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DESIGN AND FABRICATION OF A NOVEL ARTIFICIAL HAND BASED ON A "BIOMECHATRONIC"

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ABSTRACT
An "ideal" artificial hand should match the requirements of prosthetics and humanoid robotics. It can be wearable by the user which means that it can be perceived as part of the natural body and should replicate sensory-motor capabilities of the natural hand. However, such an ideal bionic prosthesis is still far from reality. This paper describes the design and fabrication of a novel artificial hand based on a "biomechatronic" and cybernetic approach. The approach is aimed at providing "natural" sensory-motor co-ordination, biomimetic mechanisms, and force and position sensors, actuators and control, and by interfacing the hand with the peripheral nervous system. This paper presents a design of an anthropomorphic biomechatronic hand, focusing on the design of the fingers & its bio-inspired flexor-extensor like low level control. Mat lab simulation result & also the first experiment of the approach can be an effective solution for the need of a hand like actuator in robotics.

Keywords- Biomechatronic Hand, Actuator, Position Sensors

1. Introduction

The objective of the work describe in this paper is to develop an artificial hand aimed at replicating the appearance and performance of the natural hand the ultimate goal of this research is to obtain a complete functional substitution of the natural hand. This means that the artificial hand should be felt by the user as the part of his/her own body and it should provide the user with the same functions of natural hand.

In medicine, prosthesis is an artificial extension that replaces a missing body part. It is part of the field of biomechatronic. Prostheses are typically used to replace parts lost by injury or missing from birth or to supplement defective body parts.

According to analysis of the state of art, the main problems to be solved in order to improve the performance of prosthetic hands are

1) Lack of sensory information gives to the amputee;
2) Lack of "natural" command interface;
3) Limited grasping capabilities;
4) Unnatural movements of fingers during grasping.

In order to solve these problems, we are developing a biomechatronic hand, designed according to mechatronic concepts.

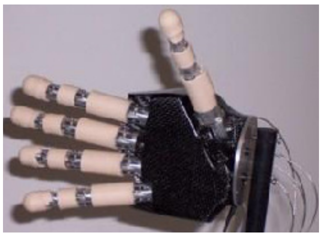

Fig.1-: Biomechatronic hand

2. Design Of The Biomechatronic Hand

A. Biomechatronic Design

The main requirements to be considered since the very beginning of prosthetic hand design are the following: cosmetics, controllability, noiselessness, lightness, and low energy consumption. These requirements can be fulfilled by an integrated design approach aimed at embedding different functions within a housing closely replicating the size, shape and appearance of the human hand. This approach can be synthesized with the term: "biomechatronic" design.

Table 1-: Table for Mechanical characteristics

Nominal force	12N
Maximum speed	20 mm/s
Weight	3.2 g
Maximum load (axial)	40 N
Maximum load (radial)	25 N
Transmission rate	1:125
Gear stages	3

B. Controller and Actuator

1) Controller -:

The controller in a biomechatronic device which relays the user's intentions to the actuators. It also interprets feedback information to the user that comes from the biosensors and mechanical sensors. The other function of the controller is to control the biomechatronic device's movements.

2) Actuator -:

The actuator is an artificial muscle. It's job is to produce force and movement. Depending on whether the device is orthotic or prosthetic the actuator can be a motor that assists or replaces the user's original muscle.

C. Kinematics Architecture

The kinematics of each finger joint is described in the following subsections.

1) MP joint: The proximal actuator is integrated in the palm and transmits the movement through a slider –crank mechanism to the proximal phalanx, thus, providing flexion/extension movement. The slider is driven by the lead screw transmission mounted directly on the motor shaft.

2) PIP joint: The same mechanism used for MP moves the PIP joint. Only the geometrical features in order that the size of the mechanism fits within the space available according to the strict specification of the biomechatronic hand.

3) DIP joint: A four bars link has been adopted for the DIP joint and its geometrical features have been designed in order to reproduce as closely as possible the natural DIP joint flexion. The mechanism has been synthesized according to the three prescribed position method.

Due to the high transmission rate (planetary Gears and lead screw transmission) friction is high and, thus, the joints are not back-drivable. This causes problem in controlling accurately in hand. However the positive side effect of friction is that the grasping forces can be exerted even when power supply is off, a very important function for hand prostheses.

D. Finger Design

The index/middle finger has been designed by reproducing, as closely as possible, the size and kinematics of a human finger. Each finger consists of three phalanges, and a palm needed to house the proximal actuator.

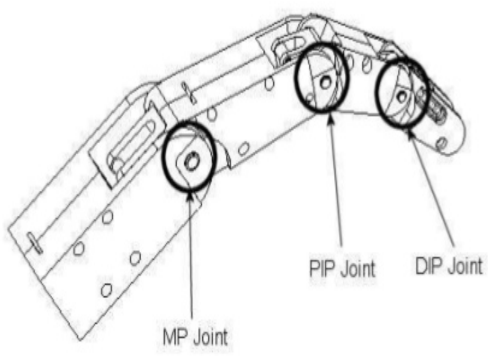

Fig. 2-: Finger design

E. Thumb Design

The thumb has been designed to perform grasping task by thumb opposition. The thumb has been obtained by simply removing the distal phalanx from the index/middle finger.

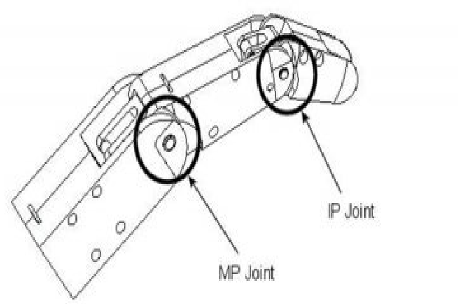

Fig. 3-: Thumb design

3. Hand Fabrications

The hand protected comprises the three fingers (index, middle and thumb), each with two-DOF's actuated by micro motors and sensorised by hall-effect position sensors and by strain gauge-based force sensors. The characteristics of the position sensors and the force sensors are illustrated in following sections.

The three fingers have been fabricated using the Fused Deposition Modeling (FDM) process. This process allows obtaining 3-E complex shapes from CAD models easily, quickly, and cheaply. The main limitation of the FDM process resides in poor mechanical characteristics of the material that must be used, which is acrylonitrile/butadiene/(ABS) however this is acceptable for a prototype.

Fig. 4-: Hand fabrications

A. Natural Hand

Fig.5-: Natural hand

B. Biomechatronic Hand

Fig.6-: The socket containing motors and control electronics.

4. How It Works

Biomechatronic devices have to be based on how the human body works. For example, four different steps must occur to be able to lift the foot to walk. First, impulses from the motor center of the brain are sent to the foot and leg muscles. Next the nerve cells in the feet send information to the brain telling it to adjust the muscle groups or amount of force required to walk across the ground. Different amounts of force are applied depending on the type of surface being walked across. The leg's muscle spindle nerve cells then sense and send the position of the floor back up to the brain. Finally, when the foot is raised to step, signals are sent to muscles in the leg and foot to set it down.

A. Biosensors

Biosensors are used to detect what the user wants to do or their intentions. In some devices the information can be relayed by the user's nervous system or muscle system. This information is related by the biosensor to a controller which can be located inside or outside the biomechatronic device. In addition biosensors receive information about the limb position and force from the limb and actuator. Biosensors come in a variety of forms. They can be wires which detect electrical activity, needle electrodes implanted in muscles, and electrode arrays with nerves growing through them.
4.2) Mechanical Sensors-:
The purpose of the mechanical sensors is to measure information about the biomechatronic device and relate that information to the biosensor or controller.

5. Position And Force Sensors

A. Sensors

Sensors are used as peripheral devices in robotics include both simple types such as limit switches and sophisticated type such as machine vision systems. Of course sensors are also used as integral components of the robots position feed back control system. Their function in a robotic work cell is to permit the robotic activities to be co-ordinate with other activities of the cell.

B. Use Of Sensors In Robotics

The major use of sensors in robotics and other automated manufacturing systems can be divided in to four basic categories.
1) Safety monitoring.
2) Inter locks in work cell control.
3) Part inspection for quality control.
4) Determining position and related information about objects in the robot cell.

C. Types Of Sensors Used In Robotics

1) Tactile Sensor: These are sensors, which respond to contact forces with another object; some

of these devices are capable of measuring the level of force involved.

2) Proximity And Range Sensor: A proximity sensor that indicates when an object is close to another object but before contact has been made. When the distance between the objects can be sensed, the device is called a range sensor.

3) Position Sensors

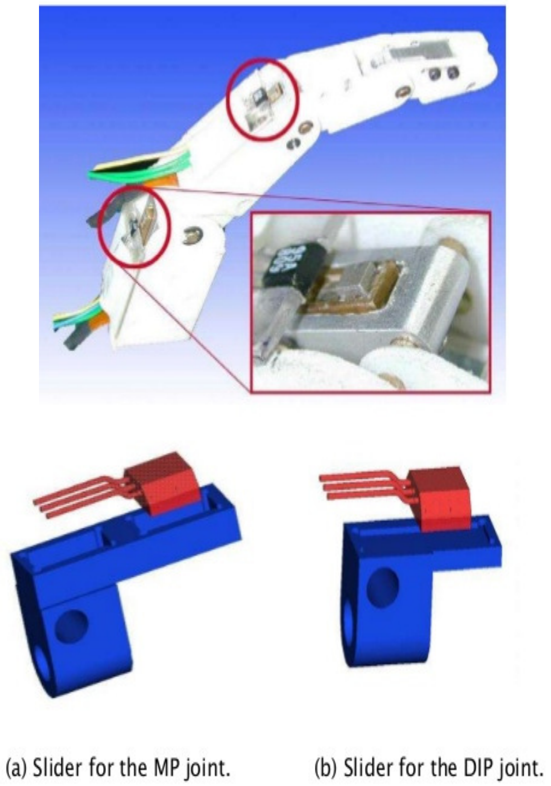

Fig.7-: Position sensors

A position sensor, based on the Hall Effect sensor is mounted at each active joint of the hand. The main advantages of Hall Effect sensors are there small sizes and their contact less working principle. In each finger, the hall sensors are fixed, respectively, to the palm and to the proximal phalanxes, where as the magnets are mounted directly on the sliders of each joint.
In this configuration the sensor measures the linear movement of the slider, which is related to the angular position of the joint. In each MP joint, the linear range of the sensor is 5.2mm, where as in the PIP joint the linear range is 8mm.

Using a micrometric translator stage we found optimal configurations for the position sensors. In the first optimal configurations two magnets are used at a distance of 3.5 mm this configuration has a working range of 5.4mm with a linearity of 5.34%. The second optimal configuration (suitable for MP joints) has six magnets and a working range of 8.4mm with a linearity of 3.81%.

D. Hall Effect Sensors
When a beam of charged particles passes through a magnetic field, forces act on the particles and the beam is deflected from its straight line path. A current flowing in a conductor is like a beam of moving charges and thus can be deflected by magnetic field. This effect is known as hall effect. Consider electrons moving in a conductive plate with a magnetic field placed at right angles to the plane of the plate. As a consequence of magnetic field, the moving electrons are deflected to one side of the plate and thus that side becomes negatively charged while the opposite side becomes positively charged since the electrons are directed away from it.
This charge separation produces an electric field in the material. The separation continues until the forces on the charged particles from the electric field just balance the forces produced by the magnetic field. The result is a transverse potential difference given by

$$V=KhBI/t$$

Where,
B is the magnetic flux density at right angles to the plate, I current through the plate, t the plate thickness, K the constant called Hall Co-efficient. Thus if a constant current source is used with a particular sensor, the Hall voltage is a measure of the magnetic flux density
Hall effect sensors are generally supplied as in integrated circuit with the necessary signal processing circuitry. These are two basic forms of such sensor, linear where the output varies in a reasonably linear manner with the magnetic flux density and threshold where the output shows a sharp drop at particular flux density.

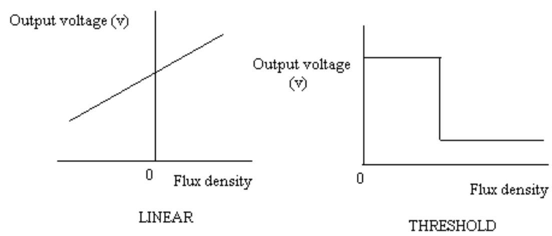

Fig. 8-: Calibration curve of the effect sensor

F. 2D Force Sensors

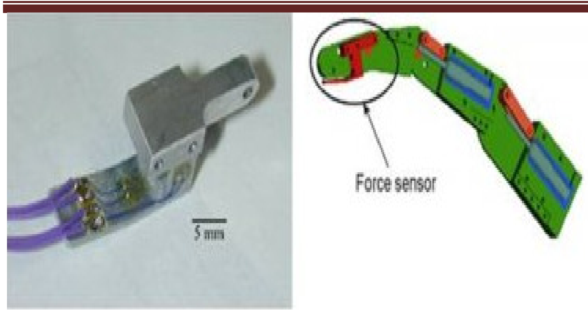

Fig.9-: Force sensors

A 2-D force sensor, based on strain gauge technology, has been developed in order to sensorize the distal phalanx of the index and middle fingers. The sensor design has been optimized using the Pro/Mechanical structure software.

G. Sensors Characterization

1) Characterization of position sensors: We found that the best simplest way to characterize these sensors is use an optical method. Used a Nikon Coolpix 950 digital camera mounted on a tripod I order to record the movement of the finger. The movement of each Smoovy actuator was driven by a CCS00001 controller (RMB, CH).each controller has a power supply of 11V, while each sensor was supplied with 6V.

For each active joint 100 different frames, 50 for flexion and 50 for extension movements where acquired. For each frame the output value of the sensor was measured with a digital multimeter and recorded, where as the position of the joint was measured using the module measures to Adobe Photoshop 5.5 with a precision of 0.1°.

Results are represented in fig 8. For the sensor in MP joints and in the PIP joints, respectively. The flexion phase is indicated with a small dark circles, while the extension is indicated small light squares.

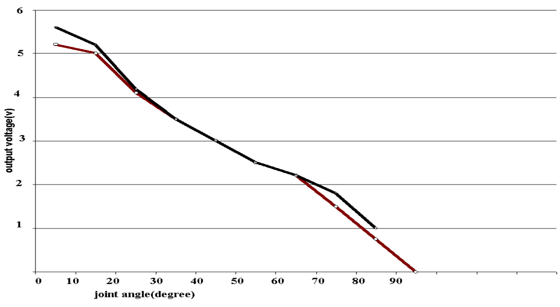

Fig. 10-: Calibration curve of the joint angle

It is important to point out the both curves for both sensors generally present low hysterieses. The difference between the flexion and the extension curves is mainly due to the mechanical clearance of the sensorised slider.

2) Characterization of 2-D force sensor: The force sensor was characterized using an INSTRON 4464 testing machine.

A traction-compression loading cycle (0N-10N-0-N) was performed for each direction. Results are presented in fig 9, for the normal loading direction and the tangential loading direction respectively. Diagram show a linear behaviour of the 2-D force sensor.

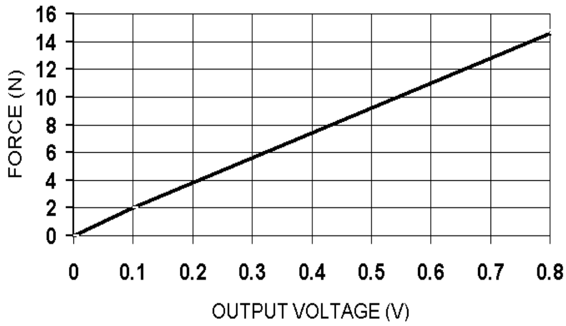

Fig. 11-: Calibration curve of the force sensor

6. Fingered Trip Force Analysis

A first set of experimental test has been performed in order to evaluate the force that the index /middle finger is able to exert on an external object. To this aim we are measuring the force resulting when the finger is pressing directly on the high accuracy piezo electric load cell corresponding to different configurations of the joints.

To pressing task were identified in order to evaluate separately and independently the force generated by actuators of the fingers.

TASK 1: The pushing action is exerted only by the distal actuator.

TASK 2: The pushing action is exerted only by the proximal actuator.

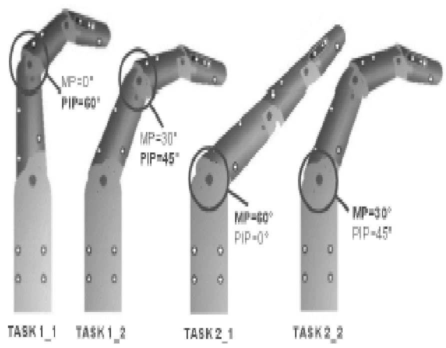

Fig.12-: Positions of fingers joints

The ten tests were performed for each subtask. The results obtained are illustrated in the fig11.

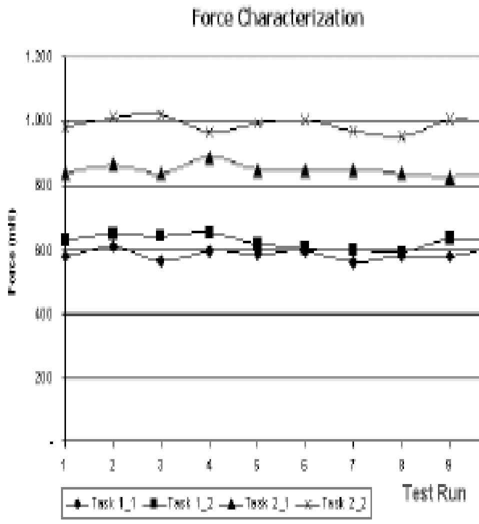

Fig.13-: Calibration curve for force characteristics

7. CONCLUSIONS

In this paper, novel approach to the design and fabrication of prosthetic hands, called biomechatronic design, has been presented. The biomechatronic design consists of integrating multiple DOF'S finger mechanisms, multisensing capabilities and distributed control in order to obtain human like appearance, simple and direct controllability and low mass. The biomechatronic design approach can lead to the development of hand and prostheses, when combined with other important factors, such as low energy consumption for adequate autonomy (at least 8 hours between recharges), noiseless operation for not disrupting social interactions, cost suitable for support by the health insurance system and above all sensory feedback to the amputee through interfaces. A biomechatronic hand prototype with three fingers and a total of six DOF's has been designed and fabricated.

Current work is directed to improve the limitations of the prosthesis is presented in this paper. First of all, a new design has been designed aimed at increasing the grasping force of the hand while retaining the main positive characteristics of previous design .The new hand architecture is based on under actuated mechanisms, comprising a total of two dc motors. The hand has nine independent DOF's (so it can still grasp rather effectively objects of complex shape) and can generate grasping force of about 30N.

8. FUTURE IMPROVEMENTS

Natural fingers movements during grasping activities will be further investigated in order to achieve a truly human like behavior of the artificial finger. Force sensor measurements will be further investigated in order to sense incipient slippage and to obtain force sensing abilities. When we joined the backbone's blood cells with any muscles then patient will move hand or leg (by using nervous system).

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