Active Human Body Model

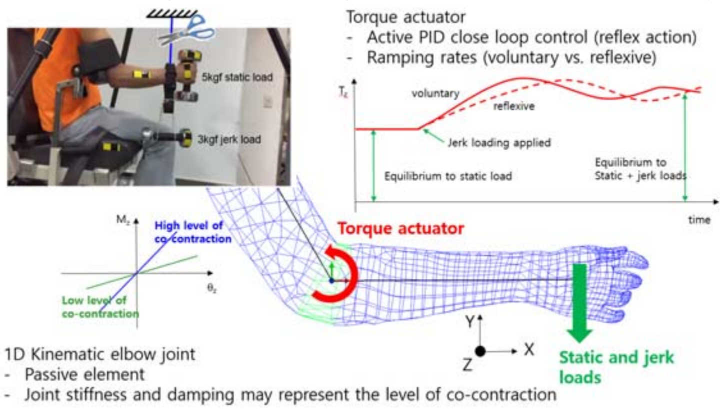
Hyung Yun Choi, Manyong Han (Hongik Univ.), Inhyeok Lee, Jungtae Yang, Wiro Lee (ESI Korea)

I. INTRODUCTION

Muscle Tensing Produces larger axial forces, stress redistribution within bones, increase in effective mass and stiffness, altered kinematics, and less excursion and smaller joint rotations [1]. Voluntary and reflexive muscle activation of vehicle driver is modeled by active joint element at each anatomical joint position (e.g., shoulder, knee, spine, and etc.). There are two basic elements at each joint, i.e., passive kinematic joint element and torque actuator. Assuming that a co-contraction of agonist and antagonist muscles stiffens the joint articulation, spring constant and damping coefficient of the passive kinematic joint element are adjusted for the different level of co-contraction, which is considered as a major mechanism of voluntary muscle activation. A vestibular reflexive muscle activation for the posture stabilization is modeled by active torque with PID close loop control. Active torque, the control signal is a sum of proportional, integral, and derivative terms between current and reference states of the joint angle.

II. JERK LOADING AT ELBOW JOINT

Both experimental and numerical investigations were performed to identify co-contraction of human articulated joint and reflexive response upon an external perturbation. The elbow joint with simple 1DOF is selected. Upper body and upper arm of test subject are restrained and the elbow joint angle is asked to maintain its initial position, i.e., keeping the forearm levelled before and after the jerk loading. There are two kind of loadings, 5kgf static loading on hand and 3kgf jerk loading on wrist which was initially carried by a string and just becomes a jerk load when string is cut. (See Fig. 1). The subject has two test conditions, 1) co-contraction and 2) recognition of jerk loading. Co-contraction or single contraction is respectively attempted by contracting both agonist (e.g., biceps) and antagonist (e.g., triceps) muscles or only agonist muscles. Recognition of the jerk loading to test subject is made by letting him to make his own observation of the action of string cut, i.e., open eye condition. On the contrary, the closed eye condition does not allow the test subject to become aware of the precise moment string cut. There are thus total four cases of test conditions, “open eye tensed” (recognized with co-contraction), “closed eye tensed” (unrecognized with co-contraction), “open eye relaxed” (recognized with single contraction), and “closed eye relaxed” (unrecognized with single contraction).



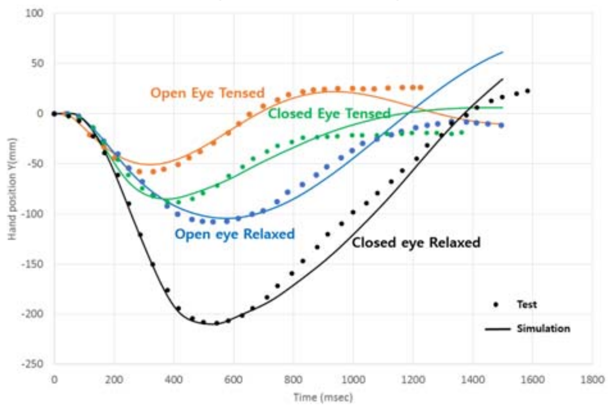


Fig. 1. Test setup (left upper photo insert), 1DOF active elbow FE model (left), comparison of hand displacements between test and simulation (right)

The numerical modeling of elbow joint and its active response to the jerk loading is designed by implementing two mechanical components, passive 1DOF kinematic joint element and torque actuator (see left in Fig. 1). The linear stiffness and damping coefficient of the passive 1DOF kinematic joint element present the level of co-contraction that stiffens the elbow joint articulation. Voluntary and reflexive muscle activation responding to the jerk loading is modeled by the torque actuator with a PID close loop feedback control.

Considering that the test subject tries to keep the initial elbow joint angle, torque (M_y) is activated to minimize the error which is the difference between the initial and current elbow joint angles. Meijer et al [2], and Brolin et al [3] presented successful applications of the active torque with PID control to their active human body models. Gain values for the PID control, i.e., Proportion, Integral, and Derivative terms determine the rates of torque generation. Faster torque generation with larger gain values stands for the recognition of jerk loading, i.e., "open eye" condition in the subject test. On the other hand, "close eye" condition for unrecognized and thus more reflexive response that is modeled by smaller gain values. Comparison of hand displacements between subject test and simulation for four cases are shown in Fig. 1. Table 1 lists modeling parameters of active elbow joint just for "Close eye Relaxed" case, the most vulnerable condition. The derivative term in PID close loop control turns out to be insensitive in this simulation of active response to the jerk loading and thus excluded. Three methods to determine modeling parameters are used and listed in Table 1. Optimization for the parameters with two different algorithms, adaptive RSM and Genetic Algorithm is performed based on initial values which are obtained from the trial and error method. Thus the CORA (CORrelation and Analysis, http://www.pdb-org.com/de/information/18-cora-download.html) scores with optimization are further increased to 0.994 and 0.982.

TABLE 1 Modeling parameters of active elbow joint

Method	Kinematic joint properties		PID close loop control gains		CORA Score	No. of iteration (generations)
	Damping C. (kNms/rad)	Stiffness (kNm/rad)	K_p (kNm/rad)	K_i (kNm/rad)		
Trial and Error	22	3	12	0.10	**0.963**	NA
Adaptive RSM	19.5	8.83	14.9	0.09	**0.994**	25
Genetic Algorithm	21.4	9.8	6.95	0.10	**0.982**	15(150)

III. WHOLE BODY MODELING

The same modeling scheme of active response at elbow joint is extensively applied to the whole body model. The version of multi body model (compare with deformable body model) consists of 25 rigid body segments and 24 articulated joints. Each articulated joint has either 1 DOF (e.g., elbow, knee, etc.) or 3 DOF (e.g., shoulder, hip, spine, etc.) depending on its biomechanical characteristics. Same kind of passive kinematic joint element and active torque as in the active elbow joint model are implemented but its mechanical characteristics, e.g., the moment-angle curve and damping coefficient are dissimilar to each other. The errors to be removed by active torques at articulated joints is a composite function of joint angle changes at every body segments. Human driver voluntarily and/or reflexively braces to maintain upright sitting posture against various kinds of G-forces during vehicle maneuvering such as emergent braking, lane change, cornering, etc. Validation of active human body model against the test data from open literature [4] is now in progress.

IV. DISCUSSION

The SISO (Single-Input Single Output) problem with 1D active elbow joint model becomes MIMO (Multiple-Input Multiple Output) problem with whole body model. Human driver's muscle recruitment strategy of active response to brace against external perturbations belong to the quite complicated behavioral kinesiology. Also inter and intra subject variations make the active human body model as one of exciting challenges.

V. REFERENCES

[1] HY Choi, et al, Experimental and numerical studies of muscular activations of bracing occupant, ESV 2005

[2] Riske Meijer, et al. Modelling of Bracing in a Multi - Body Active Human Model, IRCOBI 2013.

[3] Karin Brolin, et al. Development of an Active 6 Year Old Child Human Body Model for Simulation of Emergency Events, IRCOBI 2015.

[4] Phillip Huber, et al, Passenger kinematics in braking, lane change and oblique driving maneuvers, IRCOBI 2015