L2OrkMote: Reimagining a Low-Cost Wearable Controller for a Live Gesture-Centric Music Performance

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ABSTRACT

Laptop orchestras create music, although digitally produced, in a collaborative live performance not unlike a traditional orchestra. The recent increase in interest and investment in this style of music creation has paved the way for novel methods for musicians to create and interact with music. To this end, a number of nontraditional instruments have been constructed that enable musicians to control sound production beyond pitch and volume, integrating filtering, musical effects, etc. Wii Remotes (WiiMotes) have seen heavy use in maker communities, including laptop orchestras, for their robust sensor array and low cost. The placement of sensors and the form factor of the device itself are suited for video games, not necessarily live music creation. In this paper, the authors present a new controller design, based on the WiiMote hardware platform, to address usability in gesture-centric music performance. Based on the pilot-study data, the new controller offers unrestricted two-hand gesture production, smaller footprint, and lower muscle strain.

Author Keywords

Pd-L2Ork, laptop orchestra, wearable controller, Wii remote

CCS Concepts

•**Applied computing** → **Sound and music computing;** Performing arts;

1. INTRODUCTION

Laptop orchestras, a juxtaposition of a highly mobile, modern technology and a largely immobile, traditional music ensemble, allow musicians to interact with their craft in new ways [1]. Originally introduced at Princeton with the Princeton Laptop Orchestra (PLOrk) [2], the new performance ensemble saw rapid expansion to other universities [3, 4, 5]. A laptop orchestra is more loosely defined in terms of its instruments and organizational structure, as compared to a traditional one. A laptop is the centerpiece for each performer, but the way they interact with it and how music flows from the digital environment to the audience varies widely from group to group and even between music pieces. The typical performer's station features an interface device that feeds input to the laptop. The laptop then generates sound based on user input parameters and emits it through a dedicated omni-directional speaker. The input interface device can provide abstract controller data or an audio feed (e.g., voice) that is then used to generate and/or manipulate the ensuing audio output. A similar effect of the traditional orchestra is created through the individual speakers; each musician creates their own localized sound, and the sum total of these sounds becomes the full experience for the audience.

This type of collaborative, live music creation builds itself on the versatility and modularity of the laptop architecture. The environment surrounding a laptop orchestra resonates well with maker-culture [6]. That is to say, many different disciplines are required to make use of a laptop orchestra, including engaging students with no musical background to develop new sensors, software setups, and the instruments themselves [2]. One of the most exciting aspects of a laptop orchestra is the freedom that composers and musicians have in terms of interaction and digital signal processing. Rather than constraining themselves to the capabilities and instruments of a traditional orchestra, composers can now create new instruments, sounds, and input methods specific to their composition.

Early laptop orchestras used the laptop in a more conventional way, sitting with hands on the keyboard using keys mapped to different functionalities [7]. Quickly though, such economical and contained input methods evolved to include other, arguably more visually engaging, ways of creating music, including gaming controllers. Since its inception in 2009, the Linux Laptop Orchestra (L2Ork) relied almost exclusively on WiiMotes and gesture-based performance rooted in Taiji choreography [8], as one of the earliest examples of systematic exploration of choreography-centric performance practice. Other examples include the Machine Orchestra that makes use of five different musical robots in coordination with ten human-operated laptop stations [9], PLOrk's repurposing of a golf game controller [10], and most recently JoyStyx, a MIDI controller that acts as a granular synthesizer [11], where the user interacts with a music sample through five joysticks positioned underneath each of the user's fingertips.

Hyperinstruments, instruments that both produce and modulate sound [12], have strong alignment with the goals of a laptop orchestra. They enable performers to interact with their music in different ways. Some hyperinstruments modify, enhance, or augment existing instruments. For instance the HyperPuja, an instrumented Tibetan singing bowl, maintains the look and feel of the traditional instrument, but sound is generated through integrated sensors in the bowl [13]. The hyper-flute is an augmented and instrumented flute that plays like one, but enables the performer to modify the sound they create through additional interfaces installed on its body [14]. Similarly, the Hyper-shaku

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augments a Japanese bamboo sahkuhachi with gesture control capabilities, giving the performer access to both audio and visual controls [15]. El-Lamellophone provides gesture control capabilities through integrated sensors that enable control over the produced sound [16]. There are also options for hyperinstruments, such as the Caméra Musicale and Phalanger, that are driven through pure motion capture [17, 18]. This type of functionality has also been brought to percussive instruments, allowing gesture control based on mallet positioning [19].

Recent developments in wearable hyperinstruments open up new possibilities for performer-music interaction. Some initial efforts investigated interpreting 3-axis accelerometer data to extrapolate hand gestures [20]. Wearable hyperinstruments rapidly evolved to more robust sensor arrays such as Kontrol [21], which features individual accelerometers for each finger as well as one for the palm. Others, such as FutureGrab, take on a more glove-like aesthetic while also providing the performer with tactile interaction options [22]. The Hand-Controller provides similar functionality with an emphasis on tactile feedback, including a set of sliders underneath the user's fingers [23]. This functionality has been developed to the point of commercialization. For example, the MiMu glove captures hand gestures and offers tactile interaction options for music modification [24, 25, 26]. A corresponding toolbox was released to enable similar gesture control capabilities on other platforms [27].

Though many wearable hyperinstruments have been developed, the authors attempt to address two key areas: sensor robustness and cost point. Many of these wearables are built from the ground up, and therefore do not have a large background in signal processing robustness to ensure clean and clear input-output relationships. Systems built with this in mind, such as the MiMu glove, have a prohibitive cost point for many organizations, such as a laptop orchestra. To that end, this paper discusses the development of a wearable hyperinstrument built on the Nintendo WiiMote. This commercially available device has a low cost point along with the backing of robust signal processing, and a readily available reverse-engineered communication protocol.

2. PROBLEM FORMULATION

The Nintendo Wii console has seen international success, selling over 100 million units worldwide [28]. Its controller, the WiiMote, received strong reception from the maker community for the capabilities of its built-in sensor array paired with a low cost of $40 [29]. This combination has seen the WiiMote put to a variety of use cases outside of its original intent as a video game controller. In fact, the WiiMote has been used successfully as a music controller [5, 30, 31]. User feedback from these studies found that the controller was able to accurately respond to user inputs considering both the motion control capabilities and the haptic feedback of button presses.

In the instance of L2Ork, the performers rely almost exclusively on the WiiMote with MotionPlus and Nunchuk attachments. Although the stock controller offers a rich array of instrumentation, including analog and digital inputs, their location and distribution is less than ideal. For instance, access to some of the buttons on the WiiMote requires unusual hand positioning or an entirely different way of holding the controller. In addition, the WiiMote and Nunchuk require a constant grip that over time can generate significant strain. This is particularly problematic when the ensemble is utilizing the free-flowing and relaxed motions of Taiji. The MotionPlus is placed at the bottom of the WiiMote, where its ability to capture the full breadth of hand motion is less than optimal. Lastly, the wired connection between the WiiMote and the Nunchuk significantly limit the independence of the two hands and arms. While there are third party wireless Nunchuks, the efforts to reverse engineer their protocol, due to system complexity, have not been successful. As such, they remain unsuitable for use in NIME scenarios.

It appears that a more suitable controller is needed to realize the full potential of gesture-centric performance. Glove-like solutions, like those presented in Section 1, address most if not all of the aforesaid limitations of a WiiMote, but their cost remains prohibitively high. In fact, some exceed the entire cost of multiple L2Ork stations. More so, given L2Ork's focus on K-12 (kindergarten through 12th grade) education, such solutions are unlikely candidates for K-12 scenarios.

It appears there is an unrealized opportunity to use WiiMote hardware as the foundation for building an alternative controller that can address the identified limitations at a reasonable cost, considering the diverse array of sensors and inputs, plus the unmatched low cost of the WiiMote controller. More so, recognizing that historic improvements in instrument design were more iterative than revolutionary (i.e., perfecting an already strong design), the authors decided to seek a way to make an iterative improvement on an already compelling hardware platform. Alternative platforms exist, such as the Adafruit Feather M0 BLE [32].

3. IMPLEMENTATION

The main goals of the L2OrkMote, an alternative WiiMote hardware-based controller, are to:

1. Enable the unrestricted freedom of two hands/arms;
2. Minimize hand and arm strain by limiting the need for a constant grip while ensuring that the key analog and digital controls remain easily and quickly accessible;
3. Minimize potential discomfort due to potentially awkward and/or contextual button placement;
4. Optimize sensor location to improve the capturing of hand and arm motion, and choreography;
5. Keep the visual footprint at a minimum;
6. Maintain low cost overhead.

To meet these goals, the single WiiMote, MotionPlus, and Nunchuk system was replaced with two, one for each hand. This design choice immediately alleviated the first goal. While effectively doubling the price of the necessary hardware, its overall cost remains well below glove-like solutions. The ensuing L2OrkMote builds on L2Ork's previous reverse-engineering efforts and utilizes redesigned 3D-printed enclosures. Lastly, it makes several notable modifications to the WiiMote circuit board and its accessories.

3.1 Wearable Design

In order to accommodate a WiiMote, Nunchuk, and MotionPlus to a single hand while allowing for the controller to remain in hand without requiring a constant grip, both the WiiMote and Nunchuk had to be usable in hands-free scenarios. With few modifications, the WiiMote can be easily and comfortably strapped to the performer's forearm. Its newfound placement limits access to digital controls (e.g., buttons), requiring transplanting some of the key controls away from the WiiMote's main circuit board. In turn, this arrangement offers opportunities for minimizing the WiiMote's form factor, making it easier to cover with a sleeve or similar garment (Figure 1). The WiiMote's original casing featured additional material and space to improve the user's ability to grip the device. Strapping the device to the performer's forearm does not impose those same considerations.

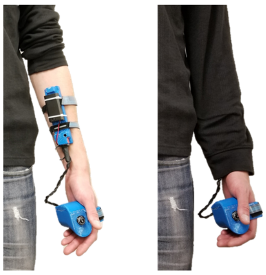

Figure 1: The L2OrkMote Prototype Design

The L2OrkMote casing was therefore designed to form-fit around the main circuit board. Transplanting sensors away from the main board (discussed in Section 3.2) also served to minimize this form factor, resulting in the design shown in Figure 1. The main board is largely sealed away from the performer, as they need very limited access to the instrumentation on the board. The synchronization button is exposed, but recessed, in order to allow the performer to swap controllers and connect as necessary.

While the WiiMote's wearability on the forearm posed few challenges, redesigning the Nunchuk device required a number of considerations. Firstly, it had to be hands-free to enable the performer to release their grip while still allowing them to reliably interface with the joystick and buttons at a moment's notice. Secondly, as the joystick and buttons are manipulated, the device had to stay firmly in the performer's palm without requiring them to hold onto it during interaction. The brace extending from the casing, shown in Figure 2, was included for this purpose. It stabilizes the device against the performer's palm, holding it in a consistent position. Thirdly, to improve the performer's comfort, soft padding was added to the interior of the brace. Finally, the device is further restrained with a set of straps, which firmly hold the device in the performer's palm regardless of hand orientation and without their direct interaction.

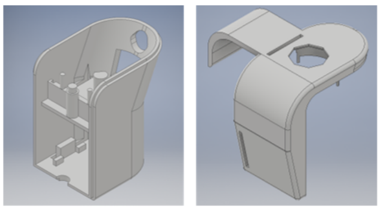

Figure 2: The L2OrkMote Nunchuk Enclosure Design

3.2 Features

The detailed design of the L2OrkMote Nunchuk was constrained by the location of its sensors. These were modified from the stock Nunchuk based on required accessibility during performances. The stock sensor placement is as follows:

WiiMote: Accelerometer, buttons (A, B, 1, 2, Minus, Home, Plus, Power, Sync, and the 4-button D-Pad), vibration motor, speaker, IR camera, bluetooth, and batteries.

Nunchuk: Two buttons (C and Z) and joystick.

Wii MotionPlus: Gyroscope.

The performers made extensive use of the gyroscope, buttons, and joystick during performances. As such, those interfaces were moved into the redesigned Nunchuk for easier access. The sync button was left in the WiiMote and made accessible through a small indentation. The remaining sensors and components were left in the redesigned WiiMote enclosure, rendering the unused buttons (i.e., 1, 2, Minus, Plus, Home, Power, and the D-Pad) effectively inaccessible. In addition, due to the WiiMote's positioning, the IR camera was also left unusable. The loss of buttons was deemed acceptable, because the original form factor made access to 1, 2, and to a lesser extent Minus, Home, and Plus cumbersome. The power button was unusable as it would interrupt connectivity, while the D-Pad was observed to cause discomfort over extended use due to sharp edges. Furthermore, the button loss was further offset by the use of a second Nunchuk-like device with an analog joystick and four buttons, including the A and B that were transplanted from the WiiMote. Moving the A and B buttons and integrating the MotionPlus gyroscope into the redesigned Nunchuk simply required extending the associated wiring.

The Nunchuk's redesigned enclosure (Figure 2), inspired by the original Nunchuk, was constrained by a circuitry form factor dominated by the thumb-centric joystick placement. The joystick and original two buttons sit in relatively similar orientations, falling at natural positions for the thumb, index, and middle fingers. The A and B buttons were brought from the WiiMote, and moved into the redesigned Nunchuk at natural positions for the ring and little fingers. Finally, the MotionPlus gyroscope was moved directly underneath the joystick. Considering the MotionPlus add-on resides on a separate circuit board, its repositioning was relatively straightforward. A curved top surface snap fits over the assembly to contain the instrumentation.

The WiiMote redesign considerations were dominated by the need for a comfortable, inconspicuous device. The casings for the WiiMote, MotionPlus, and Nunchuk circuit boards and internal instrumentation were designed to be as form-fit as possible.

3.3 Prototype Fabrication

The L2OrkMote prototype was fabricated via the material extrusion additive manufacturing process, providing the ability to rapidly iterate and improve in the spirit of the open source, collaborative nature of laptop orchestras [6]. The intention is to tune the L2OrkMote to an individual orchestra's needs and later, possibly down to the individual user, rather than mass-produce it. Mass customization such as this is perfectly suited for additive manufacturing [33]. Considering the L2Ork ensemble's infrastructure leverages open-source solutions wherever possible, in part because of its ongoing K-12 outreach mission, the L2OrkMote enclosure design will be made publicly available with the necessary supporting documentation. The complete, assembled L2OrkMote prototype can be seen in Figure 3.

Figure 3: Fabricated and Assembled L2OrkMote

4. ASSESSMENT

We conducted a pilot study to test the usability of the L2OrkMote prototype controller. A total of 10 Virginia Tech students participated in the study, of which 5 were female, 5 were male, and 4 had prior knowledge in using the WiiMote controllers. The participants used both the L2OrkMote and WiiMote controller systems with a simple music instrument designed using the Pd-L2Ork [34, 35]. The only difference between the two instruments was that the extended capability of the L2OrkMote setup allowed for concurrent control of two independent voices, whereas the WiiMote setup only allowed for one. We surveyed the confidence of participants in pressing the 4 buttons of the L2OrkMote prototype individually, and in 3 different combinations. They were also surveyed for their comfort, preference, and ease of use while utilizing each controller setup. Lastly, we surveyed their preference for the L2OrkMote over the WiiMote setup, and vice-versa. All scales were bivariate with minimum and maximum values of 1 and 5 respectively.

Ordinary least-squares (OLS) analyses of variance (with type I error of .1) for all surveyed variables in Table 1 yielded no statistical significance between the participants with and without prior knowledge in using the WiiMote for musical expression. Table 1 shows descriptive statistics and describes an expanded OLS regression estimating the unique contribution of 7 surveyed variables as predictors for the dependent variable (DV), *controller setup preference*, which yielded an excellent internal reliability of .92. The regression model 3 offers the higher adjusted R^2, thus being deemed the best fit. After testing both controller setups, the participants had the chance to write their thoughts about the study. Coding their expressed thoughts for concerns, suggestions, and comments is shown in Table 2.

Table 1: Correlation Table, and Expanded Regression Analysis of the Controller Setup Preference

	M	SD	V1	V2	V3	V4	V5	V6	V7	V8
V1	3.18	.80	(.71)							
V2	3.50	1.28	.51	(.77)						
V3	4.56	.88	-.03	-.22	–					
V4	4.11	1.27	.49	.62	-.17	–				
V5	4.17	.75	-.04	-.03	-.44	-.22	(.63)			
V6	3.22	1.39	.39	.32	-.52	.76	.14	–		
V7	2.89	1.27	.57	.39	-.50	.55	.15	.79	–	
V8	3.28	1.28	.32	.50	.46	.56	-.58	-.07	-.06	(.92)

Expanded Analysis								
Variable		r_{xy}	Model 1	Model 2	Model 3	Model 4	Model 5	R_u
Covariate								
V1		.33				.11	.01	.01
L2OrkMote IVs								
V2		.50	.37		-.04		-.04	.03
V3		.48	.61		.14		.13	.09
V4		.55	.44		1.39		1.39	.49
WiiMote IVs								
V5		.58		-.58	-.08		-.08	.06
V6		.06		-.05	-1.24		-1.24	.39
V7		.06		.08	.26		.25	.12
	R	–	.84	.58	.97	.33	.97	–
	R^2	–	.71	.33	.94	.11	.94	–
	Adj. R^2	–	.53	-.07	.76	-.00	.52	–

Note: N=10; M=Mean; SD=Standard Deviation; V1=Comfort in pressing the buttons of a L2OrkMote controller (7-item scale); V2=Comfort in using the L2OrkMote controller setup (2-item scale); V3=Liking of the 2x L2OrkMote controller set, one in each hand; V4=Ability to relax during the use of the L2OrkMote setup; V5= Comfort in using the WiiMote controller setup (2-item scale); V6= Liking of the WiiRemote plus Nunchuk controller set, one in each hand setup; V7=Ability to relax during the use of the WiiMote setup; V8=DV=Preference for the L2OrkMote over the WiiMote controller setup (2-item scale); The diagonal reports standardized internal reliability coefficients when applicable. IVs=Independent variables; r_{xy}=Linear correlation; R=Coefficient of correlation; R^2=Coefficient of determination; Adj. R^2=Adjusted R^2; R_u=Unique R contribution; Regression coefficients are standardized.

Table 2: Coding of Feedback from Participants

Frequency	**Concerns**	**Suggestions**	**Comments**
.6			Increased-creativity
.5			Unrestricted-hand-motion
.4	Position-of-buttons	Mounting-on-body	
.3	Size-of-palm-part		

Note: N=10; Frequency=Number participants over the maximum value of 10 (standardized); Increased-creativity=Comments about increased experimentation, capability, and polyphony when controlling the music instrument; Unrestricted-hand-motion=Comments on the feeling of unrestricted hands motion; Position-of-buttons=Concerns about the position/size of the 4 buttons of the L2OrkMote prototype controller; Mounting-on-body=Suggestions about the way that the prototype controller mounts on the body, and about its weight/size; Size-of-palm-part=Concerns about the size of the redesigned Nunchuk controller (L2OrkMote) that mounts on the palm.

An assessment of the design goals for the L2OrkMote prototype was based on the reported quantitative and qualitative analyses. The goal for enabling unrestricted freedom of two hands/arms was supported by the qualitative analysis. Half of the participants noted that their freedom in moving their hands was a factor in their preference of the L2OrkMote over the WiiMote setup.

The goal to minimize hand and arm strain by eliminating the need for a constant grip on the controllers was supported by the quantitative analysis. The predictor of relaxation during the use of the L2OrkMote, while ensuring that the key analog and digital controls remain easily and quickly accessible, was the most influential in the OLS regression.

The goal to minimize potential discomfort due to awkward and/or contextual button placement was not supported by the qualitative analysis as 4 participants specifically expressed their concern about the placement and functionality of the 4 buttons on the L2OrkMote prototype. The quantitative analysis also showed that the comfort in pressing the buttons of the L2OrkMote was the least influential predictor, thus it was dropped from the regression model.

The goal to optimize sensor location to improve the capturing of hand and arm motion, and choreography was a controversial matter among the study participants.

The goal to keep the visual footprint at a minimum was not supported by the qualitative analysis, because 4 participants expressed concerns about the size of the part that mounts on the palm, the way, and the weight of the part that mounts on the forearm.

The use of only a 3D-printed case, a battery pack, and minimum cabling to wire the parts of the L2OrkMote prototype supports the goal to maintain low cost overhead.

5. DISCUSSION

A substantive interpretation of the statistical, and coding findings provided feedback for the next L2OrkMote prototype iteration in terms of design goals. The L2OrkMote prototype enables the unrestricted freedom of two hands and arms and calls to be exploited by the new designs of computer-based musical instruments. For example, the capability for less restricted hand choreography poses the question of musical-gesture balance between the two hands. The use of two controllers that mirror each other's functionality may prime instrument designers to create NIMEs that have identical or similar sound-synthesis parameters controllable by each hand. In such situations, handedness may cause potentially significant difference in the performer's ability to control parameters. An alternative approach to this issue is to leverage mirrored controllability design to easily swap the dominant hand controls, rather than mirroring functionality of both hands.

Minimizing hand and arm strain by limiting the need for a constant grip is particularly important given the target ensemble's focus on choreography that is rooted in Taiji practice. However, the size and weight of the L2OrkMote prototype can be further improved, such that it will reduce the effect that the palm and finger size variance has on a performer's comfort in using the controller.

The goal to minimize potential discomfort due to potentially awkward and/or contextual button placement remains to be achieved. Variance in palm and finger size creates the need to position buttons on one or the other side of the structure's center to accommodate shorter, or longer fingers. Thus, the design challenge is to find the appropriate size and shape for the buttons, such that they can be pressed on either side. Further, the button placement may require greater spacing to accommodate larger fingers. While the opportunity to have additional controls near user's fingertips is likely advantageous, the authors posit the lack of support of this aspect of L2OrkMote's design in the user pilot study is likely due to the lack of consideration in the current prototype of the aforesaid variance in human hand and finger size, as well as the choice of microswitches that offered very little travel and as a result felt fatiguing to use.

A core idea for a new controller design was optimizing sensor location to improve the capturing of hand and arm motion, and choreography. Testing the L2OrkMote in actual music performances will provide feedback necessary to further optimize and calibrate sensor location. Maintaining low overhead cost remains a critical goal, due to the ensemble's focus on K-12 outreach and low-cost implementation that may encourage other similar ensembles to leverage similar infrastructure. Although the prototype has effectively doubled the cost of the controller, its overall cost remains significantly below alternative commercial solutions.

The pilot study reveals that the L2OrkMote can serve as a replacement to the WiiMote, due to being at least as intuitive to use, as evidenced by the absence of statistical significance between participants with, and with no prior knowledge in using the WiiMote. The study was performed under unavoidable limitations, and it was designed to assess the very first L2OrkMote prototype. First, it was framed as a comparison between the two controller setups, since the aim was to replace the WiiMote with a controller that is more focused on musical expression through finger-pressed controls, and hand-gestural control choreography. This approach did not allow for making of comparisons between two subject-groups that would have used only one or the other controller setup. Second, the sample of the pilot-study was small. Nevertheless, it provided critical feedback on the current iteration of the L2OrkMote prototype, ensuring that reconsidering the design goals for the next iteration has been informed by empirical evidence. Third, this pilot-study used only a simple computer-based musical instrument for participants to experiment with. It had two-voice polyphony (one-voice per hand) for the L2OrkMote setup, and one-voice polyphony for the WiiMote setup. Since the pilot-study aimed to gather feedback about the usability of the L2OrkMote, it was designed to require less time from each participant than what would have been required if there were more instruments available to experiment with. The difference in voice-polyphony is an essential capability of the L2OrkMote setup, thus the pilot-study did not include a testing of the use of only one prototype controller (on either hand). Fourth, the first two L2OrkMote controllers (one with left-hand, and one with right-hand orientation) were built under the design principle of early testing, which allows gathering feedback while in the process of asynchronously conditioning different aspects of the controller. Therefore, minimizing the footprint of cables was delayed to allow earlier testing. Making the cables more compact is an objective for the next design iteration.

6. CONCLUSION

In contrast to handheld controllers, wearable controllers not only improve the ability of performers to relax during gesture-centric music performances, but also improve their capability to focus on their gestures for musical expression. L2OrkMote in its first iteration has proven a compelling replacement to the existing WiiMote+MotionPlus+Nunchuk controller setup. The prototype has met four of six aspirational goals. The remaining two were hampered by design choices that can be addressed by further improving the button placement and size, the overall footprint of the redesigned Nunchuk, as well as by further testing of the relocated gyroscope's sensitivity. The hardware calibration of the prototype controller should be also accompanied by the software design principles for the creation of more advanced gestural-controls that enable unrestricted hand-choreography to empower performers of laptop orchestras. The L2OrkMote was able to maintain low-cost, a critical factor for its adoption by large musical ensembles and K-12 outreach scenarios. It also allows the transfer of dexterity developed by practicing with WiiMote setups, and together with its cost and maintenance needs is poised to further enhance ensemble's musical and gestural expressiveness.

The pilot-study participants already expressed a slight preference towards the L2OrkMote setup, which was mostly due to the ability to relax during its use. Thus, the pilot-study supports the wearable approach to redesigning the WiiMote controller. Moreover, the preference towards the L2OrkMote setup was also due to less restrictive hand-gesture choreography, when compared to the WiiMote setup. Ultimately, the pilot-study validated many design goals in reimagining a wearable controller for gesture-centric music performances while providing invaluable feedback towards the next L2OrkMote iteration.

6.1 Future Work

Like many other aspects of L2Ork, the L2OrkMote development will remain continuous and iterative. Informed by our user study, we already see opportunities for a more strategic placement of the IR camera that would enable its use in low-cost position-aware tracking. We will explore possible addition of a button to the forearm that may be triggered by flexing the forearm muscles. Also, we will look into further refinement of the four buttons and their form factor to make their presses easier and more comfortable. There are additional opportunities for minimizing redesigned Nunchuk's form factor by removing legacy connectors between the MotionPlus and Nunchuk circuitry. Most importantly, in the coming months we will build 40 additional controllers to upgrade the entire L2Ork ensemble controller infrastructure.

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