Jugaad Instruments: A Scalable Framework for Accessible Digital Musical Instruments in Resource-Constrained Contexts

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Abstract

Accessible digital musical instruments (ADMIs) hold significant potential for enabling musical expression among individuals with disabilities, yet most fail to achieve sustained use beyond their initial contexts. Cost, scalability, and adaptability are further magnified in resource-constrained environments, where the majority of the world's population lives. This paper presents a framework for scalable ADMI deployment built on a modular system of commodity game controllers, 3D-printed accessibility augmentations, and open-source Android applications. We describe the framework's design principles, present a case study from an initial deployment at a nonprofit organization in Northern India supporting women with disabilities, and discuss implications for accessible music technology in cost-sensitive contexts worldwide.

Keywords

Accessible digital musical instruments, modular toolkits, resource-constrained, mobile music-making, participatory design

1 Introduction

There is an inherent trade-off between customization and generalization in ADMI design: hyper-personalized, well-calibrated interfaces for fewer individuals, or generalized, customizable solutions that provide a more limited experience for a larger subset of users. These pressures are amplified in under-resourced contexts, where constraints on cost, maintenance, and staff time shape what can be deployed and what sees continued use. Most ADMI research is developed and disseminated within digital musical instrument (DMI) venues that are geographically concentrated in Europe and North America, and deployment in resource-constrained settings remains under-researched [8, 13]. In such deployments, accessibility includes not only ergonomic interfaces, but also maintainability, affordability, device compatibility, setup time, and the ability for local users to operate the system after researchers leave. Here, scalability refers to replication under local constraints, the ability to swap controllers and devices without redesign, and a workflow that can be taught to staff and repeated without specialized expertise. Scalability also depends on digital portability: sharing code, 3D models, and mappings to support remote iteration, maintenance, and collaboration between communities. This framework draws on a "jugaad" ethos, a Hindi term for frugal, improvisational problem-solving, prioritizing practical deployability over engineering perfection.

NIME '26, June 23–26, 2026, London, UK

2 Background

A well-studied problem in the DMI maker community is that most interfaces fail to gain widespread or sustained adoption [10, 18, 21]; Morreale and McPherson found that the vast majority of DMIs presented at NIME between 2010-2014 were used fewer than three times, inhibiting instrument pedagogy and community building. ADMIs face an additional hurdle: Frid's review of 83 ADMIs [10] found not only a lack of formal frameworks and methodologies, but difficulty in even defining such guidelines, as different use cases can require substantially different approaches. Similarly, Lucas et al. found that ADMIs often fail to achieve sustained and widespread use outside of the specific context it was designed for [18]. A proposed remedy is an emphasis on modular, standardized, and readily available hardware. Parke-Wolfe et al. argue for instrument-building toolkits that enable educators and therapists to create custom interfaces without engineering expertise [24]; further, Ward's toolkit approach stresses the "dichotomy between bespoke tailoring to one user or modular flexibility that may be 'good enough' for many users" [31].

Re-purposing video game controllers for digital music-making is well researched, from conventional gamepads [27], to the Gametrak [9], Kinect [11], and other reinventions [16]. Similarly, smartphones have been a versatile medium in computer music [30]. Combining the two can be fairly easily implemented, as many modern game controllers connect to smartphones via Bluetooth or USB as standard human interface devices (HIDs); applications such as MobMuPlat [15] allow phone interaction, including HIDs, to connect to Pure Data patches. Within the gaming community, there have been concerted efforts to redesign controllers to better meet the needs of players with disabilities. Both PlayStation [23] and Xbox [29] have released accessible controllers for their respective platforms. However, these controllers remain expensive, $100-200 USD, not including peripherals, and available in limited markets. Additionally, individuals' accessibility profiles can only be configured on their respective console ecosystems. While such controllers represent a step forward, they are priced for people who can afford new PlayStations or Xboxes, a high price of entry for much of the world.

Preceding these official offerings, a community-driven ecosystem of homemade controller modifications developed as DIY solutions. 3D-printed augmentations, freely distributed in online 3D asset repositories such as Printables and Thingiverse [20], are designed for a small set of standardized controller geometries, and can be modified further to suit specific use-cases [17]. This modularity creates a scalable and cost-effective paradigm: designs shared as digital files, personalized through further modification, and fabricated locally.

Approximately 52% of the world earns less than $3,600 USD per year; more than 80% earns less than $11,000 USD per year [12]. In this context, a $100-200 USD accessible controller is exorbitant; even a conventional Xbox or PlayStation controller is expensive at $60-80 USD. For similar reasons, Android, with more

Figure 1: A DualSense controller augmentation for one-handed operation, design files freely available on Printables.

and cheaper hardware options than iOS devices, is the dominant mobile platform worldwide, holding more than 70% of global market share, and more than 85% in developing economies according to the World Bank [7]. In such markets, Pew Research found that mobile devices are the sole computing device for the majority of households [26]. Further, the World Health Organization estimates that 16% of the world's population experiences significant disability [2]. Disability prevalence also shows an income gradient across countries, with higher rates in lower-income countries [14]. These economic realities form key design constraints for ADMIs to realistically scale in cost-sensitive contexts.

3 Design Framework

We propose a framework for scalable ADMI deployment based on three components: commodity game controllers, 3D-printed controller augmentations, and open-source applications for Android devices. Building on modular toolkit approaches for ADMIs [24, 31], this framework aims to optimize these approaches for resource-constrained environments; all components of the ADMI's hardware and software can be customized for distinct accessibility needs, cost constraints, and local availability.

The hardware is built around gamepad controllers, including official offerings, generic versions, and prior generations. Generic controllers are available globally through numerous e-commerce platforms and local vendors, typically at a fraction of the cost of name-brand versions. Gamepads are recognized as standard HIDs by Android devices, no drivers or non-Android devices are required. Crucially, since generic controllers share geometries and layouts similar to official offerings, they remain generally compatible with established community-driven repositories of accessible controller augmentations [17, 20]. These augmentations address a range of motor accessibility needs, further customized for individual user needs, and printed locally with 3D printers.

Accompanying software prioritizes lightweight Android applications capable of running on low-specification devices common in cost-sensitive markets. Pure Data, an open-source integrated computer music environment with decades of development, is an ideal audio engine [25]. Any "vanilla" Pure Data patch can be embedded into an Android app using libpd [6], a library for embedding Pure Data patches into common programming frameworks. In this arrangement, the app (GUI, controller routing, configuration) and DSP logic are cleanly separated, and different patches can be easily loaded, swapped, or modified as desired, while leaving the main app unchanged; MobMuPlat [15] and PdParty [32] are exemplars of this workflow. A JSON-based or other structured data preset system allows controller mappings to be saved and distributed digitally. Open Sound Control (OSC) extends the system to integrate with external software, fellow mobile device users, or networked ensemble setups [33].

This arrangement of independent hardware, augmentations, mappings, and audio components builds on established modular ADMI frameworks [24, 31], adapting for greater scalability in settings with limited budgets, infrastructure, and technical support. Users can redesign augmentations to better fit individual needs, audition different controller mappings, or create new software instruments to emulate local musical practices, without needing to modify separate components. Locally sourced commodity hardware ensures that purchase, repair, and replacement costs remain feasible, while consistent game controller geometries and the universal Android platform ensures aligned community development. In summary, the framework rests on a small set of design principles tailored to scalable ADMI deployment in resource-constrained contexts. Hardware is sourced from locally available commodity controllers rather than specialized interfaces, and augmentations are built from shared online repositories and fabricated locally. The software architecture separates the GUI, mapping, and audio layers so that components can be swapped independently, and JSON-based presets allow configurations to be saved and shared. On-device configuration interfaces are designed so that non-expert users and caregivers can operate and adapt the system.

4 Case Study

To validate this framework's feasibility in resource-constrained settings, we conducted an initial deployment at a nonprofit organization in rural Northern India supporting women with disabilities. The complete system was assembled with components sourced from a Tier 2 Indian city approximately 1 hour away from the nonprofit. A generic PlayStation geometry controller (Ant Esports GP400, 1,500 INR / ~$18 USD) was purchased at an electronics retailer, and the augmentations were produced at a 3D-printing shop (INR 150/hour / ~$1.80 USD/hour). We combined these parts with a Redmi 8A, an entry-level Android smartphone released in 2019 (as of August 2025, selling on secondary markets for ~INR 2,500-3,500 / ~$28-39 USD) that was already owned by the nonprofit. An official PlayStation DualSense controller and a US-market Samsung Galaxy A4 Android smartphone were also brought by the research team. Two augmentations were printed: a DualSense attachment for one-handed operation (see Figure 1) [3] and a pair of DualSense thumbstick extenders custom-made by the research team. The custom thumbsticks were easily generated in CAD software by combining an existing DualSense thumbstick extender model [4] with research techniques for gripping devices to aid individuals with cerebral palsy [5]. The total cost for all augmentation printing was INR 2,100 / ~$23 USD.

The software layer used a lightweight Kotlin-based Android application with an embedded libpd audio engine. The application had three sections: a mapping tab, configuration tab, and a controller interaction GUI. The mapping tab contained all of the

Table 1: Cost breakdown of materials (conversion rate as of August 1, 2025)

Item	Cost (INR)	Cost (USD)	Notes
Generic PlayStation Geometry Controller	INR 1,500	$17.19	Ant Esports GP400
3D Printed Augmentations	INR 2,100	$24.07	Printing cost for one-handed adapter and thumbstick toppers
Total (Excluding Smartphone)	INR 3,600	$41.26	
Total (Including Smartphone)	INR 10,099	$115.75	Redmi 8A smartphone, original retail price INR 6,499 / $74.49

possible HID output signals from the controller, either discrete on/off button presses or floating-point values from thumbsticks and triggers. These then were mapped to the audio engine using dropdown menus; discrete signals could be assigned to trigger transport events, samples, and value increments; floating-point values could be assigned to affect value sliders. The ranges of the floating-point values were also able to be scaled to specified minimum and maximum output values. The configuration tab allowed the mappings to be saved and loaded as JSON files, and also contained an interface for sending controller values, receiving external signals via OSC, and loading local WAV files on the device.

The application was configured as a dynamic remixer, allowing participants to reshape Bollywood and Nepali pop songs familiar to them. In its initial configuration, each of the two thumbsticks controlled the wet/dry mix for four audio effects, where center was dry for all effects and each direction, up, down, left, and right, blended in one of the four effects. The D-pad buttons triggered one-shot samples, and the shape-buttons controlled transport and volume. L1 and R1 buttons shifted the pitch by a semitone down or up, and the L2 and R2 triggers controlled low-pass and high-pass filters.

The women in these sessions were already members of the nonprofit's existing programs; participation was voluntary, and sessions were offered as part of the nonprofit's regular activities rather than recruited specifically for this work. Over the course of the deployment, the system was used in sessions with 7 women supported by the nonprofit, whose motor profiles included cerebral palsy, nerve damage, and limb amputation. Sessions ran 30–60 minutes and were facilitated by the research team alongside NGO staff. The aim of these sessions was not formal evaluation of participant experience, but observation of whether the system could be configured, operated, and adapted on-site under realistic deployment conditions. In practice, the controls were learnable within roughly 15 minutes of hands-on time. The accessible grip extensions provided finer control for several users, and the single-hand adapter allowed a woman with an upper-limb amputation to operate the full controller. The on-board configuration interface let sessions be tailored to song choice and effect preference, and pitch shifting supported sing-alongs in comfortable vocal ranges. NGO staff were trained on-site to assemble augmentations, pair the controller, and adjust mappings. While this deployment did not include formal evaluation metrics, it demonstrates that the entire framework could be sourced, fabricated, and implemented on-location for a practical cost while providing an engaging musical experience for users with disabilities.

5 Discussion

Initial deployment suggests that the combination of commodity controllers, local augmentations, and lower-spec mobile devices is a logistically viable method for building ADMIs and supports meaningful musical interaction. Software performance was stable across multiple Android devices, and Bluetooth and USB controller connections were reliable. Generic gamepad controllers were purchased at a nearby electronic vendor, and a 3D printing service was found within a reasonable driving distance. Participants were able to understand the controller layout and effect behavior within minutes, then personalize the experience through song choice, pitch shifting, and effect settings, shifting the interaction from researcher demonstration to participant music-making.

The system was designed as a remix instrument rather than an open-ended melodic interface. In early discussions, participants and staff emphasized a desire to work with familiar Bollywood and Nepali pop songs, and a DJ-style remixer offered a direct way to do that. Even for participants who could comfortably operate a conventional instrument such as a piano, reproducing a complex pop arrangement in a satisfying way is rarely straightforward without training and accompaniment. The remix paradigm was collaboratively designed by the research team, participants, and nonprofit staff. It kept the song recognizable and culturally relevant, while giving participants immediate control over effects, pitch, and one-shot events through mappings that could be simplified, expanded, or swapped as needed. Participant preferences translated directly into rapid changes in sounds and mappings during the deployment. One participant asked that the one-shot percussion triggers be replaced with animal sounds, which was implemented in minutes and increased engagement. Effect preferences also varied; for example, a few participants strongly disliked the ring modulator, and it was swapped for an alternative effect of each participant's choosing. Across sessions, the pitch-bending "DJ-scratch" effect was consistently popular, and semitone pitch shifting was repeatedly used to support sing-alongs in a comfortable vocal range. These moments highlight a practical advantage of the framework: mappings and sound sets can be adjusted in minutes to match individual taste, cultural context, and accessibility needs.

Nonprofit staff were able to run the system after a brief walkthrough: launching the app, pairing the controller over Bluetooth, connecting to an external speaker, selecting audio files, and adjusting mappings and settings through the on-device configuration interface. This distinction mattered in practice; staff could operate the system and tailor sessions without needing to code. At the same time, edits beyond exposed configuration parameters would likely remain a barrier without engineering support. In practice, staff can operate and configure the system locally, while researchers and skilled users contribute software changes remotely and provide updates that can be installed on-location. Sustained, equitable use of accessible music technology in resource-constrained contexts depends on partnerships where the technology is one component of a broader, ongoing relationship, rather than handed-over deliverables. In this deployment, the nonprofit shaped session goals and identified culturally relevant musical material, and the system was left in their hands with documentation and remote support so that music-making does not depend on the research team's continued presence.

App load time varied among devices; ultimately only the Redmi 8A and Samsung Galaxy A4 were used for evaluation. Access to music recordings and recording format were issues. Users expressed a desire to play along with songs found on YouTube or other streaming services, which was not possible due to Android and third-party app restrictions. MP3 files were not able to be loaded in libpd, and relying only on WAV files was inconvenient due to their large size. A more compact and streamlined process for importing or streaming audio is an important consideration.

While the thumbstick toppers fit well on both controllers, the more complicated one-handed augmentation was a clunky fit on the generic controller. It was functional, though button and joystick movements were sticky. This highlights the importance of adjustability in controller augmentation design; friction-fit mechanisms and adaptable straps and clamps should be favored over snap-fit parts. Imperfect 3D printing can also pose challenges for augmentations with tight fit tolerances, though sanding and filing can mitigate fitting issues to a degree.

Other low-tech solutions should also not be overlooked. When a stationary controller mount was needed, we could have printed one of the many controller clips available online. However, a simple tie down to the desk using a broken cable worked perfectly well (see Figure 2). This jugaad approach is essential in real-world deployments: perfectly engineered solutions are not always necessary, and practical workarounds should be likewise documented and communally shared.

Figure 2: Jugaad in action.

6 Future Work

This paper details the creation of a scalable deployment framework and a first real-world exploration of its use in a resource-constrained setting. The initial deployment was limited in scope, a single site and a small number of participants, but it establishes feasibility for sourcing hardware locally, fabricating augmentations on demand, and configuring an open-source Android instrument that can be operated by nonprofit staff. Next, we will expand deployments across additional communities, regions, and accessibility profiles to test robustness under variation in device availability, staff workflows, musical preferences, and infrastructure constraints.

To support scaling and collaboration, we will create a centralized online database that consolidates the modular components of this framework: controller-compatible 3D-printable augmentations, Android application releases and configuration presets, and interoperable audio instruments and patches. In addition to hosting files, the database will include practical deployment guidance, print and fit notes, compatibility information for common Android versions and generic controller models, and documented use-cases from field deployments. The goal is to make successful configurations portable between sites, so that local practitioners can adopt working starting points and researchers can iterate based on shared, comparable outcomes.

Additionally, Kotlin with libpd was chosen due to its robust cross-platform compatibility and Pure Data's large open-source repository; however, there are two issues with this paradigm. First, the app and the DSP engine effectively run in parallel, so even small changes often require coordinating logic across Kotlin code and Pure Data patching, and many existing patches must be adapted to fit this message-passing architecture. Second, for non-expert users, Pure Data's visual programming paradigm is difficult to modify with current LLM coding tools [28], which raises the barrier to experimentation and local customization. For these reasons, text-based embedded audio platforms such as ChucK, Faust, or Csound may offer a more accessible development path for many users.

Another avenue for rapid deployment is browser-hosted audio, where platforms such as Tone.js [19], p5.sound [1], and WebChucK [22] can distribute interactive instruments without app installation. This paradigm was initially explored by the research team; however, variability across devices, browser types and versions, permission requirements, ad blockers, and external hardware and audio support made reliable implementation difficult. Nevertheless, the distribution advantages of the browser make this worth revisiting as mobile web audio becomes more consistent and predictable across devices.

7 Conclusion

Scalable ADMI deployment can be achieved by combining commodity game controllers, locally fabricated 3D-printed augmentations, and an open-source Android instrument built around configurable mappings and presets. The initial deployment at a nonprofit in rural Northern India showed that the system could be sourced and assembled locally, learned quickly by participants with motor disabilities, and operated by staff after a brief walkthrough. Rapid updates to mappings and audio assets enabled individualized personalization while maintaining a musically familiar and culturally relevant interaction. Sustained use will depend on shared repositories and pedagogies that allow configurations, troubleshooting knowledge, and successful activities to travel between communities. These results motivate broader multi-site deployments and a shared repository of modular components to support reuse, maintenance, and collaboration across cost-sensitive contexts.

8 Ethical Standards

This work was conducted as a technology deployment in partnership with a non-profit organization, with the goal of assessing whether the proposed framework could be sourced, fabricated, and operated under local resource constraints. It was not designed as a human-subjects evaluation of participant experience, and accordingly did not collect interview data, identifying information, or formal evaluation measures. Sessions were facilitated in coordination with NGO staff and conducted in line with the ethical standards and practices of Stanford University and relevant regional and national guidelines. The authors are aware of no potential conflicts of interest.

Acknowledgments

This work was supported by CCRMA Faculty Research Funds. Special thanks to CED Society staff and members for their support and partnership.

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