Snaptics: Low-Cost Open-Source Hardware for Wearable Multi-Sensory Haptics

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***Abstract*— There has been growing interest in using haptic devices to enhance virtual experiences or to increase the amount of information transferred to a user by wearable devices. As such, the haptics community has proposed a wide range of wearable haptic devices, often featuring multi-sensory cues that convey vibration, squeeze, twist, or skin stretch. Despite these exciting advances in wearable haptic technology, these devices are difficult to reproduce outside of the research setting due to their relatively high cost, their complexity of construction, and/or their inclusion of custom components. To this end, we present Snaptics, a low-cost, open-source, haptics platform designed for rapid prototyping of fully wearable multi-sensory haptic devices. Snaptics exists to increase community engagement with and accessibility of wearable haptic devices by lowering the technical barrier to entry and cost of creating a wearable haptic device.**

I. INTRODUCTION

Wearable haptic devices enrich user experiences by providing touch-based feedback via body-worn, rather than grounded or hand-held, devices. A vast majority of wearables have been designed for the wrist and arm. Recent findings regarding the perception of cues produced by wearable haptic devices worn on the arm have shown the efficacy of using combinations of different types of cutaneous haptic cues (vibrotactile, skin stretch, and radial squeeze) to transfer detailed information to the user [1]. Given the benefit of such multi-sensory haptic cues for information transmission, and the wide variety of cues that can be conveyed to a user's arm, researchers have proposed numerous wearable devices that can create these varied haptic sensations [2], [3], [4], [5]. These devices, while conveying salient cues in a wearable form factor, tend to be designed for use in a laboratory setting, be relatively expensive, and often are difficult to reproduce based on the complexity of the mechanical design or presence of custom components. To address these limitations, we propose Snaptics, a set of wearable haptic device designs, along with control electronics, that are highly modular, adaptable, relatively easy to construct, and openly available to the community. The word "snaptic" was coined by Wong and Okamura to describe a modular, low-cost version of the haptic paddle, a widely used hardware platform for teaching concepts in dynamic systems, controls, mechatronics, and haptics [6], which enabled the coupling of two single degree-of-freedom (DOF) haptic paddles to create a 2-DOF device [7]. We envision Snaptics as a tool kit to support wearable haptic device designers both during the rapid ideation stage of device design, sometimes referred to as haptic sketching [8], and during the creation of wearable haptic prototypes, as illustrated in Figure 1. Similar to the idea of the "snaptic" paddle, Snaptics focuses on modularity, cost-effectiveness, and reducing the barrier to entry for those developing haptic device hardware. Given the modularity and customizability of Snaptics, rapid ideation and prototype testing design cycles will accelerate, allowing design refinement before significant investment of time or money. An open-source approach to distribution of Snaptics allows the creation of a community of developers who can contribute revisions and new designs to further advance the field.

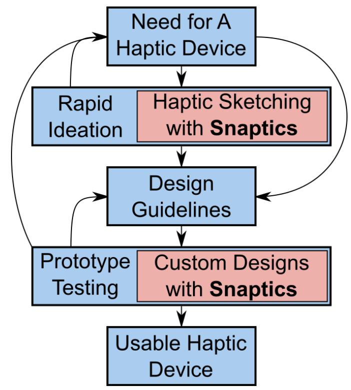

Fig. 1. Haptic Device Design Flow Diagram. After identifying a need for a haptic device, haptic designers typically work through a rapid ideation cycle and/or a prototype testing cycle before developing their final device. Snaptics offers an alternative to haptic sketching during the rapid design iteration cycle and to designing custom hardware during the prototyping testing cycle.

A. Wearable Haptic Devices

A number of wearable haptic devices have been presented in the literature, and a sample of those intended for use on the upper arm or forearm is presented in Table I. These devices are capable of conveying cutaneous cues such as skin stretch [2], [3], [4], [9], twist [10], squeeze [2], [3], [4], [5], and vibration elements [4], [5], [11]. Some of these devices comprise multiple haptic actuation modalities, including the

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TABLE I

Sample of wearable haptic devices including their haptic modalities, actuator types, power sources, and component sources.

Device	Haptic Modality	Actuator Type	Power Source	Component Source
Haptic Rocker [9]	St	S	T	O,3D
Wheeler Twist Device [10]	Tw	U	T	C
TAPS [11]	V	LRA	T	O,C
CUFF [3]	St,Sq	DC	T	3D,C
hBracelet [2]	St,Sq	S,L	T	O,3D
TASBI [5]	Sq,V	DC,LRA	T	3D,C
MISSIVE [1]	St,Sq,V	S,LRA	T	O,3D,C
Snaptics	St,Tw,V	S,ERM	B	O,3D

Haptic Modality: (St)retch, (Sq)ueeze, (Tw)ist, (V)ibration
Actuator Type: (S)ervo motor, (L)inear actuator, (DC) type motor, (U)ltrasonic motor, (LRA) type vibration motor, (ERM) type vibration motor
Power Source: (T)ethered, (B)attery powered
Component Source: (O)ff the shelf components, (3D) printed components, (C)ustom ordered components

hBracelet [2], CUFF [3], MISSIVE [1], [4], and TASBI [5].

These devices have been developed for applications such as enhancing user experiences in virtual and augmented reality [5], teleoperation [2], providing haptic feedback to prosthesis users [9], enabling haptic communication [4], [11], and exploring human perception of wearable haptic cues [1], [10], [12]. The haptic cues conveyed by these devices are achieved with various actuator types including vibration motors, linear actuators, servo motors, and DC motors. These devices are wearable, but are often tethered to a control computer for power and/or control. Many are comprised of custom rather than off-the-shelf components, making replication difficult as they require specialized fabrication. This, in turn, results in devices that are more expensive to fabricate and that require domain expertise to assemble and operate.

B. Open-Source Resources for Haptics

Developers of open-source hardware projects aim to engage makers and researchers in their respective communities via do-it-yourself platforms that spur new device development. Examples of successful efforts such as Arduino, Adafruit, SparkFun, and Raspberry Pi have lowered costs and the barrier to entry for those seeking tools for rapid prototyping of hardware and electronics. These systems focus on low-cost and modular tools for reading from sensors and controlling actuators. Various open-source haptic hardware systems have also been developed. While not wearable, low cost modular haptics platforms have been developed for kinesthetic haptic devices and have seen success beyond the research setting in education [13], [14], [15], [16]. Open-source resources have also been developed for tethered devices intended to enhance musical performances by providing haptic feedback to either the performer or the listener [17], [18]. Several researchers have developed basic guides about haptic devices [19] and how-tos on modifying commercial kinesthetic haptic devices [20], though detailed resources for fabrication and component designs are not included. There have also been efforts to create open-source software libraries to simplify the process of simulating haptic environments. CHAI 3D provides a framework to create virtual environments [21] and the Penn Haptic Texture Toolkit provides data-driven models to replicate real world textures [22]. However, these software frameworks require designers to have a commercial kinesthetic haptic device or the technical knowledge required to develop a compatible device. More recently, Syntacts, an open-source platform for presenting various vibrotactile stimuli to users, has been released [23]. While Syntacts provides guidance and resources for both hardware design and rendering, it is limited to single vibrotactors or arrays of vibrotactile actuators and does not support the other types of cutaneous cues that can be conveyed by wearable haptic devices. These open-source projects have decreased the barrier to entry for developing haptic technology and broadened participation to a wider research community, yet none are specifically targeted to wearable haptic devices.

C. Contributions

In this paper we introduce Snaptics, an open-source, low cost, multi-sensory haptics platform designed for rapid prototyping of fully wearable haptic devices. Snaptics is an open-source project intended to be used by researchers, students, hobbyists, and other interested parties. Snaptics modules are simple to construct and assemble and are built from inexpensive and readily available components. In this paper, we present the objectives of the Snaptics platform in Section II and the currently developed hardware ready for use in Section III. In Section IV, we discuss various elements of Snaptics design and present an example device built using the Snaptics platform. Snaptics designs are available at www.snaptics.org.

II. Objectives

The Snaptics platform was built according to four main guiding principles. These design objectives were defined to prioritize simplicity and modularity in design and were inspired by the design challenges presented in Section I-A.

1) Snaptics must use modular components
2) Snaptics modules must require minimal prior building experience to assemble
3) Snaptics must be untethered and powered internally
4) The overall cost of producing a Snaptics device must not exceed $100 USD.

The fully modular format allows designers to rapidly prototype different types of wearable haptic interactions. The design has also been purposefully made easy to assemble and modify, reducing the need for prior experience with electromechanical systems. For wearable haptic devices to be truly mobile and useful outside of a standard lab environment, it is necessary to integrate control electronics and power. Finally, Snaptics has been designed to ensure that any Snaptics build is cost effective. $100 was chosen as a benchmark far below the average cost of research haptic devices. This price point should allow students and makers to experiment with Snaptics modules without significant investment of time or money. By lowering the technical

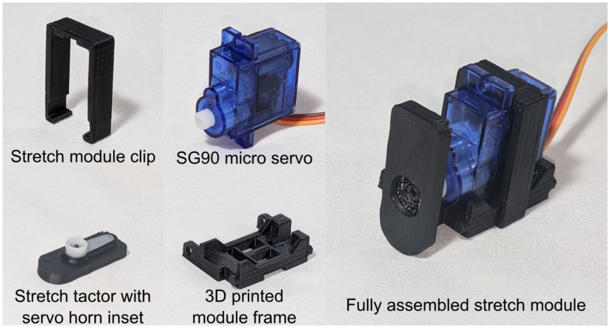

Fig. 2. The stretch module with base components. The stretch module clip holds the micro servo motor to the stretch module frame. The micro servo motor provides stretch actuation to the skin though the example stretch tactor. Designers can customize the stretch tactor shape and apply various materials to interface between the tactor and the skin.

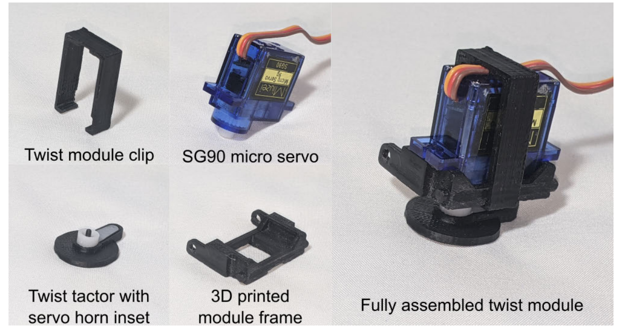

Fig. 3. The twist module with base components. The twist module clip holds the micro servo motor to the twist module frame. The micro servo motor provides the twist actuation through the example twist tactor to the skin. Designers can customize the twist tactor shape and apply various materials to interface between the tactor and the skin.

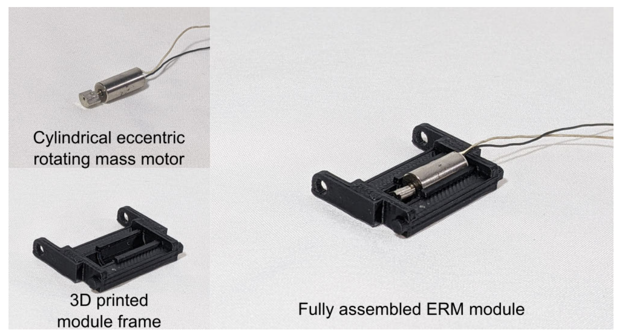

Fig. 4. ERM vibration module with base components. The cylindrical eccentric rotating mass motor is secured to the 3D-printed module frame with a light press fit. The vibration of the ERM motor is transmitted to the skin via the contact surface of the module frame.

barrier to entry to the haptics community, we hope Snaptics spurs greater interest and general use of haptics in research and in maker spaces.

III. Hardware

A. Actuation Modules

Three types of haptic actuation modules have been developed to provide different types of cutaneous haptic sensations to the skin: stretch, twist, and vibration.

1) Stretch Module: The stretch module delivers skin stretch using a servo motor actuating tangentially to the skin. The stretch module (see Fig. 2) is composed of four parts: the clip, the tactor, the actuator, and the base. The module features a SG90 micro servo motor commonly used in hobbyist applications as the primary actuator. The base of the stretch module is a 3D-printed rectangular frame of outer dimensions 32.1mm x 25mm x 9mm. This rectangular frame includes a slot just oversized for the micro servo motor tab to lightly fit within of size 11.5mm x 3mm. The entire body fits into the slot on the frame of size 12.5mm x 26.5mm. The frame features a wire guide that serves to tighten the connection of the clip to the frame. The frame uses the snap design framework to snap together with other modules. The stretch module includes a clip to hold the actuator tightly in place with the frame without requiring external components. The clip is shaped as a three-sided protruded rectangle with small hooks to support the connection to the frame of outer dimensions 18.4mm x 30.2mm x 8mm. The stretch tactor is attached to the actuator and can directly interface with the skin, or a custom tactor material can be applied. The stretch tactor is designed as a semi-circular surface to minimize discomfort as the actuator moves the tactor against the skin. The width of the tactor helps to distribute the normal force of the stretch tactor during actuation.

2) Twist Module: The twist module delivers a tangential skin twist using a servo motor orientated normal to the surface of the skin. The twist module (see Fig. 3) is composed of four parts: the clip, the tactor, the actuator, and the base. The module features a SG90 micro servo motor commonly used in hobbyist applications as the main actuator. The base of the twist module is a 3d-printed rectangular frame of outer dimensions 32.1mm x 25mm x 8.3mm. This rectangular frame includes a slot just oversized for the micro servo motor drive shaft to lightly fit within of size 15.5mm x 12.5mm. The entire body similarly fits into the slot on the frame of size 22.9mm x 12.5mm. The frame uses the same snap design framework to snap together with other modules. The twist module includes a clip to hold the actuator tightly in place with the frame without requiring external components. The clip is shaped as a three-sided protruded rectangle with small hooks to support the connection to the frame of outer dimensions 29.3mm x 18.5mm x 8mm. The twist tactor enables direct interaction with the skin, or a custom tactor material can be applied. The twist tactor employs a circular contact surface for transmitting the twist action to the skin. The circular design maximizes surface area interfacing with the skin while preventing any interference between modules.

3) Vibration Module: The vibration, or ERM, module houses a cylindrical eccentric rotating mass (ERM) motor to deliver a simple vibration cue to the surface of the skin. The ERM module (see Fig. 4) is composed of two parts: the actuator and the base. The base of the ERM module is a 3D-printed rectangular frame of outer dimensions 32.1mm x 25mm x 6mm. The frame has a cylindrical slot for the ERM to fit within of diameter 6.3mm. The frame uses the same

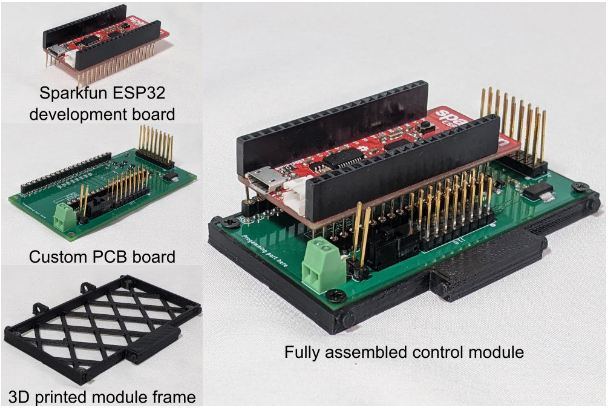

Fig. 5. Control module with base components. The custom Snaptics PCB board is secured with screws to the 3D-printed module frame. The Sparkfun ESP32 development board is mounted directly onto this custom PCB board.

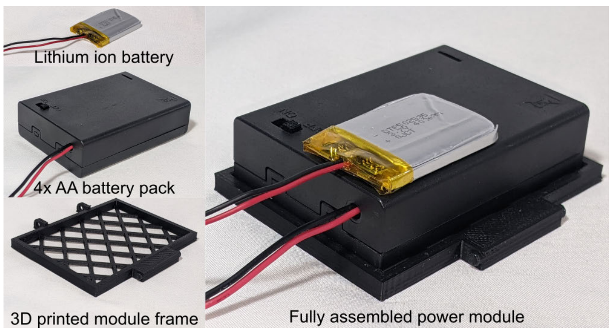

Fig. 6. Power module with base components. A 4x AA battery pack provides power for the actuators while the 3.2V lithium ion battery pack provides power to the control circuitry.

snap design framework to snap together with other modules.

B. Electronics Modules

The electronics modules are made to house the power and control elements for any project. Each module features a 3D-printed frame that connects to store bought components.

1) Control Module: The control module (see Fig. 5) houses the main control circuitry. The control board PCB serves to modularize the electronics. Rather than having the ESP32 control board interface directly with the actuators, it connects to female header pins on the PCB. The board features a frame, a custom-made printed circuit board, and a Sparkfun ESP32 Development Board. The base of the control module is a 3D-printed rectangular frame of outer dimensions 78mm x 56.5mm x 5mm. The frame uses a x-lattice structure to stabilize the base of the unit while minimizing material costs. The frame's inner dimensions match with the PCB to fit snugly at 76mm x 40mm. This PCB features a plug for an external power supply, male header pins to connect actuators with, a 5V regulator, and low-side MOSFET control for the ERM motors. The board has eight servo and ERM ports and measures 75mm x 39mm. Further discussions behind the design of the PCB board is in Section IV-C.

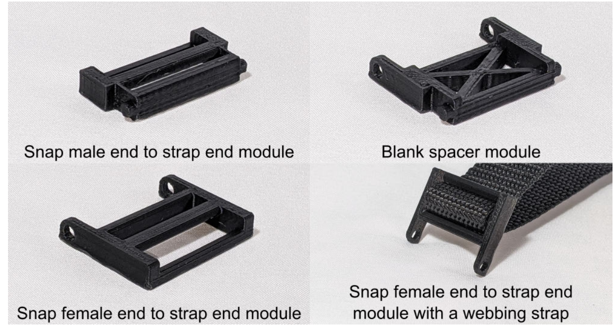

Fig. 7. Strap and blank modules. Strap modules are used at either end of a Snaptics band to secure the system to a user with webbing or velcro. Blank modules can be used strategically throughout a Snaptics band to adjust the spacing between haptic modules.

2) Power Module: The power module (see Fig. 6) features a frame that provides support for the two power sources used in this device, one battery pack for motor support and a smaller lithium ion battery pack for electronics support. The base of the power module is a 3D-printed rectangular frame of outer dimensions 75mm x 69.5mm x 5mm. The frame uses a x-lattice structure to stabilize the base of the unit while minimizing material costs. This power module connects directly into the control module PCB to provide power for the full modular setup.

C. Support Modules

Support modules give Snaptics the functionality to be applied in various wearable applications. These modules have no active electronics components and are simply designed 3D-printed pieces that can interface with the rest of the modules.

1) Blank Module: The blank module (see Fig. 7), is a simple rectangular frame of outer dimensions 32.1mm x 25mm x 6mm with a x-lattice support in the frame to provide stability. The blank module includes the same snap design framework to interface with any other module. The blank modules give designers freedom to space out modules on their desired device by adding or removing blank modules between actuation modules.

2) Strap Module: The strap module (see Fig. 7) is a converter piece between the snap design framework of the other modules to an interface that can be coupled with a simple strap or with 25mm webbing. The strap modules are adjustable and allow webbing or strapping to be tightened or loosened after attachment. The outer dimensions of this frame have two types that correspond to the male or female snap ending of the other modules: the female snap strap module has dimensions of 32.1mm x 24.5mm x 6mm and the male snap strap module has dimensions of 32.1mm x 16mm x 6mm.

D. Creating a Wearable Haptic Device with Snaptics

We demonstrate how Snaptics can be used to prototype multi-sensory wearable haptic devices by replicating MISSIVE, a wearable device that conveys skin stretch, squeeze,

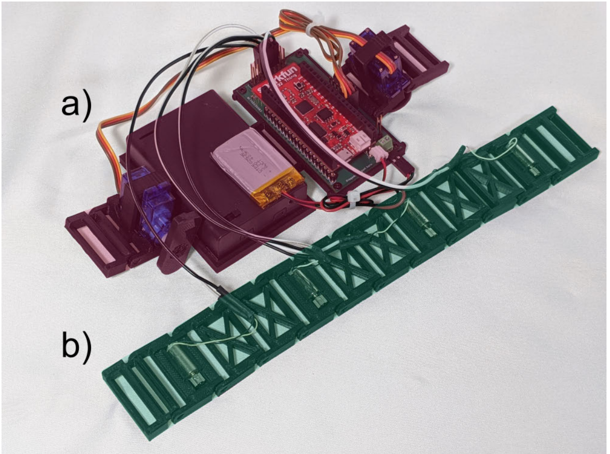

Fig. 8. Snaptics replica of the MAHI MISSIVE System that conveys multi-sensory haptic cues. a) The upper band features two strap modules, one stretch module, one twist module, one power module, and one control module b) The lower band features two strap modules, four ERM modules, and six blank modules

and vibration cues [1]. MISSIVE consists of two bands, one which includes four vibrotactors spaced around the armband, and one that comprised a haptic rocker to elicit skin stretch, and a tightening band to elicit squeeze. MISSIVE was not developed as a fully mobile device, and as such, it relies on tethering for power and computer control. Further, MISSIVE was not intended to be a low-cost device, and components and fabrication totalled nearly $3300. The device was manufactored using a high-end 3D Systems ProJet 3D printer, making this hardware difficult for other labs to replicate and modify themselves without significant expertise and investment of time and money.

Here we present a replication of MISSIVE made with the Snaptics system, shown in Fig. 8. The Snaptics MISSIVE replica includes four ERM modules, one stretch module and replaces the squeeze cue with a twist module to match the number of available cues realized in the original MISSIVE device. As reflected in the last two rows of Table I, the Snaptics MISSIVE replica offers the same size of cueset in a completely untethered format and does not require any custom components, relying instead on the open-source Snaptics module designs. The replica uses battery power allowing for experimentation outside of the laboratory environment. After accounting for all materials and components, the final cost of producing the device is approximately $75, which safely fulfills our fourth objective in Section II to ensure the overall cost of producing a Snaptics device stays below $100.

IV. Discussion

Snaptics design elements were carefully chosen in accordance with our objectives expressed in Section II.

A. Actuator Selection

Actuators used in the Snaptics modules were carefully selected to minimize costs and simplify the construction process. The cutaneous sensations to be delivered were categorized as vibration-based and shear-based.

For the vibration-based Snaptics modules, we selected a miniature cylindrical vibration ERM motor with the following specifications: 4mm motor diameter, nominal voltage of 3V, and a mass of 11 grams. The selection for vibration motors was based on the objectives expressed in Section II, specifically to lower cost and technical experience required to start using Snaptics. Due to the low cost of ERMs and the simplicity of their control, ERMs were selected to be implemented. LRAs and Piezoelelectric motors were also considered, but ultimately not chosen due to the extra control components that would be required for implementation of these actuation methods.

For the shear-based Snaptics modules, we selected a SG90 micro servo motor which is available from a handful of hobbyist companies with similar specifications: approximate stall torque of 0.15Nm at 6V, mass of 9 grams, and an operating range of 180 degrees. Wearable haptic skin deformation devices tend to be position controlled. Therefore, servo motors with built in encoders and controllers offered an ideal combination of low cost and simple control. While costs could be lowered further or higher fidelity achieved with a custom DC motor solution, designers would be required to consider gearing, encoding, power consumption, and control to select an appropriate motor solution for their application. The simplicity of a servo motor outweighed the possible benefits of a more customized motor solution for Snaptics.

B. Snap Design

All modules in the Snaptics platform use a simple “snap” design to easily attach and re-assemble various Snaptic modules. The snap design used on each module includes two male/female components to properly snap to other modules. The male side is a cylinder of diameter 3mm protruding from a tab on either side of the module of 6.5mm indentation that protrudes 2mm. The female side is a protruding tab of 8.5mm from the module that has a circular hole of diameter 3.1mm to match with the male side cylinder. The snap design is uniformly included in all Snaptics modules allowing designers to order their modules as needed for their desired projects while maintaining a tight and stable fit.

C. Electronics Design

The electronics were designed to support modularity, be easy to assemble, and minimize costs. It was necessary for the control circuity to support expansion to a large number of actuators and have integrated wireless functionality, expanding the possibilities for designers. To these ends, the SparkFun ESP32 board was decided upon as the system controller. To act as an interface between the ESP32 and the actuators, a custom PCB was designed over a more informal, “proto-board” solution to ensure consistent quality for users. Furthermore, using a PCB allowed for the integration of an external power supply and drivers for the ERM motors via MOSFETs.

D. Material Selection

Snaptics uses 3D-printing technology to make designs more accessible to students and makers. All Snaptics designs are built and tested off of hobbyist FDM 3D printers which have been decreasing in price and now can range from $200-$500 dollars for a satisfactory budget printer. On these FDM printers, the two most commonly used 3D-printed plastic materials are PLA and ABS. Practically speaking for Snaptics, these materials differ primarily in their thermal expansion properties. To allow a wide user base to print these modules, all modules were designed to be printed in either PLA or ABS with minimal changes in printer settings. Details on these settings are provided at www.snaptics.org.

V. Conclusion

We developed Snaptics to serve as an accessible and adaptable solution in wearable haptic device design. Snaptics intends to make multi-sensory wearable haptics inexpensive, simple to build, and mobile. Snaptics currently supports eight module types encompassing stretch, twist, and vibration actuation and modules to support any Snaptics wearable. Snaptics will allow researchers, students, and makers to have easy access to wearable haptic devices that they can customize and modify. With the provided designs, Snaptics will allow a wide audience to learn about wearable haptics and create their own haptic devices. We hope that Snaptics will be a common entry point for those curious about the technology and allow the field of haptics to expand in popularity among scientific crowds and the general public.

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