Mobile Devices as Musical Instruments - State of the Art and Future Prospects

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Abstract. While mobile devices were used before the advent of the iPhone, its introduction no doubt drastically accelerated the field. We take a look at the current state of the art of mobile devices as musical instruments, and explore future prospects for research in the field.

Keywords: mobile music technology, state-of-the-art, survey, prospects

1 Introduction

Mobile devices have been used for artistic performance for since 1998 at least, when Oliver Wittchow turned a gameboy into a looping instrument called nanoloop [20]. Smartphones predating the iPhone also drew research attention, but it is certainly true that the iPhone provided a substantial shift in the mobile smarthphone paradigm that firmly established the essence of the practice and research activities today. A review of the research developments of mobile devices, such as smart phones and tablets, as musical instruments, which is both current and thorough, is lacking and the purpose of this paper is to fill this void. The aim of the paper is to provide the working researcher a rapid entry into all the developments of the field and be able to identify knowledge gaps. Furthermore we seek to contextualize the current state of the field with respect to technological trend that should inform new research directions. The intent is to provide a thorough review of technical developments that support the use of commodity smart devices for musical purposes, with a strong emphasis on research activities. For this purpose we will not review literature that engages with performance practice, or with research that does not specifically look to address the mobile smart-device platform or exploit its specific benefits.

Previous surveys have addressed various aspects of mobile music. For pointers into the literature predating this review see [24]. John surveyed the literature with a view to the broader context of mobile music and provided broad classification of the research activities with respect to technological, social, and geographical characteristics [30]. Our survey's aim is to review the state-of-the art of technological aspects of mobile devices with sufficient detail to allow the reader to get a solid overview of the research activities and identify possible future directions. A large number of iOS music apps have appeared and have been catalogued [3]. A more taxonomic review of the android offerings was conducted by Dubus and co-workers [14]. Numerous apps have sprung from a research context such as ZooZbeat [69] or the catalogue of Smule apps [65]. It is surprisingly rare that existing hardware-based musical instruments are translated onto the mobile platform. A rare example is Crackle [52] which realizes a mobile version of the STEIM CrackleBox. Another is the mobile app Reactable which mimics the tabletop instrument with the same name[3]. More frequent is imitation and virtual augmentation of traditional instruments (see for example [66]). Games are a form of interactive performance, and offer incentives as part of the interactive design. Musical games or musical instruments with game elements have been explored in various projects [4] and discussed as strategy in detail [67]. Another sizable class of of research is concerened with creating new instruments that are the result of software realization on the mobile device. For example, they make use of the compass in mobile phones to facilitate performance [32].

This paper is organized into four main parts. First we review the state of the art of research on mobile musical instruments over the last ten years (section 2). Then we review the landscape of substrate technological changes relevant for mobile musical instruments and their implications for grounding future mobile music research (section 4). Finally, Section 5 discusses ongoing challenges facing mobile music research.

2 State of the Art of Mobile Musical Instrument Research

Research into mobile musical instruments can be categorized into proposals of a methodological nature, software support for the design of mobile music, augmentations or hybridizations, and mobile musical instruments for specific performance practice.

2.1 Methodologies

Various taxonomies to understand mobile possibilities for music performance have been proposed, including the use of multi-dimension design spaces [20] and drawing on taxonomies of embodiment and the classification of mapping approaches [61]. Surveys and thematic analysis was used to study user's preferences in mobile performance GUIs [62]. The use of iterative prototyping and user study cycles has been advanced as methodology [5]. Strategies to augment social engagement in mobile music collaboration was studied using survey and Modified Stimulated Retrospective Think-Aloud methodologies for qualitative assessment [51]. Yang employed controlled user studies and timed tasks to study performance differences in mobile music programming representations [71].

[3] `http://reactable.com/mobile/`

2.2 Musical Interface Software on Mobile Devices

Mobile devices are primarily made musical through software. Hence the support of mobile music through different software approaches takes a central role in the research of mobile music instruments.

Embeddable Software Libraries: Embeddable software libraries offer simplified solutions to important aspects of the software development mobile musical instruments. One of the most widely covered aspect is sound playback, recording, and synthesis. Typically these are either compilable C or C++ level wrapper and helper functions, or packaged libraries. MoMu is a set of C++ level functions that wrap important sound, networking, threading, and sensor interaction functionality into more easily accessible and higher level functionality to more rapidly create prototypes [7]. Ports of well-established synthesis environments are also available. In this category, Libpd is an embeddable version of pure-data's synthesis engine [6]. Also a embeddable mobile port of CSound has been developed [37]. Experiences in developing audio apps using embeddable libraries was reported by Erkut and co-workers [15]. An alternative to C++ level mobile programming is cross-compilation of synthesis patches from desktop or laptop software environments. MobileFaust is such as cross-compiling solution for the Faust sound synthesis language and environment [46]. Some embeddable solutions were created to service full-fledged high level mobile music environments. UrSound, developed as part of the urMus project, is such a synthesis engine [17]. It differentiates itself from legacy ports by offering patching paradigms that seek to support rapid on-the-fly patching and improved CPU utilization by employing a multi-rate patching pipeline.

Multi-touch GUI and Interaction Design: Multi-touch displays and interaction play an important new role for mobile devices, as these are their canonical forms of interaction. Substantial effort has been exerted developing approaches to design graphical interactions for multi-touch as well as to support the rapid development of flexible new solutions. Multi-touch interaction design is one of the design features of urMus [21] allowing the creating of arbitrary dynamic graphical and interactive content in the Lua programming language. The efficacy of various graphical interaction paradigms (icon-based, menu-based, and gesture-based) was studied extensively using this framework [72]. Control [54] is an OSC and Midi remote controller with customizable interface through a set of extendable graphical interaction widget elements. Extensions to Control offer OSC-induced interface changes that can be executed on the fly, automated layouting of widgets, and integration with MAX/MSP, LuaAV, and SuperCollider [55]. NexusUI is javascript based widget library for web programming meant to along mobile and non-mobile control interface design [64] taking advantage of the web's cross-platform character.Mira is a Max/MSP mobile interface that uses the idea of GUI mirroring [63]. A remote Max patcher offers interface elements that are mirrored and as needed dynamically updated as needed on the table display and that also can be interacted with. Controls are returned to the remote Max patcher. An alternative approach uses handwriting and drawing to sketch MAX/Msp style patches [56].

Mobile-based music environments: urMus is an environment to support mobile music on the mobile device itself [16]. It offers the ability to create arbitrary graphical representations and interactions, and provides a signal patching infrastructure. It supports access to a wide range of sensors and actuators, on-device as well as collaborative live-coding, networking, and machine learning. Rather than being distributed through mobile market places, it is available on an open source basis.

2.3 Machine Learning

Machine Learning approaches were incorporated into mobile music systems in various ways. Derbinsky and co-workers incorporated the Soar cognitive architecture into urMus, which offers a range of common machine learning techniques in the context of a broader cognitive framework [12]. This system was utilized to create a collaborative mobile drum circle solution where machine learning can learn and then improvise from given live human performances [13]. Moodifierlive is a collaborative mobile performance platform that uses the KTH rule-based system to control expressivity in MIDI files on multiple mobile devices. The rule-based system is driven from the sensors [23].

2.4 Hybridization and Augmentation

Augmentation in instrument design refers to the extension of an existing musical instrument with some new capability [47]. We consider hybridization when two existing musical instruments are combined to form a joint new instrument.

There are different types of augmentations and hybridization. In Miranda and Wanderley's definition augmentation refers to an existing traditional musical instrument being augmented through technological means to change or enhance its musical capabilities. For the purpose of this paper we will consider a commodity mobile device to be comparable to a traditional musical instrument, in that it is an easily available commercial artifact that is subject to extensions and modifications. In this view, augmentation and hybridization carries over to mobile devices (see for example [19]) allowing an instrument designer to create novel and more custom aspects in the context of a commodity technology.

Hybrid Instruments: An example of a traditional musical instrument being hybridized with a mobile device was introduced by Martin for vibraphones [44]. Another example of hybridization combines traditional turntable performance of scratching with mobile devices [8]. The mobile device is placed on top of the turntable and senses motion, but can access arbitrary sounds hence liberating the interaction from the need of having a fixed vinyl disk to perform. Another example of (internal) hybridization is Tok! It proposes that a mobile device can be viewed as an acoustic instrument when it is tapped against a surface [43]. Michon and co-workers introduced various examples of hybridized instruments using the iPad, a sensor-augmented electric guitar and 3D-printed acoustical horn augmentations around the iPad [45].

Augmentation of Mobile Devices: Commodity mobile devices come with a certain set of capabilities. These may not be sufficient for some musical performances. Augmentation can be used to overcome this limitation. The surface of a commercial multi-touch phone offers no discernable haptic features to orient a user of interaction elements. Allison and co-workers have proposed passive haptic overlays to improve on this problem [60]. A particular area of attention has been added force or pressure sensing [22, 50]. While iOS devices only offer binary touch information (contact or no contact), Android devices offer information about the contact size. This can be exploited for touch interactions beyond binary, and can also be used as heuristic measures of pressure, where increased contact size is assumed to correspond to increased contact pressure. MobileMuse is a platform for biometric emotion sensing that combines galvanic skin response, pulse oximetry, temperature and accelerometer sensing on custom hardware that communicates with a mobile devices for data analysis [35].

3 Mobile Music Instruments in Performance

Numerous mobile music instruments have been developed to support existing traditional performance practices. For example, apps to support spatialization [49] or choir artificial voice performance [11] have emerged.

Networked Mobile NIMEs, Audience Involvement and Participation: The ability to use numerous mobile NIMEs in a networked ensemble offers rich opportunities for artistic expression. Much of the work on networked mobile instruments has focused on audience participation. However, some research also involves generic support of network features. For example, Essl [18] proposed the use of ZeroConf network discovery to semantically organize networked mobile performances. Central to traditional notions of mobile music, geo-location was developed in a networked mobile music project by Allison and co-workers [2]. The commercial API Ableton Link provides network synchronization to support the Ableton music ecosystem and allows cross-linking of mobile apps[4].

We distinguish between audience involvement, in which the audience can respond to musical performances but is not participating in the music-making activities, and audience participation, where the audience is part of the musical performance. Examples of networked distributed audience involvement are many apps by Smule [65], in particular in the context of what Wang and co-authors call World Stage [68]. Social networking is a central part of World Stage in which

[4] `https://www.ableton.com/en/link/`

a distributed audience and feedback mechanism is generated by listening to and liking the performance.

While musicians can use audience's mobile devices as a speaker array over the network, (for example, [59]), they can distribute mobile music application where audience can directly and indirectly participate in the music making process.Mobile audience participation with mobile phones has a long history following the pioneering work of Golan Levin on Dialtones in 2001 and is perhaps the most active area of research for mobile music instrument technologies. Numerous technological approaches to supporting them have appeared. Oh and Wang explored a wide range of audience participation techniques and demonstrated them on a number of examples [48]. Challenges for audience participation in a concert space include the need to distribute the participation software or interface to participants. Numerous projects have tackled this problem. One approach exploits the captive web portal approach to ease the distribution problem. Captive portals are forced http redirects that allow the delivery of web pages without the need to specify web addresses. If the mobile performance interface is web-based, this solution solves both cross-platform issues and software download needs [27]. Another approach seeks to exploit cloud computing infrastructure for audience participation pieces. Pusher services allow massive distribution of data through the cloud. Using this approach, large numbers of participating audience members can receive vital performance data [9]. MassMobile environment that support large scale audience participation including mobile devices by taking a cloud-based database approach [70]. Network protocols for discovery and distribution in a concert hall network itself was explored in detail by Lee and co-workers [41]. A.bel is a multi-platform environment for rapid development of PD-based networked performances [10]. The echobo project provides detailed taxonomies of audience participation, design principles for mobile audience participation projects and demonstrates these principle in a concrete concert realization.[42]. Another example of applications of mobile audience participation include the control the stereo output of a lead guitarist as part of a live rock concert [29].

Web based composition interface to enable distributed composition for guided mobile music instruments [26]. The emergence of Web Audi API simplifies the realization of audience participation music performances [38]. Soundworks is a frameworks supporting collaborative mobile performances through the web [53].

Live Coding: Live Coding paradigms have entered mobile music instruments in various ways. One is in the design of mobile music environments. The patching interface of urMus was designed to allow live interactions [16, 21]. Lee and co-workers introduced the idea of live-coding mobile instruments as part of a performance [39]. One or more live coders program on laptops and submit their code interactively to a mobile phone where changes are immediately enacted to create new performance interface capabilities and sound patches. Followup research investigated the support of collaboration between mobile and laptop performers through the a live-coding environment [40]. MiniAudicle is an iPad version of Chuck's Audicle editor that was designed to allow live-coding performance [57].

4 Future Prospects through Technological Evolution

Technological changes create a changing environment of opportunity for musical expression. Many aspects of the mobile platform have seen improvements and additions over the past ten years. It is instructive to review these changes as well as to project some expected future capabilities to understand opportunities for future mobile music instruments.

Computational Performance: Computational performance is critical in setting barrier on the complexity of computation that can be completed under real-time constraints. For audio these real-time constraints are particularly tight as an audio sample only received 1/playbackrate seconds time. For typical rates (44.1Khz-48kHz) this leads to hard time limits of 22.67 µs. For visual updates (30-60hz) the real-time limits are substantially more generous at 16.66 ms.

Mobile smartphone CPUs have seen considerable gains over the last ten years. These gains have enabled more and more complex real-time software to be realized on mobile devices. However, it is important to note that mobile phones never experienced Moore's law-like gains in performance [25] and that already since 2013 power consumption of CPUs has plateaued [25]. This means that it is unclear that one can anticipate healthy performance gains for future architectures and that there might be a power-ceiling impacting CPU performance for mobile devices. Given that battery size, and hence screen size is the main limiter on power, we can anticipate that larger tablets will remain computationally more powerful than smaller devices.

Sensors and Actuators: Interaction is facilitated through sensors and actuators. The set of actuators in mobile devices has remained largely constant, and consists of audio display (speakers), visual display (touch-screen), and vibrotactile display (motor). Most quality improvements have focused on visual displays, where screen resolution has changed from 320x480 for the original iPhone, to 1080x1920 for the iPhone 6s[34]. These improvements improve fidelity rather than enable new possibilities.

In contrast, new sensing technologies have been added especially in the early years of the design evolution of mobile devices. The original iPhone offered multitouch, microphone, accelerometer, magnetometer, GPS, and distance sensing accessible to the programmer [20]. Since then, gyroscopes and video cameras have been added. Gyroscopes are attractive as they help expand gesture recognition possibilities. Cameras are particularly rich sensors that can be used both literally (by reproducing the visual content it captures) or to detect information that can be extracted from the visual content [31]. An example of the former is MadPad [36], an iPad instrument that allows to record audio and video of short sequences that can then be interactively performed. An example of the latter is the use of the camera to perform visual ambiance detection [58].

The types of sensors available has not changed in recent years. However their fidelity has improved. While numerous extensions (such as pressure sensing, see section 2.4) have been proposed it is unclear if and in what form such technologies will be integrated in commodity devices. This, however, suggests that continued work on augmenting mobile devices to make them more suitable for certain performance intentions will remain an important line of investigation.

Networking: Already the original iPhone offered three different networking capabilities: (1) bluetooth for short range networking, (2) mobile cellular networking, and (2) WIFI networking. The basic connectivity options have not changed since, though mobile cellular networking performance for data has improved over the last 10 years and prospects are promising that this trend will continue with future developments [1]. Wireless networking already today offers substantial bandwidth that is rarely fully exploited in mobile music instruments, indicating there is ample opportunity to expand the involvement of higher bandwidth demands to the network in their design.

Cloud Computing: A mobile device does not live in isolation, but rather is embedded in a technological ecology though networking. Computation in the cloud is a particular opportunity here. Given that network bandwidth is plentiful, utilizing networked resources offers itself as an opportunity. Numerous cloud-based solutions have already been proposed (see section 3) in particular in the context of helping to scale audience participation. There are certainly opportunities to find further ways to include computation in the cloud. As mobile devices might cap in power, offloading computation, particularly aspects of computation that can be predicted within a sensible time frame (network round-trip time + computation time) can be offloaded. Hindle proposed an example of this nature [28].

5 Challenges & Opportunities

One of the important challenges for gesture sensing is the ability to recover absolute positions in space. While GPS does offer low-resolution sensing for position outdoors, it is unavailable in most indoor performance spaces. Sensors incorporated into mobile devices such as accelerometers or gyroscopes do not offer absolute position, and standard integration techniques are subject to drift problems [20]. One solution for the problem was offered by Herrera and co-workers by using audio triangulation to detect position [33], though this method has certain limitations imposed by the sounding environment. Hence providing solutions to position sensing for indoor performances remain an important research topic with few avenues explored. Emerging performance practices frame numerous opportunities for mobile music instruments. Ease of access through the App store can enable rapid dissemination and participation, but further support for structure performance practices in ensembles and building of reproducability and repertoire pose a persistent challenge.

6 Conclusions

Mobile music based on multi-touch mobile devices has developed into a vibrant area of research in the ten years since the iPhone was released. We documented a wide range of research activities on mobile music instruments and their underlying technologies and investigated technological trends that will impact future prospects in the field. Audience participation is perhaps the most active area of research so far, while topics of machine learning in mobile music instruments remain underdeveloped. A range of software support for developing mobile music instruments have emerged from convenient embeddable libraries to full-fledged mobile music environments. Crowd and cloud computing have found their way into mobile music instruments pointing the way to the possibility of very large scale mobile music performances.

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