ACCESS KNOB: Parametric Design of 3D-Printable Accessible Synthesizer Controls for Users with Reduced Hand Strength

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Synthesizers and electronic musical instruments are popular tools for creating contemporary music, offering versatile expressive possibilities for music compositions that easily transfer to electronic media platforms. While these tools increase the accessibility of music production to broader populations, particularly by reducing barriers for recording and distributing music while also at times lowering the overhead towards instrumental proficiency, the physical design of the instruments presents significant accessibility barriers for users with motor impairments affecting grip strength and fine motor control. These barriers unnecessarily deter musicians bearing these impairments from creating music. To address this, the ACCESS KNOB, an open-source parametric web tool for generating customizable 3D-printable knobs, will enable the creation of replacement knobs for synthesizers and other electronic musical instruments that can be operated with reduced hand strength and sensation.

CCS Concepts: • **Human-centered computing → Accessibility technologies**; *Accessibility design and evaluation methods*; • **Applied computing → Sound and music computing**.

Additional Key Words and Phrases: accessibility, assistive technology, parametric design, 3D printing, synthesizers, motor impairments, universal design, music technology

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1 Introduction

Musical expression through synthesizers and electronic instruments requires precise tactile control of numerous parameters, such as knobs, faders, and buttons. For users with motor impairment, reduced grip strength, or diminished hand sensation, these standard interface controls can present insurmountable barriers to the usability of these tools that limit full access to music expression. The typical synthesizer knob—small in diameter, smooth or minimally textured, and requiring precision grip and fine motor control—excludes a significant population of potential users. [30]

This research presents the bespoke design of accessible synthesizer knobs, and its parametric design tool, for a retired IT professional and avid synthesizer collector who, due to dialysis-dependent kidney failure, had progressively lost hand strength and sensation. Due to his disability, his collection of rare synthesizers, accumulated over decades, had become largely unplayable. Alternative solutions and workarounds failed to produce the nuanced, expressive control integral to synthesizer performance.

Although many people will experience decreased fine motor skills and grip strength decline through age or injury, standard synthesizers and electronic instruments favor smaller knob designs with no mainstream alternatives [19]. To address the diversity of needs for fine dexterity and control, ACCESS KNOB leverages the increased availability of 3D printers and laser cutters [3] to allow musicians to generate customized 3D-printable replacement knobs using a parametric web-based tool. Building on the principles of Universal Music Design (UMD) [6, 15], ACCESS KNOB addresses motor accessibility while maintaining applicability for all users. [1]

We contribute: (1) documentation of a parametric design system for accessible synthesizer controls informed by lived disability experience; (2) an engineering evaluation of the parametric design space, physical print tolerances, and mechanical torque advantages; (3) discussion of extensibility to other instrument types and assistive device domains; and (4) reflection on open-source distribution as an accessibility strategy [28]. The research is led by a Deaf lead designer and researcher while the rest of the team consists of universal music design and HCI researchers.

2 Related Work

Research in Accessible Digital Musical Instruments (ADMIs) [11] has historically prioritized eye-tracking, occupational therapy frameworks, rapid prototyping of bespoke instruments, or entirely novel interfaces to support musicians with diverse motor and cognitive impairments [17, 22, 24, 25]. However, these approaches focus on creating new instruments rather than retrofitting existing commercial hardware, leaving classic physical synthesizers largely inaccessible. Parametric and generative design frameworks address this by enabling personalized, custom-fit physical adaptations, such as non-invasive mappable gesture sensing [29] and custom 3D-printed orthopedic grips or pneumatic controls with variable activation forces [9, 20, 27]. Generative systems further democratize fabrication by exploring design spaces algorithmically, removing manual CAD editing bottlenecks [16]. ACCESS KNOB builds on this approach to DIY fabrication by utilizing a mutation engine to generate customizable variant batches, ensuring direct user agency in selecting ergonomic shapes.

The system integrates and promotes UMD's ethos of sonic agency, coined by La Belle [18] and further explored by HCI researchers [6], to increase not only accessibility, but also ownership and agency of music technology that historically excluded DHH musicians and musicians with motor disabilities. These frameworks emphasize multimodal, cross-disability design by integrating visual, auditory, and haptic feedback channels. [4]. This framework is particularly relevant for DHH musicians who utilize vibrotactile interfaces for sensory reinforcement [5, 7]. Given that vestibular variations in DHH populations can affect motor coordination [10, 31], our parametric customization combines tactile shapes, voice/facial inputs, and auditory/haptic feedback to unify motor and sensory accessibility.

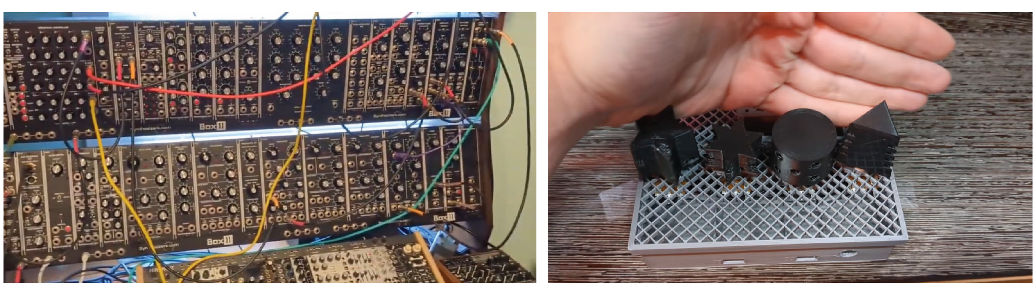

Fig. 1. On the first figure, synthesizer interface is shown with an extensive control structure using small knobs and buttons. On the second figure, 3D printed augmentation of the ACCESS KNOB outputs are shown.

[1]A video demo of this platform is available here. The video is created by the Deaf lead designer and voiced over using automatic voice generation tools.

3 System Description

ACCESS KNOB is a browser-based parametric design tool built using JavaScript, Three.js for 3D visualization, and a custom geometry engine for procedural knob generation. The interface provides a 3D real-time preview, parameter sliders, export options, and a mutation engine for the exploration of generative designs (see Figure 1). Parameteric controls are presented in Table 1 where users can adjust the following parameters via sliders and numerical inputs.

Table 1. Primary parametric knob design parameters.

Parameter	App Range / Options	Purpose & Design Context
Shape	10 profiles (tri, hex, stars, wave, etc.)	Tactile shape-coding for low-vision users [21].
Outer Diameter	10–80 mm (defaults: 19, 25, 32 mm)	Larger size increases mechanical torque advantage.
Height	10–50 mm (default: 22 mm)	Maximizes grasp area for palm-drag rotation.
Taper Ratio	0.60–1.00 (top/bottom ratio)	Improves ergonomics and tactile distinction.
Texture Mode	8 styles (flutes, rings, knurl, bumps, etc.)	Enhances surface friction and tactile feedback.
Inner Bore	6.0–50.0 mm (sleeve); 4–10 mm (direct)	Matches target synthesizer potentiometer shafts.
Slot Depth	4–40 mm	Matches shaft heights for rotational locking.
Clearance	0.1–1.0 mm (default: 0.3 mm)	Compensates for 3D printer tolerance variances.
Set Screw	None (friction), radial M2, M3, M4	Secures physical interface against high torque.

3.1 Mounting, Mutation, and Export Formats

The customizer supports two mounting strategies: **Swap-In Mode** (directly replacing the original knob) and **Slide-Over Mode** (fitting as a non-destructive sleeve over the existing control). In addition to 3D-printable meshes, ACCESS KNOB features a 2D vector SVG stacking exporter for subtractive fabrication (e.g., laser-cutting or CNC-milling). The exporter slices the 3D model into 2D layer profiles based on user-specified material sheet thickness and laser kerf width (default 0.1 mm). To facilitate quick and accurate manual assembly, the exporter automatically generates two kerf-compensated alignment rods and corresponding slots through all layers, allowing stacked pieces to be precisely aligned and glued. The design interface is shown in Figure 2.

The tool exports manifold STL meshes, OpenSCAD scripts, 2D SVG layer contours, and JSON/CSV datasets for configuration sharing. This architecture ensures that users with motor impairments retain direct design agency over their own instruments rather than relying on proxies, aligning with the sonic agency framework which asserts the right to shape one's own expressive tools [8].

3.2 Accessibility and Interface Input Options

A critical consideration in assistive technology design is whether the design tool itself is accessible [24]. A parametric knob customization system that requires fine motor control to operate would perpetuate the very barriers it aims to address. ACCESS KNOB's browser-based architecture supports platform-level accessibility features without custom client-side installation.

Apple Voice Control and Switch Control: macOS and iOS users can operate ACCESS KNOB entirely through voice commands [2] or camera-based facial gestures and head movements [1]. Voice Control enables users to speak

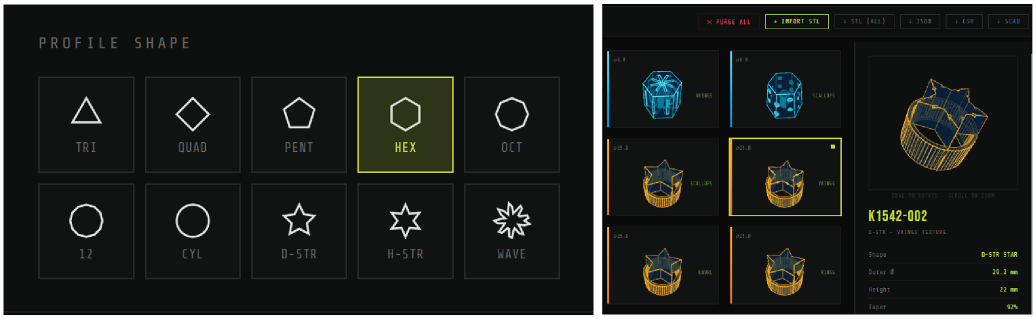

Fig. 2. First figure shows the profile shape options including triangle, diamond, pentagon, hexagon, octagon, and star configurations for tactile and visual distinction. Second figure shows ACCESS KNOB interface with a batch of 12 generated knob variants with hexagonal profiles. Parameters are displayed for the selected knob (K793-001) including shape, diameter, height, groove geometry, and bore specifications. The mutation engine enables rapid design exploration.

commands to navigate, tap buttons, adjust sliders, and trigger exports. Switch Control with camera tracking allows users to control the interface through head movements (left/right gestures) or facial expressions (e.g., smile, raised eyebrows) mapped to interface actions.

Google Project Gameface: Windows and Android users can employ Google's open-source Project Gameface system [13, 14], which translates head movements and facial gestures into cursor control and click actions. This system operates across any web-based interface, including ACCESS KNOB's parametric controls and mutation engine.

Hardware Requirements: Both Apple and Google solutions require only a standard USB webcam, making assistive input accessible at commodity price points. Higher-end implementations (e.g., Apple TrueDepth cameras on recent devices) provide enhanced facial tracking precision but are not required for functional operation.

4 Methodology

This work follows a research-through-design (RtD) methodology, in which the designed artifact and the process of its making are the primary sites of knowledge production [12, 32]. Rather than testing a hypothesis, we pursued a single bespoke design case developed with one musician in their home across four phases: (1) understanding their music practice, (2) designing the tool and a set of example knobs, (3) a deployment period of independent use, and (4) a closing reflective visit. We adopted this longitudinal, in-situ structure because the design need could not be specified in advance; it emerged through repeated contact with the participant's practice and the material conditions of their home.

4.1 Data Collection and Analysis

The data comprised field notes, written during and after each visit, capturing the participant's practice, needs, and responses alongside the first author's design reasoning and design artifacts. Consistent with an RtD orientation, analysis was interpretive and ongoing rather than a discrete stage [26]. After the final visit, I revisited the notes and artifacts together to trace the design's trajectory across the four phases, how the need was reframed, which decisions proved consequential, and what the in-home process disclosed, reading each against the other as evidence of the reasoning embedded in the design.

5 Results from Deployment and Field Study

Our initial deployment targets the individual whose needs catalyzed this project: a retired IT professional and avid musician whose dialysis-dependent kidney failure has caused progressive loss of hand strength and sensation over the past eight years. Over his lifetime he acquired roughly 20 hardware synthesizers—modular, semi-modular, and keyboard for producing electronic music and live performances, but his progressive disability made this carefully curated collection increasingly difficult to play. Our goal was to enable him to continue his music practice regardless of these physical challenges [23].

To adapt to mobility loss, this musician used the following workarounds: 1) Apply a T-wrench for leverage on small knobs (limited to knobs with compatible geometries); 2) Drag a palm across control surfaces (imprecise, fatiguing); 3) Avoid instruments with densely packed or recessed controls; and 4) Rely on software-based synthesis (reducing tactile instrument interaction). Ultimately, these modifications reportedly led to frustration due to loss of expressive control and decreased motivation to engage with hardware instruments despite continued interest in this creative practice.

The mutation engine generated a batch of variants across sizes, shapes, and heights, which the user evaluated directly—identifying large, tall profiles as most effective for his grip strategy. Once printed via ACCESS KNOB software, these initial swap-in knobs required assistance to install across his collection of roughly 20 instruments, though he could then manipulate them independently. This installation burden informed the slide-over sleeve design, which let him mount and remove knobs without assistance. Paired with other adaptations, the knobs improved usability and reduced the burden of imperfect workarounds; informal follow-up confirmed renewed engagement with his instruments, and a third-party observer noted increased quality of life and energy for other projects.

Beyond motor limitations, the browser-based customization supports keyboard navigation and platform-level hands-free interfaces (Apple Voice/Switch Control, Google Project Gameface) using commodity webcams. For blind or low-vision users, a multimodal interaction loop integrates hidden ‘aria-live‘ parameter announcements, oscillator-based parameter sonification (Web Audio API), and short haptic confirmation pulses (‘navigator.vibrate()‘).

6 Discussion

Due to the difficulty of customizing the hardware for electronic and synthetic instruments, musicians have sadly set aside their instruments and their creative music practice once mobility limitations occur. However, music instruments can now be modified for accessibility using tools like ACCESS KNOB. Core features of this tool highlight user-driven, browser-based design that allows full customization of products to their motor profiles as well as easy and inexpensive production by individual users using 3D printers and laser cutters. This tool supports user agency and independence. The non-destructive slide-over sleeves preserve commercial hardware integrity, while tactile shape-coding bridges visual and motor accessibility. Releasing the tool as open-source lowers production costs to cents per knob, though it transfers quality control to user print profiles. Future work will extend the parametric engine to physical linear faders (mixer metaphor), drum pads/triggers, foot switches, and other custom interfaces while integrating color theory using LED’s and audio metering alongside haptic feedback; and will include occupational-therapy-guided clinical trials under an approved IRB protocol to evaluate long-term ergonomic utility. Utilizing UMD concepts, we will explore the "universal" capacity of ACCESS KNOB beyond this use case ported for DHH and neurodivergent users as well as opportunities to support Universal Collaborative Artistic Practice. This work will be distilled into a curricular study for use in Accessibility and Special Education environments to evaluate efficacy while developing an original Accessible Music album.

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