FORCE AND MOMENT EXERTED BY EACH HAND ON AN INSTRUMENTED GOLF CLUB

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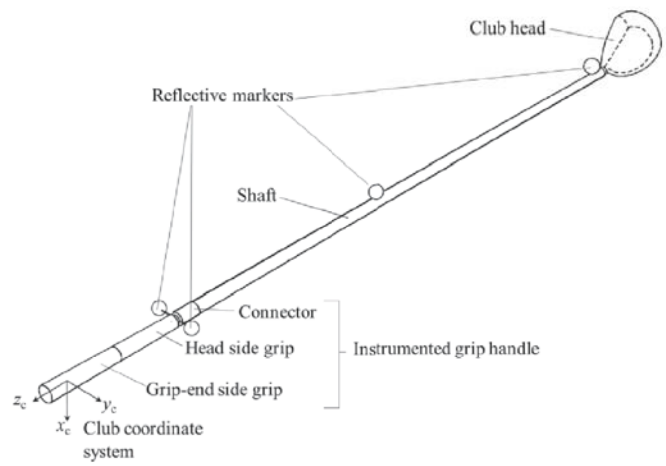
This article shows an issue of the analysis on golf swing motion, and then introduces an instrumented golf club as a solution for the issue. During the golf swing motion, the upper limbs and a club make a closed multi-segment loop, where it is impossible to calculate the forces and moments exerted by each hand via inverse dynamics due to the kinetic redundancy of the closed loop system. An instrumented grip handle equipped with twelve sets of strain gauges was designed to measure the forces and moments exerted by each hand. The results of kinetic analysis for a professional golf instructor indicates that 1) the force exerted along the club shaft by the grip-end side hand shows significant large values toward the ball impact, and 2) the forces exerted by both hands in the axes that are perpendicular to the club shaft show coupled force patterns.

KEY WORDS: golf swing, closed loop problem, kinetics of the upper limbs, grip handle

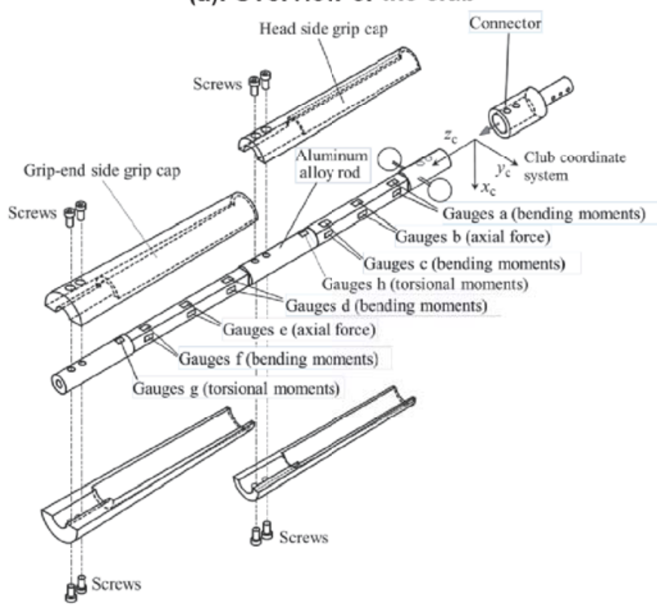
INTRODUCTION: Golfers swing a golf club to launch a golf ball into their target points. During the golf swing motion, the upper limbs and a club make a closed multi-segment loop. Since the degrees of freedom (DOFs) of club's movement is six (3 in translation and 3 in rotation) and the DOFs of both hands' kinetics is totally twelve (3 in force and 3 in moment per each hand), six DOFs of kinetic redundancy exist. In such case, there exist infinite sets of force and moment that realize the same movement of the club. Therefore, it is essentially impossible to calculate the forces and moments exerted on the grip handle of the club by each hand via inverse dynamics with only visual information; such as about movements of the club and the upper limb segments. This issue is called "closed loop problem" (Vaughan et al., 1982a, 1982b). The only way to obtain such kinetic information is to measure them directly (Koike et al., 2006). This article introduces an instrumented golf club as a solution for the closed loop problem in the analysis of golf swing motion, and shows an example of analysis result using the instrumented club.

METHODS:
Figure 1(a) shows an overview of an instrumented golf club consisting of an instrumented grip handle, shaft and club head. Figure 1(b) shows the structure of the instrumented grip handle which contains an aluminum alloy bar and two sets of covers. Twelve sets of strain gauges were attached on the bar to measure the torsional moments exerted at sensors g and h, the bending moments exerted at sensors a, c, d and f, and the longitudinal forces exerted at sensors b and e. The individual sets of strain gauges were calibrated under static load conditions. Although the forces and moments exerted by each hand on the club are distributed over the handle area, these loads were represented by vectors under the assumption that they act at the fixed points of the hands in swing motion. The force and moment acted on the fixed point of each palm are calculated from static equilibrium equations with respect to forces and moments obtained by using the strain gauges (Koike et al., 2006). The inertial forces of the handle pieces were neglected. As the location of the strain gauges are concentrated into the grip handle part, it is possible to connect the grip handle with several types of clubs.
A right-handed professional golf instructor, who volunteered to participate in this study, performed swings with a driver. Kinematic data were obtained with a motion capture system (VICON-MX; 250 Hz). Kinetic data of the individual hands were measured with the instrumented club (28 strain gauges; 1000 Hz). Kinetic data of the individual feet were measured with three force platforms (9281 [$\times$ 2], 9287, Kistler Inst.; 1000Hz). A forward swing phase was defined as a period from the top of swing to the ball impact.

RESULTS AND DISCUSSION: Figure 2 shows an example of kinetics of each hand during the forward swing motion. Fig.2 (a), (b) and (c) show the forces in x_{sp} axis, the forces in y_{sp} axis, and the moments about z_{sp} axis, respectively. The blue solid and green dashed lines represent the components of forces exerted by the head side hand and grip-end-side hand, respectively. These values were expressed in the instantaneous plane coordinate system of the golf club (Vaughan, 1981). The time curve of the x_{sp}–axial forces of the hands showed approximately coupled force. The coupled force, which accelerates the angular motion of the club, increased gradually until -0.1 sec, and then decreased rapidly toward the impact. The longitudinal force of the grip-end side hand increased toward the impact and showed significantly large value compared to that of the head side hand. The moment of the grip-end side hand about z_{sp} axis showed positive values, which accelerates the forward angular motion of the club, until -0.05sec, and then showed negative values toward the impact. The moment of the head side hand showed positive values from about -0.1 sec to the impact.
These results indicate that the longitudinal force along the grip handle exerted by the grip-end side hand would be a great contributor to the generation of the club head speed because the force shows the largest value compared to other components of exerting forces of the individual hands.



(a). Overview of the club



(b). Structure of the grip handle
Figure 1: Instrumented golf club.

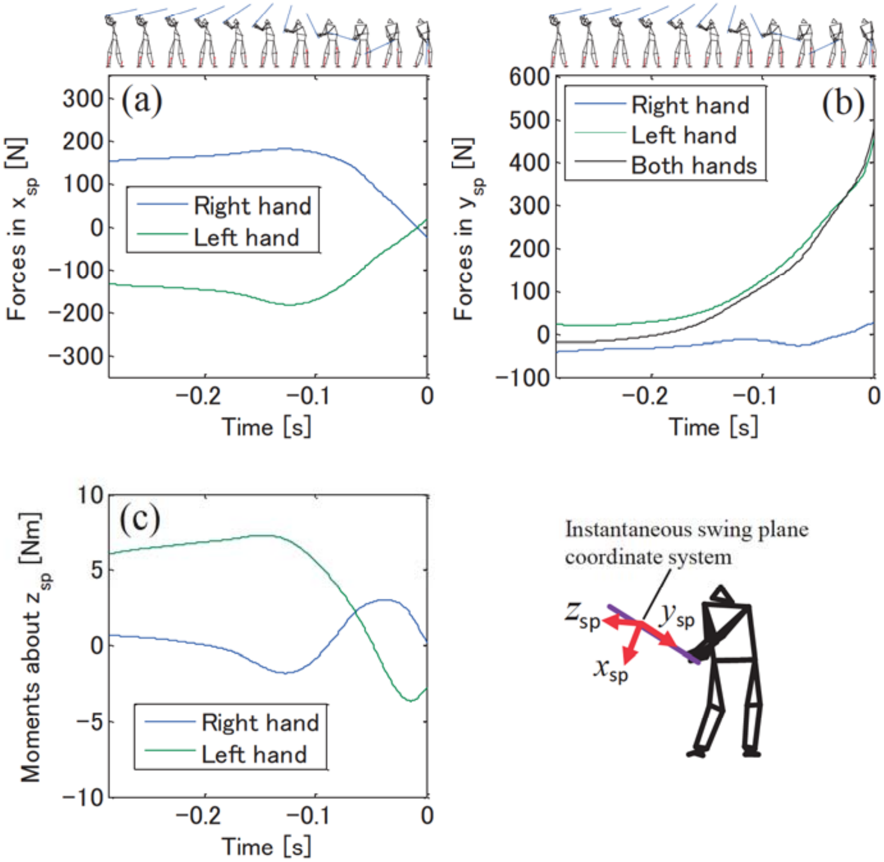


Figure 2: An example of the kinetics exerted by each hand of a right-handed golfer during the forward swing motion. The time curves of the forces and moments are expressed in the instantaneous swing plane coordinate system. Right hand and left hand denote head side hand and grip-end side hand, respectively. The axis, z_{sp}, is the normal vector of the instantaneous swing plane of the golf club, the y_{sp} is identical to the longitudinal axis of the shaft, and the x_{sp} is perpendicular to the z_{sp} and y_{sp} axes.

APPLICATION: The information about the kinetics of each hand enables us to analyse the kinetics of the upper limb joints in golf swing. This analysis tells us how large the upper limb joints exert torques and how large the joints show powers caused by the joint torques and forces. The information would be helpful for training and conditioning of golfers.

Since the golf swing is one of high-speed swing motions, the understanding of a head speed generating mechanism would also be useful information for golfers. In high-speed swing motion, motion dependent term, which consists of centrifugal force and Coriolis force, is a crucial factor to generate large speeds of distal end of human body and head of hitting tools (Putnam, 1993; Hirashima et al., 2008; Naito and Maruyama, 2008; Koike and Harada, 2014). With use of the equation of motion for the multi-body system, one can quantify the roles of joint torques in the generation of head speed of tools in consideration of generating factors of the motion-dependent term (Koike and Harada, 2014).

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