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Investigation Into Use of Soft Robotic End Effector For Assistive Gripping

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Abstract - *Researchers and scientists alike have been searching for inexpensive, robust, and a comparable substitute which integrate the functionality, compliance, versatility, and strength of human arms. Some measure of progress has been achieved in case of metal or alloy made prostheses or orthotics, composite layered bionic arms etc. However these models are hard to design and costly to make. Also, though they exhibit excellent strength characteristics their range of movements is to a major degree constrained and limited. In lieu of such difficulties, the largely untapped area of soft robotic elements offers a feasible and viable solution. Materials such as soft elastomer and rubbers on integration with other available materials such as paper, cardboard or light plastic can be easily fabricated into a variety of designs to suit the requirements. The concept of PneuNet - an internal air channel or pneumatic network which can deform in a desired direction when restrained in a certain way is justifiably applicable in such situations. Rubber incorporated with PneuNets share similar compliance of human arms and demonstrates the same natural manner of deformation. Moreover, these are relatively inexpensive to prototype and are extremely versatile. In our present work, we have attempted to design and fabricate a soft robotic end effector which can primarily act as assistive prostheses. We also introduce an electronic control system based on flex sensors and the Micro-controller Arduino Mega 2560 coupled with the simple pneumatic circuit. The air flow control is achieved by a simple modified servo valve design which will also be discussed.*

Key Words: **Compliance**, **PneuNet**, **Assistive Prostheses**, **Micro-controller**, **Flex Sensor**, **Soft Robotic**, **End Effector**

1. INTRODUCTION

The area of soft robotics being applied in the field of medicine as substitutes for various organs of the body has been extensively researched. Most of the actuators that have been synthesized till now make use of the expansion and contraction property of elastomers mainly for cardiac assist devices. Actuators have also been made to replicate the muscular motions to some accurate degree. PneuNet actuators have been primarily made to simulate the finger motion giving some compliance to its motion.

Prototype models have been made with multiple PneuNet fingers to clone hand motion. For the real time dynamic control implantable electrodes have preferred, though piezo sensors, flex sensors, shape memory alloys etc. have also been looked at. Usually these sensors are integrated with a microcontroller like Arduino Uno or similar and input values being programmed to it. A range of materials including silicone elastomers, polyurethanes, plastic resins and shape memory alloys have been successfully incorporated into working prototypes and tested. However these soft structures have yet to improve upon their strength characteristics though they do possess a higher degree of compliance.

2 Concept of PneuNet

A PneuNet is an abbreviation for pneumatic network though more precisely it denotes an internal enclosed channel for its activation by the passage of compressed air ranging from 90kPa to more than 300kPa. These so called PneuNets gained attention with its first conceptualization by the Whitesides group working at the Bio lab at Harvard. From its inception, it has always been seen as a potential substitute for human tendons and muscles attributed mainly to its comparable compliance to that of a generic human muscle.

The construction of a PneuNet is an extremely simple process; all that is needed is to sandwich two thin flexible elastomer planes on top of one another and seal the edges off so that they are air tight. If pressurized air is allowed to flow into the internal orifice it pushes the soft rubbery layers from the inside so that they bulge out in accordance with the direction or mode in which the layers are constrained. The expanding layer deforms as a consequence of the work done by the pressurized air on it. This deformation may be constructively utilized in two ways, namely:

1. By constricting the deformation such that the final shape shifting of the elastomer occurs anisotropically.

2. By connecting elements to the deforming rubber layer in a manner that they are actuated by it.

PneuNets may be created by utilizing various available techniques some of them being soft lithography, stereo lithography, elastomer casting, flexible 3-D printing etc.

PneuNets can be synthesized in various configurations, shapes modes and designs to simulate, bend, actuate or deform exactly according to the required specifications of displacement, angle, velocity and force by merely constraining the corporeal structure and varying the supply pressure.

This makes PneuNets a fascinatingly versatile piece of hardware with potentially limitless applications across myriad field including those of medicine, soft robotics, food automation, inexpensive robots, orthotics, non-destructive inspections, pick and place operations and many more.

3 Sizing and Dimensioning of the Gripper

The average size of the human hand is naturally designed to achieve the highest functionality. The relative volumes occupied by the palm to the sizing of the fingers and the extra indented orientation of the thumb also provides for the best combination of factors that is required for all hand related operations. These considerations were taken into account and hence the following choices were made. The weight of the whole actuator does not exceed 438.6 g and the thumb is proportionally smaller and is suitably oriented. the PneuNet themselves are 24 mm x 18 mm with a 12.5 mm top curvature radius and the internal air channel is about 1mm in thickness. The whole length of one actuator (finger) is about 178.45mm long. This slightly exaggerated length was chosen to study the PneuNet operation with more precision. The molds for the finger actuators were adapted from standard available designs from the World Wide Web.

Fig -1: Soft Robotic End Effector

4. Modeling

The model was prepared using Solidworks 2016 in a 3 dimensional form for ease of simulation and analysis. The various internal air channels are represented and the model is slightly simplified to ease up the simulation process. Care is taken to accurately represent each and every feature so that the structure of mold, placement of cores, sizing, and overall multi-part assemblies may be clearly visualized. After the 3-D model is created, each file representing a mold which is to be 3-D printed is converted into a .stl file. The various parts of the soft robotic end effector which were CAD modeled are subdivided into two main categories namely:

1) Parts which form the mold

2) Parts which are form the finger fixtures

3. Simulation and FEM Analysis of soft robotic finger

To gauge the behavior of a PneuNet, a rudimentary FEA was carried out on Solidworks 2016. For the simulation 3 conditions were chosen which are:

- A single PneuNet was sketched and the various stresses and strains acting on it for a variety of loads were tested.

- A simplified model of finger with PneuNets incorporated was modeled and analyzed for whole body behavior

- Another conceptual simplified model was tested with Simulia-Abaqus, a standard FEM Package for accurate deformation rate and stresses acting on it.

- The general steps that were followed for the analysis of a single PneuNet in Solidworks Simulation were:

1. CAD Modeling of the structure of PneuNet or PneuNet finger in the software package

2. Assigning material properties to the structure. In our case, rubber was the material used. The properties of rubber chosen were based on its average exhibited properties.

3. The body is then assigned fixture conditions so that the deformation about the fixture may be determined.

4. External and Internal Loading: The various loads acting on the body are assigned next. For our analysis, a constant internal pressure loading condition of 1 psi was selected and applied.

5. Mesh: Mesh size was selected as fine mesh for precision and clarity in final results. The mesh parameters were rounded of for uniform mesh size. Triangular mesh was selected for simplicity of analyses.

6. The study was then run and the results were then tabulated and conclusions drawn.

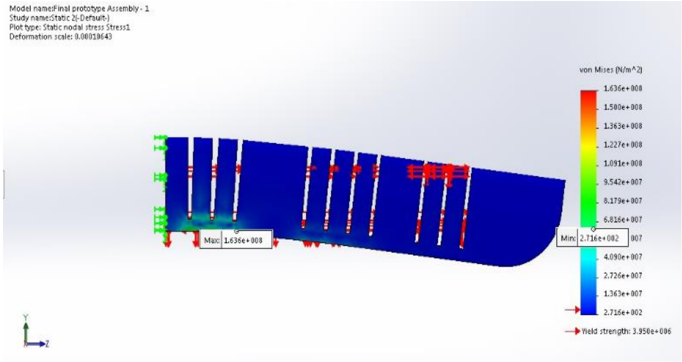

Fig -2: SolidWorks simulation of the PneuNet based finger

5. Fabrication Details

- The molds for the soft robotic finger components were generated by 3-D printing as elucidated before.
- The elastomer solution was prepared by thoroughly mixing the part A and part B constituents of the rubber solution together in the prescribed 1:1 ratio.
- The stirred solution was then poured into the molds slowly and with caution keeping in attention to uniformly fill all the cavities with rubber solution.
- The casting process was repeated for all the 4 other finger-molds, 2 thumb molds, 1 thumb pad, 1 palm skin and 1 palm pad.
- The curing time for Dragon Skin 20(Smooth-On Inc.) ranges from 4-6 hours during which the solution must be kept in a relatively cool and undisturbed place.
- After the curing was completed the molds were broken apart in order to obtain the final soft robotic part.
- One advantage of the used rubber was that the use of a release agent to facilitate product removal was efficiently eliminated.
- The assembly of the soft robotic gripper followed the completion of the molding process.
- Each soft robotic finger component was connected to its corresponding base bone part using cyanoacrylate solution for strong adhesive bonding.
- 1/16” tubes were inserted in the supply channels of each part to facilitate compressed air supply.
- The finger bone sub assembly themselves were bolted to the main palm and the same procedure carried out with the thumb.
- The thumb finger base bone has a pivoted connection to enable slightly free movement.
- The said pivoted joint was elevated in correct position using some pieces of black anti-static foam.
- The palm pad and thumb pad were glued in place and the skin inserted using strong adhesive bonding solution.
- The supply tubes themselves were connected to 3-way and 4-way connectors and finally joint to a common air supply manifold.

6. Results and Discussions

After the aforementioned simulation experiments were conducted and the results tabulated.

The following points were noted as points of interest:

1. We note that as the load applied on the finger (weight of the object being lifted) by the finger the bend angle shows a decreasing trend. This stands to logic as more the load applied equally greater will have to be the input pressure.

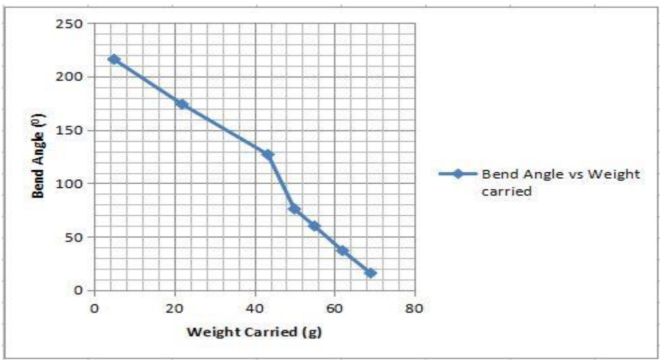

Chart -1: Graph of weight carried vs Bend Angle for Index Finger

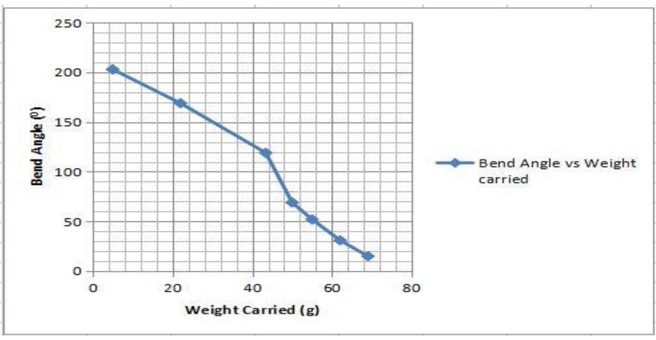

Chart 2: Graph of weight carried vs Bend Angle for Middle Finger

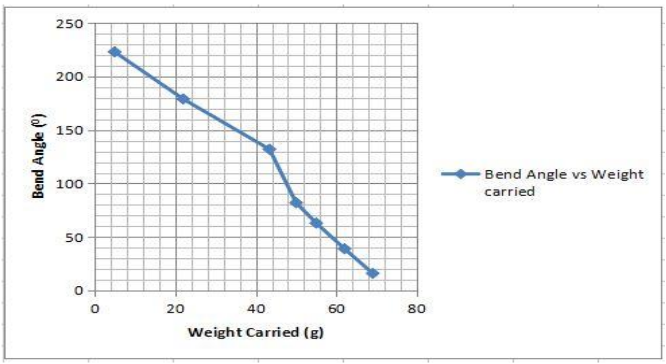

Chart -3: Graph of weight carried vs Bend Angle for Ring Finger

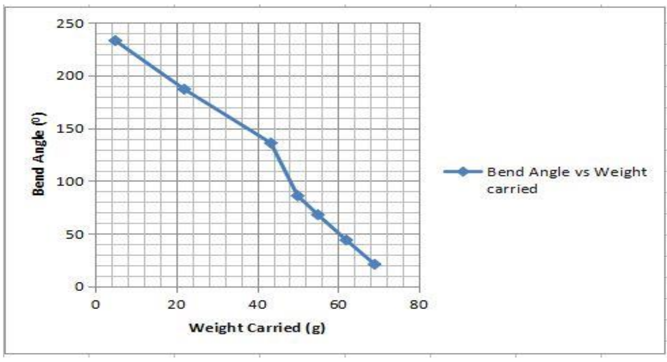

Chart -4: Graph of weight carried vs Bend Angle for Little Finger

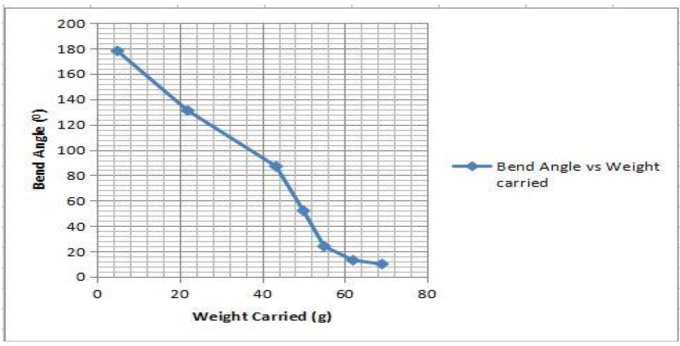

Chart -5: Graph of weight carried vs Bend Angle for Thumb Finger

2. The tip force of each finger depends upon the amount of input air discharge applied which increases in proportion. It also is observed that the size of the finger and the number of PneuNets per finger. Hence we see that the tip force exerted by the thumb is relatively less than that of the other fingers.

Table -1: Tip Force values of each finger

S NO.	FINGER	TIP FORCE (N)
1	Thumb	0.84366
2	Index	1.1962
3	Middle	1.03986
4	Ring	1.3734
5	Little	1.4715

3. The theoretical von Mises stresses, strains, and displacements for the solitary PneuNet, the finger actuator and the simplified model is obtained from the software simulation. The mode of operation and expected trajectory of motion may also be viewed.

Table -2: Values of Parameters For a Single PneuNet For input pressure of 1 psi obtained from Solidworks Simulation 2016

Parameter	Value
Maximum Von Mises Stress(N/mm^2)	2.254e+005
Minimum Von Mises Stress(N/mm^2)	2.283e+002
Maximum Displacement (mm)	2.341e+000
Minimum Displacement (mm)	1.000e-030

Table -3: Values of Parameters For a PneuNet finger For input pressure of 30 psi obtained from Solid works Simulation 2016

Parameter	Value
Maximum Von Mises Stress(N/mm^2)	1.636e+008
Minimum Von Mises Stress(N/mm^2)	2.716e+002
Maximum Displacement (mm)	1.015e+005
Minimum Displacement (mm)	1.000e-030

4. From among the bend angle values obtained, it is found out that the bend angles for the little finger were the greatest of the five while the thumb was expectedly the least for the same load. The case of the thumb finger is easily explainable as it has the lowest number of PneuNets. The variation of bend angles in case of the other fingers is mainly due to the difference in the amount of boundary separation of consecutive PneuNets. More the boundary separation within the limit greater is the space of expansion.

5. The attempt involving the incorporation of flex sensor for electronic control was partially successful. The servos operated are able to respond to the signals transmitted by the microcontroller as the result of flexure of the flex sensors but results in a lag of operation. This is attributed to the low sensitivity of the flex sensor, and certain play in the connections and its length. It is suggested that the same experiment may be carried out using a longer flex sensor.

Fig -3: Soft Robotic end effector with the flex sensor control glove

6. The experiments were conducted with a pump with a net discharge of 21 lpm. It was observed that for sustained and satisfactory bending an average discharge of about 1.5 to 1.8 times the mentioned value. It is presumed that higher bending may be observed with higher discharges of air. Also the pressure required for bending a finger actuator is about 30 psi which is also borne out by the literature.

7. On the basis of tip force and bend angle values obtained it is noticed that sufficient grip force and orientation to successfully grasp any object. The lifting capacity may be increased by increasing input air pressure and discharge.

7. CONCLUSIONS

Some of the conclusions made from this project are:

- PneuNets make for a viable and feasible idea for inexpensive body organ actuator.

- Actuation of soft actuators can be accomplished with low air pressure ranging from 0.1 to 5 bars.
- Deformation of PneuNet actuator is sufficient to cover the range of finger motion.
- Stresses developed in actuator during operation are well within the materials' yield stress values.
- The gripping is limited currently to light weight objects.
- With appropriate attachments and patient tailored hand size the PneuNet actuator may be succefully deployed as an assistive device for gripping objects.

8. SCOPE FOR FUTURE WORK

Some of the modifications which may be suggested for further improvement of the project are as follows:

- The sizing of the actuator could be made more compact by properly design the internal air channels.
- Other sensors or electrode based control elements may be introduced for better control.
- The addition of stiffening elements to the soft finger to reduce wobbling effects can be taken up.
- Lighter material substitutes for soft finger may be looked into.
- Miniature air compressors can be designed to supply power while reducing the weight.
- A complete attachment device to which the soft end effector can be connected and the other end be strapped in place of the organ.

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