LONG-TERM MEASUREMENT OF FOOT PLACEMENT DURING WALKING USING IMUS

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MOTIVATION

Foot placement and its variability can serve as indicators of mobility and walking ability as a function of age, injury, and disease in humans. Inertial measurement units (IMU) can potentially quantify foot motion without need for laboratory-based motion capture equipment, and for relatively long bouts of walking during daily living. One limitation is that integration of IMU data is sensitive to drift, referring to accumulation of errors from noisy data.

STATE OF THE ART

Foot placement parameters such as step distances and variabilities are used to quantify gait in the context of fall risk, development, and various disorders [1]. Gait is normally measured using laboratory based equipment such as gait mats and motion capture systems. Advances in IMUs offer the possibility to measure foot motion using unobtrusive sensors outside of lab environments. Inertial data is typically subject to integration drift, but recent drift correction algorithms can calculate the trajectory of a foot-mounted IMU [2] with acceptable drift. Comparisons to motion capture suggest good agreement between IMUs and lab based measurements [3].

APPROACH

Here we test our IMU processing algorithms on data from subjects walking on a variety of terrains to test robustness to varying conditions. These environments include clinical tests of at-risk elderly subjects (a figure-eight trial), walking outdoors over several distinct terrains (grass, gravel, dirt, dirt ramp, woodchips, and sidewalk). While the drift correction algorithm is not designed to localize the subject in space, it provides a position estimate which is subject to position drift over long periods of time. Because of the variety of terrains tested, proof data is not readily available, so we compare the results qualitatively to those expected from the terrain.

CURRENT RESULTS

Computed trajectories for walking in various terrains qualitatively match with expectations based on the terrain (figure 1). In some cases, the trajectories yield more information than is typically collected during a clinical trial. For example, an experimenter can conveniently time a figure-eight trial as well as assign a score for quality of walk, while the IMU trajectory records precise footfall timing and placement, instantaneous foot speeds, and turning radius. Similarly, an obstacle avoidance IMU trajectory can be used to estimate clearance height, foot placement before and after the obstacle, as well as foot orientation adjustments during swing.

BEST POSSIBLE OUTCOME

We found good qualitative tracking of walking in a variety of environments. Foot inertial tracking can also be applied to walking robots in arbitrary environments, which could benefit from a foot position sensor that does not rely on assumptions of ideal instrumented joints and continuous solid ground contact. For example, if a leg has a non-rigid segment that is difficult to instrument, a foot-mounted IMU can be fused with other sensor data to track the foot's position. Also, a stance-foot-mounted IMU provides an indication of foot slip, while the position estimate from a swing-foot-mounted IMU is unaffected by stance-foot slip. IMUs can also inform control for active prosthetic feet.

Although foot-mounted IMUs provide less information than a motion capture system about a human's overall motion, we believe that they can provide rich data from daily living, such as activity tracking, energy consumption, and measures of mobility function. Because IMUs are unobtrusive and relatively inexpensive, they can be used on a large scale to capture data from many participants in studies, allowing measurement of a large cross section of a population in a wide variety of environments.

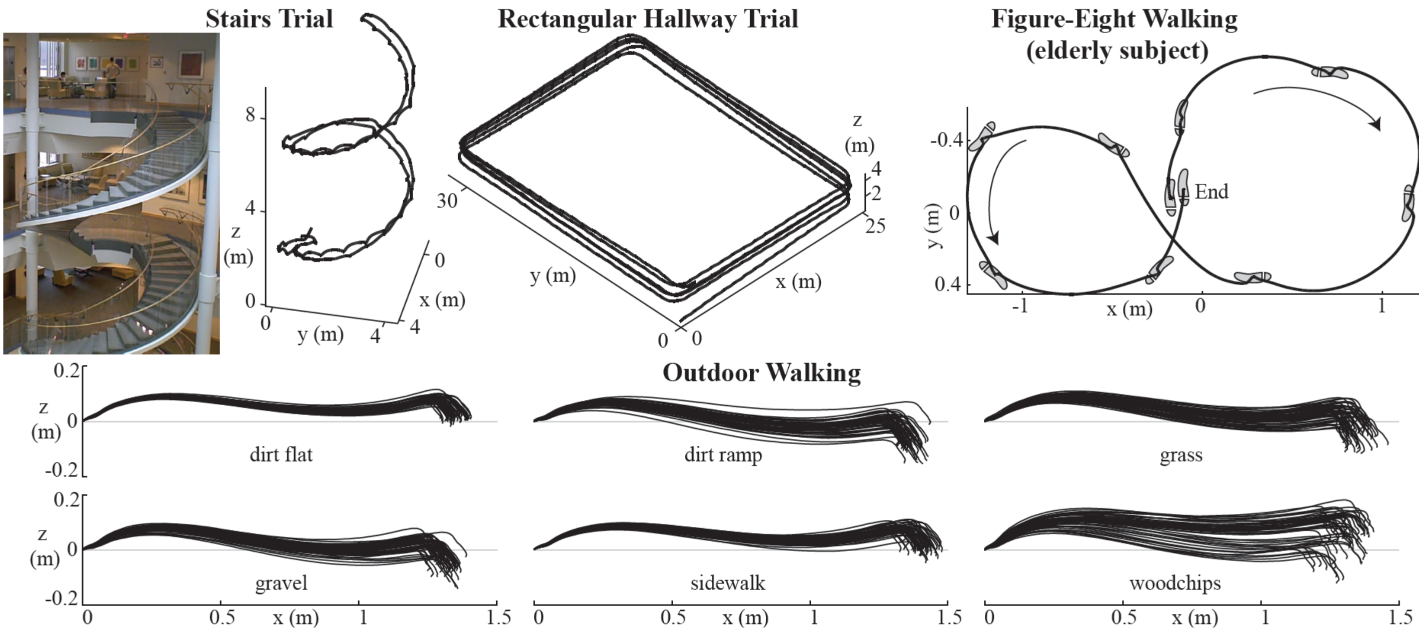

Figure 1: Examples of foot localization with IMUs in everyday environments. Shown are trajectories of one foot's motion for navigating a spiral staircase (top left), walking in a 110m hallway circuit 5 times (top middle), and a figure-eight trial for an elderly balance-impaired subject (top right). Foot trajectories for walking outdoors on various terrains are also shown (bottom).

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