Easy-to-use Calibration of Inertial Sensors-based Smart Clothing for Consumers

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***Abstract*—Inertial and magnetic sensors are nowadays available as integrated components in common portable devices (smartphones and smartwatches). Despite the continuous reduction of cost and size, their application to the body kinematics is not quite widespread in the consumer market. The main obstacles are the system calibration and setup, in terms of time and complexity. Magnetometers are hard to handle in indoor applications due to inconsistent magnetic disturbances; and the calibration of multiple units can be challenging for non technicians. In order to overcome those limitations, we developed a fast custom magnetometer-free calibration easily reproducible by non technician, to be used in our novel smart clothes [1] (the electronics is fully integrated in the clothes), for applications targeting the consumer market.**

***Index Terms*—Motion Capture, Low-cost MEMS-IMU, 3D Body Kinematics, Biomechanics, Magnetometer-free, Consumer Electronics, Metaverse.**

I. INTRODUCTION

Real time human motion tracking has a wide potential in many application fields, e.g., tele-rehabilitation, sport performance assessment, ergonomics [2]-[5]. The gold standard for 3D motion capture (MoCap) is the marker-based optical tracking system. However, those systems can only be used in laboratories with specialized technician, after a time-consuming set-up. These are the reasons why inertial sensors-based motion capture has gained huge popularity in the last few years. In particular, triaxial gyroscopes and accelerometers based on Micro-Electro-Mechanical Systems (MEMSs) are often integrated together to form Inertial Measurement Units (IMUs); if magnetic sensors are included, they are called Magnetic Inertial Measurement Units (MIMUs). MEMS IMUs are cheap, small, self-contained, light weight and easy to be worn. The orientation of the body segments (and thus the joint kinematics) can be estimated by putting those sensors on the body segments of interest. Sensor fusion (SF) and segment to sensor (STS) calibration are crucial phases that strongly affect the overall system outcome [8]-[9]. Through SF algorithms the IMU orientation is estimated by fusing the angular velocity, acceleration and the magnetic field. However, the magnetic disturbances, especially indoor, can lead to inaccuracy; besides, to properly calibrate multiple magnetometers might be too challenging for non-technicians. For what concerns the STS calibration, there is the need for a compromise between the accuracy and the usability by non-technicians. To find this compromise, we developed a magnetometer-free calibration of our smart clothes (shirt and pants with STMicroelectronics inertial sensors integrated, [1]) that can be used at home by non-technicians, once provided with a few instructions.

II. TURINGSENSE CALIBRATION

Turingsense smart clothes (Fig. 1) contain 16 STMicroelectronics LSM6DSR inertial measurement units (triaxial accelerometers and gyroscopes, [8]), are fully washable and come in different sizes. They are chargeable via micro-USB and have fully wireless communication.

Fig. 1: Turingsense smart clothes [1].

The definitions and the computational procedures needed to obtain the information of the motion of body segments starting from sensor readings (angular velocity and acceleration) are defined as *biomechanical protocol*. In particular, the main objective of the biomechanical protocol is to perform the sensor to segment calibration. The biomechanical protocol

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used in the Turinsense garment (Fig. 2) has two main steps: (1) N-pose; (2) functional motions [9].

(1) Step 1: N-pose. The first step consists in asking the user to stand still in N-pose (neutral pose). For each IMU, the acquired accelerometer data is averaged to estimate the vertical direction. This averaged accelerometer vector represents an estimate of the anatomical longitudinal direction of the underlying body segment. Moreover, the information from this step is used for the navigation reference frames alignment.

(2) Step 2: Functional motions. The second step consists in asking the user to perform two functional motions: one for the (a) upper body and the other for the (b) lower body.

(a) Upper body: a 90-degrees humeral flexion in the sagittal plane, keeping the elbow and the wrist extended, with neutral elbow pronation.

(b) Lower body: a 90-degrees femoral flexion in the sagittal plane, keeping the knee locked.

During the funcional motions, the recorded gyroscope data is transformed to unit-norm vectors to identify the axis on which the sagittal motion occurs. The average of the normalized gyroscope vectors represents an estimate of the anatomical medio-lateral direction of the body segment where the sensor is attached. [9].

Fig. 2: Turingsense STS calibration.

III. Experimental Results

The Turingsense smart clothes are currently sold in USA and Canada since December 2019. Thus, it is possible to analyze the success rate of the STS calibration among real users. The data stored in the Turingsense cloud database are used for both an inter-subject and intra-subject analyses of the STS success rate at the first try.

The STS success rate among 45 real users is reported in Table I (one trial per user), including single steps and whole procedures rate.

TABLE I: INTER-SUBJECT STS SUCCESS RATE

	N-poses	Arms	Lleg	Rleg	Full procedure
#	37	39	42	42	34
%	82	86	93	93	75

The attemps are detected through specific motion detection algorithms. It is noteworthy that the number of N-poses attempts might include poses where the user had not started to follow the instructions and, thus, not really trying. It explaines the slighlty minor number of successes of the N-pose phase.

In addition, an intra-subject analysis is proposed in Table II, where 8 trials per user have been considered to evaluate the intra-subject success rate of the STS on the first try (i.e. each STS step is performed once).

TABLE II: INTRA-SUBJECT STS SUCCESS RATE

# user	N-pose	Arms	Lleg	Rleg	Full procedure
1	87.5	100	100	100	87.5
2	87.5	87.5	87.5	100	87.5
3	75	62.5	87.5	87.5	50
4	62.5	100	100	100	62.5
5	87.5	87.5	87.5	87.5	87.5
6	100	87.5	100	100	87.5
7	87.5	100	100	100	87.5
8	75	87.5	87.5	87.5	75
9	87.5	100	100	100	87.5
10	87.5	100	100	100	87.5
11	87.5	87.5	100	100	75

IV. Discussion

Results on real user scenarios demonstrate that the calibration steps implemented are easy to perform by non-technicians, and the given instructions allow the user to reach MoCap rapidly. Furthermore, the availability of smart clothing largely simplifies the approach and the acceptability of the user to the technology.

V. Conclusion

The TS inertial system calibration has been developed to be used with TS smart garment, the first consumer clothes with electronics fully integrated. Based on the data, the TS calibration appears to be easy to perform by non-tecnician people, thus highlighting the huge potential to apply this technology to a variety of fields, such as, digital health, fitness tracking, etc.

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