Development and Application of a Gel Actuator for the Design of a Humanoid Robotic Finger

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Abstract

Humanoid robotic hands are the essential end effectors for a robot to complete tasks in human environments. Their hands need to perform restraining power grasps and dexterous precision grasps fixed similarly to the positions of human hand postures. Advanced universal robotic hands have previously utilized actuator systems in the form of pulley-cables and pneumatics. These systems often require large amounts hardware that cannot be contained in smaller structures like the humanoid robot Hubo. Hubo has shape adaptive hands that solely rely on a pulley cable mechanical system. Although Hubo has three joints per finger, there is only one motor per finger leading to a coupled phalanx finger design that fails to model precision gripping. A gel actuator has been developed for application in a newly designed humanoid robotic finger. By using this gel actuator in conjunction with an electromagnetic lock mechanism, one motor can power the three-degree of freedom robotic finger. The expected advantage in the new design is a humanoid proportional finger that has improved precision grip while maintaining power grasp adaptability.

Keywords: Gel Actuator, Hubo, Humanoid Robotic Fingers, Robotic Hands

I. Introduction

Humanoid robots are expected to function in the same spaces as humans by performing similar physical assignments and participating in human interaction. Robotic hands, those with four fingers and a thumb, have demanding responsibilities that will improve the efficiency and usefulness of the robot if they can establish a power grasp and precision grip. Human hands naturally regulate force and position according to the type of grasp while maintaining stability even in the presence of varying sized loads or slippage [1]. For performance replication, the humanoid robot's hand should be a universal robotic hand that can mimic human hand prehension and precision grip techniques in terms of hand positions and applied forces.

Human hands have 27 degrees of freedom with five-degrees of freedom in each finger and six-degrees of freedom per palm. Hands generate large grip forces from their opposable thumb and adaptive palm in conjunction with long dexterous fingers. Power grasps are distinguished by large areas of contact between the grasped object and the surfaces of the fingers and palm and by little or no ability to impart motions with the fingers. Zhang states that for power grasp stability the mechanisms need the ability to resist relatively small disturbances without the need to engage feedback control of joint torques [8].

Figure 1: Hubo is currently limited to shape adaptive grasp

Comparatively, a precision grip is used to ensure sensitivity and agility and manages an object with the tips of the thumb and fingers. In humanoid proportional robotic hands, precision grip has been difficult to achieve because it requires the presence of one actuator per joint. The challenge is that space is limited for enough actuators to activate necessary degrees of freedom [2]. Alternatively, many robotic hand designs sacrifice appearance and size for shape adaptive power grasping. The Utah-MIT hand is composed of pulleys actuated by pneumatic pistons [3]. The end result is a large hand system with three fingers and a thumb that model 16 DOF. Shadow Hand uses electric and pneumatic actuators to model 24 degrees of freedom [4]. However, its high cost and large size prevent it from being used in a humanoid robot. To accommodate hand space deficiency, Shadow Hand's pneumatic actuators and hardware sit in the forearm whereas the Utah-MIT hand has a reduced

3a.  3b. 

Figure 3a: Pneumatic actuator fingers [5]
Figure 3b. Shadowhand [4]

number of fingers [3][4]. The unrealistic aesthetics are not suitable for a humanoid robot.

Additionally, Suzumori and Zang developed a pneumatic robotic hand. Each finger is a pneumatic actuator tube internally divided into three chambers. The tube itself is silicone rubber spirally embedded with nylon fibers. Applying pressure equally in each chamber causes the actuator to stretch instead of expand in the radial direction due to the anisotropic nature of the material. The finger bends according to differences in pressure between the chambers resulting in 3 DOF fingers that can dexterously manipulate objects or restrain them in an envelope grasp [5][6]. The double acting actuator generates pushing and pulling forces. In order to generate the required force, the hardware must increase in size. However, this enlarged hardware would be oversized for Hubo's structure.

Although there are a variety of existing hand designs and technologies, each has constraints that prevent it from

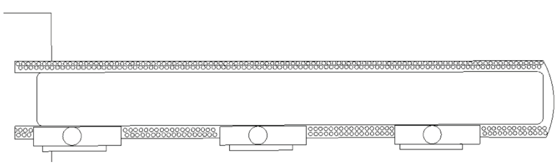

Figure 5: Finger design with anisotropic silicone shell, embedded nylon fibers, gel tube, and three electromagnetic clutch controlled joints

actuator and finger is designed for Hubo who is 1.27 meters in height. Each of Hubo's current fingers is 92 mm in length x 18 mm in width x 18 mm in depth. Presently, a Maxon gear powered cable and pulley system uses a grip wire and a release wire to turn finger joints. The hand can powerfully envelope an object of unknown shape but since each finger has one cable system powered by one motor, each of the joints on a single finger move interdependently. In it's under actuated hand, distal and middle joint movement is dependent on proximal joint movement, hence allowing Hubo to do shape adaptive power grasping but not precision grasping [7].

3. Proposed Design Overview

In the proposed design (Figure 5), a gel tube is fixed in a 130 cm long, 1 cm diameter anisotropic silicone shell above three aluminum joints. Each aluminum joint is secured in the shell to represent the proximal, middle, and distal joints of human fingers. A DC motor driven linear actuator is internally located in the hand and extends to force the gel towards the distal tip of the silicone shell. As the weight shifts to the end of the finger, the gravitational moment rotates the finger downward. Importantly, the design includes an electromagnetic clutch mechanism in each joint that allows one motor to control three degrees of freedom. A powered clutch will inhibit bending at it's joint while a released clutch will allow bending at the joint when the gel is forced towards the tip of the shell. The finger essentially reconfigures itself by locking and unlocking joints.

3.1 Electromagnetic Clutch

Electromagnetic coils are convenient lock mechanisms because they simply draw power from a battery to lock into place and stop drawing power to unlock. They also unlock if the force applied to the mechanism is greater than the attractive force between magnets. In the prototype, the finger did not naturally bend down even when the aluminum joints were placed in to guide motion. The prototype only bent when elongation was forced. If each aluminum joint has a separate electromagnetic lock mechanism joints can independently be locked or relaxed. Even though the magnets and attractive forces will be small to fit in the joint, when the fingers are handling large forces, the locked joints will not break because the finger will continue to stretch the silicone tube and bend unlocked joints.

Most magnetic locking systems crack after the applied force exceeds the attraction force between the magnets. In this case, as the applied force exceeds the attraction between magnets, the pressure will simply continue stretching the silicone tube and bending unlocked joints

4. Gel Actuator Prototype

The proposed finger is based off of the success of a gel actuator prototype. In the prototype, gel is situated in an anisotropic silicone tube with an aluminum joint between the gel and tube. Similarly to pneumatic fingers, manufacturing difficulties emerge in molding a fluid actuated material. When a force is exerted on a flexible material, such as rubber or latex, their isotropic properties cause expansion in many directions. To prevent this behavior, an anisotropic external finger shell was manufactured to inhibit expansion in the radial direction as pressure on the gel elongates the rubber finger. Drawing inspiration from the anisotropic material

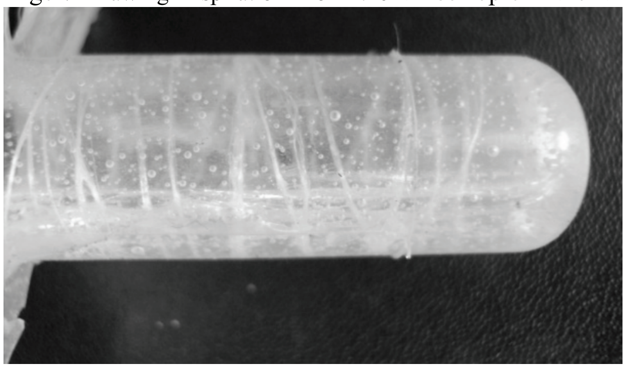

Figure 6: Anisotropic silicone shell with embedded nylon fibers

design from [5] & [6], the shell was molded from RTV silicone rubber with spirally embedded nylon fibers.

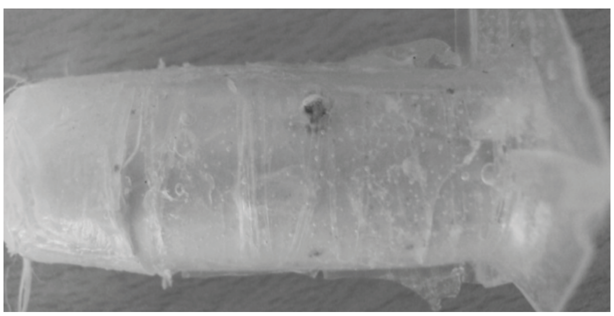

Figure 7: Prototype composed of anisotropic shell and internally located aluminum joint and gel tube

Afterwards, a latex tube filled with ordinary cationic polymer gel was inserted into the silicone rubber tube. Cationic polymer gel of volume 7 cm^3 was poured into a latex tube, adhered shut, and inserted into the shell.
As force was manually exerted on the gel tube to simulate the piston movement, the finger stretched, but did not bend. Unlike the pneumatic fingers, which push air into different chambers to cause bending, the gel is set in the whole tube causing elongation but not bending. To guide finger bending in this model, an aluminum joint, 45 mm long x 13 mm wide x 4 mm deep, was placed between the gel tube and the silicone shell. Afterwards, when a force was manually applied to the gel, the finger bent downwards. As the gel shifted toward the tip of the finger, positioned like a cantilever beam, the bending moment increased and curled the finger. Finally, an aluminum joint was placed between the latex tube and silicone rubber tube to guide bending when a normal force was applied to the face of the latex tube. The model has one joint and one degree of freedom; a fully actuated finger has an equal number of degrees of freedom and actuators.

4.1 Prototype Tests

Two tests were performed, elongation and bending. First, the silicone shell was vertically secured and different weights were hung from the distal tip. The total length of the shell was graphed against applied mass and a linear curve was expected. However, due to discrepancies in manufacturing the weights steadily stretch the finger then there's a sharp change in elongation in response to more weight. These results may be because of the air bubbles in the silicone causing material inconsistencies. Another material inconsistency is the nylon fibers are not uniformly embedded in the silicone.

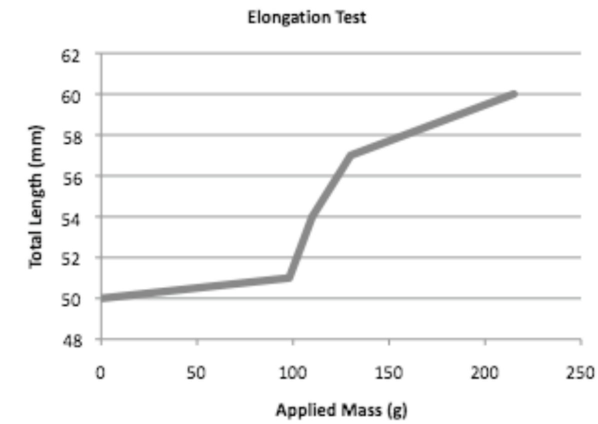

Figure 8: Elongation test on silicone shell

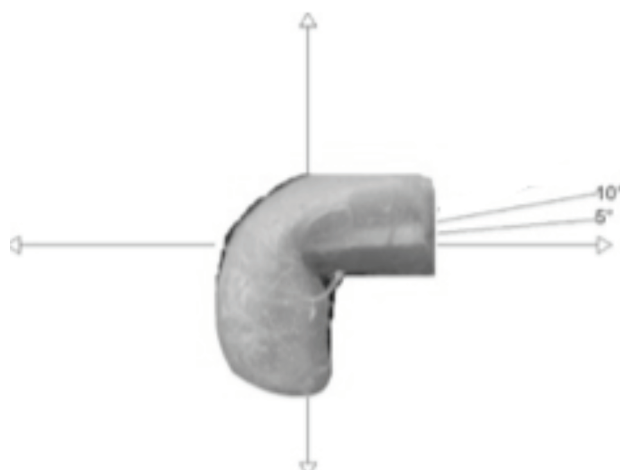

Figure 9: Prototype bending 80 degrees

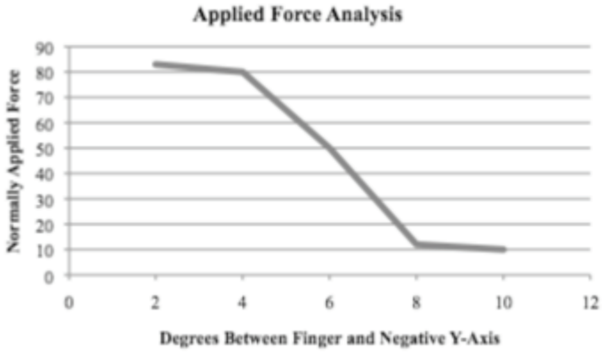

Figure 10: Prototype response under force

For the next test on the horizontally fixed prototype, various forces were normally applied to the gel tube. Increasing the force caused the finger to bend downward at a steady rate. Then, as forces increased the finger suddenly bent at a higher rate. The quick curvature is related to the elongation test that showed material discrepancies. In figure [9] the finger appears to curve a full ninety degrees but internally the aluminum joint only bends to a maximum of eighty degrees after 12 N of applied force. On the prototypes, a force greater than 12 N rips a hole in the sides or end of the silicone shell.

4.2 Materials Advantage

Since humans also control grasp force with friction forces between skin and objects, various materials have been explored as robotic finger coverings to simulate human skin to allow the robot to grip more efficiently [9]. An existential advantage of the silicone rubber shell in the presented prototype is a coefficient of friction greater than one. Object manipulation is a contact based process and during power and precision gripping a high coefficient of friction between the material and object permits lower grasping forces in a clean environment [9]. Cyberhand is a prosthetic hand built by Scuola Superiore Sant'Anna. Engineers placed a silicone glove on the hand to enhance lifelikeness [10]. The materials of the finger used in the proposed design decrease the necessary applied force in comparison to commonly used robotic materials like aluminum or plastic.

4.3 Material Disadvantage

Experimenting with the prototype was difficult because of the challenges related to manufacturing and using an anisotropic material. Despite attempts to eliminate air bubbles during silicone molding, they are spread throughout the shell and weaken the material integrity. Embedding the nylon fibers into the silicone shell cast molding is not durable and this particular method is suitable only for prototyping. Furthermore, when the fingers are handling large forces and the electromagnetic clutch is locked the strain on the silicone shell will increase. The silicone will tear after a certain In the future, more advanced materials processes will be explored for the anisotropic shell.

5. Conclusion

Hubo can meet the needs of the individual by completing tasks and interacting in ordinary environments. Improving the versatility of Hubo and other adult sized humanoid robots requires adaptive hands that behave similarly to human hands. Although existing hand technologies can achieve power grasping and precision grip, size and space constraints prevent compatibility within Hubo. Instead, a gel actuator has been developed for implementation in a robotic finger. The expected advantage is a proportional, but more dexterous robotic hand.

6. References

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