A System for Limb Modeling, Position Sensing and Stimulation Control

Dianna Han [1,2], Doug Kuschner [2], Yuan-fang Wang [1]

[1] Department of Computer Science, University of California at Santa Barbara, CA 93106
[2] Alfred Mann Foundation, 25134 Rye Canyon Loop Suite 200, Santa Clarita, CA 91355
diannah@aemf.org

Abstract

In this paper, a system is presented that has been developed for sensing, modeling and control of an upper extremity neural prosthesis. The sensing unit employs a computer vision approach wherein one or more video cameras are used to detect movement of the arm and provide the arm position information to a model. The model uses kinematics and dynamics simulation to control the stimulation and animation of the articulated links. The motion control unit integrates a priori knowledge from the trained model and the observed sensor input, smoothes the limb motion tracking results and delivers a feedback signal to guide or correct the sensing process. In our experiments we compared sensed elbow angle accuracy results between our computer vision based system and a commercial product, and showed the visualization of the arm model.

1. INTRODUCTION

Generally speaking, three essential elements are required in the design of an FES system for neural prosthesis: sensing, stimulation, and control. In our prosthesis project, we have used BION® microstimulators to provide neural stimulation, which are implantable single-channel electrical devices. When they are implanted to stimulate movement of upper extremity, the joint flexion and extension will be controlled according to the experimental data on the signal-strength to the muscle retraction/relaxation correspondence over individual patients. This mode of operation represents an open control loop and our goal is intended to enhance the system design to achieve a reliable and stable closed-loop control mechanism.

Considering that the stimulation unit is a relatively independent unit, the proposed system will only deal with the other two elements in a typical FES system - sensing and control. Specifically, different types of inputs generated by a variety of sensors can be used in the sensing unit, and an information fusion process is employed in the controller to achieve higher accuracy and reliability through sensor data fusion.

The control unit will utilize an articulated link model of the arm, which is constructed to enable simulations of both kinematics and dynamics. The model records the posture configurations and learned motion patterns, and can also provide an inverse solution given the position of the destination of the hand. Different from previous approaches on limb modeling, no muscle modeling or stimulation is involved. Using the trained limb model to provide a priori knowledge of possible arm motions, the control unit can first predict possible arm position and motion, and then verify the model prediction by integrating the sensor inputs. Then, using sensor observance as feedback, the controller corrects the limb position tracking errors and smoothes the detecting results. This serves to reduce the negative effect of noise.

Since the sensing unit is independent from the controller, multiple types of sensors can be used, such as video cameras and mechanic and electromagnetic trackers. For our special application scenario, which involves the detection of the position of the object to be acquired, computer vision based sensing may provide a suitable solution. Therefore, a hybrid sensing approach is proposed as the future work.

The remainder of the paper is organized as follows: In the Methods section, each unit in the system will be described in more detail. The Results section presents the experiments on the current vision based sensing unit and the arm dynamic model visualization. In the discussion and conclusion section, we summarize the work and give a future work description under the system framework proposed.

2. METHODS

The system consists of three main units: sensing, trained model and controller. The structure is shown in figure 1 below.

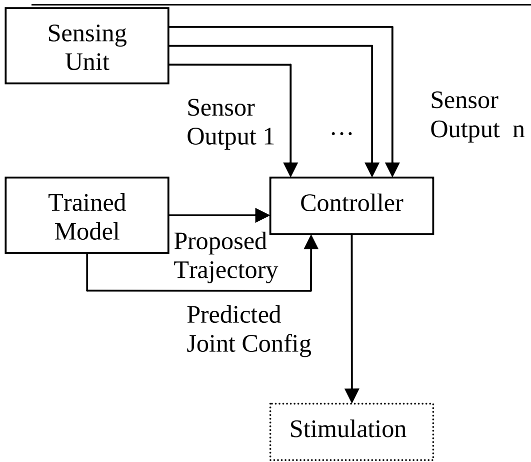

Figure 1. The System Overview

2.1. Limb Position Sensing – Computer Vision Based Approach

Depending on the type of sensors used, limb position sensing can be based on either physical sensor input (e.g., goniometers for joint angles) or video input (using cameras as video capturing devices), or both. It is important to develop reliable and robust sensing mechanisms to ensure the safety and accuracy of the stimulation. Besides the performance requirements, visual motion trackers are preferred to provide a comfortable and non-intrusive rehabilitation environment for the patient.

In the system we present here, a computer vision based sensing unit is employed for sensing an upper extremity neural prosthesis. The video devices include an ordinary web-camera (webcam) and a mid-range laptop computer. Currently with color markers worn on the subject's arm, the sensing system is able to infer the 3-D position information from the video captured by the camera. The technical details for the vision based sensing unit are described in [1].

The distinct advantage of our approach is that there are no intrusive magnetic or electrical devices attached to the patient's body. In fact, by employing more advanced computer vision techniques, vision based algorithms can work even without colored markers. Such a vision system usually uses two cameras instead of one for stereo 3-D recovery. Another advantage is that the sensors are able to detect the 3-D position of any specified object in the scene, which is usually impossible for other types of sensors.

Since the sensing unit is independent from the controller and modeling unit, it is also able to be incorporated with different type of sensors, such as goniometers. With multiple sensor outputs fed to the controller, the sensing result can be more reliable and accurate. Figure 2 shows the vision based sensing unit structure.

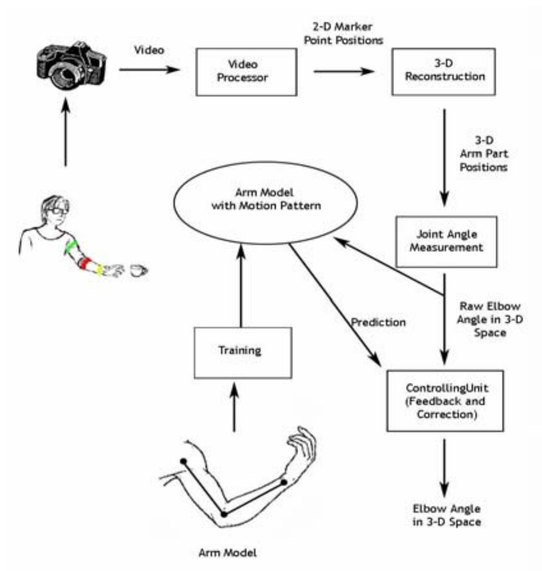

Figure 2. Sensing Unit Structure

2.2. Human Arm Motion Modeling Based on Articulated Link Model

Much work has been done in the past on human body modeling, especially in the area of biomedical engineering and computer graphics. The model we present in this paper is an articulated link model that represents upper limb posture with joint angle configuration. In contrast with previous modeling approaches in biomedical engineering area, there is no muscle modeling and stimulation involved in our model, and only the motion information is included. With both forward and inverse kinematics, the model is able to simulate the movement of an arm given joint angle configuration, and can also solve for a possible pathway to reach the destination point given the hand's position in the global universe. Integrating the arm position over time, the pathway is naturally turned into a trajectory which can be used for both guidance and prediction by the controller.

Using the techniques well established in Robotics, the arm without muscles can be simplified as an articulated link model, which consists of the shoulder, elbow and wrist joints, all of which are mathematically represented revolute joints (the type of joint that can only allow rotation of one degree of freedom). The hand is considered as an end effector, yet detail structures are also built as subunits. The structure is shown in the Results section.

2.3. Behavior Control and Future Direction: Information Fusion

The goal of the system design is to achieve closed-loop control. Based upon the stimulation offered by various kinds of stimulators and the observed limb motion, with the trained limb model that includes the presumed motion pattern, the system can smooth the tracking result, guide the stimulation with an inverse solution of the possible trajectory, and generate triggers when the joint configuration reaches a pre-set range.

In the near future, the system is required to be able to accept multiple types of sensor input, thus an information fusion mechanism is proposed as a solution to integrate the information from different sources with different error ranges. One possible fusion tool is Kalman filter which has been widely used in various engineering tasks, such as integrating input from multiple cameras in video surveillance systems [2]. With the fusion mechanism, the sensing becomes a hybrid approach which can keep the advantages of different types of sensors, thus use the information as efficiently as possible. With the previous success in the work of other areas, it is very promising that the information fusion mechanism will contribute to improve the system performance.

3. RESULTS

3.1. Sensing Unit

Benchmarking of the vision based sensing unit was done by comparing it to the Shape Sensor™ S700 manufactured by Measurand Inc. The input source was a Logitech webcam, which offered video with a resolution of 640*480. Four key degrees of elbow angles were selected, which were 45, 90, 135 and 180 degrees. The experiments were done over a total time of 30 minutes, which included about 3,000 times the arm reached the above key elbow angles. Table 1 shows the statistics of the results.

Table 1. Benchmarking With Shape Sensor™ S700

S700	45º	90º	135º	180º
Vision Sensor (Med)	37.6º	78.3º	122.7º	178.2º
Vision Sensor (Std.)	8.5º	9.2º	6.4º	4.9º
Accuracy	83.6%	87.0%	90.9%	98.9%

3.2. Modeling Unit

The articulated link model structure is shown in Table 2 and Figure 3. Also, a visualization interface is shown.

Table 2. Arm Structure

Joints	Joint Type	#Joints Used	#DoFs
shoulder	revolute	3	3
elbow	revolute	2	2
wrist	revolute	1	1
fingers	revolute	3 / each	3 / each

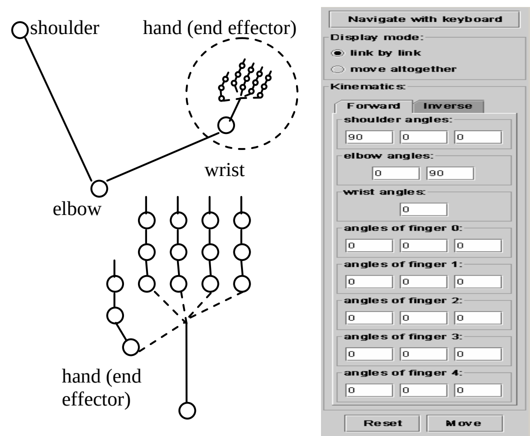

Figure 3. Arm Articulated Link Structure

4. DISCUSSION AND CONCLUSIONS

In this paper we present an FES system design for neural prostheses, in which the sensing can be achieved by both traditional physical sensors and vision-based sensors. To handle multiple types of sensor input a fusion mechanism is proposed to integrate information from different sources with different error ranges to form a hybrid sensing system with high accuracy. The articulated link model of the arm serves as a destination trajectory generator, as well as a motion predictor with the learned motion patterns. The experiments show the preliminary results to verify the system design.

The highlight of the approach is the vision based approach in sensing. In fact, integration of the vision component into control systems is a widely accepted approach in many other application areas, such as robotics and human-computer interface design based on mixed reality. The use of vision based approaches in sensing applications for FES may hence be a possible system design choice in the future given that image analysis and processing are already widely used in biomedical applications.

References

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