Force Control of a Mechanical Finger for Hand Prosthesis through Servo Motor Current Feedback

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Introduction

The technology that deals with design of myoelectric hand prosthesis has shown a great progress in the latest years (Massa et al, 2002). However, commercially available hand prosthesis that are low cost, often accomplish only simple movements, don't have a fine prehension force modulation and are heavy.

Force control for hand prosthesis is a highly convenient item to guarantee the execution of accurate and delicate movements. Some works that deal with this kind of control are reported in the literature (Chappell and Elliott, 2003; Engeberg and Meek, 2008).

Force sensors for hand prosthesis application must be small, robust, low power and easy to install. However, they require some space on the finger surface, can only measure forces applied directly over the sensor, increases complexity of the system.

This paper shows the force control design of a conceptual mechanical finger that was constructed to demonstrate the applicability of the control that, under suitable adjustments, can be used in hand prosthesis. The actual force applied by the finger is estimated indirectly from motor current level. A RC servo motor was used as actuator. The overall arrangement employs simple mechanisms and off-the-shelf components with cheap sensors and actuators.

Material and Methods

A conceptual finger mechanism was built. It is similar to that used in the RTR II project (Massa et al, 2002), but here extension is also provided by the motor, not by a spring. The mechanism was inverted and doubled using the same pulleys (Sono et al, 2009). A RC Futaba S3305 servo motor was used as the finger actuator. Current was measured by a shunt resistor in series with the motor. The amplified voltage drop on the resistors was recorded. Arm muscles biceps and triceps surface EMGs are chosen to control the robotic finger function. Biceps delivers the intention to flex the finger and modulate prehension force, while triceps commands finger extension.

Prosthesis Command System

Prosthesis control comprehends two main tasks: open or close the finger, up to the contact with the object, and modulate the desired level of prehension force. In the first, there is no contact with the grasped object and the finger movement is free. Here, the servo is set in such a way that the finger flex, extend or stop his motion, in according to the desired motion from user EMG. If motor current level overcomes a prescribed threshold, it means that finger touched the object and the control switches to the other task.

Plant model parameters identification

The first step to design the feedback control system is finding the plant model parameters. Plant model comprises the actuator coupled to the finger model a soft grasped object was identified (Fig. 1).

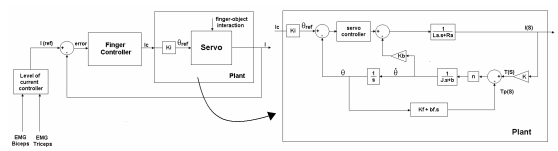

Figure 1: System plant and control architecture

Each of DC motor parameters was identified. The torque constant (K=0.7752 (Nm/A)), that relates torque delivered by the motor to the current level, was estimated from the linear slope between these variables, obtained experimentally (see details in Sono, 2008). K_b is the electric constant considered equal to torque constant K. Armature resistance (R_a=4.1Ω) was measured directly by opening the conduction coil circuit. Armature inductance (L_a=0.1H) was assumed as a low value. Motor moment of inertia (J=0.167*10^{-4} (kgm^2)) and damping coefficient (b=0.593*10^{-4} (Nm/rad/s)) were obtained from the step-response velocity curve, by measuring the time constant and DC-gain.

The value of servo motor position controller was regarded as a proportional one and was obtained empirically (K_p=11.5), comparing the response curves of the non-linear simulated system with the real one. This model has a non-linearity: servo motor controller saturation. It was taken into account only in the numerical simulations, but neglected in the plant model.

Finger and its interaction with the grasped object was modeled as a torque perturbation, which is a function of grasped object stiffness and the angular displacement and velocity. An experimental relationship between angle and current, while the finger squeezed the balloon, was found (Sono, 2008). This relation was found to be clearly non-linear, but was modeled as a first-degree polynomial function, to keep system linear for control design purposes

(K_f=0.87055*10^{-5} (Nm/rad)). Damping coefficient (b_f=0.888*10^{-1} (Nm/rad/s)) is found empirically, by direct comparison, between output curves of real and simulated systems.
Plant model was simplified using block diagram algebra up to a simple transfer. However, the obtained transfer function presented some non-controllable poles and was replaced by a minimal realization (Eq. 1), using Matlab "*minreal*" command.

$$\frac{I(S)}{I_c(S)} = \frac{360s + 1278}{s^2 + 44.55s + 1153} \qquad (1)$$

<u>Controller design</u>
Open-loop step response, without the current feedback, shows high overshoot (approximately 400%), rise time=0.00263s and settling time=0.214s. The closed-loop controller had the main purpose of reducing overshoot. It is necessary to grant the correct prosthesis functioning, avoiding squashing delicate objects. However, rise and settling time requirements could be relaxed, decreasing unnecessary control effort. A phase-lead compensator was proposed to decrease overshoot close to zero and increase settling time up to approximately 0,6s.

Experimental Setup and Results

The control system was implemented in Labview and tested in real-time. To decrease control sensibility with respect do EMG fluctuations, both input (EMG) and output (motor current) were segmented into seven discrete force level intervals.
After to collect biceps and triceps isometric MVC, the system was tested in real time with EMG signal from two normal nonamputated voluntaries. A testing protocol was used: 1) Maintain the arm relaxed keeping the elbow at 90º, during a few seconds; 2) Perform an 'intermediary' level voluntary isometric contraction, during 5 seconds; 3) Repeat item 1; 4) Perform an isometric MVC for 5 seconds.
The Figure 2 shows the current output curve (full line) obtained from EMG input (dotted), for open-loop (a) and closed-loop. For Subject 2 similar results were observed.

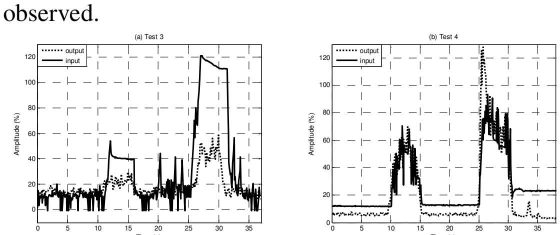

Figure 2: Experimental results for Subject 1 - (a) Open-Loop; (b) Closed-Loop

To verify the performance of the proposed strategy to control grasping force, a calibrated Force Resisting Sensor (FSR) (ELAB LDA., Portugal, Mod. SENM-A15N, Max. Force 100N) was placed on the tip of the finger and the recorded force compared offline to controlled current level. An experiment was proposed by delivering a Labview generated ramp input, while current and FSR contact force were measured simultaneously. Both open and closed-loop were tested and results are shown in Figure 3.

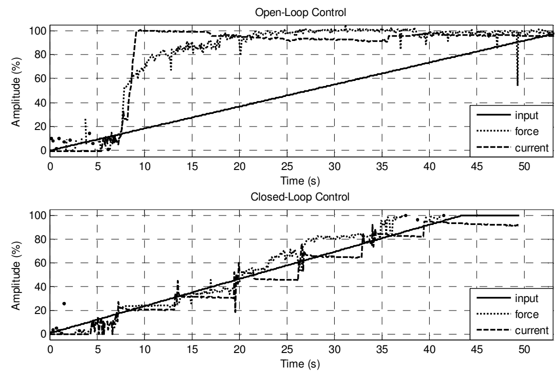

Figure 3: Experimental results for force x current, (a) Open-Loop and (b) Closed-Loop.

Discussion and Conclusion

This paper has shown that the proposed closed loop controller is able to control the current and this method is promising for modulating force in hand prosthesis finger. Among the main advantages, it can be pointed-out: simplicity, low-cost, robustness and ability to control grasping force much more precisely, when compared to open loop. Further work comprises improve and accomplish mechanical design and replacing PC, A/D board and Labview by a dedicated wearable hardware.

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