THE DEVELOPMENT OF A PROSTHETIC ARM

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ABSTRACT

Aimed at improving the quality of life for amputees, this project investigates the design of a prosthetic arm to mimic its human counterpart. In particular it examines alternative mechanisms to data acquisition and transmission.

This paper provides the basis for the development of a prosthetic limb that operates as a part of the human body's neural network. As opposed to a conventional prosthesis that only provides motion of the extremity, this design aims to lay the foundations for incorporation of added sensory feedback into the nervous system so as to provide the tactile sensations experienced by a human arm. The transform of the input signals to the required output location is done with traditional coordinate reference systems.

The physical structure of the hand has been modelled such that it can be easily assembled. It has been simplified such that it only has six of the twenty degrees of freedom while retaining some of the important motions of the human hand. A two-finger model has been constructed. This model exhibits the full range of motion required to grip an object with some degree of force. A virtual reality model package has been developed in visual basic to control the model in such a manner that it is able to demonstrate the potential of the project.

KEYWORDS: Prosthetic Limb, Robotic Arm, Anthropomorphic Design, Neural Network

1. LITERATURE REVIEW

The design and construction of robotic arms has been undertaken by a number of research institutions. These designs vary depending upon the intended use of the hand. A variety of different actuation methods have been used. The Novel Dexterous Hand uses motors located at remote positions to operate the joints of the fingers through cables attached much like the tendons of the human hand [1]. Hands such as the All Electric Prosthetic Hand utilise a series of gears to transmit the motion of motors housed in the forearm to the relevant fingers [2]. Other designs have the actuators transmitting the power directly to the joint. An example of this is the Anthroform Arm, which uses pneumatic 'muscles' mimicking the muscles of the human arm connected directly to the 'bones' it moves [3]. Shape Memory Alloy wires are also used, to both provide the force and transmit the motion. SMA wires contract when heated and return to their initial shape when cooled [4]. This method of actuation is utilised in the Shape Memory Alloy Activated Hand constructed by DeLaurentis et al [6].

Previous robotic hand designs have focused on the mechanical issues of the construction and operation of the prosthesis. Most prostheses are controlled using methods that are not intuitive, such as using the contraction of muscles of the opposite arm to close and open a prosthetic hand. No research has been identified that investigates the control of prostheses directly from the body's neural network, which is a more natural control. This project attempts to lay the foundation for an arm that can mimic the human arm, with an intuitive method of control.

2. DESIGN SPECIFICATIONS

Due to the complex nature of this project and its constraints, the project has been developed in two separate stages. To maintain a holistic approach, an ideal design featuring interaction with the human bodies nervous system has been undertaken in parallel with a simplified model. The purpose of the simplified model is to demonstrate some of the design and operation concepts involved in the ideal design. The two designs have been developed concurrently to ensure that design issues are considered and allowed for in both models. The design guidelines for each model used are listed below.

<u>Ideal Model</u>

- 26 degrees of freedom in the arm
- Fully functional hand
- Sensory feedback
- Exterior with a lifelike appearance
- Human structural form
- Minimal psychological impact on the amputee
- Controlled from the body's neural network
- Similar physical workspace to a human arm

<u>Constructed Model</u>

- 6 controlled degrees of freedom in the arm
- Retain as much functionality as is possible to a human hand
- Driven from a computer based control interface
- Similar physical workspace to a human arm

3. CONSTRUCTED MODEL

The components of the model system are outlined in the following sections.

3.1 Structure

The major design issues involved in the prosthetic's mechanical structure are the joint types, physical stops and the shape of the fingers and thumb. Pin joints allow motion in only one plane making them suitable for all of the joints except the shoulder and knuckle joints. A ball and socket joint allows for motion in two planes as well as rotation, this rotational motion needs to be restricted in the knuckle joints. The motion of a knuckle can be achieved by having two pin joints, one after the other, with the axes perpendicular to each other.

A minimum of three fully controlled fingers are required to achieve a stable grasp [1] if the fingers are not fully controlled it is not possible to apply a stable grasp. Even though the length of each cable remains the same when the finger has a force applied to it the links change position as shown in Figure 1, this is because it is not possible to control three degrees of freedom with only one restraint.

The structural design has undergone several revisions in the prototyping of the model. The initial design consisted of four fingers and a thumb attached to a palm, all of which were to be constructed from aluminium sheet metal. Actuation was to be provided using a servo motor driving a belt, through a series of pulleys to the joint requiring motion. This design was altered as it became overly complicated to create relative motion between the joints in one finger when only one motor was being used to drive three degrees of freedom in the finger.

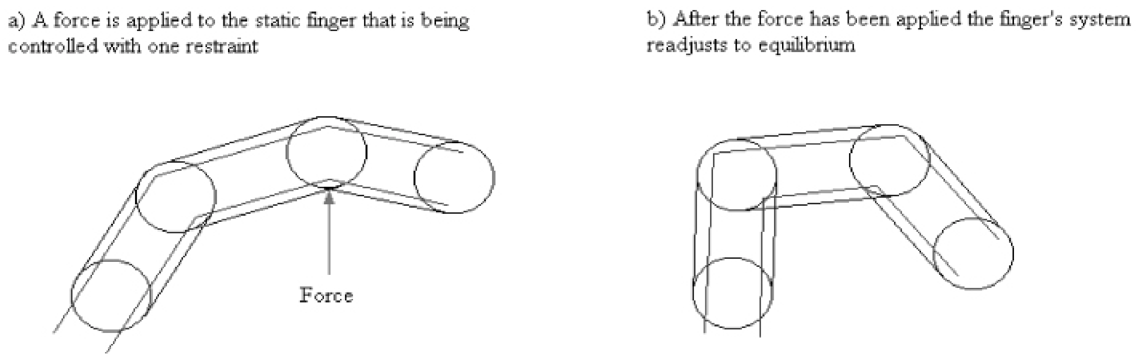

Figure 1: The Operation of a Finger with One Restraint

The model was altered such that an artificial tendon was attached to the end link of the finger and threaded through a series of pins inside the finger to the motor. The materiel for the links was changed to Delrin. Delrin is a stiff bearing material, therefore the stainless steel pins are able to rotate in it without the need for extra bearings. This design was able to give the required flexion with a small force however there was a large frictional force encountered in extension as the artificial tendon encountered too much friction from travelling around the pins.

To overcome this deficiency, the path for the cord was altered to a straight line when the finger is in its extended state. A series of mechanical stops where added so that the fingers would remain within the workspace of the human hand. This design can be seen in Figures 2 and 3.

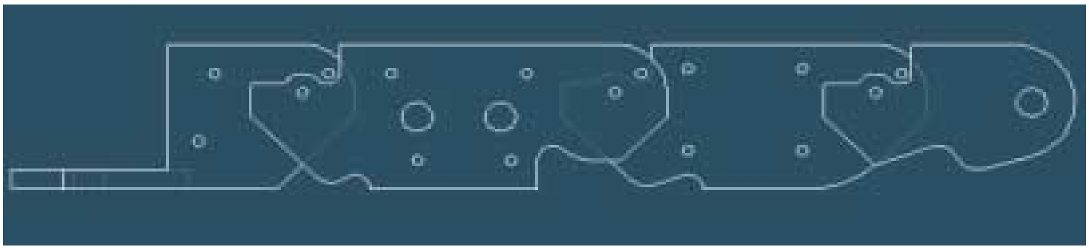

Figure 2: Finger Design Showing Mechanical Stops to Restrict Motion

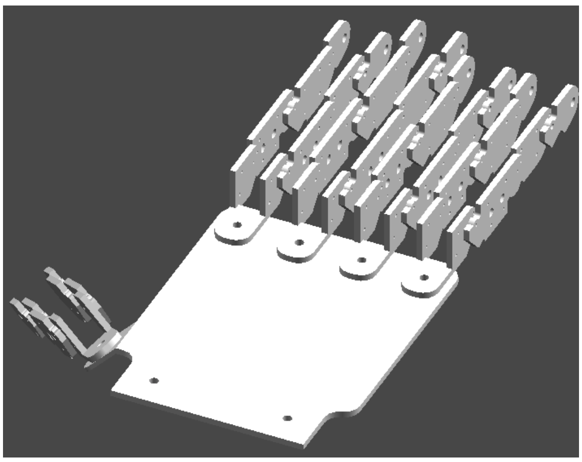

Figure 3: Entire Hand Design for Construction

The final alteration to the design of the model was to incorporate grasp so that the hand is capable of applying a gripping force. To achieve this the thumb was set to be permanently opposed to the fingers, with three degrees of freedom in the thumb and index finger such that there is no adduction and abduction in either of the digits.

3.2 Actuation

The final design utilises a number of servo motors to actuate the fingers. Servo motors are DC motors that contain built in encoders, such that the motor can be sent to a specific angle using pulse width modulation. They have a high torque to size ratios and low weight to size ratio [5]. The size of the servo motors makes them impractical for use in the ideal design. As the aim of the model is to demonstrate the potential of the project the servo motors do however provide a simple method of accurately altering the length of the artificial tendon.

The specifications for the servo motors chosen for the model are shown in Table 1. These specifications meet the requirements to move the finger sections at an acceptable speed as well as providing force feedback. This can be achieved by measuring the current through the motor, when the finger touches an object and wants to move through it the motor will physically become stuck. This will cause the controller PID algorithm in the servo motor’s inbuilt control logic to generate a large integral term and cause the motor to try to output a larger torque, resulting in an increased current in the motor.

Torque	5kg/cm
Weight	46g
Speed	60 degrees in 0.21 seconds
Dimensions	40mm long x 20mm wide x 40mm high

Table 1: S03TXF STD Grand Wing Servo Specifications

3.3 Control

The position of each servo motor is controlled using pulse width modulation. Control of the motors is achieved by sending information from a PC down the serial line to the appropriate motor controller. The information sent down the serial line is encoded such that it contains both the desired location and the number of the requested motor. This information is sent to all of the motor control circuits, which are attached in a daisy chain configuration. The micro-controller in each control circuit determines if the request is for its motor by checking the number of the requested motor against the number of its motor. If required it translates the desired location into a pulse width signal that it outputs to the motor until a new position request is sent to each circuit. If it is not required the controller continues to output the last requested signal for its motor.

Each micro-controller has two timers, one is required to continually output a pulse to hold the motor at its current position and the other is required for the operation of the micro-controller, including data acquisition. Each motor therefore requires a micro controller for operation. Once the circuit accepts the information, it then converts the signal into the appropriate pulse output to hold the motor at the correct position.

To demonstrate the real time nature of the system a simulation has been written in visual basic such that the model on the screen reflects the motions of the constructed model. The simulation takes the same data that is sent to the model, this displays the desired outcome of the data such that a comparison can be made between the actual and desired output.

4. IDEAL MODEL

The method of data acquisition and transfer in the system is of particular interest in the ideal model. To determine the best method of data acquisition three factors need to be taken into consideration. The main concern in this project is to improve the quality of life for the recipient of the artificial limb. For this reason the safety aspects of any complications in the system is of utmost importance. The second priority in the design selection is the psychological impact of the prosthetic's interaction with the peripheral nervous system. The third consideration is the ease of data extraction and interpretation from the body's neural network.

4.1 Brain Implant

The human body's nervous system is a network of nerve cells that connect every part of tissue in the human body [7]. Experiments with monkeys have shown that if the data is taken directly from the primary motor cortex, motion of the arm can be predicted at least one tenth of a second before the arm moves [8]. This is done based on the pattern that forms when the neurons fire. Less than one hundred brain cells are required to generate an accurate prediction of the arm's motion [8].

This method of data acquisition has the advantage that it does not cause cell degradation, as the hair thin electrodes do not apply any charge to the cell [8]. Simple mathematical models and an artificial neural network have been used to accurately predict the hands trajectory in real time. The downfall of this method of data acquisition is the psychological impact that may result on the person from the idea of having a "chip" in their brain.

Sensory feedback information from the hand comes in the form of contact, pressure, cold, heat and pain. This information could be feed directly back into the brain through the thalamus however this poses the inherent danger of cell damage in the neurons which would result in a loss in feedback from other parts of the body. For this reason sensory feedback is best done through the peripheral nervous system.

4.2 Peripheral nervous system interaction

When an extremity of the human body is removed the brain is still able to send information through the nervous system to where the extremity was. In the case of arm movement the signals are sent from the motor cortex down the spinal cord, through a spinal nerve to a network near the shoulder where the directions for each finger are sent along either the Radial nerve, Median nerve or the Ulnar nerve [7]. Each nerve consists of thousands of fibres, each fibre can carry an individual message.

Propagation of the signal from the nervous system to the prosthetic can be achieved using a bionic chip that acts as an interface between organic and mechanical systems. This technology has been developed at Berkley University [9] and is able to integrate itself into the human body's system without the immune system treating it as a foreign object. This method of data transmission has the advantage that it would be possible to send information back to the brain to provide tactile sensory feedback.

5. FUTURE WORK

The project requires the addition of the other fourteen degrees of freedom such that the prosthetic is able to mimic its biological counterpart. To achieve the desired performance characteristics within the confined space of the ideal arm design, SMA wires are suggested for actuation. This alternative method of actuation will determine the power requirements for the new design.

Several areas require further research and development so that the prosthetic will be able to function as a part of the human body's neural network. The levels of acceptable neuron stimulation without cell damage need to be investigated. Also the method of attaching the prosthetic to the human nervous system needs to be determined. Finally the method of interpretation and implementation of the acquired data, to generate the desired motion, needs to be established based upon the point and means of data extraction chosen.

6. CONCLUSIONS

The project has successfully demonstrated the potential of the hands design as well as providing insight into improvements of the design. With the basis of the theoretical model completed and the mechanics functioning smoothly the initial step in the process of manufacturing a prosthetic arm that is attached to the body's neural network has been completed.

7. ACKNOWLEDGEMENTS

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