Jayanth Devanathan
Computer Systems Lab
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Modeling Hand Motions using Ultrasound Imaging of Muscle Activity

Jayanth Devanathan

Introduction

The hand is an important appendage of the human body, and it has been concluded that around 90% of all daily human motions are grasp-and-release motions performed by the hand. Around 40,000 individuals in the United States are affected by upper arm amputations, which means that they have lost access to their hand for daily use. Although upper arm prosthetics are available for amputees, there have been problems with prosthetic accuracy.

The current prosthetics use a method known as electromyography, or EMG, to read in muscle movement data. In upper arm prosthetics, a subject would have at least a part of his forearm remaining for the prosthetic hardware to use. In EMG, electrodes are placed around the remaining part of a subject's forearm, and muscle movement data from various points on the arm are read in and translated into physical prosthetic movements.

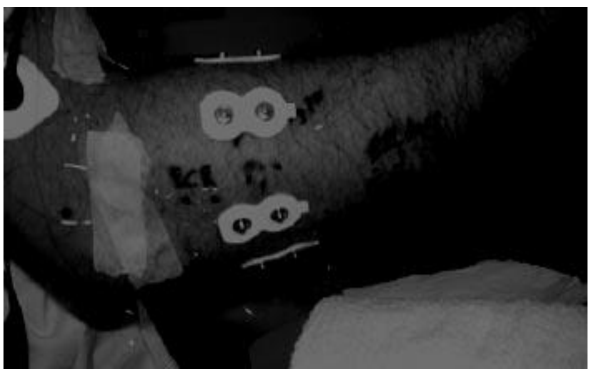


Figure 1. Electrode Placement on subject arm.

The problem with this method is that it doesn't get a clear-cut cross section of every muscle movement in the subject's arm. It also fails to obtain movement data from every muscle in the forearm, only reading the outer flexors and extensors. The hardware is therefore less complex programming-wise, as individual movements of separate muscles are generally directly correlated to prosthetic hand motions through circuitry, without any actual programming analysis. This results in a loss of muscle data through superficial readings and a loss of complexity in understanding muscle motions, both of which could be improved with a new type of prosthetic.

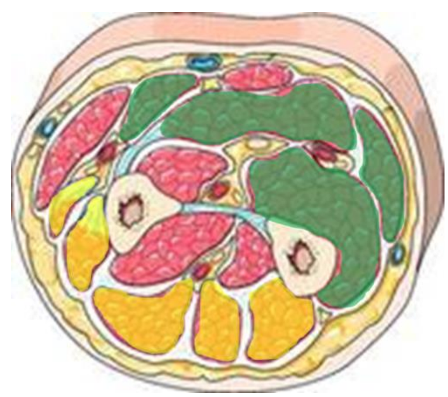


Figure 2. Cross-section of forearm. Only highlighted muscles can be read by EMG.

Ultrasound imaging as an alternative for reading muscle movements could solve the problems with current prosthetics. Ultrasound is inexpensive, non-invasive, and provides clear real-time dynamic imaging capabilities. It can avoid many of the limitations of EMG because it can visualize a clear-cut cross section of muscle movement in the forearm, as shown in Figure 3. This allows for more muscles to be read and a more thorough analysis to be used in future prosthetics. Ultrasound technology has improved to the point where handheld devices are now available. The advancements with ultrasound now make it feasible to incorporate real-time technology into a mobile prosthetic.

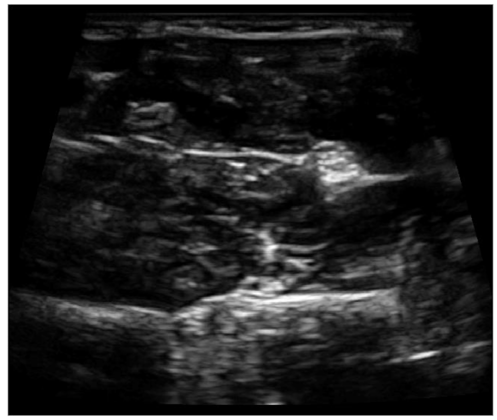


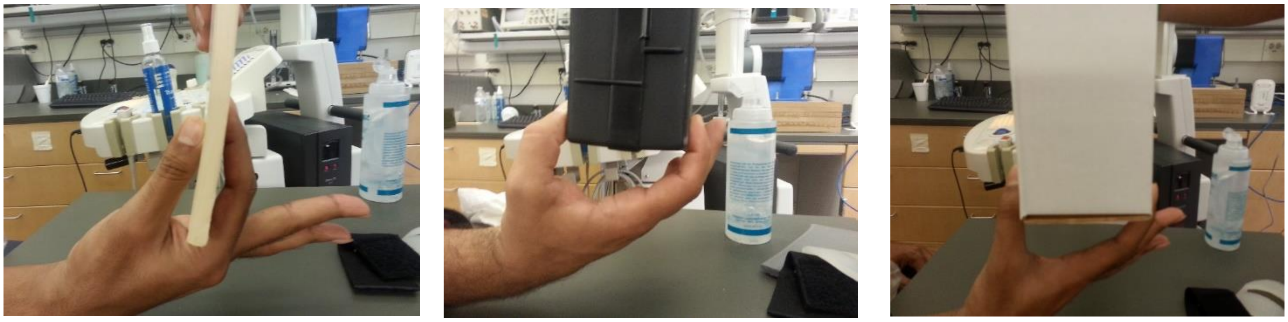
Figure 3. Cross-section of forearm, visualized through ultrasound.

This idea was developed at the Biomedical Imaging Lab in George Mason University, and currently a classification program has been made which identifies a hand motion type based on its ultrasound file. This particular project extends on the concept of degree of motion, especially in relation to pinches. For example, pinching a thick book and a page are two very different motions; the purpose of this project is to develop a program which can differentiate different pinch types.

Methods

Data was collected at the Biomedical Imaging Lab at George Mason University, using a ultrasound transducer attached to a subject via a cuff. The subject performed pinches on various objects, ranging from 10 mm to 100 mm in thickness, which were recorded by the transducer and stored in ultrasound video files.

Figure 4. Method of data collection from subject, with transducer and cuff

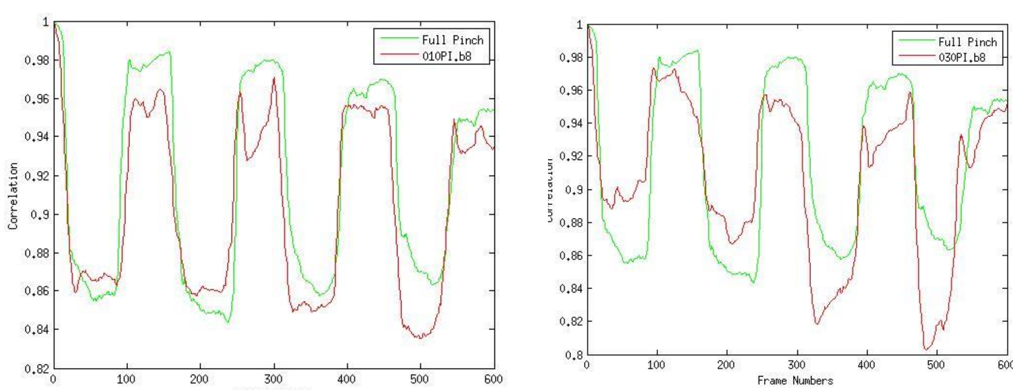


Figures 5,6,7. Various pinches(10 mm to 100 mm thick) on various objects for data collection.

Ultrasound videos of pinches of various objects were initially used, and were labeled “test files”, for which the program must determine the degree of the pinch. A separate video file of a full pinch was used as reference for comparison in the program analysis.

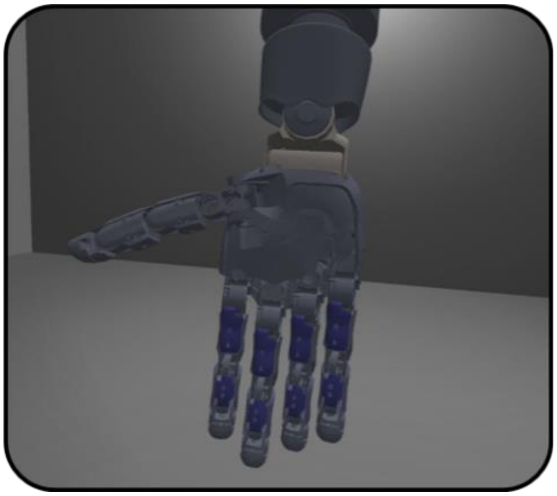
Analysis and Results

MATLAB was used for programming the analysis. A graph comparison was made with a test file, as described above, and the reference file, by comparing the first frame of each respective video file to the remaining frames in each file. Graphs were generated for all of the test files, and were visually compared with that of the reference file (full pinch). Graphs show no significant change in values between varying degrees of pinches, and are too similar to the full pinches in terms of frame comparison for any real differences to be obtained between video files **(Fig. 8,9)**



Figures 8,9. Graphs generated from graph comparison method described above. A 10 mm pinch(red) is compared with the full pinch(green), as shown on the left, and the same is done for a 30 mm pinch on the right.

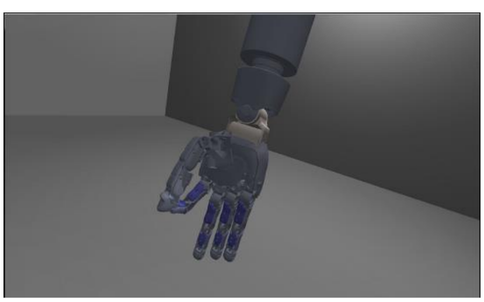
Further investigation in the analysis led to the use of a Virtual Integration Environment(VIE), which emulates a hand prosthetic in the form of a 3D virtual hand(**Fig. 10**). The hand is controlled by two sets of coordinates, one set for the arm attached to the hand, and the other for the actual joints in the hand. The coordinates that would render the 3D hand into a rest position, as shown on the right, are:



[0.17 0.97 0.29 0.00 .0 0.50 0.50],[1.00 0.32 0.32 0.32 0.00 0.32 0.00 0.00 0.00 0.25].

The first set of coordinates is for the arm, while the second set is for the hand itself, moving the palm and joints in the fingers and thumb. Different motions were then modeled using the VIE, which had strict start and end points: the fingers could not pass through each other on any particular motion, and they could not go below rest position either. Below are models of hand motions next to their respective bolded changes in coordinates.

SendNormalizedPositionsToVulcanX([0.17 0.97 0.29 0.00 .0 0.50 0.50],[1.00 **0.32 0.32 0.32** 0.00 **0.32 0.00 0.00 0.00** 0.25])
SendNormalizedPositionsToVulcanX([0.17 0.97 0.29 0.00 0.0 0.50 0.50],[1.00 **.95 .95 .95** 0.00 **.95 .45 0.95 0.45** 0.25])



SendNormalizedPositionsToVulcanX([0.17 0.97 0.29 0.00 .0 0.50 0.50],[1.00 **0.32** 0.32 0.32 0.00 0.32 **0.00 0.00** 0.00 0.25])
SendNormalizedPositionsToVulcanX([0.17 0.97 0.29 0.00 0.0 0.50 0.50],[1 **.7** .32 .32 0 0.32 **.5 0.8** 0 0.25])

Figures 11,12. Modeled positions for hand grasp and pinch, respectively.

In combining the double bounded principles of VIE communication with the code already written, an effective analysis was developed that would use both the base frame and the ending frame as a reference. The base frame was always a position of rest, and the contraction frame was always a position of contraction. By using these two as reference points, the program could effectively determine the degree of motion completed for any frame in a full pinch video file, and, given a full pinch contraction and rest frame, would be able to determine the degree of motion for any test file.

The translation of correlations from the graph to the Virtual Integration Environment are made through the following formula, in which $corr_{frame}$ is the correlation of the current frame in respect to the base frame, the $corr_{contr}$ is the correlation of the contraction frame to the base frame, and would serve as a range. This is then multiplied by the range of positions any certain appendage could take($c_f - c_i$), which is then added to c_i ,the starting position for any given appendage: $\mathbf{((1\text{-}corr_{frame})/(1\text{-}\ corr_{contr}))*(c_f - c_i) + c_i}$.

A GUI was built for this algorithm(**Figure 13),** which effectively communicates with the VIE.

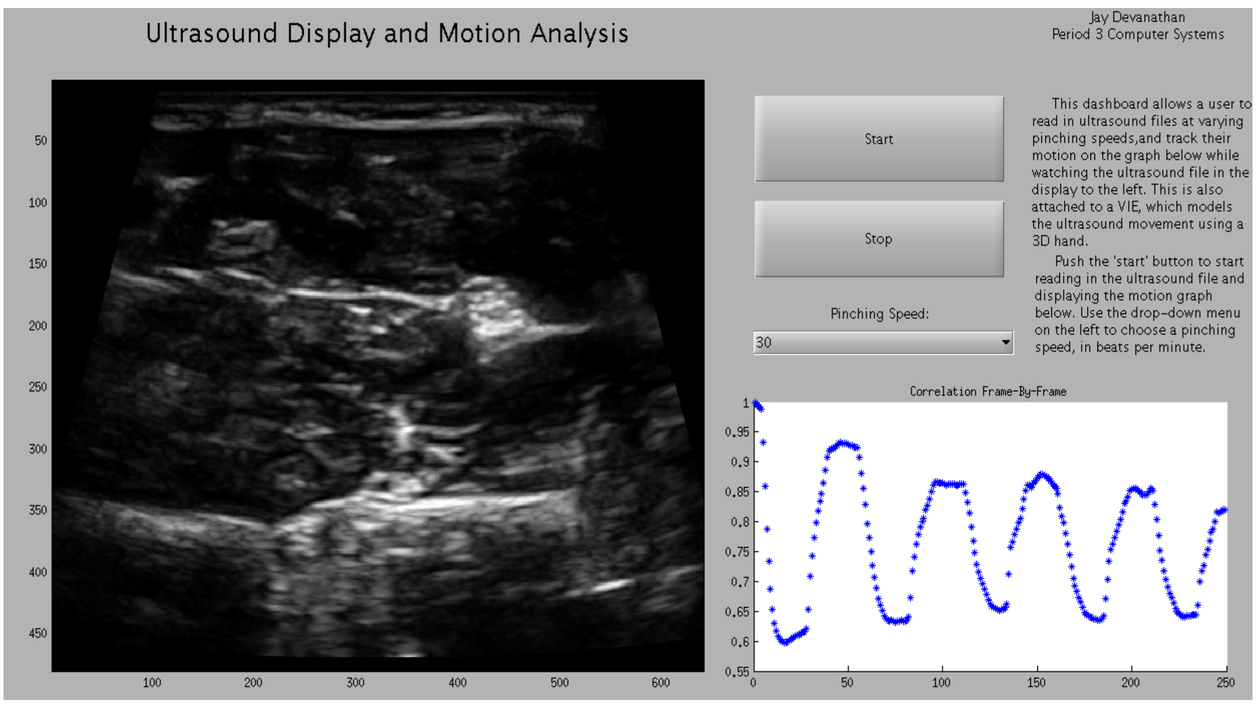


Figure 13. GUI built around final algorithm. Communicates with the VIE to get immediate virtual prosthetic motion while simultaneously reading in the ultrasound video file shown in the large display. The graph to the right tracks the correlation of the current frame.

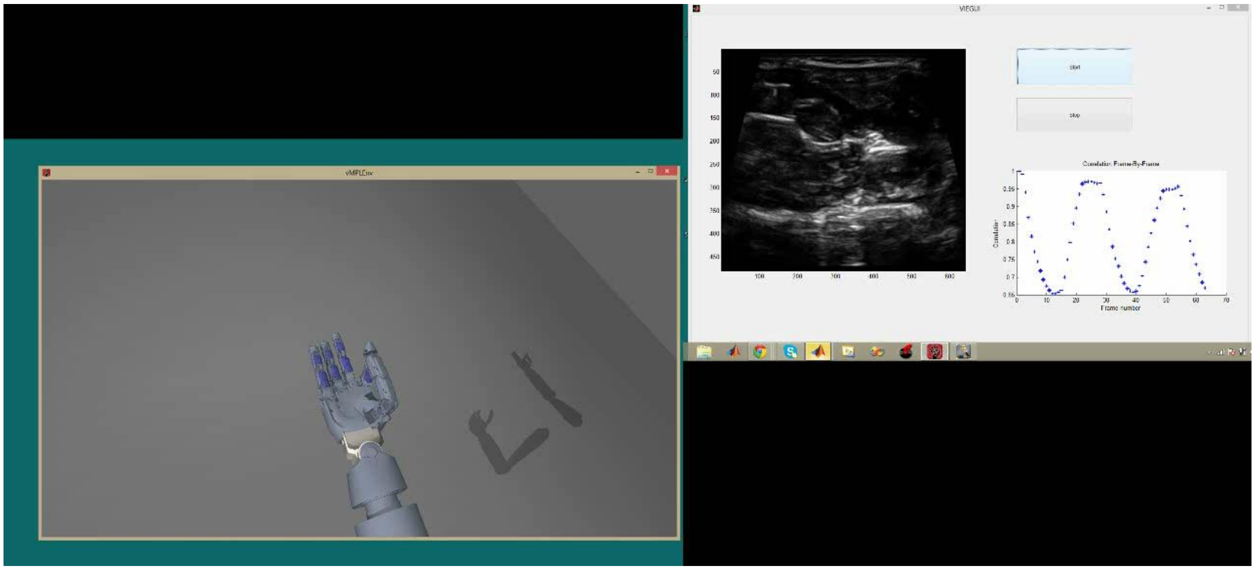


Figure 14. GUI communicating with the VIE.

Conclusions

Through the use of ultrasound, a program was developed which measured the degree to which pinches were being executed. Ultrasound, however, was not as clear-cut as originally thought, as it could not detect differences in degrees of pinching without two reference frames. Overall, the program developed is accurate, efficient, and viable for a future ultrasound-based prosthetic.

Works Cited

Banker,C.J.,Pedersen,P.C.,Szabo,T.L. (2008). Interactive Training System for Medical Ultrasound. IEEE International Ultrasonics Symposium Proceedings. 1350-1354. 10.1109/ULTSYM.2008.0327

Daley,H.,Englehart,K.,Hargrove,L.,Kuruganti,U. (2012). High density electromyography data of normally limbed and transradial amputee subjects for multifunction prosthetic control. Journal of Electromyography and Kinesiology.

Khushaba,R.N.,Kodagoda,S.,Takruri,M.,Dissanayake,G., (2012).Toward improved control of prosthetic fingers using surface electromyogram(EMG) signals. Expert Systems with Applications,Vol 39, 10731-10738.

Li, G., Schultz, A. E., & Kuiken, T. A. (April 2010). Quantifying Pattern Recognition- Based Myoelectric Control of Multifunctional Transradial Prostheses. IEEE Transactions on Nerual Systems and Rehabilitation Engineering, Vol. 18, 185-191.