Validation of an Outdoor-based Passive Optoelectric Motion Capture System

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The purpose of this study was to validate the quality of data captured outdoors in full sunlight using a passive optoelectric camera system. A golf swing analysis was performed outdoors and indoors using the same system; the outdoor collection was performed in full sunlight. Golf club rotation (deg) and angular velocity ($deg \cdot s^{-1}$) data were calculated about the X, Y, and Z axes of the golf club for a single male subject. Outdoor and indoor angle and angular velocity data were similar about each of the three primary axes of the club, with r values≥ 0.970. The highest correlation values were found to exist among the angle data. This study demonstrated that data quality captured with an outdoor system is comparable in quality to data captured indoors.

Introduction: Many motion capture systems measure gross human movement, including photogrammetric (Bergemann, 1974; Marzan and Karara, 1975; Miller and Petak, 1973; Shapiro, 1978), optoelectric (Greaves, 1983; Scheirman, 1992), magnetic field (Luo, Niebur, and An, 1996), accelerometric (Frisch, 1989; Breniere and Dietrich, 1992; Lafortune, Henning and Valiant, 1995) or goniometric (Chao, Laughman, Schneider and Stauffer, 1983; Strathy, Chao and Laughman, 1983). Each of these various methods has unique benefits and deficiencies. However, within the last decade, optoelectric methods have become the preferred tool to measure human movement. Exceptional measurement accuracy and a wide range of acceptable image capture equipment are largely responsible for this preference. Currently, optoelectric technologies image the movement with specialized high resolution chips, and then use processors within the camera to identify retro-reflective markers and compute their positions in the image. These markers can be discs, hemispheres or spheres that are covered with retro-reflective coatings. Infrared LEDs ringing the cameras cause these markers to contrast with the background, thus permitting the system to detect their positions in real-time. Typical applications encircle four or more cameras around the space where the action is to take place. From one to hundreds of retro-reflective markers are attached onto the subject at the locations of interest for tracking. Two-dimensional coordinates are passed to the computer, usually via gigabit Ethernet, where software on the computer determines in real-time the three-dimensional coordinates of the markers from data seen by two or more cameras. This method has been well accepted in the biomechanics field because it does not require expensive, calibrated equipment, allows flexibility of camera locations and has proven to be adequately accurate.

Once cameras are calibrated, the system is ready to capture data from markers placed on the subject. Sophisticated template matching routines are then used to create frame-to-frame marker paths over time and resolve any possible occlusions. Identifying templates are defined allowing subjects to be identified in real-time. The real-time identification allows kinematic and kinetic data to be calculated, typically with less than 10ms of latency, giving coaches and trainers instant feedback on performance. These calculations can also be used with sophisticated biofeedback algorithms that give coaches the ability for behavioral modification training.

As robust and as widely used as optoelectric systems are, they all have had one critical limitation: systems that track strictly passive retro-reflective markers, and most that track active LED markers, could not be used outdoors in full or partial sunlight. The light from the camera ringlights has been insufficient for passive optoelectric systems to differentiate the marker from the ambient background illumination. In addition, cameras have not had the ability to process the large amount of data resulting from the sunlight and typically get backed up with data before being sent to the analysis computer. It is for these reasons that passive optoelectric systems have been relegated to indoor use only or to outdoors at night. If outdoor capture in full sunlight was desired, video-based systems (e.g., Innovision Systems, Dartfish) were required. Unfortunately, these video-based systems can have accuracies around 1mm (Richards, 1999), and accuracy tends to diminish rapidly if the system requires manual digitization of the markers. Needless to say, passive optoelectric capture in full sunlight has been a much desired and, in some cases, a needed feature of 3D sports motion capture, particularly when sub-millimeter accuracy is required.

The purpose of this study is to validate the quality of data captured outdoors in full sunlight using a passive optoelectric camera system. To accomplish this task, an analysis of golf club swing kinematics was performed using data collected both indoors (out of the sun) and outdoors in full sunlight.

Methods: Kinematic data were recorded using eight high-speed optoelectric cameras (Raptor-E, Motion Analysis Corporation, Santa Rosa, CA, U.S.A.; 200Hz) and collected using Cortex 2 software (Motion Analysis Corporation). Previous research has shown sampling golf swing data at 180Hz is sufficient for data capture (Mitchell et al., 2003; Nesbit, 2005), but to allow synchronization with other video devices, 200Hz was chosen. Cameras were positioned around the volume to ensure that each marker was visible to at least two cameras at all times throughout the data collection volume. Data were further reduced in post processing using Cortex 2. Golf swing marker data were smoothed with a zero-phase, fourth-order Butterworth filter with a cutoff frequency of 12Hz (Mitchell et al., 2003). The golf swing cycle was defined using events created in Cortex 2. All data were collected from a single male subject (A: 33 y/o; H: 1.73m; M: 81.6kg).

A marker set consisting of 37 strategically placed markers were applied to the subject and golf club. Markers were placed at appropriate locations to define joint centers and track segmental motion. Markers were adhered to the subject using Velcro patches placed over the clothing and directly to the club using adhesive tape. Kinematic data from the markers placed on the subject were used only as a reference and will not be reported in this study.

Four markers were placed on the golf club at the following locations: 50% and 75% of the distance from the top of the handle to the end of the shaft, heel, and toe. The club was modeled as a rigid object to simply data analysis, using an XYZ convention similar to that described by Nesbit (2005). The club X-axis is defined as the axis about which the swinging action is performed with positive pointing forward; the Y-axis represents the pitch of the club with positive to the club's right; the Z-axis represents the rotation about the long axis of the club with positive pointing down the shaft towards the club head. The global coordinate system was defined as X pointing to the subject's rear, Y pointing vertically, and Z pointing towards the direction of the target.

A foam golf ball was placed on a synthetic grass mat and the subject was asked to swing a golf club of his choosing (8-iron). The subject was allowed as many practice swings as necessary and data were collected until three successful trials were completed. A hitting net was placed 2.4m in front of the subject and a successful trial was defined as the subject successfully hitting the ball into a 0.6m x 0.5m square on the net. The square location and size was created based on the resulting ball locations from the practice swing hits.

Golf club rotation (deg) and angular velocity ($\text{deg}\cdot\text{s}^{-1}$) data were calculated in the KinTools RT software (Motion Analysis Corporation) using the XYZ rotation convention (Nesbit, 2005). The swing phase was defined as the top of the backswing (minimum club head speed) to ball impact (maximum velocity along the global Z axis). Club follow-through was ignored for the purposes of this study. Club angle and angular velocity data were exported as ASCII files from KinTools RT and additional processing was performed in MATLAB (MathWorks, Inc., Natick, MA, U.S.A.).

Kinematic data were time normalized and averaged. Data similarity was compared across the indoor and outdoor golf swing angle and angular velocity data using the Pearson coefficient (r).

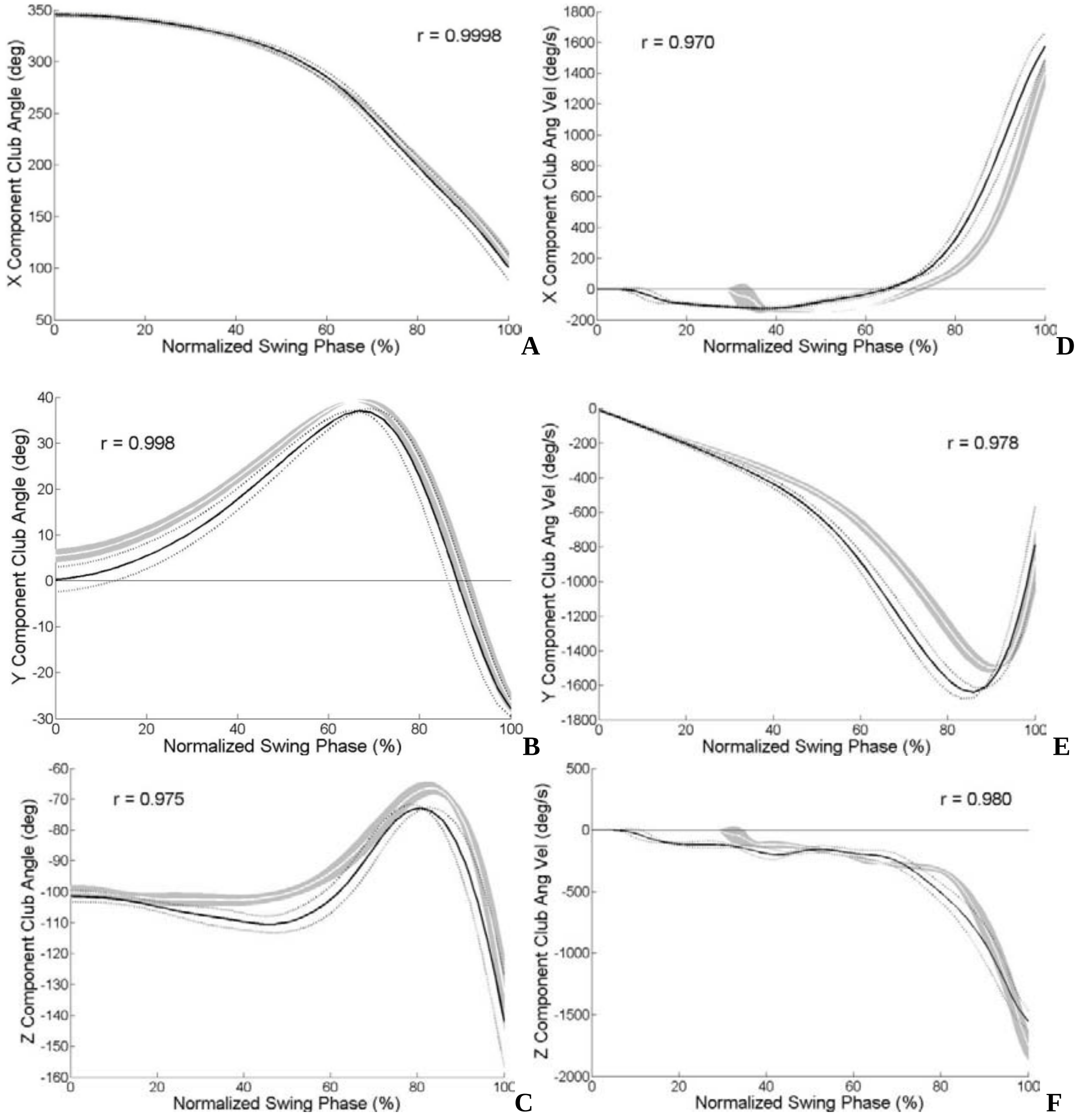

Figure 1. Golf Club Angle (A-C) and Angular Velocity (D-F) over the Normalized Swing Phase (%). The Swing Phase is defined as the maximum take-away position to ball impact. Mean Indoor Golf Club data (white line) ± 1 standard deviation (grey area) shown alongside Mean Outdoor Golf Club data (solid black line) ± 1 standard deviation (dotted black lines). Pearson correlation-coefficients (r) are shown. The X component (A,D) represents the swinging action of the club; the Y component (B,E) represents the pitch motion of the club; the Z component (C,F) represents the rotation about the long axis of the club.

Results: The golf club angle and angular velocity data overall were similar for the motions about each of the three axes. The indoor and outdoor data all had r values ≥ 0.970 (Figure 1).

Discussion: Overall, the outdoor club angle and angular velocity data showed a high correlation with the indoor data ($r \geq 0.970$). The lowest correlation values, in general, were found to exist between the indoor and outdoor angular velocity data. This is not surprising since environmental factors such as heat and glare, which were not present with indoor captures, were mentioned to be possible issues by the subject, potentially affecting the rate of club swing. The X and Z components of the club angular velocity agree with previously published data, but the Y component only appears to follow the general trend (Nesbit, 2005).

Data captured outdoors are subject to environmental factors which can affect system accuracy. In addition, various cognitive factors (e.g., feel, comfort) can affect how a subject behaves in various environments, thereby altering how a subject would perform an activity.

This study shows that not only is it possible for passive-based optoelectric motion capture systems to collect data outdoors in full sunlight, it is possible for those data to have comparable quality to data collected indoors.

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