Hardware Set-Up Recommendations for an Outdoor Motion Capture System with an Application in Overground Running

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ABSTRACT

Gait analysis laboratories are a successful and useful resource in the medical field, but oftentimes, progressed rehabilitation and testing requirements outgrow the restrictions of an indoor laboratory. Naval Medical Center San Diego's (NMCSD) mobile motion capture system is used to collect overground running data on part of an outdoor 400m track. The set-up consists of 12 Raptor-E motion capture cameras (Motion Analysis Corp., Santa Rosa, CA) collecting 3D positional kinematic data at 300Hz and four portable force plates (Kistler Instrument Corp., Amherst, NY) collecting kinetic data at 1800Hz. Placing the motion capture cameras on tall tripods and aiming them down at the capture volume proves successful at minimizing extraneous reflections caused by sunlight reflecting off surrounding objects. Aluminum plates are positioned underneath all force plates and spacers to decrease unwanted movement that is a result of being placed on a polyurethane track. This short communication is designed to share the set-up techniques of a successful outdoor, overground motion capture system collecting accurate and reliable data that is comparable to a more controlled indoor environment. The ability to confidently collect data under such conditions permits the freedom to study a range of activities in various locations, providing a subject with the most natural environment in which to perform. In a military setting, this technology is helpful in assisting the return of wounded warriors to a more active lifestyle.

INTRODUCTION

For overground running research and clinical evaluations, where kinematic and kinetic data are desired, it is important that the subject has enough room to sufficiently increase and decrease their speed outside of the capture volume. This amount of space is not always available with indoor laboratories and often results in researchers observing treadmill running instead of overground running. Therefore, in order to assess natural, overground running mechanics with no limitations to space, an outdoor motion capture system is needed. The motion capture set-up procedures established with Naval Medical Center San Diego's (NMCSD) mobile overground system have proven to be efficient and accurate. Ideally, this short communication can guide others wanting to develop similar set-ups as there is confidence these methods will prove successful and versatile in adjusting to various activities and testing environments.

METHODS

Figure 1. NMCSDs outdoor motion capture set-up on the straight-a-way of a 400m track.

NMCSD's mobile motion capture system is set up each day of data collection on a 50m section of a 400m track and occupies a total physical space of 16m with a resulting capture volume that

is 7m in length (Figure 1). The set-up consists of 12 Raptor-E motion capture cameras (Motion Analysis Corp., Santa Rosa, CA) collecting 3D positional kinematic data at 300Hz and four portable force plates (Kistler Instrument Corp., Amherst, NY) collecting kinetic data at 1800Hz. Two Nikon cameras (Digital West Imaging, San Diego, CA) are also included in the set-up to collect reference video. A generator provides power for all of the equipment since an electrical source is not available.

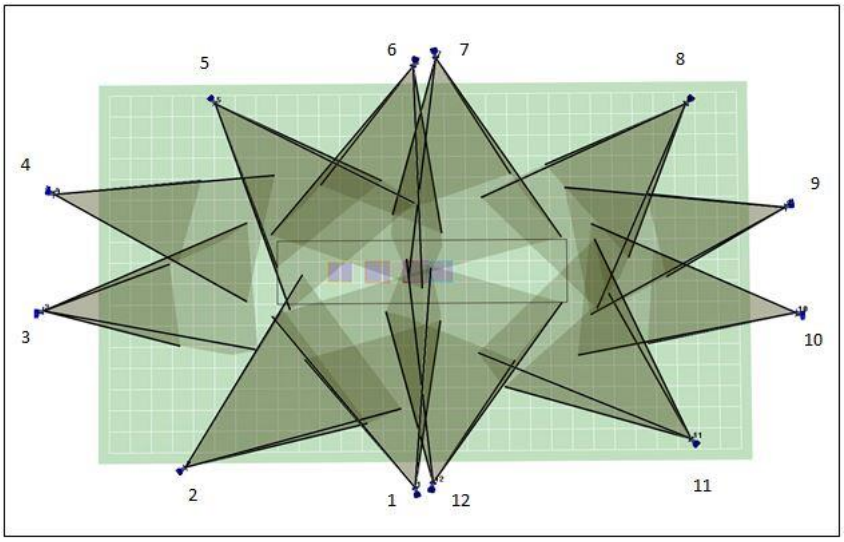


Figure 2. Overview of motion capture set-up and each camera's field-of-view.

<u>Cameras:</u> The most successful camera set-up and arrangement (Figure 2) includes placing Raptor-E cameras on sturdy tripods and raising them to their maximum height of around 2.6m, resulting in cameras that are aimed down towards the data collection space. By using this technique, unwanted reflections from the surrounding area are avoided, and camera positioning requires less troubleshooting and attention during a day of data collection. This allows the staff to focus on the subject and not on re-masking and controlling new, unwanted reflections. To increase the depth of view down the capture volume cameras 3 and 9 are rotated 90° to their right if one were to look at the lens while standing in front of the camera, and cameras 4 and 10 are

rotated 90° to their left. All remaining cameras are upright on their tripods. For this set-up, the grayscale floor is set to 650 pixels with camera thresholds set to 550 pixels. The Nikon cameras are used to record reference videos in the frontal and sagittal planes and can be relocated during data collection to obtain reference video from all desired angles.

Although this set-up does not include sensors to monitor speed at this time, a Cortex (Motion Analysis Corp., Santa Rosa, CA) post-processing presentation graph tool provides the ability to immediately calculate velocity of a marker as an estimate of the subject's speed. From here, the researcher can use verbal feedback to instruct the subject to adjust their speed as necessary. Full post-processing of previously collected data confirmed that the velocity calculated using the Cortex presentation graphs on site was accurate within 0.06m/s on average of that compared to the velocity calculated through post-processing techniques.

Force Plates: The four Kistler® force plates (60cm x 50cm x 5cm) are arranged in tandem, numbered 1-4, with spacers (30cm x 50cm x 5cm) between plates 1 (FP1) and 2 (FP2), and between plates 2 and 3 (FP3) (Figure 3). Force plates 3 and 4 (FP4) are adjacent to one another, and through post-processing techniques, a single foot strike that lands across both plates can be used. Because it is ideal to get a clean force plate strike with both the left and right feet in a single trial, having FP3 and FP4 adjacent to one another offers the best chance that subjects will strike either plate separately or land across both plates following an initial foot strike on FP1 or FP2. An aluminum plate that is 3.175mm thick is placed underneath each of the four force plates to decrease unwanted movement in the vertical direction by dissipating the force. The unwanted movement comes from the soft, underlying polyurethane track material. The aluminum plates need to be thin enough to not cause a height discrepancy between the force plates and the spacers or surrounding walkway so as not to introduce a tripping hazard for the subjects. To decrease

movement in the anterior/posterior direction and to ensure forces are not underestimated due to transition of forces to surrounding objects (i.e. walkway components), the force plates are secured to the underlying aluminum plates with screws. Following these procedures it was verified, through placement of reflective markers on the corners of each plate and post-processing as a rigid body, the center of mass (COM) of each plate did not move more than 5mm in any direction when contacted by a foot at jogging speed (about $3.2 m \cdot s^{-1}$) or during a few hard, targeted steps. The force plates are also surrounded by a portable walkway (9m x 1.5m), made by Kistler® Group, and all individual walkway pieces are covered in grip tape to create a non-slip surface and help decrease the reflectiveness of the original painted surface. Small ramp pieces are placed at the beginning of the walkway (1.8m before FP1) and at the end of the walkway (3.6m after FP4) to create an easy transition on and off the capture area. The sensitivity range of each force plate that is used for this set-up has proven appropriate for running speeds ranging from $3.0 m \cdot s^{-1}$ to $7.4 m \cdot s^{-1}$ (F_{xi}, F_{yi}: ~3.8 mV/N; F_{zi}: ~1.9 mV/N) but can be easily adjusted as necessary. The settings outlined here are per manufacturers specifications and may change if using a different force plate provider. A picture of the force plate and walkway layout can be found in Figure 3. Prior to each data collection session, the CalTester testing procedure (C-Motion, Inc., Germantown, MD) is executed to verify the degree of center of pressure (COP) agreement between the force plates and surrounding motion capture cameras (Holden, Selbie, & Stanhope, 2003). One example of a CalTester Report generated before a data collection session began is provided as Figure 4.

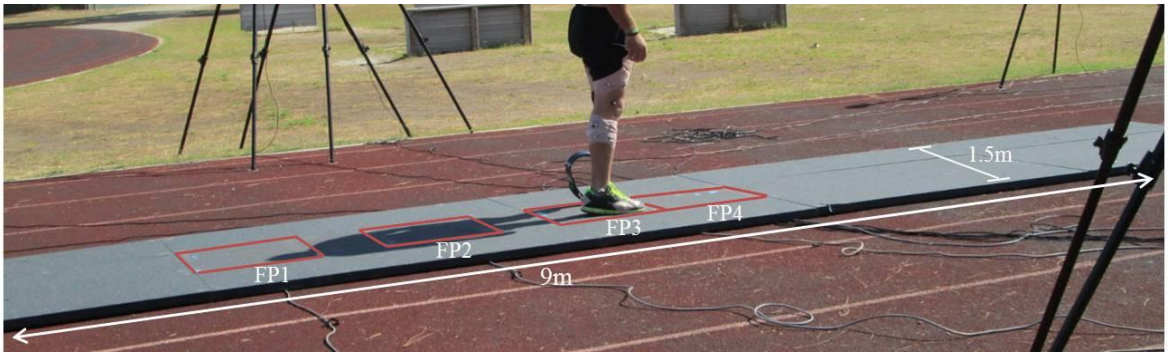


Figure 3. Force plate (FP) and walkway layout.

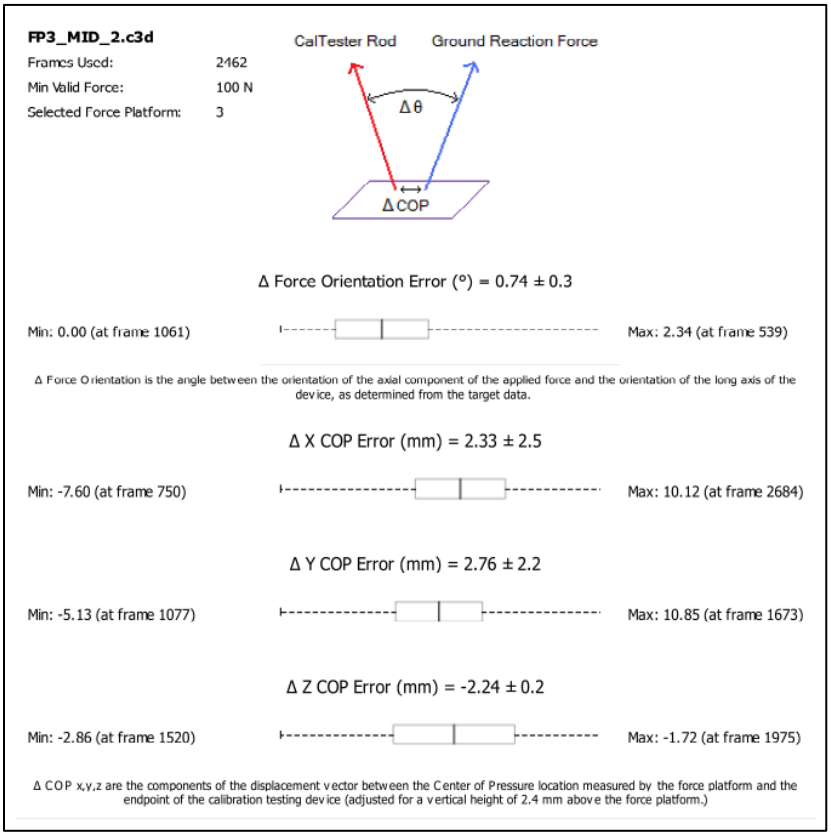
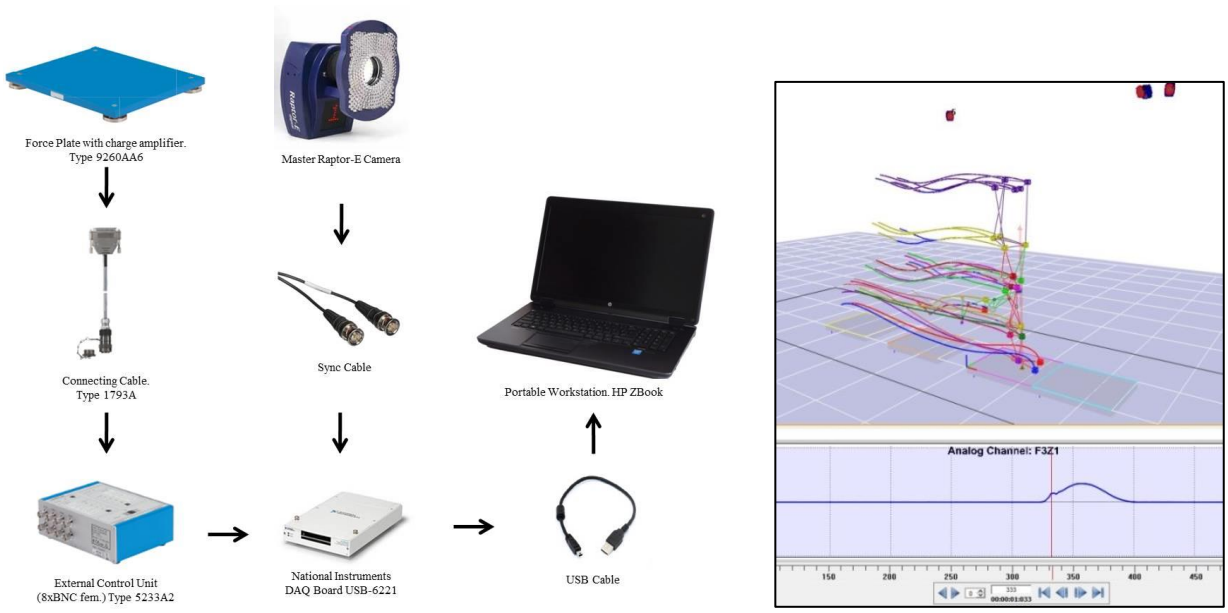


Figure 4. CalTester Report from a single force plate (FP3), executed at the beginning of a day of data collection.

<u>Analog and Digital Signal Flow:</u> To sync the analog output signal coming from the force plates with the digital signal from the cameras, various pieces of hardware are required. First, each force plate is connected to its specific External Control Unit (Kistler, Type5233A2) by a connecting cable (Kistler, Type 1793A). Changes to the sensitivity range can be directly adjusted

on the individual External Control Units to match the need of the task being collected. This is also where the researcher can make sure each plate is at baseline or “zero” prior to a trial. Per Kistler® recommendations based on how the force plates are designed, each plate is “zeroed” before every running trial to ensure quality force plate measurements are being collected across all trials. From here, another connecting cable brings the analog signal to a data acquisition (DAQ) board (National Instruments, USB-6221). The digital camera signal from the master camera is also carried to this DAQ board via the sync cable provided with the Raptor-E optical cameras. Finally, the DAQ board and laptop are connected through a USB cord (Figure 5). The laptop records all the kinematic and kinetic data synchronously using Cortex software (Figure 6).



Figures 5 & 6. On the left: Analog and digital signal flow diagram. On the right: A screenshot of Cortex software displaying both kinetic and kinematic data that is collected during each session.

RESULTS AND DISCUSSION

This short communication outlines equipment and operating procedures that provide accurate and reliable outdoor, overground running data and are believed to be adaptable for various

activities and testing locations. Regardless of outdoor conditions including sun and wind, these set-up procedures have repeatedly provided calibration results that mirror those of the indoor laboratory while the specified sampling frequencies are believed to be sufficient to capture running and can be adjusted for other activities. Being outdoors ensures the subject has enough room to reach their desired speed before entering the capture volume and enough space to safely slow down upon exiting. This flexibility results in as much steady state running as possible through the capture volume without periods of increased or decreased velocity due to space restrictions. Because the resulting capture volume allows the collection of at least one full stride on the right and left legs during each running trial, a complete picture of the subject's running mechanics is captured. Immediately following each trial, the subject can receive feedback on their velocity and adjust accordingly depending on the desired outcome. The ability to control speed in an overground environment allows the possibility for a more accurate biomechanical comparison between subjects and between subject visits as some kinetic and kinematic variables are speed dependent.

REFERENCE

1. Holden J. P., Selbie W. S., Stanhope S. J., 2003. A proposed test to support the clinical movement analysis laboratory. Gait and Posture 17, 205-213.

ACKNOWLEDGEMENTS

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