A Wholistic Approach for A Dependable, Sustainable Bionic Lower Limb Device

Aditi Bhattamishra

Amity Regional High School

aditibmishra@gmail.com

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Background

Technological advancements in batteries, sensors, and controls for robots and drones are in turn influencing the push for improving the quality of life of amputees. The initiative is to develop accessible robotic prostheses to replace the typical passive prosthesis, which provides a limited ability to walk but is slower, more strenuous to use, unstable, and forces the user to modify their natural gait pattern because of excess energy usage from no net-positive mechanical energy. State-of-the-art robotic lower limb prosthetic technologies, however, are still far away from providing a proper quality of life for amputees due to lack of sustainability. Current robotic prosthetics are heavy, bulky, and expensive. For child amputees, these problems are more critical and obvious, as the prosthetic must be scalable to keep up with child growth. Additionally, robotic prosthetics are still not energy efficient to provide a dependable usage in a single charge. All of this is primarily due to the type of actuators used. Researchers at UMichigan created the "Open-Source Bionic Leg" as a baseline of the most common robotic prosthetic technology, using servo motors from drones, gear and belt transmissions, and related control electronics.

Concept

There is a need to explore more energy efficient actuation methods suitable for prosthetics, which can provide higher power transmission efficiency, an option to support low or no power consumption when not moving but still can be backdrivable, simplified components that can be produced through additive manufacturing process (3D printing) which will enable scalable, customizable and affordable robotic prosthetic devices. There are electro-hydraulic actuators (EHAs) consisting of compact, self-contained hydraulic pumps paired with a hydraulic piston, and are electrically actuated and controlled. They have raised the possibility of converting heavy equipment to smart machinery. But these actuators use complex valves and hydraulic fluid lines and tend to be very unwieldy, making them unsuitable for use in wearables and mobile robots. However, a recent hydraulically-propelled drone used an EHA to sustain long flight duration [5]. This research explores the possibility of novel fluidic actuator alternatives for traditional electro-mechanical actuators.

Approaches

Approach One: Actuator—Higher Efficiency

Like how humans convert linear muscle contractions/extensions into joint movements through pressurized body fluids, the proposed fluidic actuator uses a novel approach of combining an electric positive displacement pump (PDP) with a suitable linear or rotary pneumatic/hydraulic actuator controlled through a smart PID servo controller to achieve bionic motion.

Approach Two: Materials and Manufacturing—Beyond Conventional

Several proof-of-concept (PoC) prototypes were built using 3D printed photopolymer housing; however, the ankle is most optimal with aluminum alloy housing. Additionally, careful component selection is important. Empirical tests showed that either a peristaltic pump or an external gear pump can act as a check valve when not moving; external gear pumps allow for the use of high-speed drone motors, which improve overall efficiency.

Approach Three: Power Management—Energy Conservation

More efficient power management will allow for smaller battery packs that provide adequate amounts of prosthetic usage. Mechanical systems result in lots of energy lost to the environment. This ambient energy can be harnessed using energy harvesting nanogenerators, which can provide enough energy to run on-board electronics. This will allow for battery power to be fully allocated for driving the main motor.

Approach Four: Controller—Energy Efficiency

A smart controller that can fully utilize and monitor the joint, power consumption, and on-board electronics. While closed-loop PID controllers exist, they are not compatible with brushless DC motors, like the ones proposed for use. As such, one must be developed, with the intention of expanding the controller to account for smart energy reallocation, as discussed in Approach Three.

Evaluation Status

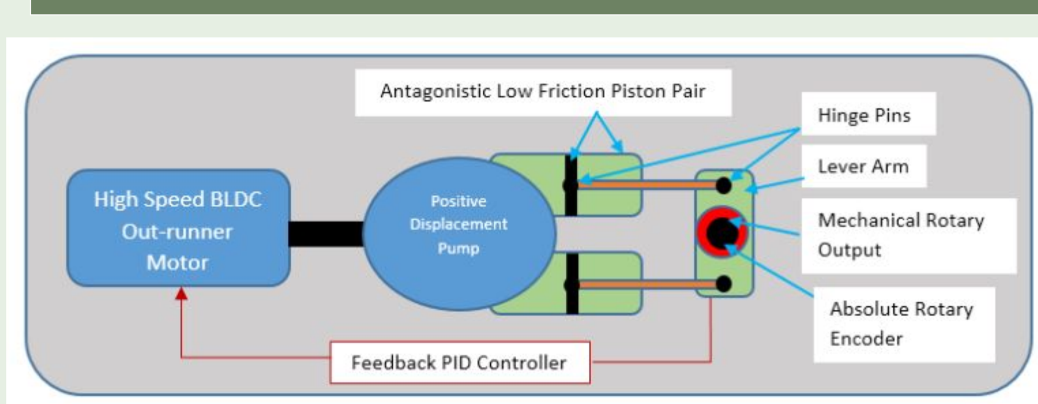

Figure 1: Actuator Schematic

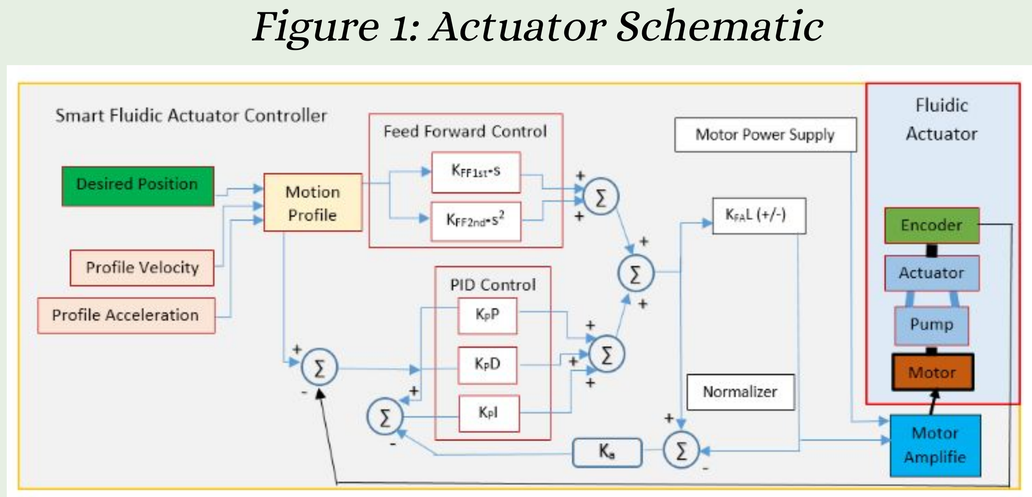

Figure 2: Control Schematic

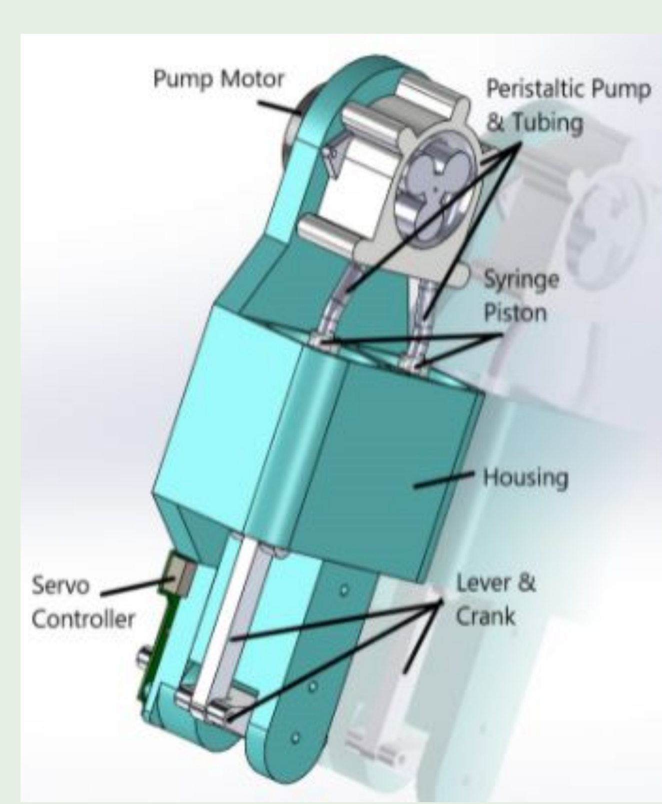

Figure 3: Actuator CAD Model

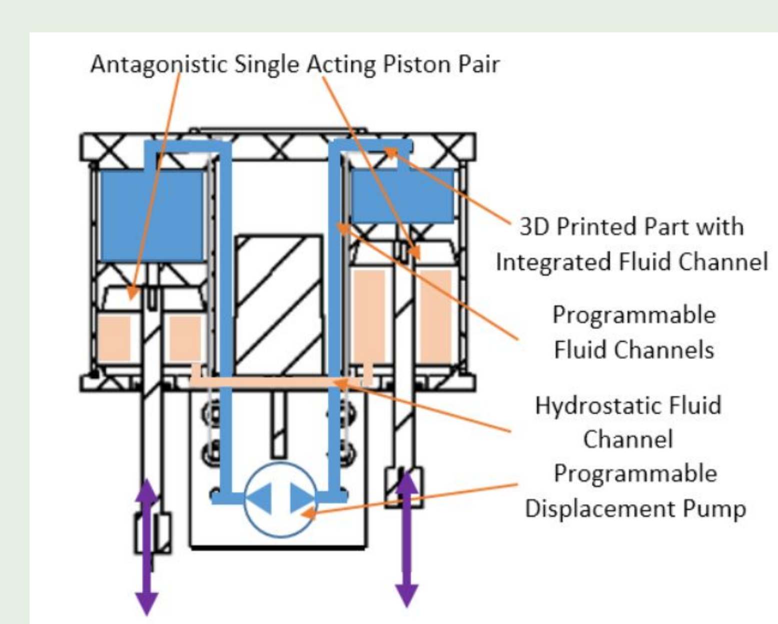

Figure 4: Actuator Cross-Section

Conclusions

Several proof-of-concept (PoC) prototypes were built using 3D printed housing. These were then tested with different pump types as a functional validation and initial parameterization for the theoretical design of an ankle prosthesis. The empirical study showed encouraging torque-to-weight densities (over 4 times of the OSL). With the elimination of transmission components through the piston-cylinder pairs and links, the proposed actuator promises significant weight reduction as well. Empirical tests showed that both a peristaltic pump or an external gear pump can act as a check valve when not moving, thus retaining the pressure difference between both input and output ports and making the actuator inherently non-backdrivable. This enables a potential power-saving feature for both static and dynamic gaits. For backdrivability, an on-demand bypass fluid channel was tested. The motor torque is isolated from joint torque, and so operates at lower power demand. With the use of higher efficiency motion transmission (98-99% efficiency of piston/belt drive and 90% for fluidic pumps), the design is extrapolated to have lower power consumption than the conventional electromechanical actuators.

References

Windrich, Michael, et al. "Active Lower Limb Prosthetics: A Systematic Review of Design Issues and Solutions." Biomedical Engineering Online, doi:10.1186/s12938-016-0284-9. Accessed 15 Nov. 2020.

Azocar, Alejandro F., et al. "Design and Clinical Implementation of an Open-Source Bionic Leg." Nature Biomedical Engineering. Nature Biomedical Engineering, doi:10.1038/s41551-020-00619-3. Accessed 15 Nov. 2020.

McGimpsey, and Terry Bradford. Limb Prosthetics Services and Devices Critical Unmet Need: Market Analysis White Paper Bioengineering Institute Center for Neuroprosthetics Worcester Polytechnic Institution. Bioengineering Institute Center for Neuroprosthetics Worcester Polytechnic Institution, 2008.

Cummings, Donald R. "Pediatric Prosthetics: An Update." Physical Medicine and Rehabilitation Clinics of North America, vol. 17, no. 1, Feb. 2006, pp. 15–21, https://doi.org/10.1016/j.pmr.2005.10.002. Accessed 13 Oct. 2021.

Technology. (n.d.). Flowcopter. Retrieved February 16, 2023, from https://flowcopter.com/technology/