TRANSRADIAL PROSTHETIC ARM ACTUATED BY MECHANICALLY ADVANTAGED SHAPE MEMORY ALLOY WIRES

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INTRODUCTION

Over two million people live with limb loss in the US alone, leaving many of those affected by this disability to settle for a less-than adequate lifestyle. Accordingly, many amputees tend to fall into an isolated lifestyle where depression, mental illness, and anxiety persist [1]. Prosthetic arms offer hope to those individuals by providing a solution to their lost limb, allowing them to regain functionality and live independently. Regardless of these solutions being available, 81% of amputees do not have the financial means to afford a prosthetic limb due to the exponential costs of maintenance. Individuals who do incur the financial expenses tend to not utilize the prosthetic as a result of the excessive weight [2]. Therefore, it is crucial to provide those individuals with the option of having a low cost, lightweight transradial prosthetic arm.

This paper is presenting a new transradial prosthetic arm design. The fingers and forearm core structures are 3D printed, while the forearm shell is made of a composite laminate. Dual control approach is used to control the prosthetic through myoelectric sensors and voice recognition. The fingers are actuated by thermally-controlled Shape Memory Alloy (SMA) wires, which are much lighter than servo motors. The SMA wires contract by 4% of their lengths when being Joule heated, as the material transforms from Martensite to Austenite phase. The SMA wires are connected to an array of innovative “Clever-Lever-and-Locking” (CLL) systems that enhance the actuation stroke and lock the fingers in their positions after actuation to maintain the desired grip without continuously drawing electric current in the SMA actuators, hence conserving power.

METHODS

A new finger design was developed to provide rigidity as well as restoring force that returns the fingers to their original positions when releasing a grip. This new design utilizes a 3D-printed sandwich structure made of rigid and flexible materials. Polylactic acid (PLA), which consist of the upper and lower segments, makes up the proximal, middle, and distal phalanges, while the flexible thermoplastic polyurethane (TPU) core layer functions as finger joints as shown in Fig. 1 (left). The new finger design is a non-antagonistic design that uses the TPU insert as a means of providing a restoring force.

Figure 1: (left) Non-antagonistic finger design, (right) a single Clever-Lever

A computer application was created on MATLAB to simulate the finger deformation as the SMA wire is being heated. The nonlinear SMA behavior was considered based on Ref. [3], and the finger joint mechanism model in Ref. [4] was used to model the finger deformation. The application receives the material properties, diameter and length of the SMA wire, dimensions of the finger phalanges, relationships between joint angles, and applied electric current as inputs then plots the resulting strain of the SMA wire and finger deformation. In order to get full actuation of the index finger, which corresponds to 78° rotation of the MCP joint as shown in Fig. 2, 0.85” wire contraction is required. With a Dynalloy’s 0.02” Flexinol® wire actuator that has a maximum of 4% strain, this contraction can be achieved with 21.25” wire length.

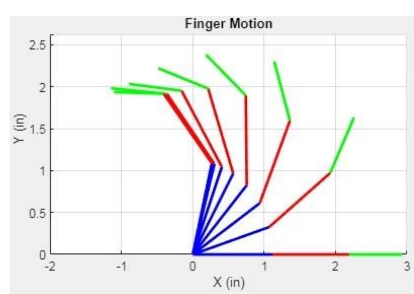

Figure 2: Index finger motion resulting from actuating the SMA wire

Since the minimum length of SMA required for full actuation is too long for the forearm, we developed the concept of the Clever-Lever, shown in Fig. 1 (right). The Clever-Lever was implemented so that the SMA wires would have a mechanical advantage of 1/5. This resulted in a force reduction by a fifth, but also resulted in only a fifth of the wire length required to reach the stroke length necessary for full finger flexion. The output force is enough to ensure strong grip of most household items.

In order to avoid the need to supply continuous electric current to the SMA wire actuators to maintain a finger deformation, a locking mechanism was integrated to the Clever-Lever. The Clever-Lever locking system is composed of an integrated pawl and ratchet system centered around the lever's pivot. One side of each Clever-Lever has a ratchet that can only rotate in one direction because a pawl meshes with the teeth of the ratchet, preventing backward rotation. A linear spring is used to force the pawl into the ratchet teeth. Fig. 3 shows an array of four CLL systems that are used to actuate all five fingers. The thumb, index, and middle finger actuate individually, while the ring and pinky fingers actuate together. As for unlocking the pawl, there is a solenoid on the far end of the CLL array. Once the solenoid is activated, it produces an upward force onto a bar positioned under the pawls to lift them, which allows the ratchets to rotate in the opposite direction releasing the fingers back into an open palm position. This design saves space by keeping most of the mechanical components densely packed at the base of the forearm as shown in Fig. 4.

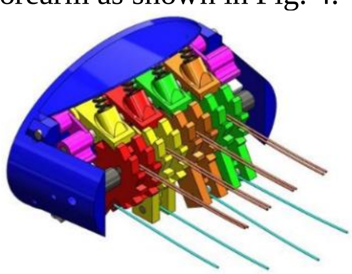

Figure 3: Clever Lever and Locking (CLL) array

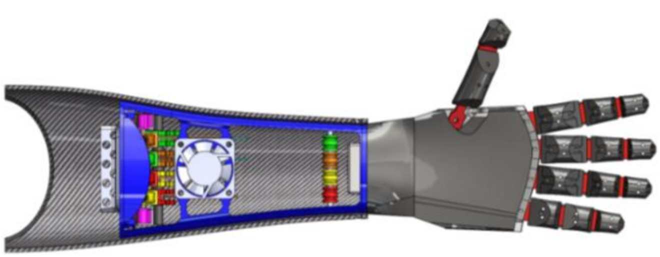

Figure 4: Full smart prosthetic assembly with CLL, fan, and spools

RESULTS AND DISCUSSION

A setup shown in Fig. 5 was built to test the actuation and locking of one finger as a proof of concept. The test proved the effectiveness of the CLL design to actuate and lock the finger. The measured output force and stroke length with the CLL system were 29% and 430% of that without the CLL. All components of the proposed prosthetic design have been manufactured, and the whole prosthetic has been assembled. The weight of the arm is approximately 2 lbs. with hardware components included and the approximate final cost is $200.

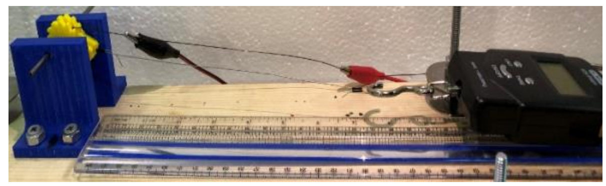

Figure 5: Testbench setup for the CLL system

CONCLUSIONS

The proposed transradial prosthetic arm features a new finger design that provides strength and flexibility through a sandwich configuration, a CLL system that enhances the actuation stroke and conserves power by locking finger rotation to maintain a strong grip, and a composite forearm shell that protects all internal components. The new design ensured the minimum possible overall weight and cost of the prosthetic while offering the user excellent functionality and control.

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