Wireless Instrumented Cane for Walking Monitoring in Parkinson Patients

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***Abstract*—Instrumentation of conventional aids (walking stick, ortho-cane, crutch, walker, etc.) can generate numerous benefits for both the clinician and the patient, aiming at the improvement of walking activity. In this paper, a designed, fabricated and tested instrumented cane is presented. Its versatile characteristics permit an adoption for different applications. In this paper, the instrumented cane is personalized and tested in order to monitor the ambulation of Parkinson patients. The cane permits to monitor axial forces by means of a strain-bridge and movements by means of an Inertial Measurement Unit (IMU). It is also composed of a conditioning and transmission circuit, and a power management circuit. All the circuits are integrated on a circuit board. The designed device has been made in order to miniaturize the circuit board and improve the output signal during gait. A Bluetooth module transmits the data wirelessly to a remote computer. The acquisition data can be saved and viewed by a developed user interface realized with LabVIEW. The tilt and force sensing of the cane have been tested, and characterized in the laboratory. The mean experimental standard deviation was about 20 N for axial forces. Hysteresis, linearity, and drift were calculated, and the obtained accuracy was about 0.8°. The instrumented cane prototype is under trials to be adopted for the Parkinsonian community, in order to monitor their ambulation during rehabilitation sessions and as a proposal to detect the "mysterious clinical phenomenon" that is the Freezing of Gait (FoG).**

Keywords— Instrumented cane; Microcontroller; Force measurements; Inertial measurement unit; Accelerometer; Walking monitoring; Freezing of gait (FOG); Parkinson Patients

I. INTRODUCTION

Nowadays, mobility aids are largely used over the world. For instance, in the United States, according to the National Center for Health Statistics and the Centers for Disease Control and Prevention, over 4.7 million people are using canes to assist their mobility and more than 500.000 are using crutches. It is now common knowledge that a cane helps assisting ambulation after injury, and helps with balance and/or postural stability issues [1]. Studies have also shown that a cane increases the stable area during both single and double limb support, as long as the center of gravity of the ambulatory is within the bounds of the base area [2]. Furthermore, an external tool, despite his functional help, can create confidence and a sentiment of safety to its elderly users [1]. Research studies also underscored the benefits of the utilization of walking aids for many different group of people. The adoption of a cane has important impacts for frailty people, for example, the stance time on the affected leg of a stroke patient is decreased, while their walking speed is increased [3]. For people with hemiparesis, postural sway is reduced with a quad cane use [4]. A cane helps with body weight support and improve the balance to the ones with hemiplegia. [5]. However, injuries and problems led by the long-term use of those walking aids is not rare. Problems can arise at the hand, arm, shoulder or axilla, depending on which kind of cane and crutches the patient is using. The common injuries are at the ulnar [6], median [7], and the suprascapular [8] nerves. Two reasons can explain those issues, one is that the mobility aid is unfit and the second one is the misuse of the tool. Indeed, the physiotherapist habitually corrects the patient when he misuses the mobility aid during rehabilitation. However, the clinician and physiotherapist most often carries out the correct use of walking aids only using visual analysis, therefore the perception of the proper use of walking aids is usually subjected to considerable errors [9]. That is why the instrumentation of walking aids is important, in order to have an objective and quantitative tool. For instance, the instrumented aids can help to assess if the center of gravity is within the base area, or if the balance of the weight or the cane position is correct. Furthermore, they could assist and assess the progress of the patient during both rehabilitation and daily life activities.

Instrumentation of walking aids can be a viable solution for different applications, such as a tool to assist the clinicians into correcting the patient use of canes, deambulators, crutches and as an interface between an exoskeleton and its user [10]–[13]. In [10], instrumented crutches are proposed for gait monitoring and weight bearing analysis. In [11], the authors developed a system that measures angle and angular velocity of a crutch aiming at estimating and visualizing the motion of a crutch. In [12]-[13], sensors are implemented in crutches to evaluate stability, consumed energy and user's comfort during sessions with exoskeleton. However, the instrumented devices, reported in the previous examples, can difficulty be adopted for monitoring ambulation of frailty people such as Parkinson Patients.

Parkinson's disease (PD) is an affection of the Central Nervous System. Almost 10 million people are perturbed with PD (300.000 in Italy) and we expect this number to be four times higher by the year 2020. Gait disorders are a common and significant cause of reduced quality of life and independence in the Parkinson disease (PD), it is also the main cause of fear of falling (FOF) in the Parkinson community [14]. Parkinsonian gait has specific features, including the Freezing of Gait (FoG). FoG is defined as a brief episodic absence or marked reduction of forward progression of the feet despite the intention to walk. It occurs in several situations such as gait initiation, turning over,

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in a confine space, when they almost reach the destination, double task (motor or cognitive), or emotional factors (stress, fear, joy, etc.) [15]. Since 2011, methods to identify and characterize FoG have been developed to underline behavioral and neuronal mechanism of this 'mysterious clinical phenomenon' but also to classify patients as freezers or non-freezers [16], [17]. Multiple studies have been performed and are still on-going to study the multifactorial nature of the FoG (5 conjectures of its origin [15]). Whilst therapeutic treatment of the Parkinson's disease is rather successful, many issues remain unresolved, particularly in relation to displacement and sustainability of autonomy. One of the most important expressions of autonomy is walking activity. Researchers investigated the potential therapeutic role of external physical cues for freezers. But simple cues may not be sufficient to decrease FoG episodes [18].

This paper presents an instrumented cane with wireless transmission in order to monitor the ambulation of Parkinson patients. The instrumented cane is proposed as patient interface with the capacity to monitor this clinical phenomenon (FoG) and deliver a bespoke external cue to improve the mobility of the patient. The focus is on patients with advanced state of the disease that need walking aids in their daily life, during scheduled rehabilitation session or patients that are injured. Unfortunately, the likelihood of recurrent falls is higher to those with disease severity and duration, motor impairment, FOF, FoG, etc. [19]. That is why, the main goal is to challenge the walking difficulties of the PD patient, in order to reduce FOF, FoG and all others aspects that is hindering the daily life activity [14]. The cane permits to monitor the axial force by means of a strain-bridge and movements by means of an Inertial Measurement Unit (IMU). The instrumented cane was tested in laboratory and then in clinical trials with PD patients. Therefore, the proposed cane was adopted in a concrete use case, in order to monitor the ambulation of Parkinson patients. The description of the wireless instrumented cane and the preliminary experimental results are reported in the following.

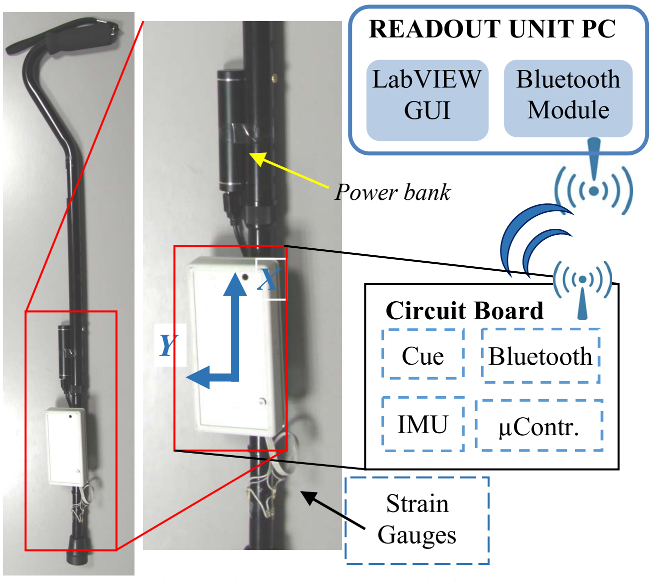

Fig. 1. Instrumented cane scheme and circuit board scheme.

II. DESCRIPTION OF THE WIRELESS INSTRUMENTED CANE

The proposed cane is reported in Fig. 1. This prototype is equipped with strain gauges to monitor the interaction between the ground and the user. Moreover, a 3D Inertial Unit Measurement (IMU) is adopted as a tilt sensor. An electronic circuit board manages the data conditioning, acquisition and wireless transmission. A rechargeable power bank is used as power supply. In addition, an auditory cue is given by the integration of a buzzer. The data are wirelessly transmitted via Bluetooth; the data are processed and displayed by an interface created with LabVIEW.

A. Sensing capabilities

Four strain gauges connected in a Wheatstone bridge configuration are glued to the cane by means of Cyanoacrylate at about 7 cm from the ground, as shown on Fig. 2. The extensometers are the commercialized RS 2 mm from the RS Company, with a gauge factor (G) of about two and with a nominal resistance of 120 Ω. The Wheatstone bridge is connected to the circuit board by means of a flat cable of few centimeters.

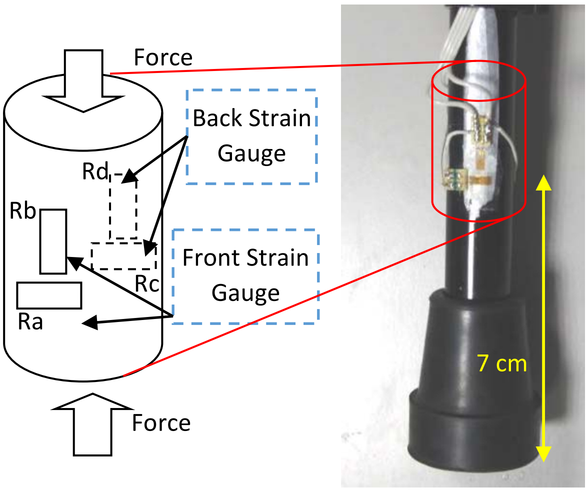

Fig. 2. Mechanical and electrical representation of the Wheatstone bridge

The employment of IMU permits to have a complete and accurate description of the movement of the cane. In our case, we used the LSM9DS1 IMU commercialized by STmicroelectronics. It is composed of a triaxial accelerometer, a triaxial gyroscope, a magnetometer, and a temperature sensor that could compensate thermal drift and then correct the read values. It also allows the implementation of the idle mode for the reduction of energy consumption.

B. Hardware architecture

Fig. 3 shows the circuit board with the indication of each component, designed by the software OrCAD. The use of 8-bit microcontroller ATmega328 of Atmel integrated in the Arduino Nano board deals with the operations of conditioning, conversion, and management of communication with the inertial sensor. The embedded 10-bit analog-to-digital converter (ADC) is used to acquire the conditioned Wheatstone bridge voltage.

By means of serial peripheral interface (SPI) communication, the microcontroller programs and manages the inertial sensor, while, communicates to the Bluetooth module (Parani ESD200) by means of serial communication interface (SCI). The ESD200 has an integrated serial UART and an antenna, which has a 30-meter range of action. The rechargeable power banks of 2200 mAh capacity is used to supply the circuits and it permits more than five hours of autonomy. Furthermore, the USB connection to the circuit is robust and the recharge of battery is easier. Arduino Nano board is supplied by the power bank using the mini-USB connector. The ESD200 and the IMU are powered at 3.3 Volt supplied by Arduino Nano board, which can provide a stable rectified 3.3 V.

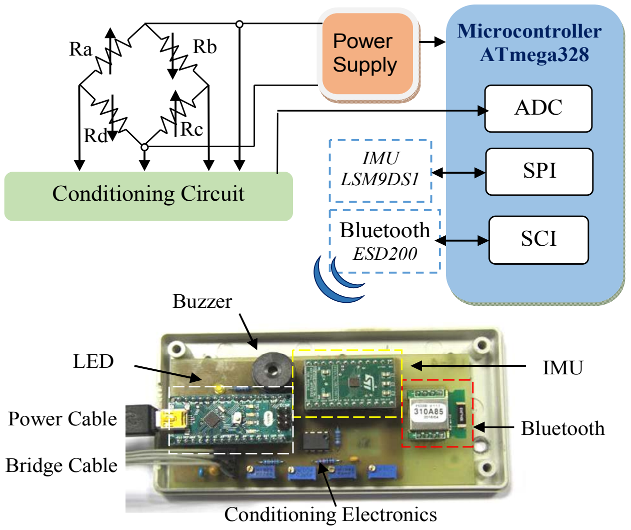

Fig. 3. Circuit board scheme and image of the realized board.

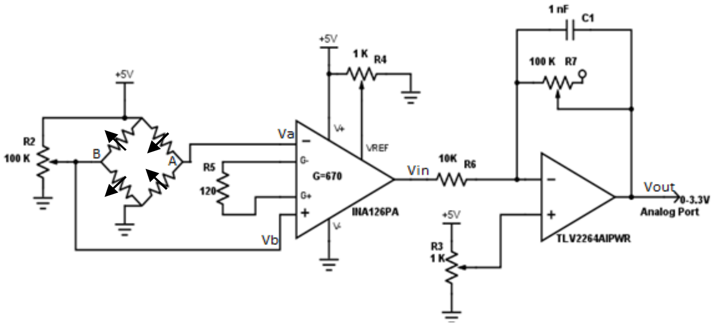

Fig. 4. Conditioning circuit for the Wheatstone bridge.

The conditioning circuit for the Wheatstone bridge is shown in Fig. 4. A sharp amplification of the unbalanced bridge-signal is necessary due to the small compression forces on the cane by Parkinson Patients. In addition, the zero offset calibration due to the non-homogeneity of the extensometer has been done. For the first step of amplification, the differential amplifier INA126 is used. One trimmer is used for the zeroing of the Wheatstone bridge, another one to give an adequate reference voltage. Then comes the second step of the amplification and filtering, with the operational amplifier TLV2264.

C. *Software architecture*

Thanks to the use of Arduino Nano connected via mini-USB and its IDE, the programming of the microcontroller is more flexible and easily configurable for different applications. The firmware is written in C++ used as an object-oriented. Initially the implemented firmware configures the LSM9DS1, then a measurement loop is executed every 20 ms. During each loop the data are acquired and transmitted to the Bluetooth. The data are transmitted as a stream of characters (#xXyY zZxxyyzzSSRR), 3 accelerations, 3 angular velocities, the Wheatstone bridge voltage and the reference voltage. For debug and synchronization, the char "#" is used at the beginning of the string and followed by the 16 characters bearing the information. In the implemented configuration, the data are transmitted to a PC integrating a Bluetooth module. However, any device integrating a Bluetooth can be adopted. A Virtual Instrument (VI) user interface has been designed using LabVIEW software. It allows recording and viewing of the measured data in real time, via Bluetooth connection.

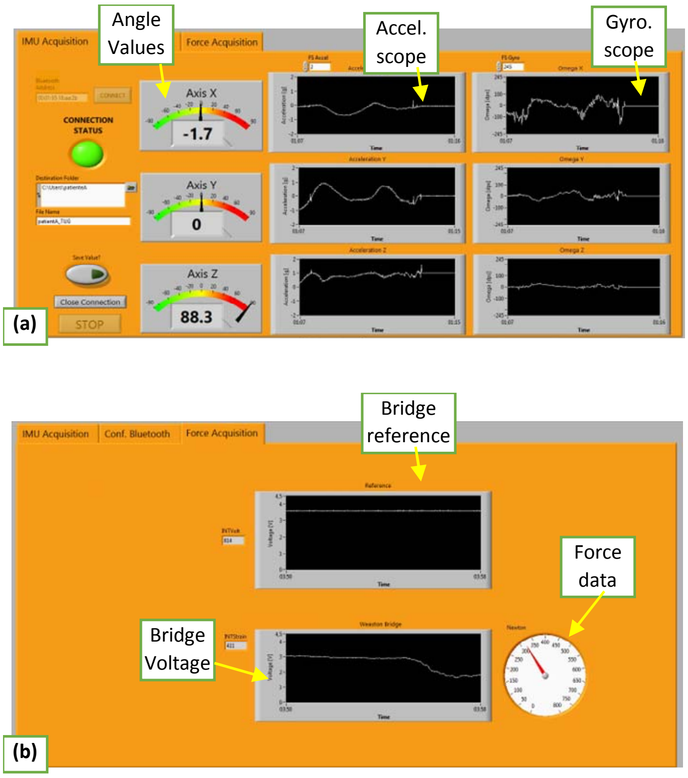

Fig. 5. a. Window of the presentation of the IMU data. b. Window of the presentation of the Strain-gauges bridge.

In Fig. 5.a, the angle value of each axis is shown on the left part. Whereas, on the right one, the real-time data of the accelerometer and gyroscope of each axis are displayed. Moreover, it is possible to connect and disconnect the Bluetooth, and choose a file where to save the data of the current acquisition, if further processing is needed. In Fig. 5.b, from the two scopes, the values of the analog input at a 3.3V reference (upper one) and the signal output of the Wheatstone bridge (lower one) are displayed. An indicator of the actual force on the cane has also been added. The program extracts the first 12 bytes after the # char, which correspond to the accelerometer and gyroscope data of the three axes. Then the data are processed to get the axis' angles. They are processed by means of a fusion algorithm described in [20].

III. EXPERIMENTAL LABORATORY ANALYSIS

The cane was tested in the laboratory by means of a mechanical structure, which rotates, to verify the response of the accelerometer, whereas different masses of known values has been used to characterize the Wheatstone bridge. At this stage, it has not been possible to test the gyroscope, and then the characterization analysis reported in the datasheet were considered.

A. Testing the Accelerometer as Inclinometer

The inclination of the two more used axes, i.e. X and Y, was measured. Then it was compared (Fig. 7) to the known angle values stage by the experimental setup. The r2 values are respectively, 0.9985 and 0.9996. The linearity of both the axes of the accelerometer is 99%. Hysteresis, linearity, and drift were calculated, and the obtained accuracy was about 0.8°.

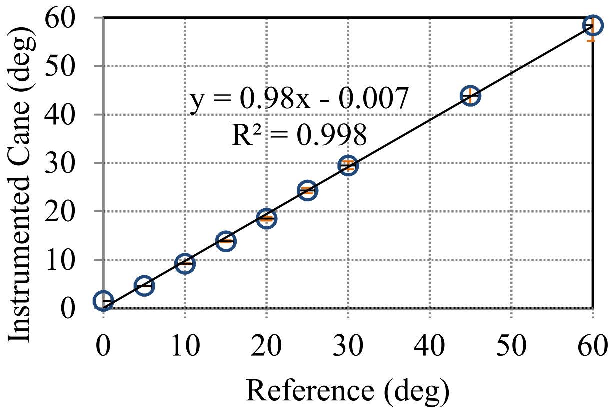

Fig. 6. Measured inclination in terms of the reference (X axis) with standard deviation

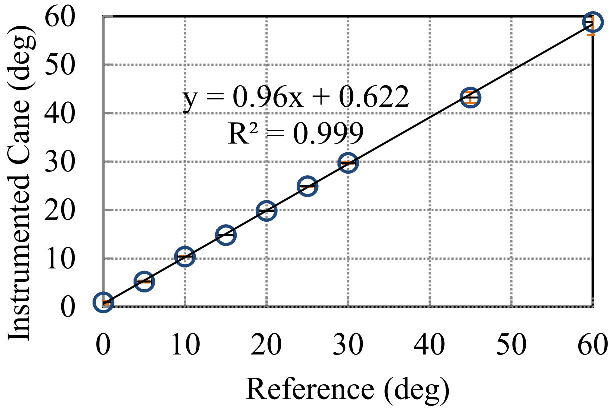

Fig. 7. Measured inclination in terms of the reference (Y axis) with standard deviation

B. Force sensing

The linear regression has been conducted of the compression test of the strain-gauge bridge. The results are shown on the Fig. 8. To do the test, the cane was mounted on a mechanical structure, and then static loads was applied in the axial axis using different masses (1-60 kg). The non-linearity is about 5%. The mean experimental standard deviation was about 20 N for axial forces.

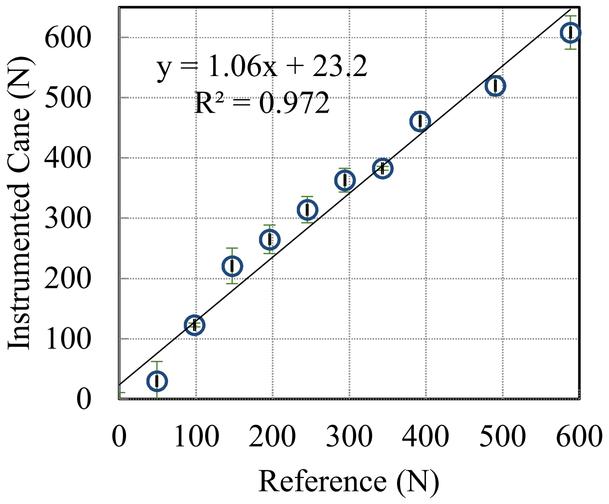

Fig. 8. Measured Force in terms of the reference with standard deviation

IV. METHODOLOGY FOR CLINICAL TRIALS ON PARKINSON PATIENTS

The fabricated cane has been tested in a use case in order to monitor Parkinson Patient ambulation and to detect the Freezing of Gait. Trials have been carried out at the Civil Hospital of Brescia to assess the use of the instrumented cane for FoG detection.

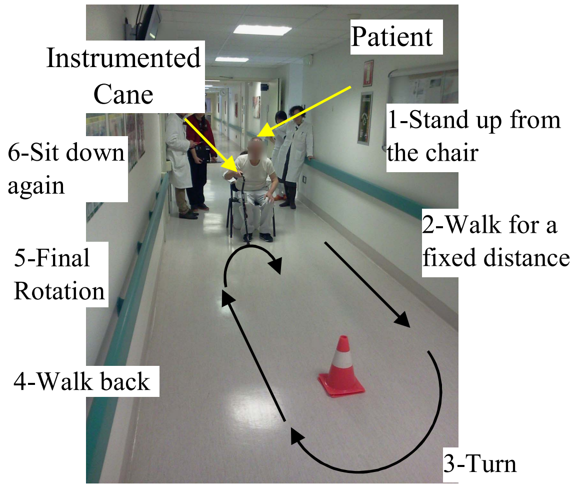

Fig. 9. Test of the cane by a PD patient

The protocol of the trial (Fig. 9) consists of evaluating the gait of the patient during different situation and limitation of the environment (that trigger FoG):

- Time up and go
- U-turns
- One or more full turns to the right and then turn left
- Passed a narrow passage or obstacle (doorway)
- Task interfering in the way: cognitive (count)

The patient is asked to perform the Timed Up and Go task (TUG) as a reference, and then some other tasks that trigger FoG, such as adding double tasking during TUG or some obstacles (Fig. 9).

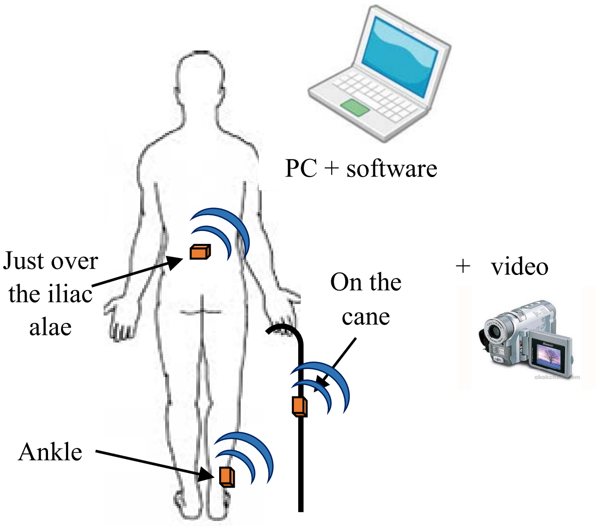

Fig. 10. Acquisition Protocol for Gold Standard Instrumentation

Three IMU products of Xsens are used for gait analysis of the patient with the cane (Fig. 10). One is put on the cane to permits the synchronization of the IMU and the cane, another on the shank and the last one over the iliac alae. In addition, FoG occurrences are registered during the exercises in real-time, by means of an ON/OFF button designed on the LabVIEW interface, to get a logical signal. However, to avoid some delay and errors, clinicians also marked the events, thanks to a post-hoc video analysis.

V. PRELIMINARY EXPERIMENTAL RESULTS ON PARKINSON PATIENTS

In Fig. 11, the acceleration signals of all three axes, the anterior-posterior, the medio-lateral angle and the FoG event marked by the clinicians, during a test by a PD patient are shown. Green bars above the data indicate the locomotion phase corresponding to Fig. 9. More trials are undergoing aiming at acquiring enough FoG occurrences. An algorithm for FoG detection is being made. It will be tested with the upcoming trials data, in order to verify if we can in fact detect FOG by means of the instrumented cane. Indeed, the big challenge using this instrumentation is to find a marker/parameter that will permit to detect -and in the ideal case predict- the occurrences of the FOG without having a direct access to the ambulation of the subject. Hence, we have to find other parameters than the freezing index [21] while using a cane. With the help of clinicians, we conjectured three possible parameters. The promising parameters can be the assessment of:

- stride time;
- anterior-posterior cane movement;
- and axial force on the cane

When a parameter will be determined then, further development will be done for the cueing compensation strategy.

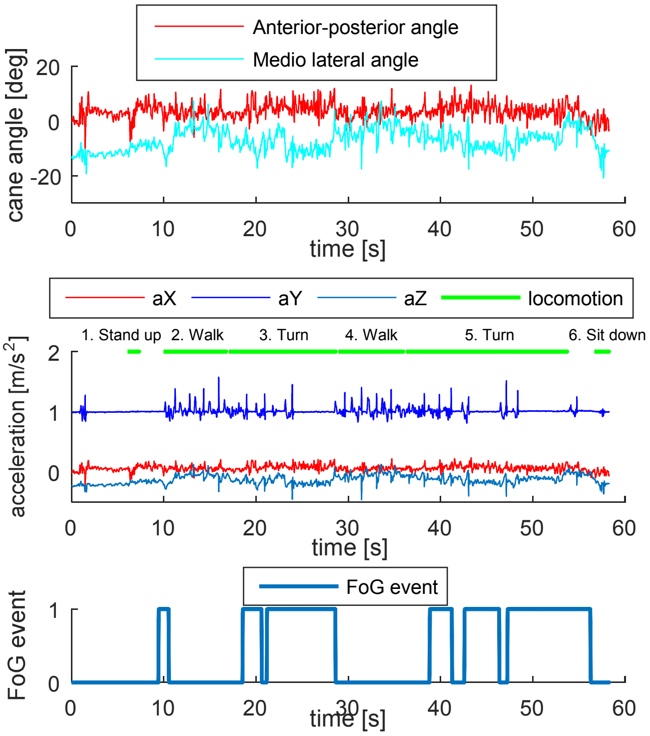

Fig. 11 Output signals and FoG event in terms of the time

VI. CONCLUSIONS

An instrumented walking aid has been presented and design considerations are reported. Power banks are used as supply, which provides around 5 hours of working autonomy. It can assess the tilt movement and the axial force of the cane, transmitting the data to a remote computer via Bluetooth. The prototype has been designed to be versatile and can be modified to match the purpose of several applications. The system has been developed and an experimental laboratory analysis has been done. Trials are ongoing in a clinical environment to evaluate the system behavior on several patients with the assistance of physicians. Features that will be evaluated are easiness to use, simplicity to set up, accuracy, perceived invasiveness and acceptance of subjects and clinicians.

ACKNOWLEDGMENT

We wish to thank Dott. Andrea Pilotto and Prof. Alessandro Padovani, Ospedale Civile Brescia, Italy, for assistance in trials in this work.

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