Preliminary study on gait variability analysis with a single axis gyroscope for Alzheimer and Parkinson's diseases

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***Abstract*—** Gait analysis methods to evaluate the spatiotemporal variability based on Inertial Measurements Units (IMUs) are present in literature. In this paper a preliminary study on the time gait variability as a tool for early diagnosis is presented. The system is non-invasive as it is composed by only a single axis gyroscope positioned on the patient shin. The unit uses a Bluetooth Low Energy interface for automatic data download and analysis. Twenty cognitively normal subjects have been used in order to exploit the system's capability, with very good results. They were asked to use the device during the day in the normal activity. The algorithm is able to isolate the walk session and to calculate the global duration, the mean and the standard deviation of the gait duration. The proposed wearable gait analysis device is a promising tool for clinical study.

***Keywords*—**Alzheimer's disease, gait analysis, inertial systems, Parkinson's disease, wearable sensors.

I. Introduction

THE life span expectation strongly increased in the second half of 20th century. As a result, many diseases strongly bound to the aging of the society, such as senile dementia and Alzheimer's disease (AD), become more commune and apparent. This latter disease, AD, implies severe limitation as patients' conditions worsen and gait disorder, balance and cognitive problems, dementia and memory evanescence become extremely apparent [1-2]. The gait disorders and balance by themselves represent a threat to patient and strongly limit their independence. Recent literature reported that the gait and balance monitoring not only represent a clinical tool but also furnish a predictive tool for potential AD diagnosis [3]. A comparison between groups of early AD patients and healthy people showed that the first group had slower velocity, slower cadence, and shorter stride length than the second group [4].

Several techniques have been introduced to support the researches in this field, mainly based video monitoring or special pressure sensitive mats.

The availability of ever integrated and compact electronic devices furnishes new fields of investigation to the research. In particular, the availability of three-axial gyroscopes and accelerometers, joint to micro-baric sensors gives some basic bricks to be integrated in a very compact and wearable diagnostic device. Some preliminary paper reports the potentialities of such approach [5].

The present paper introduces an experimental wearable system based on a single integrated unit which integrates a single-axis gyroscope with an RF link, creating an ad-hoc wireless sensor network (WSN). The data collected by the system are remotely processed using a proprietary algorithm that furnishes, as a result, indications regarding patient gait variability.

In the forthcoming sections, the system architecture will be discussed, giving some insight on the hardware and algorithm organization. At the end, some preliminary data are reported and discussed.

II. System Architecture

The systems basic brick is a wearable, inexpensive and automated Inertial Measurement Unit (IMU) able independently measures the movement patterns during daily life. Starting from the measured inertial data an algorithm allows an accurate gait analysis and the assessment of spatiotemporal gait parameters (stance-swing phase, stride time and its variability, etc.).

An expert neurological team has supported the IMU development and the final objective is the definition of an automated and impartial procedure based on IMU and software for the preliminary variability gait analysis of patients with Parkinson's disease, validated by authorized health service providers.

The main challenge was to obtain a system able to accurately measure gait parameters during daily life activities. The clinical picture assessed during an outpatient check up in the medical office poorly represents the real (actual) clinical status, especially in fluctuating patients. For this reason, recently researches on automatic systems based on wearable sensors to evaluate motor of PD patients have been developed. In general, the most common evaluated performances are motor tasks, such as "sit-to-stand", gait cycle.

There are alternative gait analysis systems available, but none meet all these criteria. Camera-based systems give high accuracy but are relatively costly, time-consuming to use, and gait analysis is typically restricted to laboratory settings. Pressure sensing mat systems are also relatively expensive, with data collection limited to 5–6 walking strides per pass, and are typically restricted to laboratory or clinical settings. Further, pressure sensing systems report reduced measurement reliability when subjects exhibit certain clinical gait patterns (for example, shuffling gait patterns).

The IMU must be small and lightweight to ensure its effective wearability and with a long battery life. The data can be either locally stored or remotely transmitted.

The algorithm performs the gait duration by processing the data only from a single axis gyroscope.

III. The Hardware

The Fig. 2 shows the basic unit which is composed by a single low power 32bit processor Cortex-M0, a Bluetooth Low Energy (BLE) RF interface, a single axis gyroscope, an on board memory and a coin battery with a lifetime of about six months.

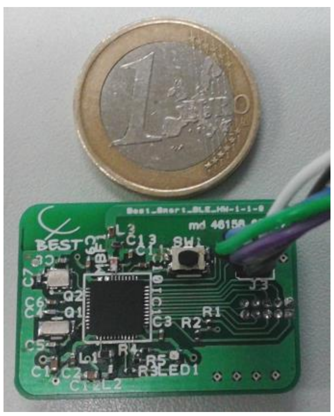

Fig. 1 – Inertial Measurement Unit (IMU)

The hardware is able to collect the data from the gyroscope and transfer the data over the air with the Bluetooth interface to a central server for the off-line analysis.

As an example of the wearability, Fig.3 illustrates the typical positions of the unit and the experimental results are reported in the final section.

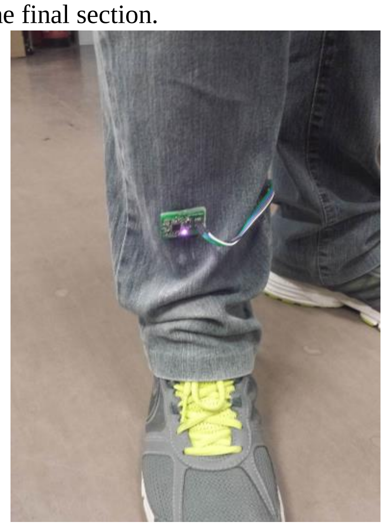

Fig. 2 - Installation positions of the IMU

IV. The Algorithm

The step analysis algorithm implements a methodology that evaluates the step variations analyzing the fundamental phase characteristics of the whole walking cycle [6], as depicted in Fig. 3.

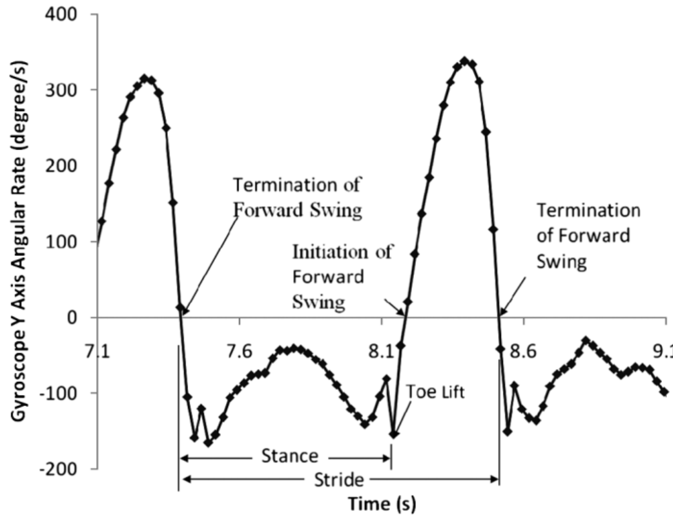

Fig. 3 – Deambulation phases

So the algorithm is very simple and it has to isolate the Termination of Forward Swing (TOFS), the Initiation of Forward Swing (IOFS) and the Toe Lift. Taking into account that the gyroscope output is expressed in degree/s, the algorithm steps are:

- Identify the session walk among the entire dataset with a moving average. The sequent steps are made for every session walk.
- Identify the zero crossing
- Identify the positive and negative peaks
- Remove the first and the last K peaks in order to eliminate the start-up and slow-down.
- Remove all positive peaks below 25°/s or a settable value
- Identify the TOFS as the first zero crossing after each positive peak
- Identify the IOFS as the first zero crossing before each positive peak

V. Experimental Results

For the validation of this preliminary study, a great number of lab tests were made. In this phase, patients with Alzheimer or Parkinson’s disease have not been involved. Twenty cognitively normal subject wore the IMU for one half a day and they walked normally during the tests. In Fig. 4 it is shown an example of a part of walk, a little stop and again the walk. The algorithm is able to isolate correctly the walk sessions.

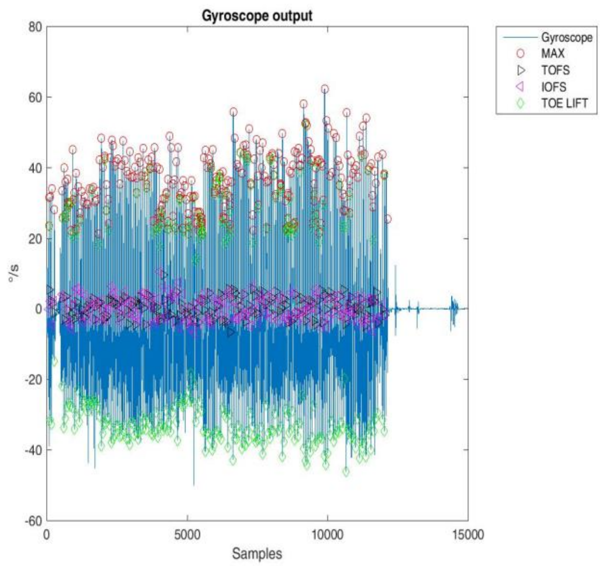

Fig. 4 – Two walk sessions

In Fig. 5 another example is reported. In this case the velocity is increased and the step time is decreased. In Fig. 6 and Fig. 7 the stance distribution and the stride distribution are reported respectively. Finally in Fig. 8 and Fig. 9 the stance and stride graph.

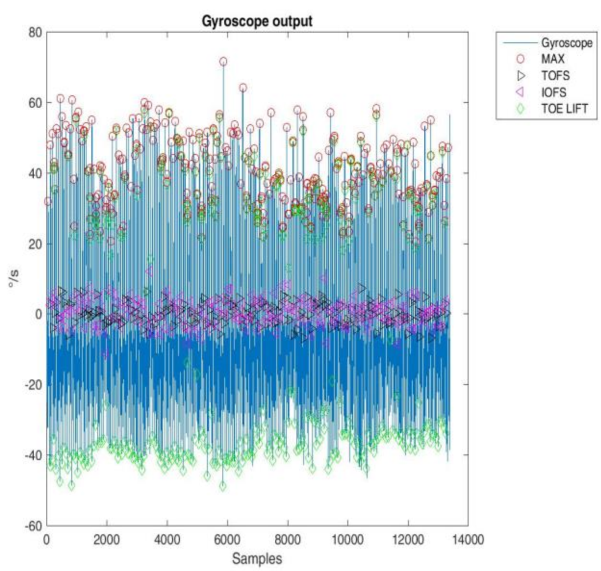

Fig. 5– Generic walk sessions

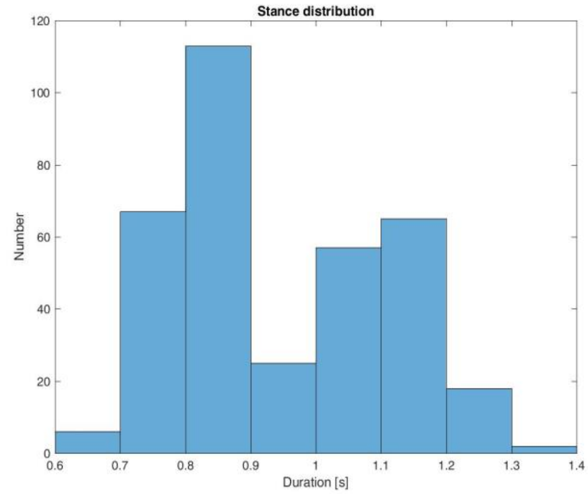

Fig. 6– Generic walk sessions stance distribution

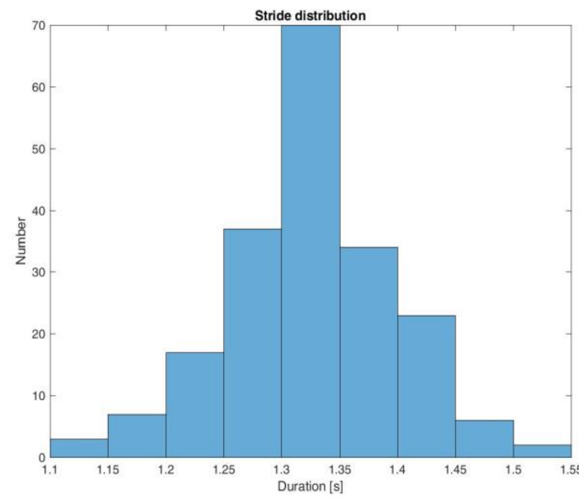

Fig. 7– Generic walk sessions stride distribution

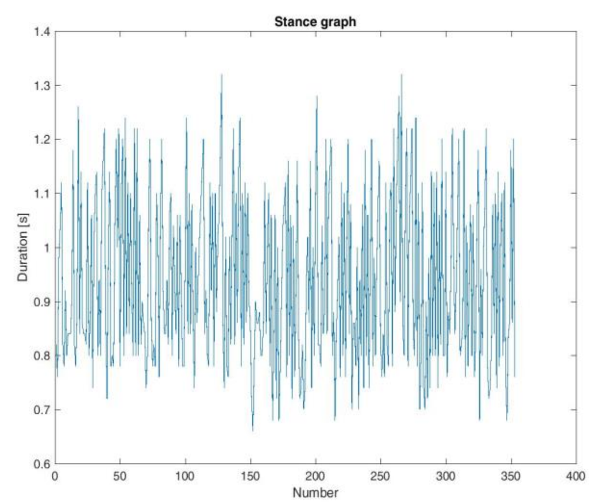

Fig. 8– Generic walk sessions stance graph

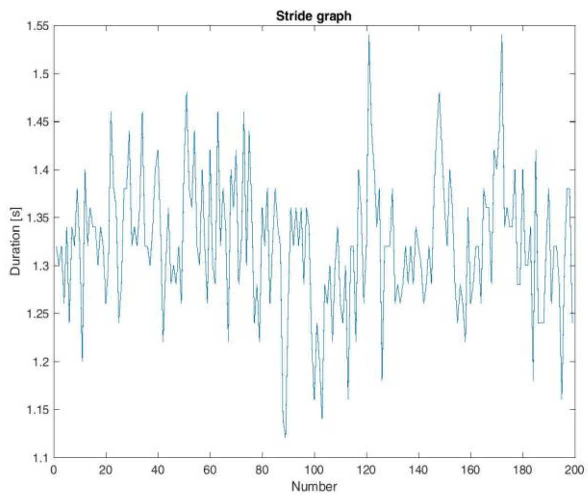

Fig. 9– Generic walk sessions stride graph

In Table I some experimental results are shows.

TABLE I

Subject #	Type of walk	Mean stride duration (s)	Standard deviation stride duration (s)	Mean stance duration (s)	Standard deviation stance duration (s)
1	Normal for 15 minutes	1.2552	0.0425	0.8312	0.0965
1	Normal for 8 minutes	1.2414	0.0325	0.8245	0.0314
2	Normal for 13 minutes	1.3578	0.0814	0.7547	0.0945
2	Shuffle for 5 minutes	1.3841	0.4885	1.008	0.6369
8	Shuffle for 15 minutes	1.2698	0.5723	0.9851	0.7987
15	Fast for 5 minutes	1.1512	0.0622	0.7538	0.1222
15	Shuffle for 9 minutes	1.2789	0.2308	0.9852	0.3525

VI. Conclusions

A promising rugged diagnostic tool for gait duration analysis has been presented. The preliminary study has given very good results in terms of simplicity of use, portability and effectiveness.

In the next future it will be used by AD and PD patients as early diagnostic tool and it will be investigates the use of and adequate number of sensor in order to monitor not only the gait duration and variation, but also the gait length variability.

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