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Technical note

Suitability of commercial barometric pressure sensors to distinguish sitting and standing activities for wearable monitoring

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ABSTRACT

Despite its medical relevance, accurate recognition of sedentary (sitting and lying) and dynamic activities (e.g. standing and walking) remains challenging using a single wearable device. Currently, trunk-worn wearable systems can differentiate sitting from standing with moderate success, as activity classifiers often rely on inertial signals at the transition period (e.g. from sitting to standing) which contains limited information. Discriminating sitting from standing thus requires additional sources of information such as elevation change.

The aim of this study is to demonstrate the suitability of barometric pressure, providing an absolute estimate of elevation, for evaluating sitting and standing periods during daily activities. Three sensors were evaluated in both calm laboratory conditions and a pilot study involving seven healthy subjects performing 322 sitting and standing transitions, both indoor and outdoor, in real-world conditions.

The MS5611-BA01 barometric pressure sensor (Measurement Specialties, USA) demonstrated superior performance to counterparts. It discriminates actual sitting and standing transitions from stationary postures with 99.5% accuracy and is also capable to completely dissociate Sit-to-Stand from Stand-to-Sit transitions.

1. Introduction

Recent evidence has shown that increased bouts of sedentary behaviour are associated with a range of negative health issues, high levels of body fat/obesity, blood glucose levels and Type-2 diabetes as well as cardiovascular problems [1]. The quantification of sedentary behaviour has traditionally been performed using self-report, proven to be an unreliable method [2], and more recently using body worn inertial sensors. Extensive research has thus been performed into activity classification, given this recent advancement in MEMS (microelectromechanical systems) inertial sensor technology, however the distinction between sedentary activities, e.g. sitting and lying, and dynamic (non-sedentary) activities, such as standing and walking, has been faced with a number of challenges. Sedentary behaviour refers to activities that do not increase energy expenditure significantly above the resting level while in a sitting or lying position [3].

Single inertial sensor solutions attached at the trunk or lower-limb currently are insufficiently accurate [4,5] for posture transition detection, even when supplemented by powerful signal processing techniques: advanced machine learning techniques [6] or pattern recognition methods based on Dynamic Time-Warping [7]. Although thigh-mounted sensors offer higher performance when distinguishing between sitting and standing, they not only struggle to differentiate sitting from lying but also may misclassify non-standard standing postures [8]. A multi-sensor system approach provides greater accuracy [4], however this solution requires higher power consumption, accurate sensor synchronisation, higher data computation and is less practical than an individual sensor. In order to produce greater accuracy when distinguishing sedentary behaviour from dynamic behaviour, great recognition between sitting and standing (STS) is thus required.

Fundamentally, the stand-to-sit (StSi) and sit-to-stand (SiSt) transitions involve an altitude change of the trunk and waist, primarily caused by hip and knee flexion and extension [9]. Assuming a minimum detectable STS transition height change corresponding to the thigh length, recorded as 0.53 m for the 5th percentile adult female [10], this requires the detection of a relatively small change in atmospheric pressure (6.1 Pa [11]). Recent advances in barometric pressure sensor technology potentially allow for these altitude changes to be measured with sufficient accuracy so as to enable the detection between sitting and standing using a single trunk-worn monitoring device.

The use of barometric pressure sensors for human movement monitoring has been employed by a number of researchers for energy expenditure estimation [12] and fall detection [13,14]. However to date, to our knowledge, no research has attempted to use

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barometric pressure sensors to distinguish between sitting (sedentary behaviour) and standing (dynamic behaviour).

The aim of this study is thus to investigate whether, single location, wearable barometric pressure sensing technology is suitable to distinguish between sitting and standing activities. Commercially-available barometric pressure sensors, appropriate for wearable monitoring, were tested simultaneously in laboratory and real-world (both indoor and outdoor) conditions to assess their performance STS recognition. The optimal sensor could then be integrated into a wearable monitoring system allowing for improved activity recognition.

2. Methods

In order to determine if barometric pressure sensing technology is suitable for the application, a number of commercially available devices were selected using the inclusion criteria detailed below. These sensors were then evaluated using a wearable sensor evaluation platform developed, to log simultaneously the reading, from all included devices for later off-line analysis. This allows for the direct performance comparison under the same environmental and recording conditions.

2.1. Barometric pressure sensor selection

Height estimation errors from barometric pressure sensors stem from factors such as: electrical noise, temperature changes, weather changes and/or sudden air flow (e.g. door opening) [11]. The ability of the sensing component to cope with such factors in real-world conditions was investigated. The selection process was hence divided into three steps:

(1) Components are first selected based on characteristic information, where available, using the following inclusion criteria:
   (a) Form factor—sensors should be of a size and weight suitable for integration into a wearable device.
   (b) Power consumption—sensors should require low power consumption suitable for a monitoring system capable of recording for up to 24 hours.
   (c) Precision—sensors should exhibit a precision (random error) less than 6.1 Pa [11], corresponding to the 5th percentile thigh length of a Caucasian female (0.531 m) at sea-level.
   (d) Commercial availability—sensors should be available for purchase from a main distributor.

   Pressure measurement accuracy (systematic error) was not added as an inclusion criterion as the objective is to measure the relative pressure change associated with a postural transition.
(2) The candidate sensors were then mounted on a custom prototype to estimate the noise level and stability (linear trend) performance under motionless calm conditions and the same temperature.
(3) A study conducted in real-world conditions was then used to assess the performance of included sensors at both indoor and outdoor locations. For this purpose, a data analysis, as described in Section 2.5, was performed on the collected data to select the optimum sensor suitable for integration in a wearable monitoring device.

2.2. Wearable sensor evaluation platform

A prototype printed circuit board was populated with the selected components that satisfied the inclusion criteria. This sensor evaluation platform was attached to the trunk at the sternum. Trunk motion during daily activity requires a bandwidth of up to 4 Hz [15]. A sampling frequency of 12.5 Hz was used to record simultaneously the selected pressure sensors. The sensor evaluation platform consisted of: a microSD card socket for data recording, a MSP430F5508 microcontroller (Texas Instruments, USA) for collecting the sensor digital information and a power regulator LP2981(Texas Instruments, USA) to ensure a stable supply voltage to the platform.

2.3. Laboratory assessment

Data from the selected sensors were recorded for 500s (6250 samples) in steady conditions for noise characterization. Sensors were maintained in a motionless state on the desk while the openings (doors and windows) remained closed thus achieving calm recording conditions. The pressure output was temperature-compensated with the algorithm provided in the manufacturers' datasheets.

2.4. Experimental setup for real-world condition measurement

Seven healthy volunteers (six males and one female/age: 27.8 ± 2.1 years/BMI: 23.9 ± 4.5 kg/m^2/height: 1.80 ± 0.075 m, minimum height: 1.68 m) were recorded performing a scripted set of activities of daily-living (ADL) (Table 1). This included sedentary behaviour (e.g., sitting), postural transitions (e.g. sit-to-stand, stand-to-sit) and dynamic behaviour (standing, walking, climbing up/down stairs).

These activities were carried out, in both indoor and outdoor locations, to evaluate the ability of each device to operate in conditions challenging to barometric pressure sensors, which can be sensitive to changes in temperature and weather. Chair heights were respectively 42 cm (standard office chair) and 34 cm (outside bench) for indoor and outdoor locations. Data were collected during each trial with the sensor evaluation platform. Subjects were video recorded during the trial for reference. This was used to identify the transitions which were manually annotated by one of the authors. This data collection protocol thus allowed us to acquire a

Table 1
Description of the real-world experiment protocol.

Location	Activity	Duration
Office	13 × SiSt/Remain standing for 15 sec/StSi/Rest for 15 sec	400 s
Corridor	Walk along the corridor and back	60 s
Corridor Hall	Walk along the corridor, open the door and walk in the hall until the staircase	60 s
Stairs	Walk down the staircase (15 steps) to the entrance	15 s
Entrance Outdoor	Walk around the building up to outdoor bench	50 s
Outdoor	10 × SiSt/Remain standing for 15 s/StSi/Rest for 15 s	300 s
Hall Corridor Office	Walk up to the door, open the door and walk along the corridor to the office	45 s