CONTROL SYSTEM OF A MUSCULAR CONTROLLED, EXPERIMENTAL GLENOHUMERAL SIMULATOR

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Introduction

Shoulder joint and muscle forces cannot be easily and accurately measured directly in-vivo. An ex-vivo approach is often chosen to conduct biomechanical studies of the shoulder, especially when investigating the active and passive contribution of individual muscles, and various glenohumeral simulators have been developed [1]. However, currently only few simulators can simulate dynamic glenohumeral motion induced by active muscle forces, and a standard for such an experimental set-up and its control system is lacking. In this work, we present a control system for a shoulder simulator with the goal of mimicking physiological glenohumeral motion while tackling the challenge of over actuation.

Methods

The current simulator is a further development of an existing unconstraint glenohumeral simulator [2] designed for ex-vivo experiments with different rotator cuff injuries and hand-held weight conditions (0kg, 2kg, 4kg; Figure 1). The simulator consists of eight active muscle units, three segments each of the rotator cuff and the deltoid muscles, pectoralis major and latissimus dorsi muscles and a simulated arm with appropriate weight. A cascade feedback control system was developed to activate the eight muscle units to control six degrees of freedom in the glenohumeral joint (Figure 2). The outer cascade controls the position of the humerus and yields the net torques $\tau_{corrected}$ which is used as input to an optimization scheme. The optimizer provides $F_{desired}$ to actuate the glenohumeral joint. The optimization minimizes the loss function

$$L = \alpha \cdot F_{desired}^{T} \cdot F_{desired} + \beta \cdot F_{estimated}^{T} \cdot F_{estimated} \qquad (1)$$
$$s.t \qquad MA \cdot F = \tau_{corrected}$$

where α and β are weighting parameters, $F_{estimated}$ is a model-based estimation of the muscle forces and MA a matrix stored with the current moment arm of the muscles. The inner cascade is implemented to ensure that the $F_{desired}$ is reached.

Results

The repeatability of the simulator was tested by running the same abduction motion multiple times. The mean (standard deviation) of the motion at its peak abduction angle was -35° (3.6°).

Discussion

The experimental setup reproduces the given motion profile well. The optimization scheme actuates the humerus in a physiological manner. The limitations of this experimental setup include the approximation of the line of action of the muscles. The activation level of each muscle group can only be estimated, and hence does not necessarily reproduce the in-vivo situation [3]. These limitations are inherent to all glenohumeral simulators [1]. These limitations are addressed with adjustable insertion points of the muscles and the optimization scheme presented here. This simulator shows promising potential to simulate and track the complete kinematics of the glenohumeral joint and further improve its repeatability.

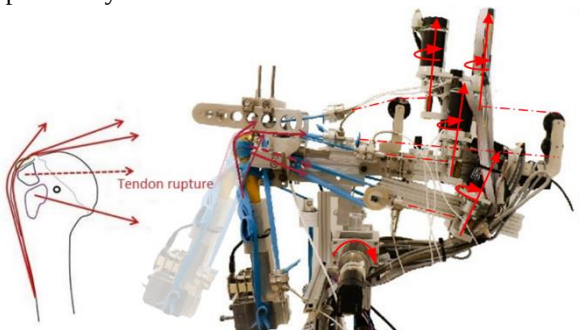

Figure 1: Illustration and photograph of the simulator and the muscles included. The muscles are actuated with EC-Motors and wound onto a rope winch.

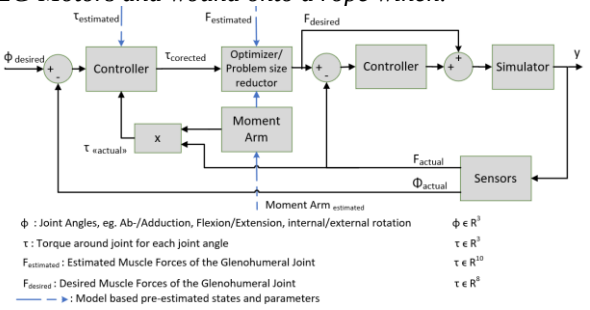

Figure 2: Control scheme of the shoulder simulator.

References

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