Long Term Measurement of Spontaneous Walking with Foot Mounted Inertial Sensors

John R. Rebula, Peter G. Adamczyk, Lauro Ojeda, Arthur D. Kuo
University of Michigan, Ann Arbor, MI
E-mail: jrebula@umich.edu Web: http://hbcl.engin.umich.edu

Motivation

Measures of stride distances and variabilities during walking can help to quantify mobility and balance. For example, stride width variability can serve as an indicator of fall risk in older persons [1]. It may be preferable to measure spontaneous walking during daily living, but stride variabilities are difficult to obtain without motion capture equipment, which typically necessitates a gait laboratory. Body-worn inertial measurement units (IMUs), consisting of gyroscopes and accelerometers, can be deployed without a laboratory and are increasingly used to detect gross measures of motion and speed. Current methods do not yield measures of stride variability, due to position drift from integrated IMU signals. Appropriate drift correction may allow a foot-mounted IMU to estimate stride length and width accurately from spontaneous walking.

State of the Art

We propose to adapt recent advances in IMU processing algorithms to perform gait measurement comparable to motion capture systems. Recent methods for processing foot-mounted IMUs have been used to track pedestrians during walking both indoors and outdoors [2]. The methods achieve close tracking accuracy through careful gyroscope calibration as well as taking advantage of the phasic nature of walking to correct for small integration errors that accumulate each step. While these methods are designed for absolute localization tasks, we adapt them for gait measurement.

Our Approach

Our proposed method uses ground contact information to reduce the drift due to IMU integration. Drift occurs due to the lack of a fixed position reference in inertial measurements. Some existing methods [1] reduce position drift by using well-calibrated gyroscope measurements, and by correcting translational velocities using ground contact each step. Here we also adjust velocites throughout each step using a linear velocity error model. The corrected velocities are then double integrated to yield position trajectories. Using the average heading from multiple steps, each stride is decomposed into length and width.

To test our method, we measured healthy subjects (N = 9) walking along a hallway followed by a cart-mounted motion capture system to yield proof data, and compared that to simultaneously collected data from a foot mounted IMU. Subjects walked with eyes open and eyes closed to test the sensitivity of the IMU to abnormal gait. A wireless IMU was attached to the heel of each shoe. We determined swing and stance phases

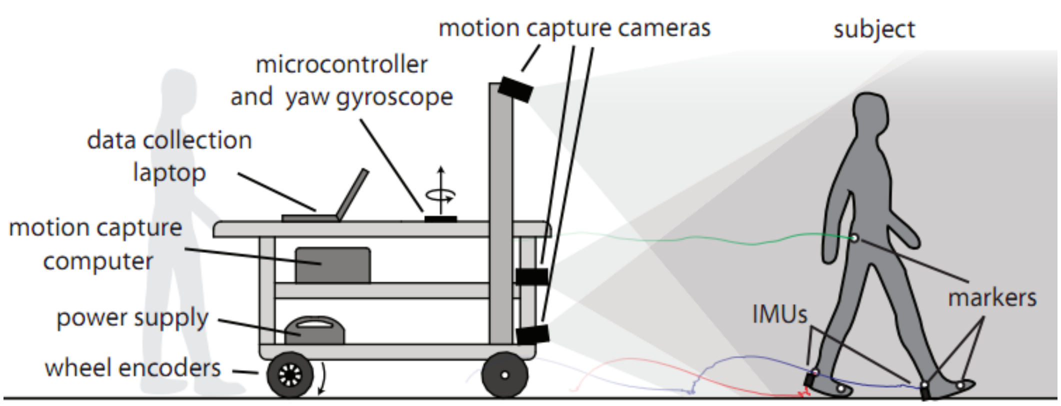

Figure 1: Representation of the experimental setup. Subjects with foot-mounted IMUs and motion capture markers walked unconstrained in a hallway followed by an experimentor pushing a cart with a Phasespace motion capture system. The cart was instrumented with a z-axis gyroscope and quadrature encoders for dead reckoning to calculate the motion of the subject in a world frame to provide a comparison between motion capture and IMU results.

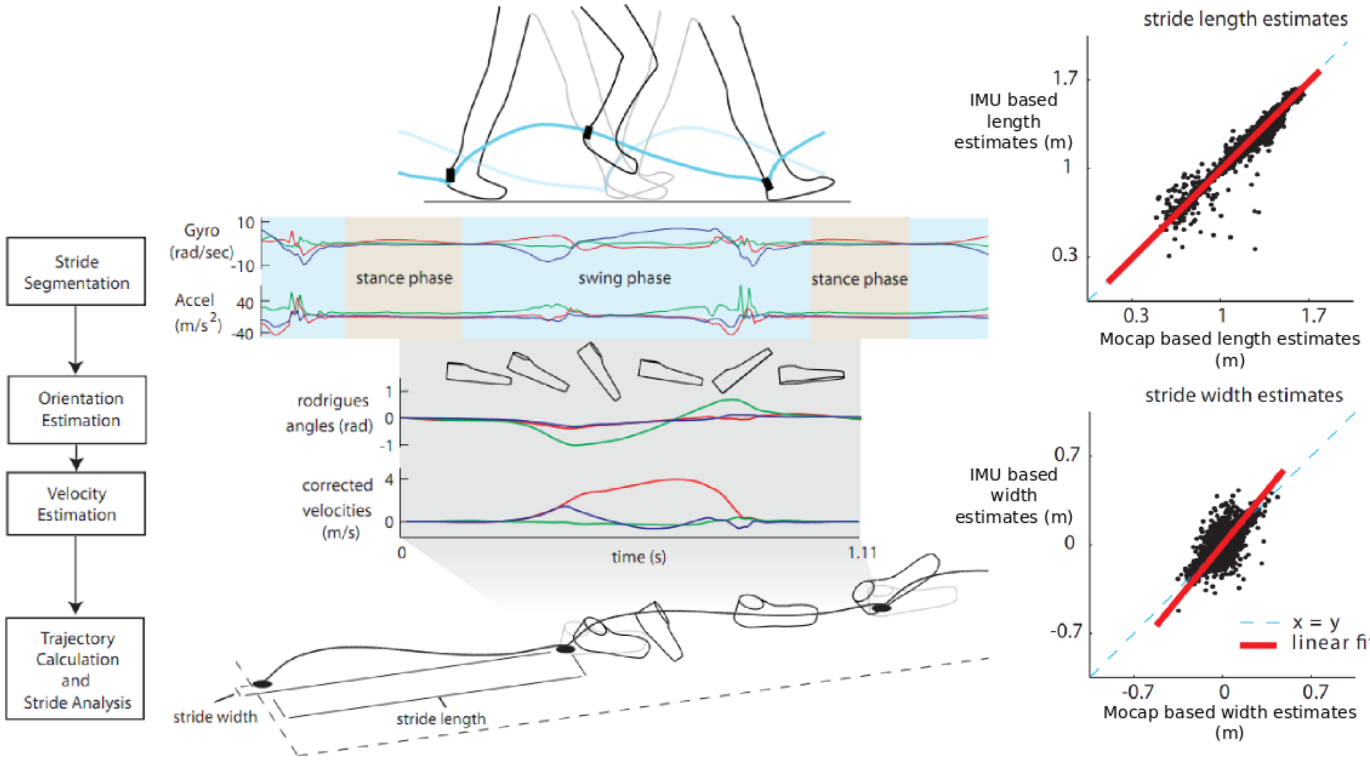

Figure 2: Conceptual overview of the processing method of the IMU signals during walking. The IMU signals are segmented into strides. The IMU orientation is estimated by integrating the gyroscopes, and a corrected velocity is calculated based on the accelerometers. These velocities are integrated to yield the foot's trajectory and gait parameters.

primarily using thresholds on gyroscope and accelerometer magnitudes [2]. We then calculated stride length and width from the IMU and compared them to motion capture data. The motion capture position trajectories were similarly segmented and decomposed along the direction of travel. A comparison of the motion capture and IMU estimates is shown in figure 2.

Discussion outline

We have found that foot mounted IMUs measuring level ground walking can provide gait measures roughly comparable to those measured with motion capture. IMUs can provide rich measurements of natural walking, which could elucide differences between natural walking and lab based locomotion tasks. The effect of medicine, rehabilitation interventions, and walking prosthesis alterations on gait can currently be easily measured with short lab based trials, but these tests might not fully describe the subject's performance in daily life over a longer period of time. For example, IMUs can capture natural variations of speed during long walks that are not evident in normal treadmill walking. IMUs could also provide insight into how fatigue affects a person in daily life, by comparing the speed and variability of gait at the beginning of the day to that at the end of a day. We are interested in a discussion on potential differences between commonly measured gait in lab differs from natural walking and clinical relevence of these differences.

Format: Poster or lightning talk.

References

1. Brach, J.S. (2005) J Neuroengineering Rehabil. 2(21)
2. Ojeda, L. et al. (2007) Proceedings of Safety, Security and Rescue Robotics, Roma, Italy