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Inertial Sensor and Cluster Analysis for Discriminating Agility Run Technique

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Abstract: Performance in an agility run drill is often used to characterize an athlete's ability to quickly and explosively change direction. Beyond athletic applications, agility tasks are also used to assess the physical readiness of warfighters for battle and the influence that their equipment has on their performance. However, in all of these applications, performance is currently assessed solely by reporting the time it takes to complete the drill. While completion time quite meaningfully discriminates bottom-line performance, it does not reveal the underlying biomechanics that contributes to or limits that performance. Biomechanical metrics that accurately identify performance strengths and weaknesses could promote rapid performance gains via tailored training programs and inform equipment design improvements. To these ends, we propose using a belt-worn wireless inertial measurement unit (IMU) to quantify the biomechanical metrics underlying speed and agility performance in agility assessment tasks. Herein, we describe a drift correction methodology that enables estimates of displacement, velocity, and acceleration of a subject's sacrum provided a course with known waypoints. We demonstrate the utility of this methodology through analysis of a large data set collected from 32 subjects completing a slalom run. A k-means cluster analysis of proposed performance metrics reveals two distinct groups of subjects who use fundamentally different techniques to negotiate the turns of the course. We believe that this measurement methodology can be used widely for agility assessment to provide athletes, trainers and researchers with actionable data to inform training plans and equipment modifications.

Keywords: Inertial Measurement Units, Optimization, Drift Correction, Human Performance, Agility.

1. INTRODUCTION

Agility is defined as "a rapid whole body movement with change of velocity or direction in response to a stimulus''(Sheppard and Young, 2006). Therefore, agility can be broken down into two distinct tasks: 1) perception and interpretation of a stimulus, and 2) rapid biomechanical reaction to that stimulus through a change of direction or velocity. Success in both of these tasks is required for superior agility performance. Agility run drills are commonly used to test a subject's ability to quickly and explosively change direction which speaks directly to task 2 (Sheppard and Young, 2006). However, performance in these tests is currently assessed solely by reporting the time it takes to complete the drill. While completion time quite meaningfully discriminates bottom-line performance, it does not reveal the underlying biomechanics that contributes to or limits that performance.

Human biomechanics are often quantified using video-based methods where a subject is tracked by a system of cameras that capture the motion of skin-mounted reflective markers (see validation of (Rebula et al., 2013), for example). However, video methods typically require expensive camera systems, skilled operators, and significant data reduction and post processing before meaningful information can be generated. These limitations restrict their use to highly controlled (often laboratory) settings which prevents wide adoption by athletes, trainers, coaches, and researchers.

Recent advances in miniaturized inertial measurement units (IMUs) have enabled accurate measurement of human biomechanics without the constraints imposed by video-based systems and at a fraction of the cost (McGinnis et al., 2015; Seel et al., 2014). However, IMUs are limited in their ability to estimate trajectory, as doing so requires an error-prone double integration of acceleration (Titterton and Weston, 2004). In the study of human ambulation, this limitation is often overcome by mounting a device to the foot of a subject and utilizing established pedestrian localization techniques to extract the trajectory of the foot (Rebula et al., 2013). Unfortunately, the accuracy of this approach relies on reliable gait patterns so that the stance phase of gait can be detected. In agility-type tasks, these periodic gait events cannot be guaranteed. Moreover, foot trajectory data does not provide information about how a subject's sacrum is moving during ambulation, which is also a close approximation for the subject's mass center. Studying the trajectory of a subject's sacrum, often requires data from multiple sensors that are combined to provide a full description of the kinematic chain of the legs originating from a ground contact point (Takeda et al., 2009). While these techniques provide a

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wealth of biomechanical data, they rely on the use of multiple sensors which increases experimental complexity and thus reduces the likelihood of translation outside of research contexts.

In an effort to minimize the operational requirements for athletes, coaches, or the like, we propose the use of a single belt-worn IMU for quantifying the trajectory, velocity, acceleration, orientation, and angular velocity of the sacrum during drills used to assess agility performance. In so doing, we also detail a new drift correction algorithm and demonstrate its utility by using the corrected kinematics to identifying two groups in a large dataset of 32 subjects who employ different turning techniques while completing a slalom run.

2. METHODS

2.1 Human Subject Testing

Thirty-two subjects were recruited for participation in this study from the local university population. Prior to testing, informed consent was obtained from each participant and the testing protocol was approved by the University of Michigan Institutional Review Board. Following a familiarization period, each subject was instructed to complete a slalom run course as quickly as possible. The course was composed of seven cones spaced 5 m apart to define five changes of direction.

2.2 Measurement and Estimation of Sacral Kinematics

The motion of each subject was tracked using a belt-worn inertial measurement unit (APDM Opal, Portland, OR, USA) as they completed the slalom course. The IMU measures three components of linear acceleration ($\vec{a}_m$) and angular velocity ($\vec{\omega}_m$) in a body-fixed frame F_M characterized by the orthonormal vector triad (X_M, Y_M, Z_M, see Fig. 2) and assumed to originate from the subject's sacrum with an arbitrary orientation relative to the body. The time when the subject starts and finishes the slalom run is indicated in the data using a synchronized trigger that provides a unit pulse in a single data stream when a button is pressed by the study staff.

We employ the IMU data to estimate the acceleration, velocity, displacement, angular velocity, and orientation of the sacrum relative to the path followed by each subject and the cones that define the slalom course. A high level summary of the steps used to transform IMU data (Step 1) into these quantities is provided in Fig. 1.

As suggested in Step 2, before each subject completed the slalom run, data from a simple calibration routine that includes standing still, walking in a straight line, and touching the toes was used to define the fixed transformation from the IMU measurement frame to an anatomical reference frame for each subject (X_{ANA}, Y_{ANA}, Z_{ANA}). As shown in Fig. 2, the anatomical frame was defined such that the axes aligned with the medial-lateral (ML, approximately X_{ANA}), anterior-posterior (AP, approximately Y_{ANA}), and longitudinal (L, approximately Z_{ANA}) axes of the subject. The transformation was then used to resolve the measured kinematics in this frame yielding $\vec{a}_{ANA}$ and $\vec{\omega}_{ANA}$.

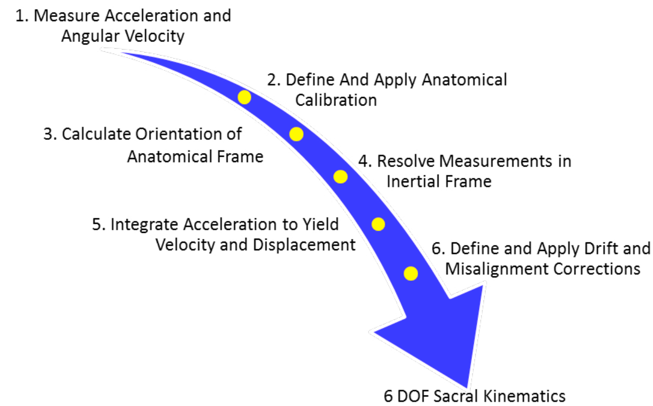

Fig. 1. High level summary of data reduction steps.

Defining measured kinematical quantities in the anatomical reference frame F_{ANA} shown in Fig. 2 provides the angular velocity of the sacrum (one of our desired outputs) which is needed for determining the sacral orientation as described next.

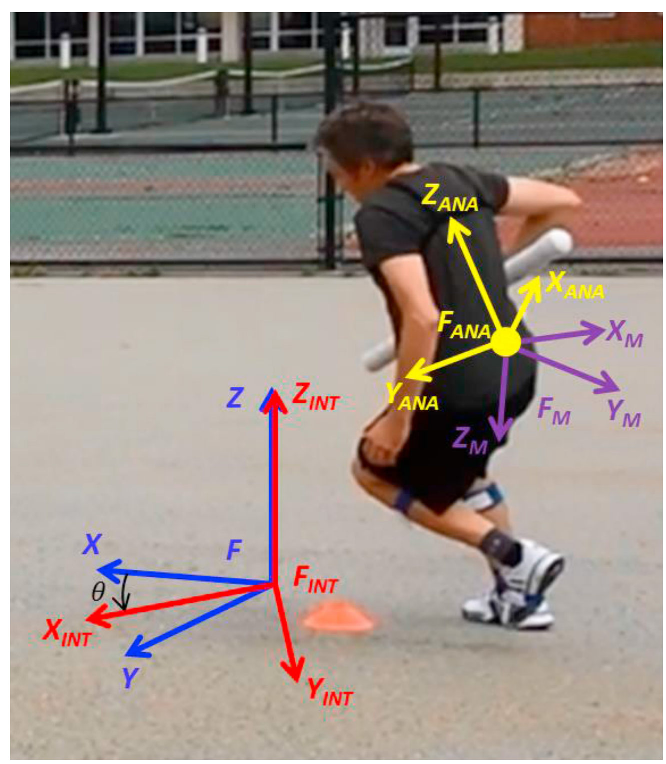

Fig. 2. Four reference frames defined in the study: measurement frame of the IMU (F_M, orange), anatomical frame (F_{ANA}, yellow), inertial frame (F_{INT}, red), and course frame (F, blue).

As per Step 3 of Fig. 1, the orientation of the subject's sacrum is defined by the direction cosine matrix $C_{INT/ANA}$ which quantifies the orientation of an inertial reference frame, F_{INT}, defined by the orthonormal triad (X_{INT}, Y_{INT}, Z_{INT},