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Linear shape memory alloy (Nitinol) actuators in a 3D printed hand prosthesis

Parshotam, D S

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Executive Summary

There is a need for affordable prosthetic hands in developing countries. This is due to poor healthcare, substandard infrastructure, poor service delivery, and political instability. 3D printing has enabled NGOs and research institutions to rapidly design and manufacture low-cost prosthetic hands. In 2017, the University of the Witwatersrand (Wits) produced a tendon-driven prosthetic hand, powered by low-cost SG90 servomotors. The hand was deemed partially successful due to the low grip strength of 6 N achieved by the SG90 servomotor-actuation. In this research, linear shape memory alloy (nitinol) actuators were developed to actuate a 3D printed prosthetic hand; using a modified two-link transmission. The purpose of the two-link transmission was to replace the traditional tendon-driven designs, which lead to poor force transference between the actuators and fingers. An analytical model was developed to evaluate the positioning performance (response time and accuracy) of the nitinol-powered design. The analytical results were further supported with experimental data, which concluded that the design outperformed past nitinol-powered hands which utilized tendon-driven systems. A square step signal was used to evaluate the system's response time, while a ramp signal was used to test the path tracking performance. Input voltage and sampling frequency parameters were varied to determine the best combination for positioning performance. A 9 V input with a 500 Hz sampling frequency was concluded to be the best combination, which produced a step-up time constant (heating) of 0.06 s with a max finger speed of 152 $^\circ/s$, and a step-down time constant (cooling) of 0.11 s with a max finger speed of 123.6 $^\circ/s$. Average path tracking errors of 1.134° and 0.651° were obtained for the step and ramp signals, respectively. Another analytical model was developed to track the fingertip force with respect to the proximal interphalangeal joint (PIP) angle. It was found that as the PIP angle increased (finger curls inwards) the fingertip force was reduced. This trend was supported by experimental results. An HBM C9C load cell was used to measure the fingertip forces which ranged between 2.03-2.91 N for a 0° PIP angle, and 1.38-1.96 N for a 30° PIP angle, similar in range to past functional 3D printed hands. The developed nitinol-powered prosthesis generated an average power grip force of 16.6 N, 2.76 times larger than the past Wits SG90-powered hand. The measured tripod and pinch grip strengths were 7.3 N and 4.4 N, respectively. Silicon fingertip pads with an embedded force-sensing resistor were used to increase the contact area and absorb the initial impact with an object. This enabled the hand to manipulate objects as small as a 12 mm diameter marble. The nitinol-driven hand successfully performed the required power, hook, sphere, cylinder grips as well as a tripod grip and pinch. The nitinol actuators performed acceptably, and are deemed suitable to replace low-cost SG90 servomotors.