Multi-sensor integration and data fusion for enhancing gait assessment In and Out of the laboratory

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INTRODUCTION

Recently, there has been a growing interest in methods for monitoring individual motor performance during daily-life activities. To this end, inertial miniaturized units (IMU) turned out to be the most relevant technological solution. From direct measures of angular velocity and proper acceleration of sensed body segments, a broad set of spatio-temporal gait variables can be derived through signal morphology analysis, biomechanical models and machine learning techniques. However, the validity of IMU-based methods depends on several factors, including motor impairment severity, environmental context, IMU location. Accurate displacement estimations can be particularly critical. Full acceptance of IMU-based methods for «real world» mobility assessment in clinical programmes needs a rigorous validation and this, in turn, advocates for the development of suitable gold standards. This work deals with the design of a wearable multi-sensor system (INDIP) that, by integrating different sensing technologies, aims at providing the best possible reference for digital gait assessment in real world scenarios.

METHODS

The INDIP system includes a magneto-IMU, 2 distance sensors, and a plantar pressure insole (Fig.1a). Data are acquired by an ultra-low-power microcontroller and stored in an onboard flash storage for up to 4hrs of data logging. The system allows third-party devices to be synchronized via an external trigger. Multiple INDIP systems can be synchronized via a BLE protocol. The workflow for the data processing (Fig.1b) includes: *(i)* bilateral description of temporal events at foot level - this operation primarily relies on pressure data and secondarily on inertial and distance data; *(ii)* description of the foot position and orientation. This operation mainly relies on inertial data. Gait periodicity is exploited to implement zero velocity update techniques and self-tuning sensor fusion algorithms for the reduction of the integration drift errors [1]; *(iii)* walking bouts identification based on information provided in *(i)*−*(ii)* and according to standardized operational definitions; *(iv)*−*(v)* estimation of spatio-temporal gait variables for different walking bouts lengths.

RESULTS

Preliminary results based on IMU signals allowed the recognition of strides, walking bouts definition, and discrimination between straight and curvilinear portions. Foot clearance and inter-shank distance were obtained from distance sensor 1 and 2, respectively.

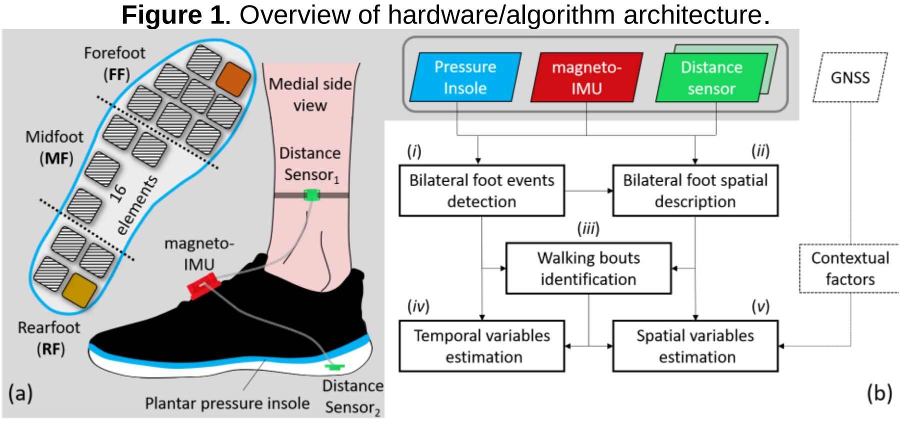

Figure 1. Overview of hardware/algorithm architecture.

DISCUSSION

Multi-sensor selection allowed to take full advantage of complementary characteristics of each sensing technology, providing a richer set of information to enhance gait assessment. For instance, by exploiting the 16-element pressure readings, it is possible to differentiate initial and final contacts for the different foot subareas (IC_{RF}, IC_{FF}, FC_{RF}, FC_{FF}). This allows to achieve a finer gait cycle segmentation compared to IMU-based methods only [1]. Thanks to the use of the distance sensors, the foot displacements estimated from the inertial data can be supplemented with information on foot clearance and inter-shank distance. These data can prove useful when analyzing highly abnormal gait patterns (e.g. foot-dragging walks, freezing). As supervised single-sensor machine learning methods require good labelled data, the INDIP system can also be used for generating reliable training data set. Finally, geolocation techniques can be easily integrated via BLE to correlate gait variables with contextual factors (Fig.1a).

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REFERENCES

[1] Trojaniello D, et al. JNER 2014, 11:152.
[2] Bertuletti S, et al. JoB 2019, 84:274−277.