GOLF SWING MOTION ANALYSIS: CHALLENGES AND SOLUTIONS

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With advanced motion capture technologies available, the scope and depth of motion analysis now is mainly limited by the capability of the analysis software. Golf swing analysis requires advanced motion analysis methods such as detection of the true impact instant, computation of the impact conditions, definition and use of local reference frames (body and club) in various ways, and determination and use of the functional swing plane. The purpose of this paper was to identify and present solutions for the unique challenges encountered in golf swing motion analysis and to demonstrate the application of such solutions by using Kwon3D, a comprehensive motion analysis program.

KEY WORDS: Motion analysis software, motion capture, golf swing analysis.

INTRODUCTION:

The ultimate capability of a motion analysis system is determined by two major factors: motion capture capability and scope and depth of analysis allowed by the analysis software. The motion capture capability of a system depends largely on the hardware used (cameras, image processor, and controller) and the control software. With recent advancements in the real-time motion capture technologies and availability of the real-time systems, the capability of the data analysis software has become the main limiting factor.

Computation of select meaningful kinematic and kinetic parameters based on the raw position data, the outcome of motion capture, is the primary role of the analysis program. The kinds of biomechanical analyses allowed and the types of kinematic and kinetic variables provided are limited by the capability of the analysis software. For this reason, it is not rare for investigators to develop additional study-specific software programs to overcome the limitations of the general-purpose motion analysis program attached to the motion capture system. The downside of this route, however, is that each study will require a study-specific program which may not be applicable to other types of studies. When a change is made in the analysis, the program codes must be changed accordingly.

The ultimate solution to this problem is to develop a flexible, adaptive and comprehensive motion analysis program in which the scope and depth of analysis can be expanded and the need for additional study-specific programming is practically eliminated. Kwon3D (Visol, Inc., Seoul, Korea) is an example of such a program, characterized by high flexibility, adaptability, and expandability. The notion of a comprehensive analysis program is particularly attractive as the raw data now can be transferred easily from one platform to another via the file formats commonly supported by different motion captures systems, e.g. the C3D format.

A golf swing is a complex movement that presents unique challenges to the investigators, requiring advanced motion analysis methods. For instance, the outcome of a golf shot is determined by the impact conditions (the clubhead velocity and clubface orientation at impact and the impact location on the face) but computation of the impact conditions is not simple because the clubhead-ball impact does not allow placement of markers on the clubface in the dynamic trials and the sampling frequency typically used in a golf swing motion capture is not high enough to provide a sufficient time resolution. A swing analysis-specific marker set is required to locate the hand and joint centers. Definition of the local reference frames fixed to the body segments and club (head and shaft) is essential in the angular kinematics. The functional swing plane characterizes the downswing motion of a golfer but computation of its orientation and position requires a special computation algorithm. The purpose of this paper was to identify the unique challenges encountered in golf swing motion analysis, an advanced application of motion analysis, and to present solutions for these challenges.

MARKER SET AND SECONDARY POINTS:

A golf-specific marker set was developed with a total of 55 primary points (tracked markers) including five club markers. In addition, a total of 24 secondary points were defined and computed based on the primary points and the static trials (ball trial, club trial, and setup trial) (Table 1). Appropriate secondary point computation methods (general and joint-specific; wand, mid-point, static point, rigid body, weighted mean, etc.) were selected and configured during the body model setup process. For example, the 'rigid body method' (Schmidt, Disselhorst-Klug, Silny, & Rau, 1999) was used for the arm joints, while the 'Tylkowski-Andriacchi hybrid method' (Bell, Pedersen, & Brand, 1990) was used for the hip joint in the golf-specific body model.

Table 1. Golf Swing Analysis-Specific Marker Set

Group	Markers	Notes
Pelvis (3)	Right & left ASIS and sacrum	ASIS: anterior-superior iliac spine
Leg (8 each)	Greater trochanter (GT), lateral thigh, lateral & medial epicondyles, lateral & medial malleoli, heel, and toe	The GT marker is used in locating the hip joint. The medial markers are used in locating the knee and ankle joints. These markers are removed in the swing trials.
Trunk (4)	Right & left acromial processes, C7, and T12	
Arm (12 each)	Two shoulder markers, three upperarm markers, lateral & medial epicondyles, lateral & medial styloid processes, and three hand markers	The shoulder markers are used in locating the shoulder joints. The medial markers are used in locating the elbow and wrist joints. These are removed in the swing trials.
Head (3)	Three head markers	
Club (5)	Two proximal shaft, two distal shaft, and one clubtoe markers	
Secondary (24)	Ball, eight club markers (four clubface markers, clubhead center, right & left hand centers, and grip end), twelve joints (hips, knees, ankles, shoulders, elbows, and wrists), L4/L5, mid-hand, and hub	The ball and clubface markers and joints require the static trials (ball trial, club trial, and setup trial).

Data collection was conducted in the following steps:
1. A static trial with the ball only was first captured (ball trial). The ball was covered with reflective tape and placed on the tee or at a pre-determined location on the mat.
2. A static trial with the club only was then captured (club trial). The club markers include four shaft markers, four face markers, and one clubtoe marker (Table 1).
3. A static trial with the golfer in the setup position was captured (setup trial). The clubface markers were removed in this trial.
4. Dynamic (swing) trials were captured. Several body markers including the medial markers (Table 1) were removed in these trials as they could interfere with the swing motion.
During data processing, the static trials were registered and the secondary marker locations were computed automatically based on the static trials and the primary markers, including the ball, clubface points, and joint centers.

EVENTS AND IMPACT CONDITIONS:

A total of nine events were defined for the golf swing analysis: Start (ST), Address (BA), Top of Backswing (BT), Upright Club Position during Downswing (DV), Horizontal Club Position during Downswing (DH), Ball Impact (BI), Mid Follow-Through (MF), Start of Impact Zone

(IZ1), and End of Impact Zone (IZ2). The event frames were identified by the automatic event detection function based on a set of standard and user-defined variables.
To compute the impact conditions, the precise locations of the ball and clubhead, and orientation of the clubface at impact must be known and a pre-requisite for this is an accurate determination of the impact instant. When the sampling rate is not sufficiently high, interpolation of the position data is necessary to improve the time resolution. Auto detection of the BI, IZ1, and IZ2 events involved the following steps:
1. The position data were re-sampled (interpolated) at 2,000 Hz. All standard and user-defined kinematic and kinetic variables were re-computed accordingly.
2. The first frame in which the clubface was in contact with the ball was selected as the BI event. Fifteen centimeters before and after the impact position were set to IZ1 and IZ2, respectively. IZ1 and IZ2 define the 'impact zone' for the assessment of the error margins.

IMPACT CONDITIONS AND ERROR MARGINS:

The impact conditions include the clubhead velocity, clubface orientation, and impact location on the clubface at the true impact instant, not BI. The following steps were taken in the computation of the impact conditions:
1. The clubface reference frame was defined based on the clubface markers (Williams & Sih, 2002): X - away from the body; Y - normal to the clubface; Z - upward. The origin of the clubface reference frame was set at the clubhead center, the mean of the four clubface markers (Figure 1).
2. The first frame the Y-coordinate of the ball described in the clubface reference frame became smaller than +2.134 cm (radius of the ball) after the DH event was automatically selected as the BI event. As a result, the true impact instant (when the Y-coordinate of the ball described in the clubface frame becomes equal to the radius of the ball) occurs sometime between the BI frame and one frame before. The true impact instant was determined by the sub-frame data reading function.

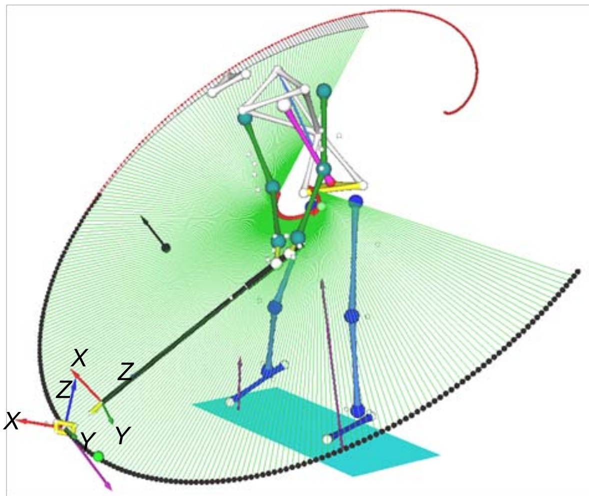

Figure 1. The downswing motion of a golfer. The clubhead velocity vector (pink arrow), clubface frame axes (red, green, and blue arrows), the functional swing plane (black trajectory), rotation centers (red balls), and rotation arms (green lines) are shown.

3. The velocity of the clubhead center was used as the clubhead velocity (Figure 1). The angles formed by the Y-axis unit vector of the clubface frame with respect to the global horizontal and vertical planes toward the hole-cup were used as the clubface orientation parameters. The impact location on the clubface (X- and Z-coordinates) was determined by the ball position described in the clubface reference frame at the true impact instant.
4. The ranges of the clubhead velocity, clubface orientation, and ball position described in the clubface frame within the impact zone (IZ1 to IZ2) were used as the error margins.

FUNCTIONAL SWING PLANE:

The functional swing plane (FSP) characterizes a golfer's downswing motion (Shin, Casebolt, Lambert, Kim, & Kwon, 2008). The FSP is the plane formed by the clubhead trajectory within the delivery zone (DH to MF) (Figure 1). The FSP parameters (planarity, slope, and direction angle) were computed using the 'Plane Analysis' function. A special plane fitting algorithm based on the Newton-Raphson method is used in this function. The locations of the instantaneous rotation centers and radii of the rotation arms were computed (Figure 1).

For the computation of the orientation of the clubshaft to the FSP, the shaft reference frame was defined by the shaft points and the X-axis of the clubface frame: Z - along the shaft toward the grip; Y - perpendicular to the Z-axis of the shaft and the X-axis of the clubface; X - perpendicular to the YZ-plane of the shaft (Figure 1). The angle formed by the X-axis of the shaft with respect to the swing plane was used as the shaft orientation angle.
The mid-hand point and the left shoulder joint (Table 1) were used in finding the motion planes of the hands and left shoulder, respectively. The 'Plane Analysis' function was used for the body motion planes as well. The orientation of the body planes were described with respect to the FSP by defining a series of user-defined variables.

SEGMENT ORIENTATIONS AND JOINT MOTIONS:

Various body orientations and joint motions should be computed in the golf swing analysis based on the local reference frames fixed to the body segments. In a segment at least three fixed points are required to define a reference frame. The golf-specific marker set presented in Table 1 provides a complete array of local reference frames of the golfer's body segments and club.
Reference frames were defined easily along with the relative orientation relationships and rotation sequences (e.g. mediolateral-anteroposterior-longitudinal sequence). In some cases, a segment (e.g. hand-club) was defined multiple times to assign different relative orientation relationships. The forearm segment was divided into ulna and radius and the pronation/supination of the forearm was computed separately from the wrist joint motion. The clubshaft and clubhead segments were also included in the model.
One way to expand the scope of analysis is to define and use various imaginary segments in addition to the real body segments. For instance, the FSP segment was included in the body model as an imaginary segment to utilize the FSP reference frame in the analysis. The shoulder girdle segment (and reference frame) was also defined to analyze the rotational motion of the shoulder about the hub.

SUMMARY:

To meet the unique challenges encountered in various analysis settings, it is important to develop/use a comprehensive motion analysis program characterized by strong mechanical foundation, flexibility, adaptability, and expandability. The program structure must allow the users to easily create/modify body models and the body models should define the mechanical characteristics of the body in detail. A vast array of processing capabilities and functions should be available and configurable by the user to streamline the analysis while eliminating the need for additional user programming. Golf swing analysis is an advanced application of motion analysis in which advanced analysis methods are required to resolve unique challenges encountered. It was demonstrated how the unique challenges could be resolved in golf swing analysis by using a comprehensive motion analysis program, such as Kwon3D.

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