Ambulatory Estimation of XCoM using Pressure Insoles and IMUs

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Introduction

Ambulatory gait assessment using minimal sensors has quite an impact for different applications requiring localised sensing. ForceShoes™ was developed as one such solution. It consists of two IMUs, and two 6DoF force and moment (F&M) sensors on each foot[1]. Additionally, an ultrasound system was added [2]. The complete system, also referred to as Ambulatory Gait and Balance System (AGBS), is used to measure ambulatory kinematics and kinetics of the feet while walking. The AGBS has been validated against standard systems[2,3]. Using the measured F&M, and position estimations from IMUs, the low and high-frequency information of Center of Mass (CoM) is estimated. This was used to estimate the Extrapolated Center of Mass (XCoM)[4]. XCoM along with base of support provides information about stability during walking[4]. The unique advantage of the AGBS is its portability and ambulatory measurement when compared to standard systems.

The F&M sensors in the AGBS however, are quite bulky, making it heavier and taller than normal shoes. As an alternative, using 1D pressure sensors was studied. Pressure sensors are thin and easy to slip as insoles in shoes. Therefore, they show potential in making the ambulatory system less bulky.

Research Question

Can a minimal setup of 1D pressure insoles for estimating CoM, and eventually XCoM be an alternative to the heavy F&M sensors in the AGBS?

Methods

A medilogic pressure insole consisting of 151 resistive pressure sensors is inserted into the ForceShoes™. Six subjects were instructed to walk with this setup six times in four different walking tasks. First, they walked at a preferred speed (*Normal*), then at a slower speeds (*Slow*), and (*V Slow*). For the fourth task, they walked at preferred speed while wearing a bag weighing 5kg (*Bag*). All participants signed the informed consent form and the study was approved by the University of Twente's ethical committee.

Using the position of each pressure sensor in the global frame estimated from the IMUs, along with 1D pressures, the Centre of Pressure (CoP) for each foot was estimated. Different sensor configurations were studied, which include all sensors (*ALL*), sensors at the toe, metatarsal, arch, and heel (*FF*), sensors at the toe and heel (*T+H*), sensors at the heel (*H*), and sensors at the toe (*T*). The number of sensors are reduced in each configuration. The CoP derived in these configurations are used to estimate the CoM, and eventually XCoM. The XCoM is compared with that of the AGBS seen in Fig. 1.

Discussion

In the graph, X-axis is in the walking direction, and Y-axis is directed to the left of it. The box plot of distributions of correlations and RMS of the differences between AGBS and current method is shown. As the number of sensors is reduced, the RMS of differences increases for the X-Axis. This is because the different sensor configurations influence the position of CoP. Surprisingly, in the Y axis, the RMS of differences have similar statistics. This could be because the range of coordinates in the Y-axis is similar across different sensor configurations.

Here, we estimate XCoM only from the CoP. Therefore, only the low-frequency information of the CoM is used. However, the CoM estimated in AGBS consists of both low and high-frequency information. In spite of this, the current method shows good correlations and low RMS of differences when compared to AGBS. We could also see that *T+H* is potential option having a good trade-off between sensor number and accuracy. This could suggest that for the given speeds of walking, low-frequency information is sufficient to estimate the XCoM. This suggests that the system has potential uses in populations with slow walking speeds, such as stroke.

Thus, it is shown that with a minimal setup (IMUs, and pressure sensors), a good estimate of gait and balance measures can be obtained. This has a great impact on ambulatory gait and balance sensing applications.

Results

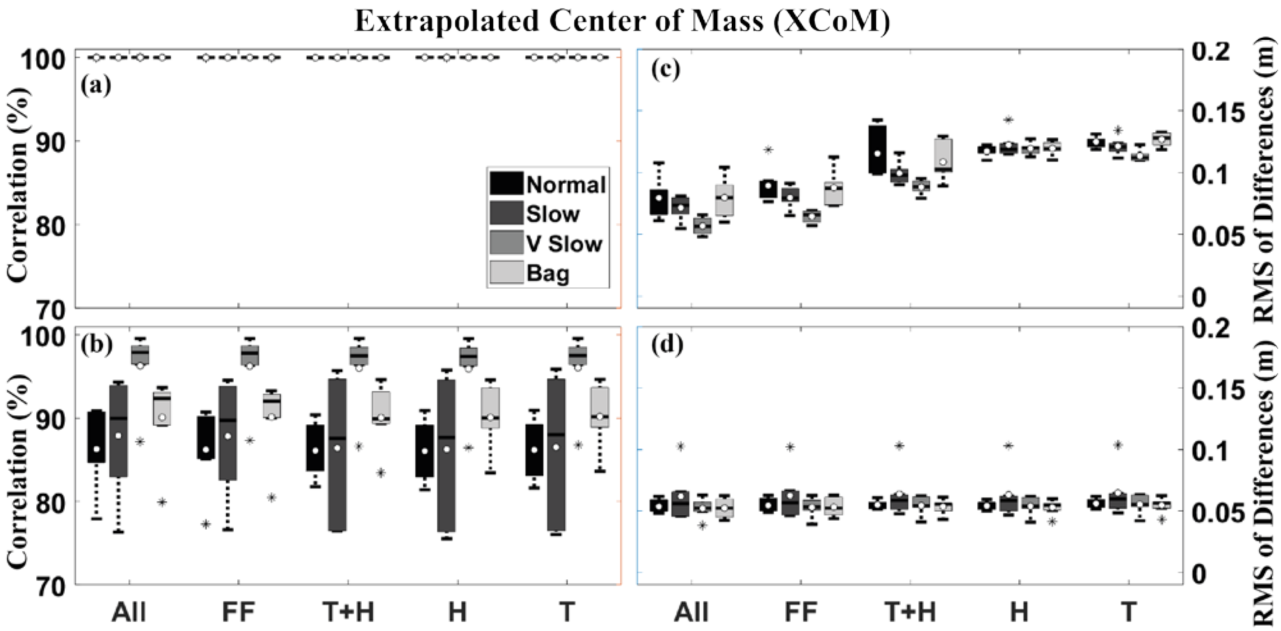

Fig 1. Comparison between the XCoM estimated using AGBS with different sensor configurations of pressure sensors. (a), and (b) show the correlations in the X and Y-axis, and (c), and (d) show the RMS of differences. Box plots of the mean values are shown for the different walking tasks for each sensor configuration used.

References

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