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Development of a method for monitoring clubhead path and orientation through impact

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Abstract

This study reports the development of a golf clubhead trajectory monitoring system which utilises PONTOS, a 3D motion analysis package from GOM. This paper demonstrates how this system can be used to monitor clubhead path and orientation and position throughout impact with future scope to simultaneously measure ball launch conditions. Six subjects performed 10 swings with a driver and a selection of these shots were analysed in detail. Face angle and dynamic loft were calculated as indicators of clubhead orientation and the effect of off-centre impacts on head rotation were quantified. When considering clubhead velocity, the flexibility of the system allowed velocities at different locations to be monitored. It was found that the velocity of the toe and heel differed by up to 5.7ms^{-1} at the moment of impact.

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1. Introduction

In golf, clubhead path and orientation prior to and throughout impact can vary due to player characteristics and equipment parameters. Monitoring this variance is important as it has a significant influence on ball launch conditions and, therefore, the overall performance of a shot; a change of 2° in the angle of the clubface can result in a shot either hooked or sliced into the rough at a distance of 200yds from the tee [1]. A system which provides this information can act as a training tool and assist with testing equipment performance. This paper describes a methodology developed to track and monitor the change in clubhead path and orientation throughout impact using a passive marker motion tracking system and high speed video cameras.

Information such as dynamic loft provides invaluable input to the design and manufacture of the next generation golf clubs, an example of this is the increase of driver loft in more recent years [2]. Previously it was thought that a longer distance shot could be achieved with a greater loft, a conclusion reached when the required ball data was not

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available. Since the introduction of launch monitors, it has been observed that a higher loft increases backspin causing the Magnus effect, which results in greater lift and drag forces and therefore shorter overall carry [1,3]. When designing a clubhead, the location and distribution of its mass is very important. A clubhead with a low moment of inertia will have limited resistance to rotation around its centre of mass during an off-centre impact and thus increase the 'gear effect'. This in turn results in high side spin and a reduced carry of the ball. Another use for a system such as this would be to assist in understanding the role of the shaft in a swing. According to Butler and Winfield [4], ideally the shaft should be straight at impact so that kinetic energy is maximized and potential energy minimised [4]. This can be tricky to time, as a clubhead will typically lead and droop at impact as the centre of mass of the clubhead attempts to align itself with the shaft. The method developed allows many parameters of the clubhead to be monitored, providing information about where the clubhead is in relation to shaft deflection. The knowledge of the shaft deflection gives an indication to the twist of the club head as found in an experiment by Butler and Winfield, for each 1 inch deflection of the shaft, the clubhead rotated 0.33° [4]. This ratio was measured in a static test whereas the system proposed in this paper would allow these variables to be measured during an actual swing.

Current commercially available clubhead trajectory monitors only provide limited results. Image based systems typically have limited frame rates providing a single measurement at impact but do not consider the change in variables during impact, such as the change in face angle during an off-centre shot. Callaway Golf have developed an image based Performance Analysis System [5] which takes a single image containing up to 20 exposures during and after impact resulting in a system with a similar frame rate to the one presented in this paper, however, it is unable to track areas of the clubhead that are not in view of the cameras and also is not commercially available. Systems exploiting radar technology can measure clubhead path but the orientation of the clubhead is based on calculations from an impact model rather than actual measurements and many assumptions are made.

It is apparent that a more comprehensive method of measuring clubhead trajectory is required that is more accurate than current systems and provides a sample rate high enough to enable a fast moving clubhead to be tracked through a very short duration impact (typically around 0.5ms). The method presented in this paper aims to address this need.

2. Methods

2.1. System selection

The Sports Technology Institute (STI) at Loughborough University has a number of 3D motion analysis systems, all of which were considered for this application. PONTOS, a passive marker based system developed by GOM, was selected as the most suitable for several reasons. PONTOS is a highly accurate (0.01 to 0.05mm [6]), passive marker system consisting of two cameras which can track a point in 3D space based on the triangulation method. The passivity and size of its markers allows large numbers of markers to be used without affecting clubhead properties.

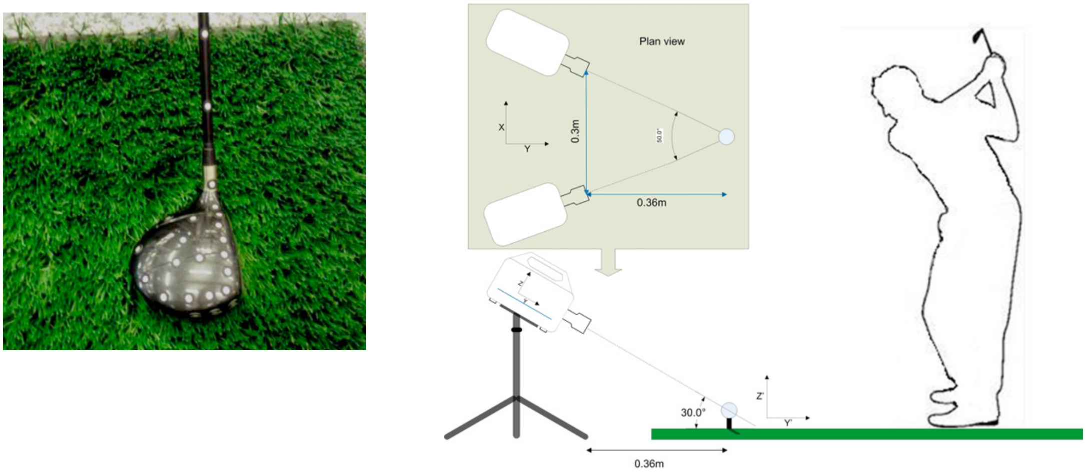


Figure 1- (a) Marker locations on the clubhead and shaft of a driver; (b) Schematic diagram

This is desirable as increased weight on the clubhead can affect variables such as swingweight [7] and mass distribution. Through the use of a sister program, TRITOP, a series of images of the clubhead taken from different viewpoints can be stitched together to form a 'point cloud' of the object to be tracked. This point cloud definition allows points to be tracked in PONTOS, even when not in view, through knowledge of the location of each point in relation to the others. Crucially, the feature which sets this system apart is the ability to replace the standard PONTOS cameras with high speed video (HSV) cameras. Although this results in a longer data processing time, high sampling rates are possible, which are vital for monitoring a clubhead moving in excess of 100mph [8] and enables markers to be tracked during impact.

2.2. TRITOP

Before the player testing took place, a TRITOP model was generated in order to exploit the features mentioned above. A number of passive reflective markers were positioned randomly onto the clubhead to define its geometry along with some markers at key locations, selected for points on the clubhead which required tracking such as on the clubface. Some marker locations can be seen in Figure 1a. The clubhead was clamped in an upright position and surrounded by calibration crosses and scale bars; these were required to enable the software to determine the scale of the object and the position of the markers. Still images were then captured of this set up from different viewpoints with a digital SLR camera. Enough images had to be taken so that each marker appeared in several images. This process was then repeated for the underside of the clubhead and the two sets of images (upper and lower) were then imported into the TRITOP program as two separate models. Markers identified in both models allowed them to be stitched together to form a single point cloud of the whole clubhead. Elements, such as virtual points and planes were then defined relative to the positions of the points in the cloud so that when imported into PONTOS, they could also be tracked. The most effective way of monitoring the orientation of the clubface at impact was to define a plane to represent it. In order to define a plane, three points are required so 3 markers were positioned centrally on the clubface for this purpose. Other main areas of interest, and therefore marker locations, were the toe, heel and centre of the clubface.

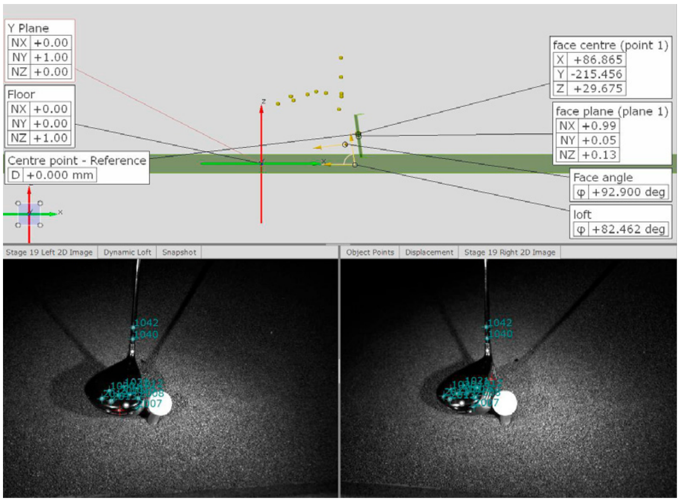
2.3. Test Protocol

A calibration was performed before testing using a calibration board provided with the GOM system. The selection of calibration device is based on the desired capture volume; for this study 0.7m^3 was deemed suitable. The calibration involved taking a series of images of the board in a number of orientations following a standard procedure. A satisfactory calibration quality value is given as being below 0.04 pixels [9], which was achieved.

Six male golfers aged from 23 to 40 years and with handicaps between 5 to 20 were asked to perform 10 full swings with the instrumented driver. Sufficient time was provided between each shot for warming up and practice shots. Shots were hit into a net in the STI laboratory from an artificial turf matt with a rubber tee. A manual trigger was used to initiate data collection just after the takeaway and data was captured for 1.9s; this was later cropped down to the frames in which the clubhead was present. Two Photron Fastcam Ultimate APX HSV cameras were used, set at a frame rate of 5,000 frames per second and a shutter speed of 1/30,000s. They were positioned so that the clubhead could be captured for approximately 30mm before and after impact. This was achieved by tilting the cameras 30° from horizontal and angled in towards the tee at a distance of 0.36m as illustrated in Figure 1b. The high shutter speed was required to prevent motion blur; a consequence of this was underexposed images and this was corrected for by using two ARRI pocket par 400 light.

3. Results

After testing, the HSV was saved as a series of individual images and each series was loaded into the PONTOS software and a new project created for each subject's swing. The software then computed each image, or stage as they are referred to by the software, recognizing the reflective markers as points. Once each stage had been found to contain a suitable number of points, an axis transformation was then completed. By default, PONTOS creates a coordinate axis relative to the camera position and angle (x, y, z). As this study involved the calculation of positions relative to the floor, it was desirable to complete a transformation of the axis (x', y', z'); this was done using an axis transformation tool and an inbuilt function of the software. At this stage in the analysis, the markers do not have an identity and no relationship exists between each other or each image. A relationship was created by importing the TRITOP model produced previously along with its adapters. This allowed many different aspects of the clubhead's orientation at impact to be monitored. Figure 2 shows a typical screen from the PONTOS analysis; the still images from the HSV camera captures accompany the digitized clubhead markers and adapters.


Y Plane
NX +0.00
NY +1.00
NZ +0.00

Floor
NX +0.00
NY +0.00
NZ +1.00

Centre point - Reference
D +0.000 mm

face centre (point 1)
X +86.865
Y -215.456
Z +29.675

face plane (plane 1)
NX +0.99
NY +0.05
NZ +0.13

Face angle
φ +92.900 deg

loft
φ +82.462 deg

Figure 2- PONTOS analysis, the angle of the face plane is calculated relative to the floor plane, a read out of the results are given image by image

3.1 Face angle

Face angle is a measure of the angle of the clubface relative to a plane perpendicular to the target line. An open face is one which exhibits a clockwise rotation from this position, a closed face describes an anticlockwise rotation when viewed from above. For the purpose of this paper, a negative angle represents a closed face and a positive angle, an open one. Calculations of this angle through impact involved defining a plane perpendicular to the target line (the X plane) in the PONTOS software and, at each stage, the angle between the X-plane and the clubface plane adapter was found.

Swings were selected for analysis based on impact location and where possible, so that results were consistent, were from one golfer. The graph in Figure 3 shows the face angle of the clubhead from 30ms before to 30ms after impact for four of Subject Five's swings. The duration of impact has been highlighted with the start of impact at the frame before impact and the duration set to a typical 0.5ms. The swings were selected based on their impact location from heel to toe to demonstrate how this affects face angle. A high-toe impact describes an impact that was high on the clubface but in the toe region, a mid-toe impact, is central regarding height but in the toe region. It can be seen that the face gradually closes before impact by up to 2.9deg/ms as the golfer rotates the clubhead about the shaft axis. During impact, the face angle typically changes and the magnitude of change is dependent on the distance of the impact location from the sweet spot (the centre of gravity projection onto the clubface). For central impacts, little change is seen in face angle progression but for toe impacts the closing of the clubface is halted.

3.1. Dynamic loft

Every club has a static loft and this is defined as the angle of the clubface relative to a vertical plane. During impact however, the shaft is bent, this leads to a change in the loft, referred to as dynamic loft. For this paper, dynamic loft is defined as the angle between the clubface and a plane perpendicular to the ground and target line.

This angle was calculated using the same methodology as the face angle however comparing the rotation of the club face around the Y-axis with the X-plane.

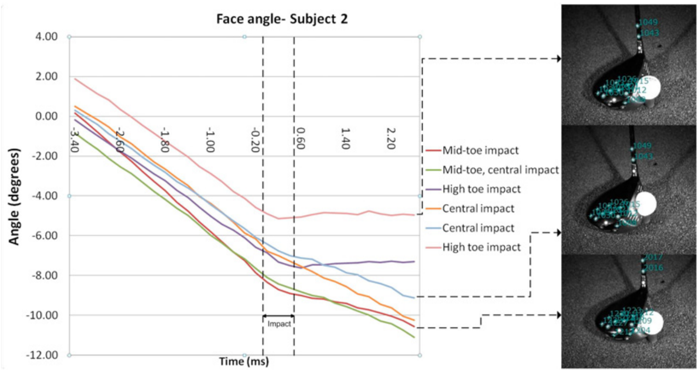


Figure 3- The effect of impact location on face angle (positive values denote an open face)

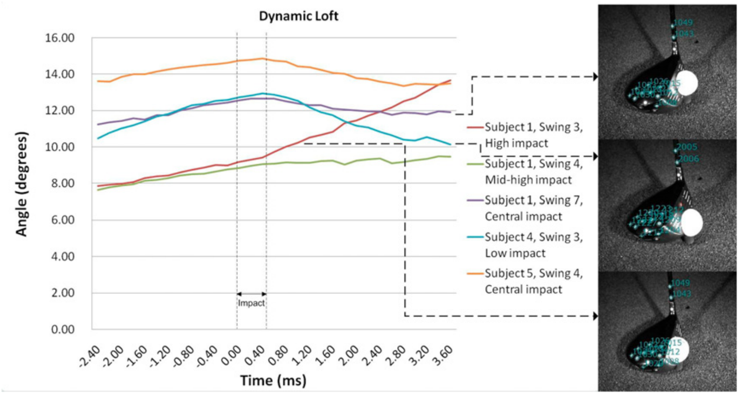


Figure 4- The effect of impact location on dynamic loft

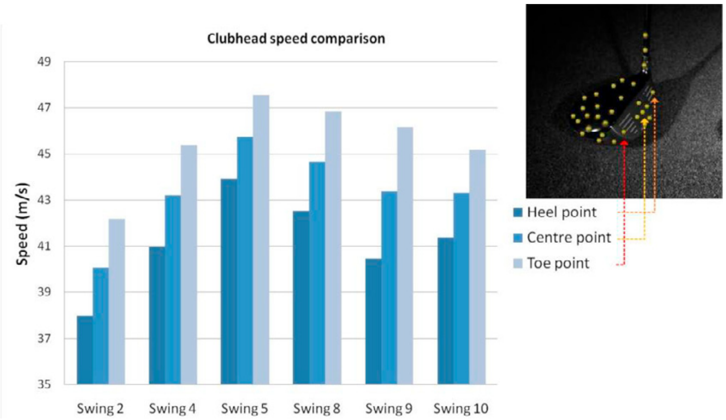


Figure 5- Comparison of velocities at three locations on the clubhead for six of subject two's swings

The two planes can be seen in Figure 2. Again the effect of impact location on the orientation of the clubhead was considered and the results are illustrated in Figure 4. This graph shows that, leading up to impact, the dynamic loft of the club gradually increases, and this is followed by a decrease of up to $1.8^{\circ}ms^{-1}$ for shots low on the clubface. A central impact can be seen to produce a more gradual decrease of dynamic loft with a peak value of 0.9deg/ms. A shot that has a particularly high impact location can be seen to increase by 2.4deg/ms.

3.2. Clubhead velocity

Velocity was measured at three locations on the clubface for every swing, the toe, centre of the face and the heel. The velocity of a clubhead is usually considered as a whole but with the evident rotation of the clubhead at impact, the speed at different locations was predicted to be different. Figure 5 shows a chart of clubhead velocity for six of Subject Two's swings. In each swing there is a clear difference in velocity from the toe to the heel with the largest difference being 5.7m/s.

4. Discussion

An interesting outcome from the data collected was an issue raised with the location of the centre of gravity with respect the centre of the clubhead. It was found that in shots with a seemingly central impact, there was still a degree of rotation imparted to the clubface; this would infer that the geometric centre of the clubface is not in line with the centre of mass and therefore the sweet spot of the club.

The plane created on the face of the clubhead was drawn through three central points on the face. A clubface, however, is curved and the assumption that the face is planar would have resulted in some inaccuracies in the measurement of the face orientation in the toe and heel regions. This could be overcome by positioning a greater number of markers onto the clubface and creating a number of planes to be used for analysing different impact locations. It should be realised that even with this small error, this method produces a far more realistic measurement of clubhead orientation than other commercially available systems.

5. Conclusions

This report has demonstrated an effective new method for monitoring clubhead orientation. Face angle, dynamic loft and clubhead velocity were all calculated at a rate of 5KHz enabling measurements to be recorded during impact. Many other parameters could easily be calculated and higher frame rates could be used if necessary. The method could be further developed to include ball launch data through instrumentation of a ball. By tracking a ball's launch characteristics, relationships could be identified between the parameters measured from the clubhead and the ball flight. An example of this would be a study on the phenomena of vertical and horizontal gear effect; the measured change in clubhead orientation should be related to the amount of spin imparted onto the ball.

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