論 文 内 容 の 要 旨

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Few if any athletic disciplines have formed the basis for as many models and simulations as the golf swing. Some of the reasons for this could be the sport's general popularity, the large turnovers in the golf industry, or most likely, the underlying complexity of the seemingly simple task of bringing a golf club in contact with a ball. A recent review of the research efforts in golf pointed out that understanding of the golfer's interaction with the club is still too crude to fit clubs to people properly. Given that approximately 55 million people play golf worldwide, it is important that the interaction between the golfer and equipment is better understood.

This study is made in believe that understanding of dynamics of the golf swing should help players to increase both the distance and the precision they achieve in their shot. More specifically, the doctoral dissertation mainly contains five parts as follows:

（1）In order to clarify the mechanism of the release point of the golf swing and the effect of the parameters of a club and a human body on dynamic behavior at the release point.　First, the mathematical model of the golf swing is assumed to be a 2-dimensional double pendulum connected with a nonlinear rotational spring at the wrist joint.　By applying Lagrange's equation to this system, equations of the golf swing motion were derived. Assuming that the player's wrist joint begins to turn naturally under the centrifugal force of the swing. When the angular velocity of the arm and the centrifugal force become to be sufficiently large compared to the angular acceleration and tangential inertial force, uncocking begins naturally without driving torque applied to the wrist joint. We derive simple approximate equations which express the relationship between angular velocity and acceleration at the release point. Based on derived equations and the motion control equations, mathematical expressions that demonstrate the effect of the parameters of a golf club on the dynamic behavior at the release point were deduced. According to the expressions, parameters (e.g. lengthen of shaft, gravity

center of shaft, and head weight) of a golf club affects significantly on the head speed, and calculation and discussion are carried out on the effect of the parameters of the club , the cock angle and the active wrist torque on the release point. Through the discussion, it can be seen that the derived simple approximate equations exhibit a physical insight of the phenomena at the release point and will be helpful to understand the effect of the club parameters on the dynamic behavior of the double pendulum at the release point.

（2）Considering　that uncocking begins naturally without driving torque applied to the wrist joint he angular velocity of the arm and the centrifugal force become to be sufficiently large compared to the angular acceleration and tangential inertial force. Establish the approximate equations which express the relationship between angular velocity and acceleration at the release point. Based on simple equations and different acceleration patterns of the down swing, calculation methods are derived to estimate the effect of the acceleration patterns expressed by the polynomial of time on the dynamic behavior at the release point which may affect significantly on the head speed. According to the results of simulation, we discussed two type acceleration patterns which are expressed by the 1st order function of time affect to the release point. Through the discussion, it can be seen that acceleration pattern which has positive gradient gives high angular velocity of the release point and later release point, and negative gradient pattern shows low angular velocity and earlier release point and these results can explain mechanism of so-called late hitting.

（3）Based on the double pendulum mode, take club speed and dynamic energy transition at impact into consideration, simulate different situations (specifically on the release point and patterns of uncocking) according to various parameters and variables (including patterns of torque, length ratio of club shaft to wrist, mass ratio of club shaft and ball, and uncocking angles).　A new golf robot with one actuated joint and one passive joint was designed to simulate the natural uncocking progress during swing.　Considering that the special mechanism with the non-holonomic constraint of swing robot and the high speed motion, a PID controller was designed to controller the rotation of a 250watt DC motor with different accelerations. The methodology is divided into two parts which is software development and hardware implementation. The works in software

development are calculation of DC motor transfer function, simulation to determine the parameter value of PID and developing the software controller. Ziegler-Nichols Closed-Loop Method is used to obtain the value for K_p, K_i and K_d. The other part is to interface the controller with hardware. After finish both parts, this system can be tune by using the PID value to do the analysis on it response.

（4） Golf requires a complicated sequence of motions to swing the golf club properly with the primary goal of propelling the golf ball a certain distance in a desired direction. A proper golf swing can make the difference between a long straight ball flight and a shorter hook or slice as a result of an improper swing. A repeatable and consistent golf swing can also dramatically improve a golfer's score. However, this single movement which has such a major impact on the player's overall game is difficult to master and execute consistently for players who are new to the sport or have little experience. To resolve all of these complications, players who are serious about their game seek out instructors, golf instructional books, or other training aids to help them to obtain the "perfect" golf swing. These players can potentially benefit from wearable sensor systems where information on the quality of the per formed swing can be provided in real time. Such a system must be mobile to be usable at the location where the sport takes place. In this research, a wearable sensor system was designed for velocity, acceleration, and energy transition measurement during golf swing. The sensor nodes collect data for the sequence of actions in a swing which is then preprocessed locally to facilitate subsequent in network operations. The data is then sent to a base station for further analysis. At the base station, the quality of each segment is expressed as the amount of deviations from target line. In order to realize a simplified swing analysis system using wearable sensor system. A joint angle measurement method using Kalman filter to correct gyroscope signals from accelerometer signals was examined in measurement of play's wrist and thumb with the wireless wearable sensor system, in which sensors were attached on the body instead of on the golf shaft. In the measurement, Kalman filtering based measurement method was examined with the wearable sensor system during golf swing to reference data obtained form an optical camera system.

（5） With the wearable sensor system, measure exactly the way player's body moves during swing, then isolate the mechanics and physical (stability, flexibility, balance) issues in swing and provide a three-dimensional assessment. In this research, kinematic analysis is performed to obtain both the linear and rotational accelerations of each model segment. This is for instance done by tracking small reflective balls by means of multiple synchronized video cameras and reconstructing the motion of the points from the images. However, the main complications associated with creating the link between measured marker trajectories and the multi-body model are noise, kinematic over-determinacy, kinematic under-determinacy, missing marker visibility. Aim to that, a new method for kinematic analysis of rigid multi body systems subject to holonomic constraints was designed. This is accomplished by introducing a constrained optimization problem with the objective function given as a function of the set of system equations that are allowed to be violated while the remaining equations define the feasible set.