Soft Haptic Actuators from Artimus Robotics

1. Introduction

Artimus Robotics offers a new class of haptic actuators that provide controllable and organic motion for realistic haptic feedback across a wide range of frequencies. Touch perception is an integral part of how people interact with the physical world. As a result, simulating touch feedback with haptic technologies has become an important component of modern electronic devices.

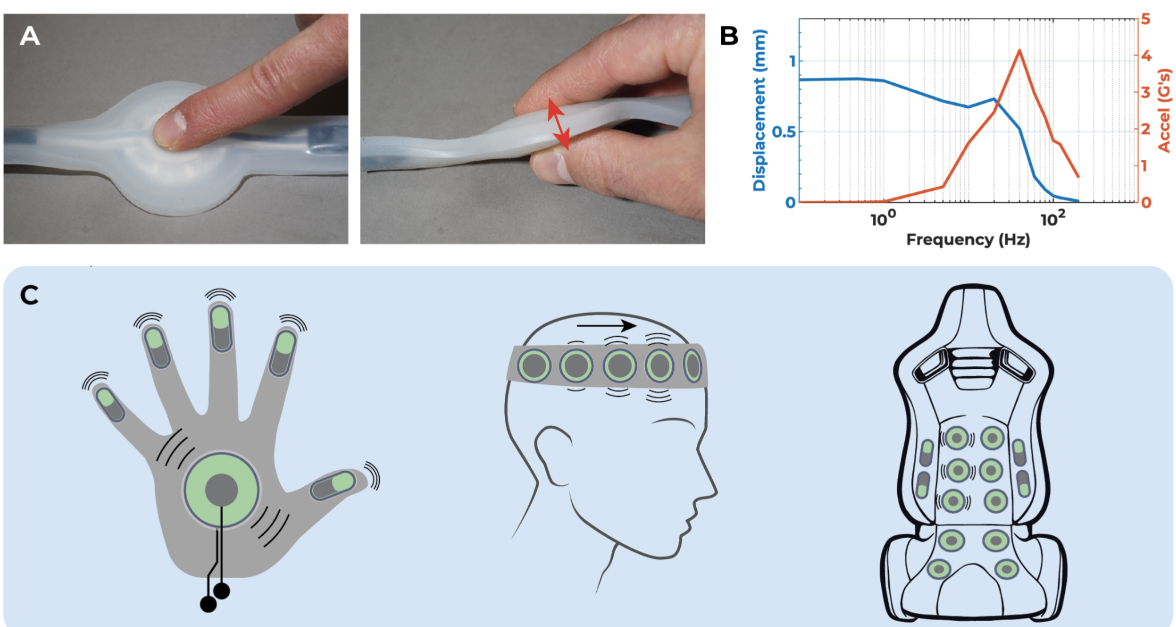

Figure 1. A) Compliant expanding actuators provide tactile feedback to users. **B)** Unique benefits of Artimus haptic actuators include large displacement and wide bandwidth acceleration. **C)** Compliant

actuators can be easily integrated into various haptic devices including wearables, seating, and other devices that provide tactile sensations.

Humans are already overwhelmed with visual and auditory information, especially in scenarios with a high cognitive load. As a result, haptics is attractive as an alternative method for communicating information with low cognitive load [1]. Haptic vibrations are a familiar part of the user experience for phones and gaming controllers, but the amount and quality of information from buzzing motors is limited. As daily lives become more connected and technologies strive to be more immersive, there is a need for haptic actuators that are effective at communicating a diverse range of signals and information.

2. Background on Traditional Haptic Actuators

Most haptic actuators today are either eccentric rotating motors (ERMs), linear resonant actuators (LRAs), or voice coils actuators (VCAs). These actuators are great for providing vibrations in the 100 - 300 Hz range. As a result, most haptic devices today transmit information by buzzing at different frequencies and amplitudes. Other signals are imitated by controlling variables such as duration and intensity. However, most physical interactions - such as clicking a button, grasping an object, or embracing a loved one - occur at lower frequencies and are not adequately represented by the buzzing of traditional haptic actuators. In fact, important nerve endings known as Meissner corpuscles are the most sensitive to motion within the range of 10 - 50 Hz [2]. Additionally, slowly adapting (SA) mechanoreceptors are responsive to frequencies as low as 0.4 Hz and are important for perceiving shapes and direction of motion along the skin. Sensations at these low frequencies can be imitated with various tricks using traditional haptic actuators, but the effect is a poor representation of reality.

Finally, ERMs, LRAs, and VCAs are all actuated by electromagnetic forces. As a result, they are made from a variety of rigid materials and require several moving parts. Besides added complexity, these factors make it difficult to integrate electromagnetic actuators into devices such as wearables that need to be comfortable and unobtrusive for a user. Additionally, due to the mechanical impedance mismatch of stiff rigid materials and soft human tissue, the transfer of energy from an electromagnetic actuator to a user is inefficient.

To address these challenges, Artimus Robotics has developed a new class of soft haptic actuators that provide controllable tactile feedback over a wide frequency range and can be easily customized to meet the size and shape requirements of a given application.

3. Operating Principle of Artimus Robotics Actuator Technology

The Artimus Robotics soft actuator technology uses electrostatic forces to pressurize hydraulic fluids, driving shape change in soft hydraulic structures. Figure 2 illustrates these operating principles using a simplified cross-section of an Artimus Robotics actuator. The actuators consist of three main components - a flexible polymer pouch, a dielectric liquid, and at least one pair of electrodes. Importantly, these components can be made from commodity materials that are widely available at a low cost. This is in stark contrast to electromagnetic actuators which use precision metal components, or piezoelectric actuators which rely on specialty ceramics.

Artimus actuator technology can be used for either expanding (Link) or contracting (Link) linear motion, depending on the shape of the polymer pouch and electrodes. Below, typical performance is discussed for circular expanding actuators (E-0015 series) which are well suited for many haptic applications. While it is not discussed here, it should be noted that contracting actuators can be utilized for kinesthetic haptic feedback. Additionally, other actuation modes can be achieved through material selection, geometric design, and integration strategies.

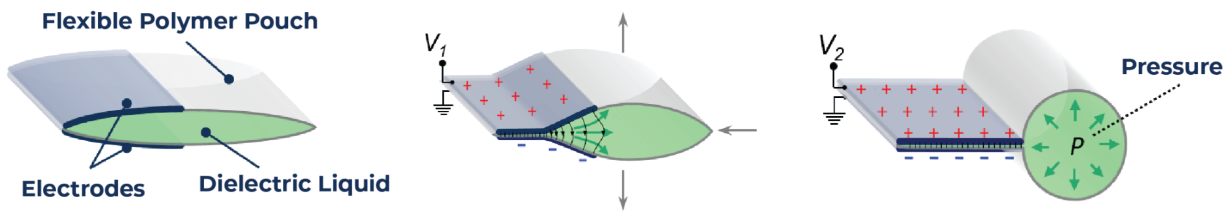

Figure 2. Basic cross-section of a HASEL actuator from Artimus Robotics. The actuator consists of three main components: a flexible polymer pouch, dielectric liquid, and electrodes. The electrodes cover part of the pouch, and when voltage, V_1, is applied to the electrodes, the pouch begins to zip together. This displaces the liquid dielectric which results in an overall change in the pouch shape and an increase in pressure within the pouch. Actuation displacement and output force are controlled by varying the applied voltage. In the idealized schematic shown here, at voltage V_2, the electrodes have fully zipped together and half of the pouch takes a circular cross-section.

4. Artimus Robotics Haptic Actuator Performance

A circular expanding actuator (E-0015 series) provides a performance and form factor well suited for haptic performance (Figure 3). A single layer actuator is very thin (0.3 mm) which is ideal for integrating into flexible structures (Figure 3A). Actuator stroke can be increased by stacking multiple actuators together. Actuators are typically encapsulated in an elastomer which makes them safe to touch during operation (Figure 3B). The actuators are made from flexible materials and can conform to different shapes or withstand repeated bending and twisting (Figures 3C & 3D). Performance of single layer (E-0015-01), four layer (E-0015-04), and fourteen layer (E-0015-14) actuators are evaluated below. All of these actuators have a nominal diameter of 3 cm, but larger and smaller diameters, as well as other shapes, are possible.

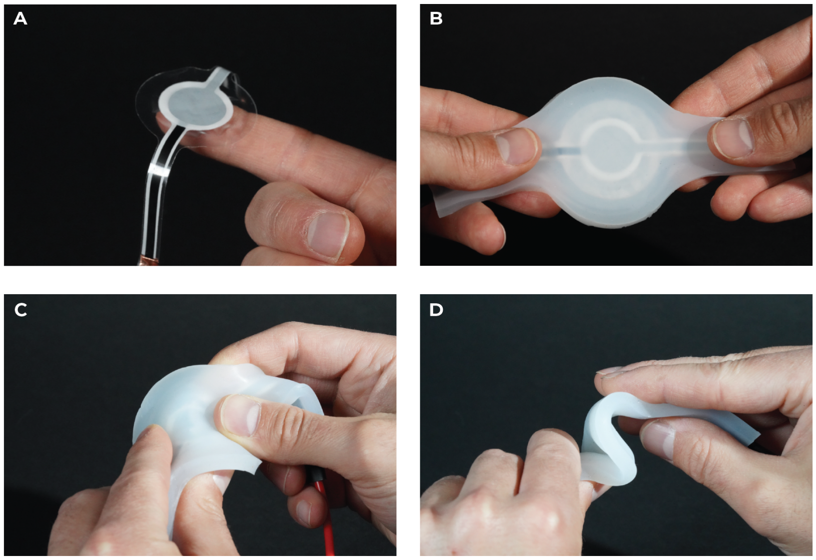

Figure 3. A) A standard single layer 3 cm expanding actuator (E-0015-04-01). Multiple actuators can be stacked to increase stroke. **B)** The actuator can be encapsulated for safe interaction with a user. **C)** & **D)** The actuators are made from a variety of compliant materials and are robust to repeated bending and twisting, which is ideal for comfortable integration into wearables or a variety of deformable interfaces.

Figures 4 & 5 highlight the wide bandwidth performance of Artimus haptic actuators in response to a sinusoidal driving signal from a power supply capable of providing high voltage and limited current (< 1 mA). Peak-to-peak displacement is nearly constant until it starts to roll-off at 10-30 Hz (Figure 4). As expected, actuators with more layers have more displacement - compare the fourteen layer (E-0015-04-14) and the single layer actuators (E-0015-04-01).

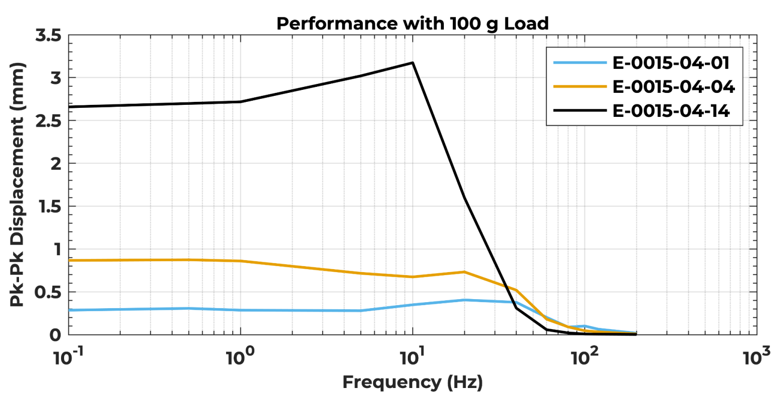

Figure 4. Peak to peak displacement for varying frequencies of a sinusoidal input signal. Actuators are tested with a 100 g load.

For haptic applications where force sensation to the user is important, it's more common to evaluate peak-to-peak acceleration as a function of frequency, as shown in Figure 5. As expected, acceleration is small if not negligible at low driving frequencies, but the actuators provide significant acceleration above 1 Hz. The fourteen layer actuator (E-0015-14) provides greater than 1 G of acceleration in the frequency range of 4 - 100 Hz. The thinner actuators have higher maximum acceleration (>4 G) and operate at a higher frequency range. The single and four layer actuators have a higher frequency range than the fourteen layer actuator because they are a smaller capacitive load on the power supply, which is limited to 1 mA output current. Smaller stacks are preferred in cases where acceleration is more important than displacement and power input is limited. Importantly, the demonstrated ranges of performance highlight the ability to tune haptic performance with different actuator sizes.

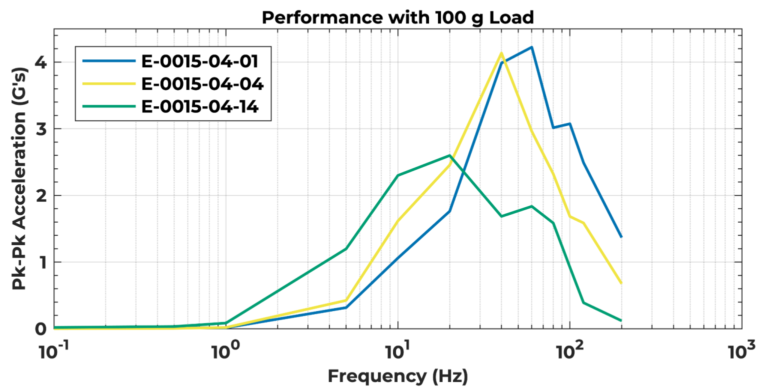

Figure 5. Peak to peak acceleration for varying frequencies of a sinusoidal input signal. Actuators are tested with a 100 g load.

Figure 6 shows the static performance of Artimus haptic actuators. Force output varies with stroke - starting with a maximum force (blocked force) at zero displacement and decreasing at higher displacement. It is also possible to adjust the actuator size (i.e. diameter), number of actuators in parallel, and number of actuator layers to meet the specific performance and size requirements of an application.

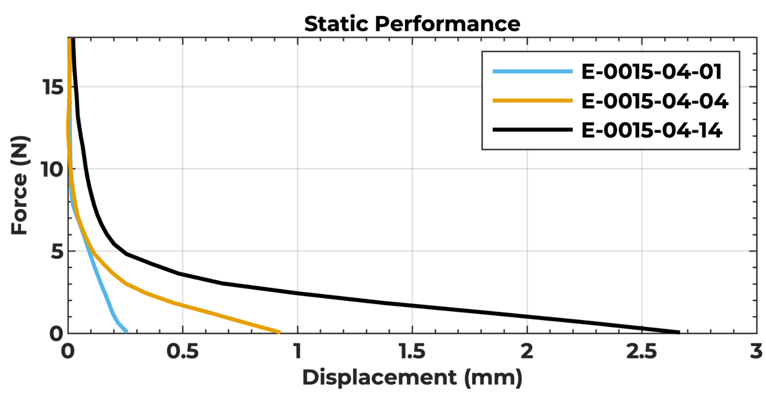

Figure 6. Static force as a function of actuator displacement. Displacement scales with the number of actuator layers, while blocked force (force at 0 mm) is the same for actuators of the same diameter.

Actuator response time is important for effectively transmitting haptic information. For low latency communication, the actuator should have a short response time to a changing input signal. Additionally, a short response time indicates higher acceleration which produces a greater sensation to the user. Figure 7 shows the response time of expanding actuators to a square wave input signal. For the actuators tested, turn-on time was 0.04 s and turn-off time

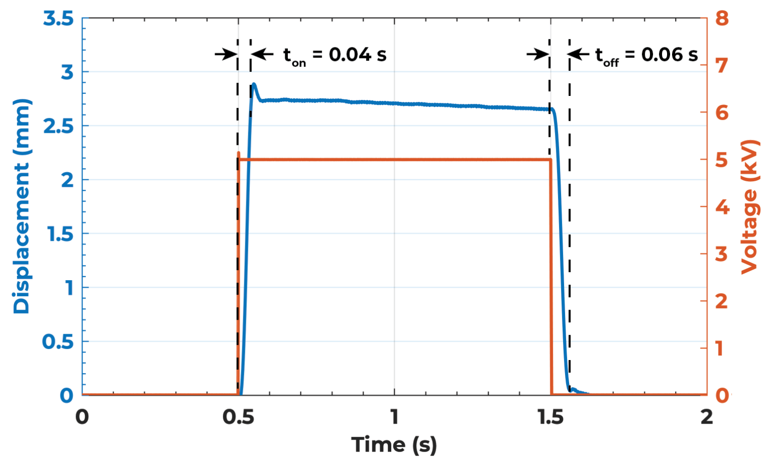

Figure 7. Actuator response time to a square wave input. Turn-on time (t_{on}) is 0.04 s while turn-off time (t_{off}) is 0.06 s. This fast response reduces latency of haptic communication and provides crisp-feeling haptic feedback.

was 0.06 s in response to a square wave input. These response times can be easily modified and depend on many factors including range of displacement, actuator size, and materials. Importantly, the fast response to a square wave input provides a crisp actuation feel to the user which is in stark contrast to ERMs and LRAs which attempt to imitate events such as button clicks with specifically tuned vibration patterns (Figure 8).

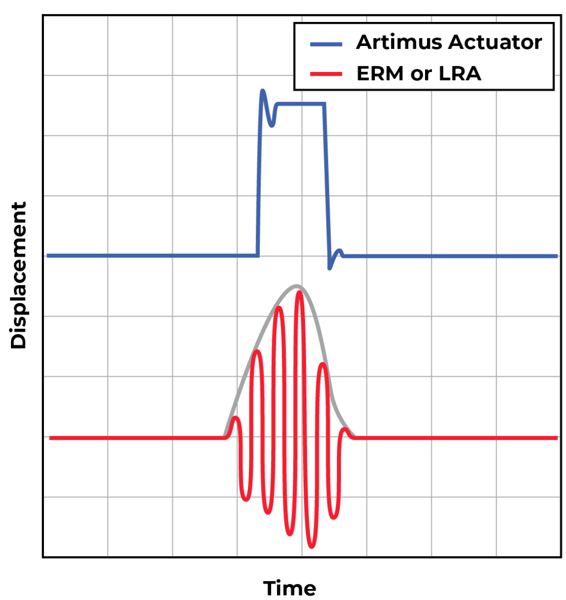

Figure 8. Typical actuation profile for an ERM or LRA compared with an Artimus haptic actuator that is meant to convey a button click. An ERM or LRA will vibrate at a high frequency with varying amplitude (red line), while an Artimus haptic actuator will respond with a crisp square displacement profile.

5. *User Feedback Through Self-Sensing*

Finally, Artimus haptic actuators are capable of self-sensing their deformation based on the capacitance of the actuator electrodes. Referring back to Figure 2, actuator capacitance increases as the electrodes zip together and actuator displacement increases. Applying a vertical compressive load to a fully zipped actuator will cause the capacitance to decrease as the electrodes unzip and the actuator displacement decreases. Signals for capacitive sensing can be integrated with the actuator driving signal allowing for simultaneous sensing and actuation. This combination of actuation and sensing for two-way haptic communication is beneficial for haptic applications that may have limited space for actuators and sensors. For example, a button could detect when a user presses it and can provide vibration feedback to the user. The inherent self-sensing ability of Artimus Robotics actuators is highlighted in the following videos:

- Actuation and sensing combined: Link
- Sensing resolution demo: Link

6. *Additional Attributes of Artimus Robotics Haptic Actuators*

A few additional attributes of Artimus actuators are discussed below in the context of haptics applications. First, since Artimus haptic actuators rely on electrostatic principles, the operating voltage is high - typically ranging from 3 - 6 kV. While high voltage is a safety concern and presents challenges for integration, the actuators can be properly insulated using a variety of polymers, elastomers, and flexible electronics to satisfy common safety regulations like CE, UL, and IEC. Additionally, operating current is very low (< 1 mA) and the total electrical power consumption is low. For example, power consumption at 40 Hz (peak acceleration in Figure 5) ranged from 2.0 W peak (0.4 W RMS) for a single layer actuator to 10.2 W peak (3.8 W RMS) for a 14 stack. As a result, actuators can be operated using battery-powered portable power supplies.

An added benefit of the low current consumption is that Artimus haptic actuators do not generate heat during operation (Link). This is especially beneficial for applications that are sensitive to temperature or that may require arrays of actuators. The lack of metal components and low current also means that haptic actuators from Artimus Robotics are capable of operating in environments that are sensitive to magnetic fields. Finally, Artimus haptic actuators have no moving parts and as a result are nearly silent, as demonstrated in this video: Link.

7. *Conclusions*

Soft electrostatic actuators from Artimus Robotics offer many advantages over conventional haptic actuators. The ability to provide movement and sensations over a wide frequency range (DC to 200 Hz) is especially attractive for enabling new haptic experiences. In contrast to traditional haptic actuators which are made from rigid parts and provide high frequency vibrations, Artimus Robotics actuators are soft, compliant, and can provide lifelike sensations.

Artimus haptic actuators also simplify integration as they can be easily incorporated into wearables, soft structures, or other surfaces that have limited space.

The data presented here is representative of just a few different actuators that Artimus Robotics offers. A variety of sizes, shapes, and performance characteristics are available, as shown in Figure 9. Additionally, Artimus can easily customize actuators for optimal integration into customer systems or products.

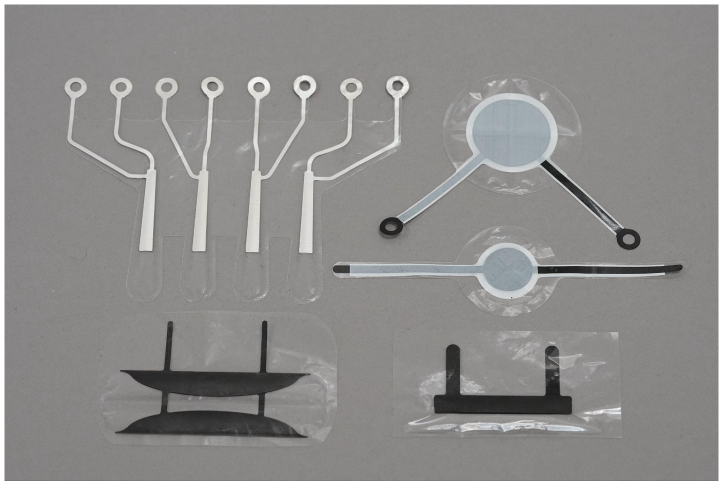

Figure 9. Examples of various sizes and shapes for haptic actuators. The specific size and shape of an actuator can be customized to meet the performance and integration requirements of a specific application.

Please contact info@artimusrobotics.com to learn more about Artimus Robotics haptic actuators.

8. References

[1] MacLean, Karon E. “Putting Haptics into the Ambience.” *IEEE Transactions on Haptics* 2, no. 3 (2009): 123–35. https://doi.org/10.1109/TOH.2009.33.

[2] Jones, Lynette. *Haptics*. MIT Press Essential Knowledge. The MIT Press, 2018.