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A VIRTUAL TRAINING ENVIRONMENT FOR PROSTHETIC CONTROL

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INTRODUCTION

Lack of a limb, due to either traumatic or congenital amputation, limits an individual's independence and quality of life. Prostheses restore some level of functionality and independence to amputees. Myoelectric control of upper-limb prostheses permits the user to control grasping using electromyography (EMG) signals from the residual muscles. Feedback regarding task performance is typically visual. Multiple studies have shown that some form of feedback in addition to traditional visual feedback improved grasping performance [1]–[5]. Task performance was measured using a calculated score based on two metrics: speed of task completion, and the amount of grasp force produced for the task, compared to the required force. At the moment, there are no commercial upper-limb prostheses that provide vibrotactile feedback as a supplement to visual feedback [1].

EMG controlled visual feedback virtual prosthesis systems have been developed for training, design, and experimentation with upper-limb powered prostheses [6]–[11]. However, none of these systems incorporate vibrotactile feedback, object and hand simulation, and simple two-site differential EMG grasp control in a single package. Such a system could be used to test the effectiveness of adding vibrotactile feedback to an upper limb prosthesis for grasping every-day objects. As well, the system could be used as a virtual training environment to learn myoelectric control of a prosthetic hand, with and without vibrotactile feedback as that feature can be easily disabled.

A notable example of a virtual prosthesis, called Virtu-Limb (Touch Bionics Inc.[1]), is used by prosthetists for device fitting and user training. The company provides a range of upper-limb prosthesis solutions from finger to hand replacements. Each prosthetic device can perform multiple grasps such as a power grip, lateral grip, or index point, which can be changed using a mobile app, rotating the prosthetic hand, or through muscle control. However, not all options are available on all devices. Virtu-Limb is designed to familiarize a user with the features of a prosthetic limb and simulate its use, but it does not have the capability of simulating virtual objects, nor does it provide any form of tactile feedback to the user.

The goal of this research is to create a virtual environment which can generate basic objects to represent everyday items, with corresponding physical properties, and test how well a user can grasp the objects with a myoelectrically controlled virtual hand. A well performed grasp is done as quickly as possible, with the proper amount of applied force. A relatively simple two-site control scheme, which provides a general grasping capability, is used. To test the system, a user will be asked to grasp a series of objects displayed on the computer screen. The system will provide either visual or visual plus vibrotactile feedback based on the total magnitude of the grasping force. Subjects will be tested on their ability to learn to control the grasping force of the virtual hand under both feedback conditions.

VIRTUAL ENVIRONMENT DESIGN

The block diagram of the virtual system is shown in Figure 1. Hand initialization, which generates the hand object, and Object generation, which generates the corresponding

[1] http://www.touchbionics.com/products

object for the trial, are executed only once when the system is initiated; after that time the "Run" feedback loop is used. Initialize/Run control is a simulation time signal which is read by the Initialize/Run switches block which reroutes the signal path after the first simulation step. The Control signal block generates a value to control the speed and direction of the grasp from processed EMG signals. The hand control block then flexes or extends the virtual hand and sends the resulting hand and object for animation, provides vibrotactile feedback (if selected), and then returns to the input through the Initialize/run switches.

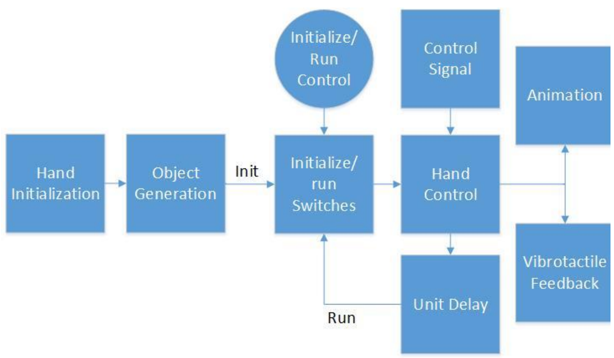

Figure 1: Block diagram of the virtual environment

SynGrasp

SynGrasp is an open-source toolbox in MATLAB (The MathWorks Inc.[2]) designed to test the quality of grasping different shapes, for a number of existing robotic hands and a human hand, in a virtual environment [12]. The toolbox provides a convenient framework for grasp analysis, but is not designed for use in real-time. It is however well suited for locating contact points, and calculating contact forces which are necessary for this study. The toolbox was modified to run in real-time in Simulink (The MathWorks Inc.[2]). A 20 degrees-of-freedom (DOF) hand was chosen from the toolbox to represent a human hand with full digit articulation, which is sufficient for this study. Porting the toolbox to Simulink involved insuring that the strict rules of Simulink programming, particularly memory allocation, were met and that all built-in MATLAB functions were compatible with Simulink. This required initialization of all variables used, or if that was not possible, specification of their maximum allowable size. Simulink does not support 3D MATLAB visualization through the use of surf() commands, therefore it was necessary to completely reanimate the hand and objects, as discussed below.

Visualization

SynGrasp uses a set of surface plots in MATLAB to draw a 3D hand and objects. EMG signals are obtained via a data acquisition board that uses its own library in Simulink called QUARC (Quanser Inc.[3]) The library includes 3D simulation capability, in which the hand and objects were recreated. Digits were formed from available sphere and cylinder templates while the palm was created in Blender (Blender Institute[4]) 3D modeling software and imported into Simulink. Animation commands are provided by the joint angles calculated by the SynGrasp toolbox.

Data acquisition and EMG

EMG is recorded from the ventral and dorsal surfaces of the forearm to control hand opening via wrist extension, and hand closing via wrist flexion. The SEMG signals are detected using two active bipolar AE100 electrodes (Invenium Technologies[5]), amplified via a custom board based on the AD210AN isolation amplifier (Analog Devices Inc.[6]), and then sampled at 1 kHz using a Sensoray model 626 (SENSORAY[7]) data acquisition board. Although the active electrodes provide on-board band-pass filtering from 25-500 Hz, the signal was deemed to be too noisy when attempting to assign thresholds for the control signal. Therefore, the sampled signals were additionally filtered using an 11^{th} order Butterworth band-pass filter with corner frequencies of 20 and 490 Hz. A mean absolute value (MAV) filter with a window length of 100 samples was then applied to the signals to obtain the linear envelopes. All processing after amplification was performed in Simulink. Depending on individual subject requirements,

[2] http://www.mathworks.com
[3] http://www.quanser.com
[4] https://www.blender.org
[5] http://www.invenium.ca
[6] http://www.analog.com
[7] http://www.sensoray.com

additional amplification is available within Simulink and is adjusted during the calibration phase of the experiment.

The EMG signal processing block diagram is shown in Figure 2.

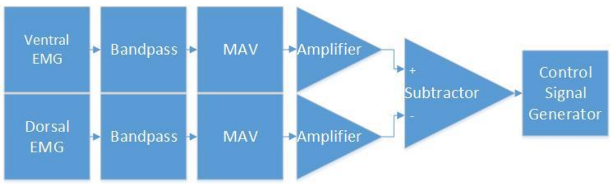

Figure 2: 2-channel EMG signal processing diagram

The control signal generator equation is given below. The amplifiers after the MAV filter are for calibration purposes to ensure that the amplitude during activation of each muscle group is approximately the same for extensors and flexors.

$$\frac{x_{dif}-\theta}{10\cdot x_{MVC}-\theta}=\sigma \tag{1}$$

It is required that the control signal is between -0.1 and 0.1 where 0 is the virtual hand is at rest, 0.1 is hand closing at maximum allowable speed, and -0.1 is hand opening at maximum allowable speed. The control signal magnitude, σ in Equation 1, specifies the change in the angle in radians of all of the active joints in a grasp, in a simulation time step. In other words, if the control signal is 0.05, then all of the joints in the hand will close by 0.05 radians during the simulation step. The simulation runs at 10 steps per second, therefore the total maximum allowable speed for hand closing or opening is 1 radian per second per joint. A joint remains active unless it is deactivated when the corresponding finger link comes into contact with the object, or it reaches its maximum allowable angle of $\pi/2$ radians. A joint cannot be overextended either, therefore finger extension will be disabled when the finger links are parallel with the palm.

The difference signal x_{dif} in Equation 1 is the output from the subtractor in Figure 2. The virtual hand can be in three possible states: closing, opening, or rest. The value of the difference signal determines the hand state. To determine the trinary state of the hand two thresholds are needed and they are determined by visual inspection of the difference signal. Ideally, if the difference signal is between the upper and lower thresholds, the hand is in the rest state. If it is above the upper threshold, then the hand is in the closing state. Similarly, if the difference signal is below the lower threshold then the hand is in the opening state. Each condition (open, close, rest) produces an internal tristate value. Along with the thresholds, there are 2 MVC values as well. The MVC values are obtained by asking the subject to flex and then extend the wrist as strongly as possible without injury. The correct MVC value x_{MVC}, and threshold value θ are plugged into Equation 1 depending on the tristate value. The control signal is forced to 0 at rest. Since Equation 1 will always yield a positive value the tristate value was also used to change the sign of the control signal if the hand was in the opening state. Equation 1 describes a proportional control approach similar to the one described in [13].

Vibrotactile Feedback

Vibrotactile feedback is provided using a C08-001 linear resonant actuator (Precision Microdrives Ltd.[8]) driven with a DRV2605L haptic driver (Texas Instruments Inc.[9]) through the output port of the data acquisition card. The actuator operates at 235 Hz and its vibrational amplitude is proportional to the applied force of the virtual hand on the object. At the breaking point of the object the vibrational amplitude is set to 80% of maximum.

SYSTEM TESTING

A preliminary experiment was carried out on a single subject, a healthy 22 year-old male. The subject gave informed consent before participating in the experiment. The subject was provided only with a visual feedback of the orientation of virtual hand fingers. He did not have any feedback of the force that the virtual hand exerted on the object. The purpose of this experiment was to get oral feedback from the subject regarding the hand control intuition, comfort, and ease-of-use.

[8] http://www.precisionmicrodrives.com

[9] http://www.ti.com

The subject reported some initial control difficulty as the EMG signal amplitude was mapped to the velocity of the virtual hand. The difficulty subsided as the subject became more familiar with the system. However, when asked to close the hand as slowly as possible there was noticeable virtual hand wobble as both the flexors and extensors are activated during the exercise. This can be improved by increasing the window length of the MAV filter to 200 samples to further smooth the EMG linear envelope, although this would add an additional 100 ms delay. Subsequent testing will include visual and vibrotactile feedback prior to the full experiment. Visual force feedback will be delivered by varying the intensity of the red colour of the object. A larger amount of exerted force will yield a higher intensity of red in the object.

CONCLUSION

The team has created a virtual environment that provides proportional myoelectric control of a virtual hand with the ability to grasp objects. Although this is based on the use of SynGrasp, a major portion of the toolbox had to be rewritten for real-time use. At the moment the team is developing a suite of objects with various material properties to represent every-day items, along with integrating visual and vibrotactile feedback for hand-object force interaction. The system will be tested on a number of subjects to test the hypothesis that adding vibrotactile feedback will improve grasp performance.

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