ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

# Distinguishing Sitting and Standing Activities Using a Wearable Barometric Pressure Monitor

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## SUMMARY

Recent advancements in wearable inertial sensor technology have enabled extensive research into activity classification. However, the distinction between the sitting and standing activities using trunk-worn wearable monitoring systems remains challenging, thus requiring additional sources of information such as elevation change.

The aim of this study is to demonstrate the suitability of barometric pressure, an absolute estimate of elevation, for distinguishing between sitting and standing (STS), as part of a wearable system. A barometric pressure sensor was integrated in a comfortable, miniaturized wearable sensor device suitable for improved long-term activity recognition. It enabled discriminating STS transitions from stationary postures with an accuracy of 99.5%, sensitivity of 99.7% and specificity of 99.3% and is capable of completely discriminating Sit-to-Stand from Stand-to-Sit transitions.

## INTRODUCTION

Distinguishing sitting (sedentary behaviour) and standing (dynamic behaviour) as part of general activity classification has traditionally been performed using self-report (proven to be an unreliable method) and more recently using body worn inertial sensors. However the distinction between sitting and standing has been faced with a number of issues Although single inertial sensor solutions affixed to the trunk or lower limb are suitable for detecting a postural transition [1], the current posture recognitions are insufficiently accurate [2,3]. The use of barometric pressure sensors for human movement monitoring has been proposed for energy expenditure estimation [4] and fall detection [5]. However to date, no research has attempted to use barometric pressure sensors to distinguish between sitting (sedentary behaviour) and standing (dynamic behaviour).

The aim of this study is thus to demonstrate the suitability of barometric pressure, an absolute estimate of elevation, for distinguishing between sitting and standing (STS) as part of a wearable system. The system was tested in real-world (both indoor and outdoor) conditions to assess the performance of STS recognition for final inclusion.

## METHODS

### *Wearable prototype*

The barometric pressure sensor, embedded in the wearable prototype, shall be selected assuming that the minimum detectable STS transition height change corresponds to the thigh length, recorded as 0.496m for an average height adult female resulting in 5.7Pa of barometric pressure change. The device shall be designed for long-term monitoring: lightweight, comfortable, safe and packaging and designed such that it can record during the active part of the day and recharged overnight. It will also include an inertial sensor for additional activity recognition (e.g. walking).

### *Pilot study - Real-world condition measurement*

A pilot study was conducted with 7 healthy volunteers (6 Males and 1 Female / Age: 27.8±2.1 years / BMI: 23.9±4.5 / Height: 1.80±0.075 m). Subjects were recorded performing a set of activities of daily-life including static postures (e.g., sitting or standing), postural transitions (e.g sit-to-stand, stand-to-sit) and dynamic activities (walking, climbing up/down stairs). These activities were carried out, in both indoor and outdoor locations (chair heights 42cm and 34cm respectively), to evaluate the ability of the barometric pressure sensor to operate in conditions challenging, sensitive to changes in temperature and weather conditions. Subjects were also video recorded during the trial as a reference. The protocol was approved by the local ethics committee.

### *Data analysis*

For each recorded Sit-to-Stand (SiSt) and Stand-to-Sit (StSi) transition (N), a time gap fixed at 2sec is maintained before and after each transition to ensure that the sensor reaches a steady state. Using a time window $\Delta t_{average}$, the pressure is then averaged before ($P_{before}^N$) and after ($P_{after}^N$) the transition and the difference of pressure ($\Delta P_{TR}^N = P_{after}^N - P_{before}^N$) is extracted. An equal number of non-transitions when the volunteer was stationary, sitting or standing, were extracted. The pressure difference of each non-transition ($\Delta P_{NoTR}^N$) is computed similarly by considering the difference of the pressure average during $\Delta t_{average}$ between sitting and standing activities. Thus an equal number of transitions and non-transitions pressure readings are used for statistical analysis.

In order to both detect STS transitions and then correctly classify them as either SiSt or StSi a number of parameters were investigated. Firstly a threshold, $\tau_{Pressure}$, was applied on $\Delta P_{TR}^N$ and $\Delta P_{NoTR}^N$ to discriminate transitions from non-transitions. The number of true positives (TP), false negatives (FN), false positives (FP), and true negatives (TN) are therefore respectively defined as the number of events during which $|\Delta P_{TR}^N| > \tau_{Pressure}$, $|\Delta P_{TR}^N| \leq \tau_{Pressure}$,

$|\Delta P_{NoTR}^{N}|>\tau_{Pressure}$, and $|\Delta P_{NoTR}^{N}|\leq\tau_{Pressure}$. Accuracy is defined ACC= (TP+TN)/(TP+TN+FP+FN), sensitivity as SE=TP/(TP+FN), and specificity as SP= TN/(FP+TN). To attenuate the potential effect stemming from the selection of parameters ($\tau_{Pressure}$,$\Delta t_{average}$), the sensitivity, specificity, and related parameters are computed across a set of different values. $\Delta t_{average}$ was set to vary from 0.08 seconds (sampling period) up to 13 seconds with increments of 0.08 seconds. The decision threshold ($\tau_{Pressure}$) varied from 0 to 10 Pa (~0.9m) with steps of 0.02 Pa. Secondly, for the distinction between SiSt and StSi transitions, the change in pressure $\Delta P_{TR}^{N}$ for each identified transition was then grouped by identified transitions, SiSt and StSi, ($\Delta P_{TR}^{SiSt}$ and $\Delta P_{TR}^{StSi}$, respectively) and computed at the transition time using $\Delta t_{average}^{ACC}$ that yields to a maximum ACC.

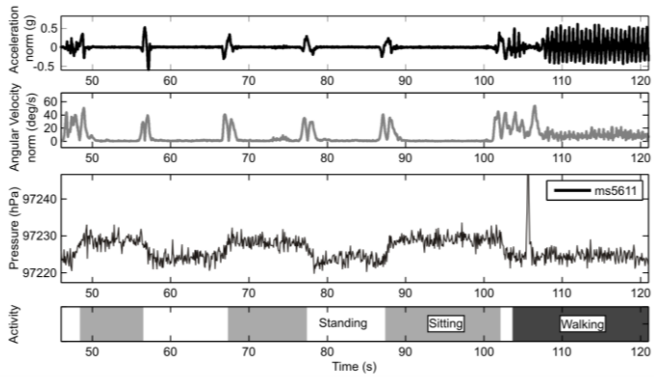


**Figure 1 –** Evolution of different modalities recorded with the wearable sensor. Norm of trunk acceleration (top plot) and angular velocity (second plot) sampled at 200Hz. (Third plot) Raw barometric pressure from the MS5611 sampled at 12.5 Hz. The peak of pressure at 105 seconds corresponds to a door opening. (Fourth plot) Activity chart

## RESULTS AND DISCUSSION

### *Wearable prototype*

A wearable prototype was designed to integrate the MS5611-BA01 (Meas. Specialties, CH) barometric pressure sensor, selected thanks to its low noise level (1.5Pa). Moreover, the 3D accelerometer and gyroscope LSM330D (ST Micro, CH) was embedded to provide inertial measurements. The low-power MSP430 microcontroller (Texas Instruments, USA) was added to easily connect the sensor modules with both the MicroSD card for data recording and the low-power nRFAP2 radio transceiver (Nordic Semi, NO) for radio communication. The wearable prototype was powered by a 120 mAh li-ion battery, enabling a lifetime of 20h+. The packaging (OKW Minitec–52x32x15 $mm^3$) was splash-proof (IP41 rated) and the total weight was less than 20 grams.

Figure 1, presents inertial and pressure data from collected by the new wearable system. The norm of trunk acceleration and angular velocity are typical signals that are used as inputs for activity recognition algorithms. Repetitive patterns in the trunk acceleration can also be used to detect walking periods (Figure 1, from 97 to 125 seconds).

### *Real-world condition measurement*

Each volunteer performed 46 postural transitions (13 SiSt/StSi indoor and 10 SiSt/StSi outdoor) representing a total of 322 recorded transitions. A total 322 non-transitions were also extracted. The wearable prototype achieved a high accuracy (ACC=99.5% / SE=99.7% / SP=99.3%) with an optimal $\tau_{Pressure}$=3.12Pa and a low reactivity time ($\Delta t_{average}^{ACC}$=4.16s). Moroever, a reduced accuracy of 98% can be achieved with a $\Delta t_{average}^{98\%}$ =0.32s enabling faster activity recognition. Regarding the $\Delta P_{TR}^{SiSt}$ and $\Delta P_{TR}^{StSi}$ values, the wearable prototype enabled a perfect separation between the two groups with simply a sign-based threshold.

Pressure sensors are traditionally very sensitive to temperature which can cause the pressure signal to drift. The pilot study, described previously, was thus conducted to assess performance in both indoor and outdoor conditions. At the time of the experiment the temperature was 24°C inside and 5°C outside, wind speed less than 2.78m/s (10km/h). Despite this temperature shift, no difference was seen in terms of accuracy between indoor and outdoor conditions, likely due to the short computation window.

Furthermore, barometric pressure sensors are also sensitive to external phenomenon (not related to elevation changes) such as a sudden air flow (door/window opening). To overcome this issue, fusing inertial with barometric pressure information could be performed, for a better tracking of the elevation and detection of a potential transition.

While previous studies restricted the use of barometric pressure sensor to application requiring large altitude change such as enhancing fall detection [5] or distinguishing level walking from stair climbing, this study demonstrated the suitability of barometric pressure sensors for acute STS transition detection and recognition through careful selection and validation process.

## CONCLUSION

This study addresses the challenging issue of distinguishing between sitting (sedentary behaviour) and standing (dynamic behaviour) using a single wearable device attached to the trunk. Barometric pressure measurement was proposed as it provides an absolute estimate of sensor altitude which may be a complementary data to inertial sensors signals.

Firstly a wearable prototype was designed to accommodate a precise barometric pressure sensor with an emphasis on long-term monitoring requirements. The system was then evaluated in a pilot study in real-world conditions, with both indoor and outdoor locations, and achieved a high accuracy. The wearable monitor presented here can thus be used to supplement existing activity classification algorithms when distinguishing sitting and standing activities.

## ACKNOWLEDGEMENTS

Rehabilitatitve Wayout In Responsive home Environments (REWIRE). REWIRE is funded by the Seventh Framework Program (FP7), contract N. 287713. www.rewire-project.eu

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