the operations performed by the system. All the components except the GPS receiver are embedded into the Sensor Tile Ensemble. The firmware is based on the FreeRTOS Real-Time Operative System and it is executed on the SensorTile microcontroller. The SensorTile embeds also the battery which is required for powering the system and the bluetooth transceiver which is used for the communication with PC and Smart Phones

relaxed time constraints, having just to acquire the data with a low sampling rate.

A specific task, the Data Merging and Collection System, is responsible to collect all the data provided by the other tasks. In particular, it creates in the RAM a temporary buffer of all the acquired and decoded data, as they are provided by the primary tasks. Data are allocated in a specific structure according to the type of the sensor they refer to. It is required to have this task always synchronized with the primary ones to avoid any possible misalignment of the data.

Finally, there are the secondary tasks which use the data stored by the Data Merging and Collection System. There is a specific task for each communication interface available on the system. Specifically:

- The Bluetooth Manager is responsible for the Bluetooth Low Energy communication. The manager is built over the Bluetooth stack and the driver provided by the STMicroelectronics. It manages the specific functions related to the system: data exchanging and system configuration.
- The MicroSD Manager creates a backup copy of all the acquired and processed data on the microSD card available on the system. The manager employs a freely available library for the management of the FAT filesystem used to store data in the memory card. This way, the card is compatible with most of the computers and data exchanging can be performed without a specific application.
- The USB Manager is used to interface the USB port. The USB communication provides similar functionalities of the Bluetooth, but requires a dedicated program running on the host PC.

IV. SYSTEM CALIBRATION

The system has been subjected to a preliminary calibration in order to acquire useful information regarding the expected performance. The ranges of the inertial sensors employed in the application have been selected: $8\ \mathrm{g}$ for accelerometers and $20000\ \mathrm{mdps}$ for gyroscopes (the employment of the STMicroelectronics drivers allowed the reduction of the development time even if it limited the maximum acceleration range to 8g). Selected sampling rate is $200\ \mathrm{Hz}$. The calibration has been performed on the inertial module iNemo LSM6DSM with the goal to compensate for intrinsic misalignments of the sensor coordinate system, sensitivity errors and biases [9]. Periodic calibration of the system can be required in order to address thermal derives of both sensitivity and biases. The calibration procedure provides a set of parameters (sensor bias, sensitivity and cross-axis effect) that can be used to correct measured acceleration according to the following matrix equation:

$$\mathbf{A} = \mathbf{C_a} \cdot \mathbf{K_a} \cdot (\mathbf{A_m} - \mathbf{A_b}) \tag{1}$$

where $\mathbf{A}$ is the compensated acceleration vector, $\mathbf{A_m}$ is the acceleration vector as measured by the sensor using nominal sensitivities, $\mathbf{A_b}$ is the bias vector of the accelerometers, $\mathbf{K_a}$ is a diagonal matrix containing the sensitivity correction coefficients, and $\mathbf{C_a}$ is a matrix which takes into account the cross-axis effects. The $\mathbf{C_a}$ matrix can be simplified if the x axis is considered coincident with the x sensitivity axis. In this case it can be written:

$$\mathbf{C_a} = \begin{bmatrix} 1 & j_{a-xy} & k_{a-xz} \\ 0 & 1 & k_{a-yz} \\ 0 & 0 & 1 \end{bmatrix} \quad (2)$$

being j_{a-xy}, k_{a-xz}, k_{a-yz} the projection coefficients.

A similar approach can be used also for compensating the angular velocities measured by the gyroscope:

$$\omega = \mathbf{R}_\omega \cdot \mathbf{K}_\omega \cdot (\omega - \omega_\mathbf{b}) \quad (3)$$

where ω is the vector of the angular velocities as measured by the gyroscope using nominal sensitivities, $\omega_\mathbf{b}$ is the bias vector the gyroscope, $\mathbf{K}_\omega$ is the diagonal matrix containing the sensitivity correction coefficients, and $\mathbf{R}_\omega$ is the matrix which takes into account the cross-axis effects. No simplification can be performed on the $\mathbf{R}_\omega$ matrix, which can be written as:

$$\mathbf{R}_\omega = \begin{bmatrix} 1 & j_{g-xy} & k_{g-xz} \\ i_{g-yx} & 1 & k_{g-yz} \\ i_{g-zx} & j_{g-zy} & 1 \end{bmatrix} \quad (4)$$

The employed calibration procedure is able to provide the nine parameters required to fully compensate acceleration errors according to (1). It should be noted that the accelerometers are ever subjected to local gravity acceleration and no zero-acceleration measurement can be performed. For this reason calibration is performed measuring static gravity acceleration along the three axis at several inclinations on the three possible orientations of the sensor. The acquired data are processed taking into account that the total acceleration has to be always equal to the local gravity acceleration:

$$|\mathbf{A}| = \sqrt{{a_x}^2 + {a_y}^2 + {a_z}^2} = g \quad (5)$$

The calibration parameters are calculated in order to minimize the acceleration error in (1) employing the least square estimation algorithm. Static acceleration is measured at 12 different inclinations (step of 30°) turning the sensor around each coordinate axis. Fig. 4 reports the calibration results obtained using the explained procedure.

The acceleration values measured by the sensor without performing any calibration are affected by a significant mean errors ($\sim 0.2\ \mathrm{m/s^2}$) and are not consistent on the three axis. Instead, after calibration and compensation, the acceleration mean error is minimized. The standard deviation is reduced to $0.0531\ \mathrm{m/s^2}$, and consistent results are obtained on all of the three axis.

V. EXPERIMENTAL RESULTS

In order to evaluate the effectiveness of the system in on-field use, several measurements have been carried out using a golf club and a golf ball and performing complete swings with and without hitting the ball. The acquired data for acceleration and angular velocity are reported in Fig. 5. Four complete swings are shown in the graph. For each episode the main features of a typical golf swing are clearly visible: address, back swing, top of swing, down swing, impact (in the fourth

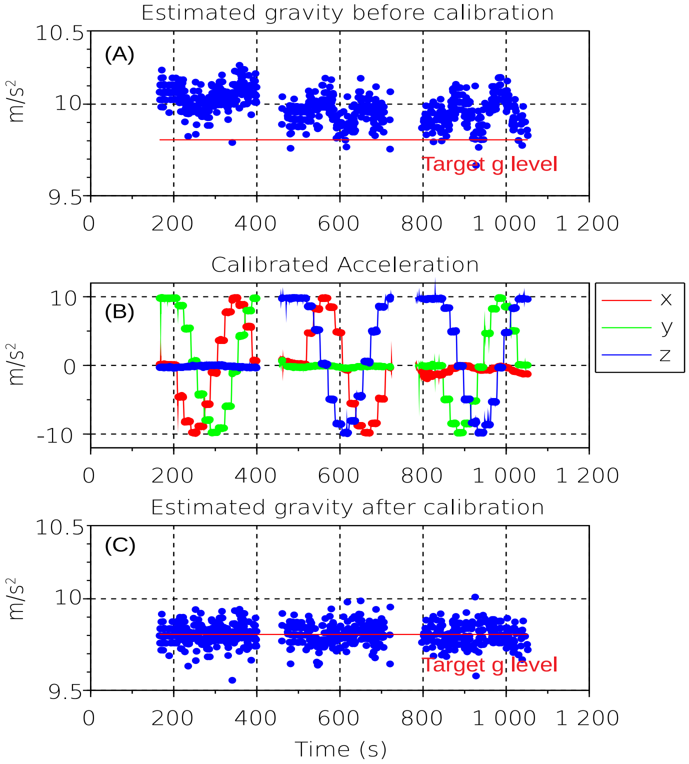

Fig. 4. Results of the calibration procedure for the accelerometers. (A) static acceleration values acquired without any calibration, the mean error is about $\sim 0.2\ \mathrm{m/s^2}$ and different values are obtained on the three axis. (B) acquired values during calibration procedure compensated with the extracted parameters, are clearly visible the 12 steps for each of the three axis. (C) error evaluation after compensation, mean error is almost nullified and result are consistent on all of the three axis.

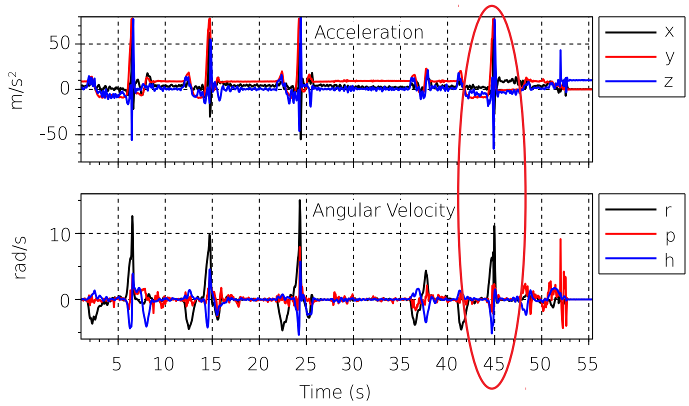

Fig. 5. Data acquired with a golf club in real situations. Four complete golf swings are reported, but only in the fourth the ball is hit. All the typical features of a golf swing are clearly visible. The last episode, highlighted with a red circle, shows the effects of the ball impact both on the acceleration and angular velocity. Angular velocity components are expressed in terms of roll (r), pitch (p) and heading (h).

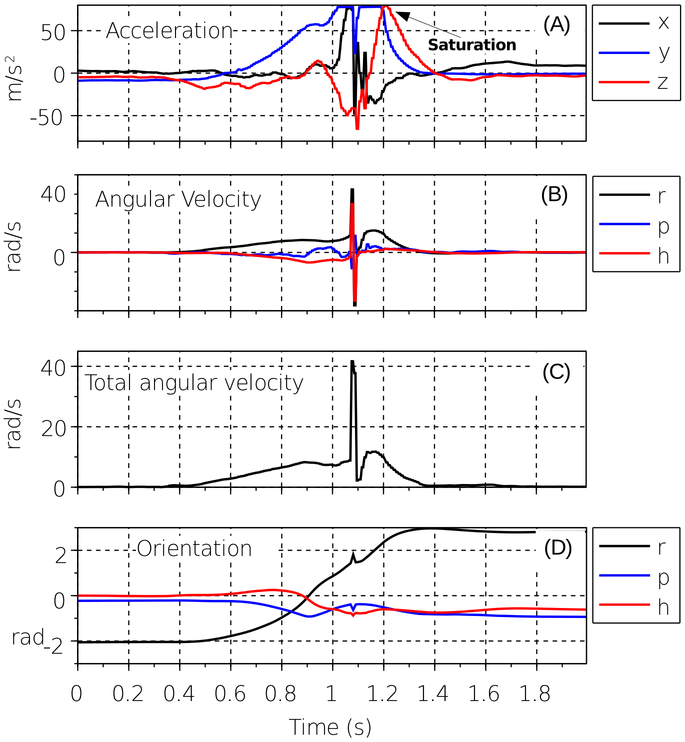

Fig. 6. Data acquired with a golf club in real situations during an impact event (episode highlighted with red circle in Fig. 5). The acceleration components (A) exhibit dumped oscillations due to the club elasticity. Saturation of acceleration components occurs during the swing. The problem is being addressed increasing up to 16 $\mathrm{m/s^2}$ the acceleration full-scale range. The impact event is clearly visible in the angular velocity components (B) and in the total angular velocity (C). Integration of the three angular velocities allows to obtain the angular position (D) of the golf club during the swing.

episode only) and follow through.

The ball is hit only in the fourth episode, reported in detail in Fig. 6, where the effect of the hitting is clearly visible on both the acceleration and the angular velocity. The accelerations exhibit a resonance effect due to the club intrinsic elasticity: dumped oscillations (with characteristic frequency of $\sim$ 30 Hz) appear just after the impact. Oscillations disappear within about 0.2 s since the impact. This makes difficult to use acceleration for detecting the ball hitting event. Fortunately, the ball impact has very clear effects on the angular velocity. An abrupt descending edge occurs on two of the three angular velocities at the impact. This is even more clearly visible in the total angular velocity computed from the three components. After the impact event (which lasts few milliseconds) the angular velocity rises again and goes on decreasing gradually following the follow through of the player.

The integration of the angular velocities provided by the gyroscopes allows the calculation of the angular position of the club during the swing. This can be used to reconstruct the trajectory of the club and evaluate the technique of the player. The maximum rotation is, obviously, on the roll where an almost complete rotation occurs.

The positioning of the sensor near the club head leads to accelerations during the swing that exceed the full range values of 80 $\mathrm{m/s^2}$. Sensor saturation is visible in Fig. 6, and authors are addressing this problem increasing up to 16 g the full range of the accelerometers. Also the whole microcontroller firmware is being reviewed in order to increase sampling rate above 200 Hz and improve resolution of the ball impact events.

VI. CONCLUSIONS

The proposed golf aid system lets players both to verify their performance and review their games. In the first use the system can track the club swing and monitor the strike strength. In the second use, the system is designed to record all strokes, tagging them with the player position as provided by the GPS and adding details regarding the environmental conditions and the player orientation with respect to the sun. This way it is possible to observe if correlations exist with respect to these quantities and to help users to cope with them. The system is designed to be installed close to the golf club head and is light enough to avoid significant alterations of the game experience. The extreme low cost, the capability of storing all data for off-line analysis at game-end and the capability of connecting to both player smart-phones and PC makes it an interesting companion of most golf players. The preliminary results are promising, even though some improvements in the microcontroller firmware are required. In particular, the accelerometer driver needs changes in order to increase the maximum acceleration range up to 16 g and to reduce the risk of saturation on the strongest hits. Furthermore, an increase of the sampling rate well above 200 Hz would be beneficial for augmenting data resolution during hit events, but this will involve a general optimization of all the firmware.

REFERENCES

[1] M. Parvis, S. Corbellini, L. Lombardo, L. Iannucci, S. Grassini, E. Angelini "Inertial measurement system for swimming rehabilitation", MeMeA 2017, May 7-10, 2017, Rochester MN, USA, pp. 361-366
[2] M. Bachlin, G. Troster, "Swimming performance and technique evaluation with wearable acceleration sensors", Pervasive and Mobile Computing Vol. 8 pp. 68âĂŞ81, 2012
[3] C. Crema, A. Depari, A. Flammini, E. Sisinni, A. Vezzoli, P. Bellagente, "Virtual Respiratory Rate Sensors: An Example of A Smartphone-Based Integrated and Multiparametric mHealth Gateway", IEEE Trans. Instrumentation and Measurement, September, 2017, Vol. 66, N. 9, pp. 2456-2463, ISSN 0018-9456, DOI 10.1109/TIM.2017.2707838.
[4] M. Rizzi, P. Ferrari, A. Flammini and E. Sisinni, "Evaluation of the IoT LoRaWAN Solution for Distributed Measurement Applications," in IEEE Transactions on Instrumentation and Measurement, 2017, vol. PP, no. 99, pp. 1-10. doi: 10.1109/TIM.2017.2746378
[5] Sekiya Koike, "Force and moment exerted by each hand on an instrument golf club", 34rd International Conference on Biomechanics in sports, Tsukubam, Japan, July 18-22, 2016
[6] ZeppGolf Smart-Coach, available at http://www.zepp.com/en-us/golf/smart-coach/, last checked on Dec, 10 2017.
[7] ArcCos 360 Golf Performance Tracking System, available at https://arccosgolf.uk/, last checked on Dec, 10 2017.
[8] Free RTOS Real-Time Operative System, available at https://www.freertos.org/, last checked on Dec, 10 2017.
[9] M. Parvis, S. Grassini, E. Angelini, P. Scattareggia, "Swimming symmetry assessment via multiple inertial measurements", 2016 IEEE International Symposium on Medical Measurements and Applications, Proceedings 7533765.