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A Biomechanical Golfer Model and its Application to Golf Club Design

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Abstract

Multibody dynamic simulation of the golf swing can be useful for studying the biomechanics of the golfer and improving club design. In this work, we develop a complete model of the golf drive, including the biomechanics of the golfer, dynamics of the golf club and impact with the ball, and aerodynamics of the resulting ball trajectories. The complete model is shown in Figure 1.

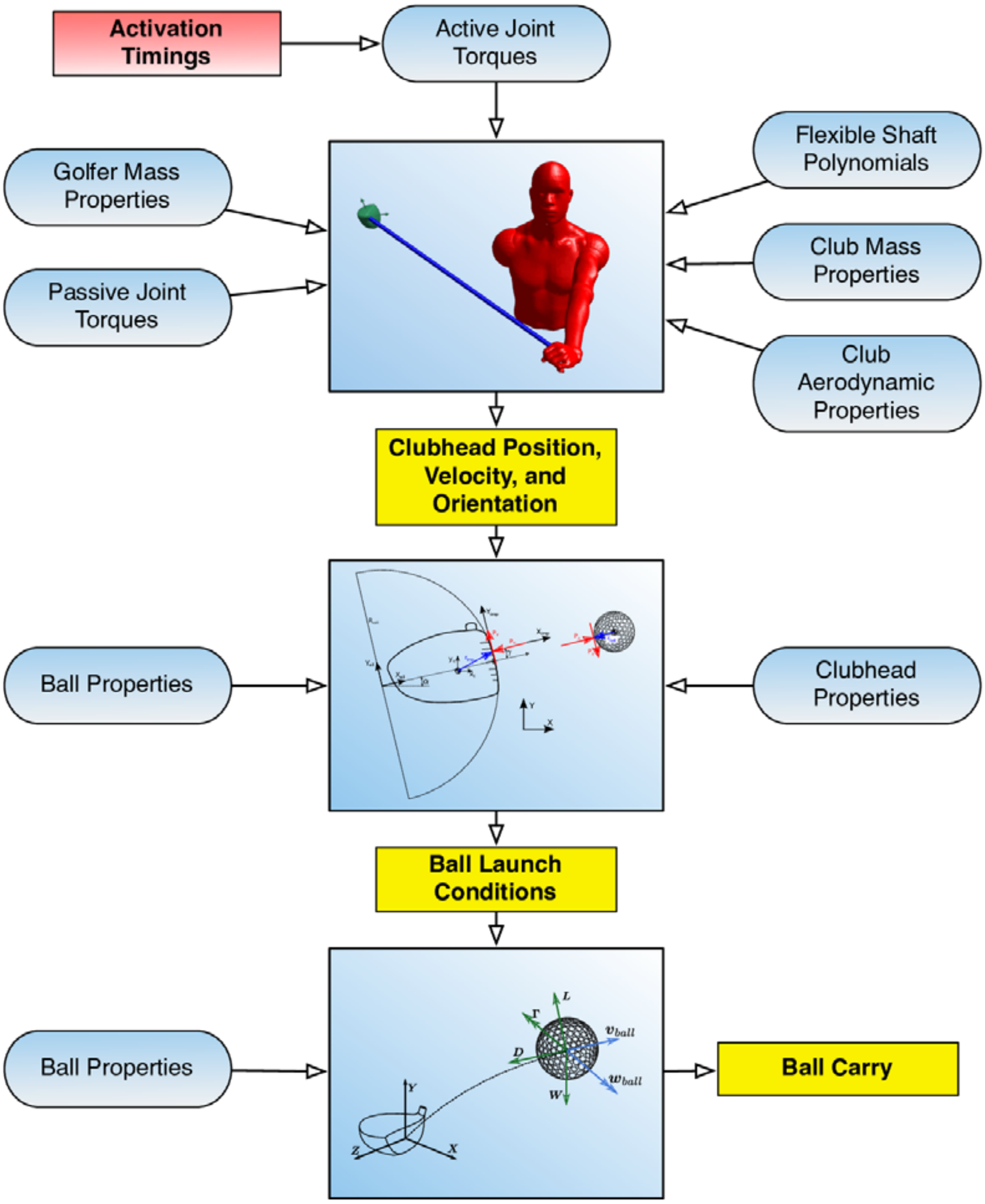

Figure 1: The complete multibody dynamic model including golfer biomechanics, flexible shaft, rigid clubhead, impulse-momentum model of impact, and aerodynamic ball trajectory.

Previous work in golf modelling has focused on examining individual aspects of the swing. Mackenzie and Sprigings [1] and Sharp [2] investigated the golfer and club using 3-body models. Mackenzie's model included a lumped-parameter flexible club while Sharp's model consisted entirely of rigid bodies. These models focused on the mechanics of the swing, seeking to optimize the clubhead speed at impact. Others have investigated the impact with the golf ball [3] and its subsequent aerodynamic flight [4]. In this work, we present a single integrated model of a golf drive, including 3D golfer biomechanics, golf club with flexible shaft, impact, and ball trajectories.

First, a multibody dynamic non-planar model of the golfer, essentially an extension to the work of Mackenzie and Sprigings [1], was developed in the MapleSim software. The golfer has 4 degrees of freedom corresponding to torso, shoulder, and wrist rotations, plus pronation/supination of the forearm. These joints are actuated by torques that capture the force-velocity characteristics of Hill-type muscle models.

The shaft was modelled using Rayleigh beam theory [4], which allows for continuous bending in the 2 transverse directions plus twist about the shaft. Shaft properties have been supplied by a well-known golf club manufacturer. The clubhead is a rigid body with specified moments of inertia and center of mass location. Impact is modelled using impulse-momentum theory, assuming the coefficient of restitution to be at the USGA/R&A limit of 0.83. The ball trajectory is determined by weight, lift, and drag forces, plus a spin damping moment.

A pattern search optimization algorithm is then used to find the joint torque timings that result in the longest carry of the golf ball. With this optimization of the unified multibody model of the golf drive, we are able to confirm the kinematic sequencing of joints, from proximal to distal, in optimal golf drives. Furthermore, we are able to run "what-if" simulations to investigate several important issues in current golf club design:

- What is the optimal clubhead mass? Cleveland Golf claims that "lighter is longer".
- What is the effect of the clubhead center of mass (CoM) position on golf club performance? Taylormade claims that the CoM should be closer to the clubface than current practice.
- What is the optimal distribution of shaft flexibility for a given golfer?
- What effect does the clubhead moments of inertia have on ball trajectories?

Many of these questions are hotly debated by current golf equipment designers, and we seek to answer these questions and others using a scientific multibody dynamics approach.

In the ECCOMAS presentation, the model will be described in detail along with validation of the various components making up the unified model. A number of simulations will be presented to demonstrate the effects of different club design parameters on the golf drive.

References

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