Gesture-Based Controllers for Computer Instruments

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Abstract

Computer-based music brings with it an immense world of possibility that is beginning to be tapped. Once an avant garde novelty, the computer as an instrument has risen to the edge of the mainstream and is begging to be introduced to the layman musician as an accessible sound-making tool. The computer instrument is capable of creating a type of sound that doesn't conform to the traditional paradigms of pitch and harmony; as a result of this there needs to be a new way of controlling algorithmic instruments. I researched and created a musical interface using computer vision algorithms to follow the hand gestures of a performer illuminated in ultraviolet light. The object of my interface is to satisfy the conditions conceived by Gurevich and von Muehlen in their publication on new instruments with a special focus on promoting virtuosic use. A case study was performed using the interface prototype with promising results for future development.

Background

At the beginning of the 1950's serialist composers such as Pierre Boulez, Karlheinz Stockhausen, and Milton Babbitt began to experiment with electronics as tools for musical expression. Similar to the modernist painters of the time, the serialists strove for art that was pure and perfect. They viewed the human inclinations of tonality, familiar timbres, and even harmony and melody as musical impurities, created by an imperfect human rationale. The serialists believed music was an absolute truth, a force of nature to be unclothed. This perspective led to experimentation, the use of found objects as orchestral instruments, and the conception of mathematical methodologies for composition that removed tonality altogether.

Also like the modernist painters of the time, the serialist composers had a strong affinity for technology. In the post-war boom new technologies exploded on to the scene; innovations that promised electronic sound production had begun to blossom and the serialists were the first to capitalize on these discoveries. Electronics allowed composers to create pure sound based on formulas, freeing their music of the baggage carried by traditional instrument timbres such as those of the piano or clarinet. Magnetic tape allowed composers for the first time to record and manipulate sound without the personal bias of a performer coming between them and their music; at the same time, electronic oscillators let composers build sound from the most fundamental building block of all music – the simple sine wave. **(2)** Serial composers had found their fervently sought purity of sound, in an overwhelming abundance.

(1960) Milton Babbitt working with the RCA Mark II Music Synthesizer

The work of these early pioneers led to continued development of electronics, in particular the computer, as compositional devices; today, the personal computer is readily affordable and equipped with processing power unimaginable compared to the electronic devices of the 1950's. Software sound synthesis applications afford the layman musician the freedom to create any virtual instrument they can imagine – beyond that any shape or texture of sound, in any timing. The computer is the most powerful, flexible instrument available to musicians today. But when asked which instrument they play, there are not many computer music practitioners who would immediately reply, "the computer". Why is this? **(5)**

Computers as Live Performance Instruments

The serialist composers of the mid 20th century saw electronics as a way to eliminate the ambiguity of musical notation from coming between them and their vision. When manipulating tape, and later using digital computer sequencers, the composer effectively became the entire orchestra. The idea was to eliminate the whims of live performance, and often a "live" performance of electronically composed music was somebody pushing "play" on a tape player. Even now the computer remains mostly a compositional tool rather than a performance instrument. But this is a time of reactionary thought and further innovation in music. The low cost and high processor speeds of current computing technology makes it highly viable as a live performance tool, as an instrument capable of far more than a piano, clarinet, or traditional device could ever dream of. Attesting to this fact are a large number of experimental musicians who perform out of their laptop computers every night, and the emergence of the "laptop DJ" as a force in the underground dance music scene. Still, computer instruments have neatly sidestepped the mainstream.

Computer interfaces are intimidating at best, usually in the form of walls containing dozens of virtual knobs and dials with, if you're lucky, something that roughly resembles a piano keyboard. As an issue of accessibility to the computer as an instrument, the lack of acceptance by mainstream musicians should be expected. If everyone who wanted to play the guitar needed a college education in signal processing then there would be a lot fewer rock bands in the world. This is a simple issue of human computer interaction. There is a need for accessibility.

visual interface for the DreamStation software synthesizer (rather intimidating)

Filling Gaps Between the Real and Virtual

Computer technology brings with it a host of special considerations for musical instrumentation. Traditionally, a performer is in direct contact with the sound production mechanism of their instrument – a guitarist plucks a string, a trumpet player blows into their horn, etc... The performer's mechanical gesture plays a direct role in exciting the acoustic space. In their paper on intimate musical control of computers, Wessel and Wright call this mapping of traditional instrumentation a one gesture to one acoustic event paradigm. **(5)** In most computer interfaces, some type of sensor (a mouse, glove, gyroscope, etc...) is used to detect the gesture and then a computer generates the acoustic response. There is a detachment between the performer and the instrument. This is especially true when one notes that the vast majority of new musical input devices are used to create sound that seems to have no intuitive relationship to the gestures of the performer, and they rarely if ever follow the one gesture/one event paradigm.

Wessel and Wright created a conceptual model for their controller research and development, which appears to be accurate for the current state of musical computer interfaces. (FIG. 1) Initially the human performer has intentions to produce a specific musical result. These intentions are communicated by the brain to the sensory motor system to produce gestures. The gestures are received by the physical interface of a controller and read into the computer which interprets the data via an algorithm. The algorithm produces resulting data and outputs it as sound the performer can hear. The performer perceives the sound they have produced and adjusts their intentions from there. **(5)**

It is important to note that the connection between the performer's gestures and the perceived sound is what perpetuates the system. According to this conceptual model the most important aspect of a successful musical interface is that the gestures reliably, and above all intuitively, connect to the sound that is produced.

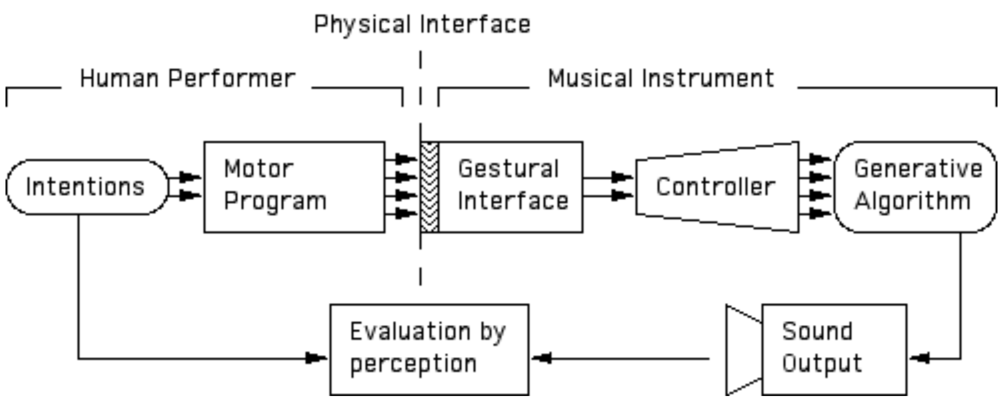

FIG. 1

As a musician, I believe it is important to have these produced sounds be consistent but also meaningful. A consistent result from a given gesture gives the performer a feeling of control, which is absolutely essential when seeking high competency of a system. Meaningful response means that the sound produced by an instrument should somehow intuitively follow the form of the gesture (for example, in a drum-like interface, you would not expect a soft flute sound from striking the surface). With a computer instrument that is both consistent and meaningful, the instrumentalist is free to develop skill and creative style without having to be hindered by the technology. Essentially, the computer is to be so well hidden that it's invisible.

Current Controllers

A virtual instrument, or computer instrument, is a software algorithm within the machine that can be controlled in real time to generate sound. There are a vast number of such instruments available today, ranging from commercially built "software synths" such as Propellerhead's Reason and Native Instruments' Reaktor to anything you can make yourself using signal processing algorithms and your favorite programming language. Currently the most widely accepted method for someone to interact with a virtual instrument is by using a MIDI (Musical Instrument Digital Interface) controller. A MIDI controller is a device that communicates with the computer via the MIDI protocol over a digital communication line. MIDI has been around since the early 1980's as a universal protocol for musical equipment of all kinds to communicate. MIDI controllers are now the defacto standard for controlling virtual instruments and any type of device (game controllers, cameras, pressure-sensitive shoes, anything) can be fashioned to send MIDI data to a computer. Unfortunately the standard MIDI control device is not so creative. In general, most musicians use something along the lines of a piano keyboard accompanied by a few buttons and knobs to control their virtual instruments, and this is wonderful if you want to play a virtual piano you've created, but what good is it for playing an instrument that has no real-world counterpart?

Special Consideration: Timbral Virtual Instruments

To design new physical interfaces for virtual instruments one should first consider what has been successful in traditional instruments. Many paradigms might spring to mind – woodwind, string, and brass. The guitar, for example, is a set of strings that are pulled across the instrument body and plucked. The strings are stopped at calculated divisions of their length in order to produce specific pitches. Another popular design is the woodwind; for example, the flute is a long tube filled with air that vibrates when the performer blows over the mouth hole. The body of the flute has holes at different divisions of its length that can be stopped and unstopped by the performer to change the size of the column of air, and therefore change the pitch being produced. Most traditional instruments share one key similarity – they are all centered on an effective way of controlling pitch. This is a sensible design if one looks at the type of music composed over the past centuries; symphonies and concertos, composed based on the sequence and combination of pitch values to create melody and harmony. Pitch, however, is not the only aural quality that makes music pleasing to the ear. Take, for example, a group of people singing songs together around a campfire – there is a woman who sings with a voluminous, ringing voice and there is an old man whose froggy croak is reminiscent of an Egyptian mummy. They both sing exactly the same song, the same pitches, why does the songbird so outshine the old-man? The answer lies in mathematics and the science of sound. Any natural auditory phenomenon has a complex spectrum of frequencies at different intensities that together make up the overall character of the sound. The organization of these frequencies in the woman's voice are more pleasant than those in the old man's voice. This is not an issue of pitch, but rather one of timbre, the essential frequency spectrum of a sound. It's what makes a clarinet sound like a clarinet and a trumpet like a trumpet. And in this case, the timbre of the woman's voice is what makes it sound good – regardless of pitch. The fact that the clarinet and trumpet have very pleasurable timbres is a testament to why they have persevered over the centuries; however, if composers wanted to use timbre as a compositional element they were usually out of luck. Traditional musicians generally have very little control over the timbre of their instruments and composers are only able to change the timbre of their work through clever orchestration.

Music is no longer as cut and dry as it once was. With the introduction of electronic sound synthesis composition is now possible in the realm of sound itself (rather than just pitch). This field of music is referred to as “electroacoustic” music. Electroacoustic music is an art of frequency spectrums and changing timbres. Some electroacoustic works can be as moving as a Beethoven symphony while some fall flat and come off as a bunch of quirky sound effects. This hit-or-miss quality of electroacoustic music owes itself party to the infancy of the art form and partly to the lack of intuitive control systems for the virtual instruments which personify the style. The solution to the first problem is time. But what about the second? The standard MIDI keyboard controller is no longer adequate (if it ever was for anything other that virtual keyboard instruments) when playing an instrument that maps out frequency spectrums instead of musical notes.

the Oxygen MIDIMAN MIDI controller

Simplicity vs. Virtuosic Value

According to research done by Dr. Perry Cook of Princeton’s SoundLab, there are a set of humanistic/artistic principles that must be followed when creating a usable controller. One principle is that “smart instruments are often not smart” – this means that a good instrument shouldn’t offer as much programmability, variability, and control over the music as using a mouse and keyboard on the computer would. **(1)** In other words, Dr. Cook believes that the walls of knobs and switches common to virtual instrument interfaces should be done away with in favor of simplicity. The PhISEM controllers, designed by Cook to control a newly developed stochastic music algorithm, resemble frog-eyed maracas that have one element of control – you shake them. The shakings set rhythmic and timbral parameters for the algorithms to generate complex and interesting music. This level of simplicity, consistency, and intuitive control made the frog maraca very successful with both adults and children who had little musical experience. But what about serious musicians? According to Cook’s principles, a person should be able to “pick up and play” an instrument without knowing the ins and outs of its capabilities.

This is not true of most traditional instruments, and so I feel it is not a good principle to follow when creating an interface that attempts to be more than a toy or novelty. Cook's philosophies are the equivalent of somebody sitting at a piano their first time, pressing a button, and playing a Chopin etude. This is fine design from a perspective of accessibility, but the ability to compose music that almost all musicians desire is completely lost. There is a certain depth of musicality and virtuosity possible in traditional instruments that needs to somehow be brought over into the realm of computer interfaces to make them appealing to serious practitioners. While simplicity and accessibility are very important in making the computer a viable option for live performance, they can only be improved at the sacrifice of instrument breadth. That is, although a computer is capable of being an entire orchestra, and indeed it is in the case of Dr. Cook's PhISEM controllers, the capabilities of the computer must be specialized in order to improve accessibility without sacrificing the possibility for virtuoso performance. I believe the starting point for this is to create interfaces that follow the one gesture/one event paradigm; the composition of these single, precise events is what makes virtuosity possible.

Controllers within the one gesture/one event Paradigm

One of the earliest attempts at creating new electronic instruments was made by Leon Theremin in 1918. He created an instrument consisting of a wooden box with two antennae on different ends of it. The instrument set up low-power, high-frequency electromagnetic fields around its two antennae (one controlling pitch and the other volume). The player's hands altered the fields by varying their distance to the antennas and therefore altered the pitch and volume. The performer never actually touched the instrument, rather played the air around it. This instrument was called the Theremin after its inventor and has been used as a performance device by such popular musical groups as Pink Floyd, The Rolling Stones, Aerosmith, and the Beach Boys. What is so fascinating about the theremin is that it is one of the very few new instruments to have acquired virtuoso performers playing solo and concert repertoire written specifically for it by major composers. Of note was theremin virtuoso Clara Rockmore, who is considered one of the greatest female instrumentalists of the 20^{th} century.

Clara Rockmore playing the Theremin

The theremin's success as a virtuosic instrument merits some investigation. It is an extremely simple device with only two variables (pitch and loudness); the phrase "a minute to learn but a lifetime to master" comes to mind. It is reasonable to believe that the simplicity of the theremin is what made it so successful; but still, the clarinet is also very successful and not nearly as easy to pick up as the theremin's intuitive design. Then again, the clarinet has been around for ages and is a hard written part of musical dogma. Creating a new instrument then is a difficult compromise between approachability and complexity.

Elements of a Successful Controller

In their research creating the Accordiatron (a virtuosic controller modeled after the accordion), Michael Gurevich and Stephan von Muehlen developed a set of design criteria for the development of new instruments:

Multi-Dimensionality - Instruments such as the clarinet and piano are capable of creating variation in multiple dimensions (pitch, velocity, vibrato, etc...) all of which can be controlled at various rates to produce auditory results in real time. In order to be useful as an acoustic instrument for interactive applications, a controller similarly needs to provide several unique streams of data that simultaneously control multiple aspects of the produced sound. The Theremin, for example, has two dimensions of control – pitch and velocity, which accord the player a modest amount of musical control.

Discrete and Continuous Data - A violinist has the ability to pluck single notes or slide a note from one to the other without plucking in between – this is effectively the difference between discrete data and continuous data. Discrete data comes in the form of "on or off", impulse, and switch type messages. Continuous data comes as a constant value stream that is changing in real time, like the constantly changing pitch of a violin sliding from one stop to another. One limiting factor of the Theremin is that its control is all continuous; there is no way of making a sharp staccato note with the Theremin (while not necessarily a bad thing, is limiting nonetheless). In general allowing discrete data in a controller is an advantage. And beyond triggering sharp staccato notes, an additional advantage of allowing discrete events in your system is that it allows for the use of triggers and toggle switches, which are often seen today in electronic music.

Visual Intrigue - A live audience generally wants some sort of correspondence between the actions of the performers on stage and what they hear. The lack of this connection is what causes most people to lose interest in musical interfaces that seem to be producing sound that has nothing to do with the gestures of the performer (this is also frustrating for a novice performer who is attempting to learn the system). In order to satisfy the desire for visual and auditory correspondences, a new controller should have an intuitive link between the gestures of the performer and the resulting sounds. A new controller should also have strong visual appeal. A performance instrument should be interesting to watch as well as to hear, otherwise part of the purpose of live performance is lost. The theremin, which amazed audiences via the waving of hands associated with its ethereal sound, was especially well designed in this regard

Constrained Motion -The final design criterion is that the gestures of the performer need to be constrained in some fashion. Indeed every traditional instrument alive has a very constrained field of motion. Even the theremin, which is played by a performer waving their hands around in the space around the instrument, requires that the motion about it be very precise and constrained to accurately control pitch and volume. While free motion in space is visually impressive and very expressive, it is near impossible to translate into useful information with the level of control that musicians desire. Motion with limited constraint allows for the control and precision required for musical expression. **(2)**

A UV-Light Tracking Virtual Instrument Controller

Using my research and the criteria devised by Gurevich and von Muehlen I began creation of a new musical controller for deft and precise control of a single virtual instrument. I used current (as of 2005) inexpensive computer vision technology to create a "touchless" but expressive interface where the performer stands in front of a video camera and their motions are tracked by computer to produce useful musical information in multiple dimensions.

Design

At its most rudimentary level, the controller consists of a video input device (DV camcorder or webcam in this case) connected to a computer running image recognition (color blob tracking) software of my own design utilizing Intel's OpenCV C++ library. The image recognition software generates meaningful MIDI data from the video input data and routes it to a separate program (or possibly a separate computer) running sound synthesis algorithms. The sound synthesis program and computer vision program are in constant communication with each other using MIDI. The performer is front-lit with ultraviolet light (black-lights) and uses objects and gloves covered with fluorescent paint to control sound parameters. Some control schemes for different instruments I have implemented are: the x,y-position of an object continuously controls pitch, the apparent size of an object determines loudness, each object controls an instance of the same instrument to allow harmonies, after striking a discrete pitch movement in the x,y direction controls timbre of the sound.

Other Attempts

Eric Singer's Cyclops Multi-drums is a similar attempt at creating a video-based interface. The Multi-drums uses computer vision technology to watch the performer and respond to their hand gestures. The performer stands in front of a video camera and moves their hands into "zones" above them, each zone or combination of zones then triggers a drum pattern. My approach also uses video tracking and computer vision to read hand gestures, but controls a single instrument instead of triggering complex rhythmic patterns. The Cyclops Multi-drums is easily played by anyone who approaches it, but lacks depth beyond its conception. The UV-Light controller is intended to be approachable, like a piano, where anyone can go up to it and make sound, but with a level of nuance conducive to virtuosic performance.

video feed from Eric Singer's Cyclops Multi-drums

The Musical Ribbon, developed by Georgia-Anna Farmaki and Adem Toprak, is an interface that involves video tracking of a performer swinging a ribbon around through the air – whenever the ribbon makes a circle the computer generates a melodic gesture. My controller uses the performer's hands as the gesture device for its interface, and uses video tracking much like the Musical Ribbon. However, I believe that using video tracking on something as skittish as a ribbon becomes too difficult for precise expression by the performer. Although I am use similar algorithms for the video tracking in my interface, the UV-Tracker provide the performer with multiple dimensions of control (pitch, velocity, timbre, harmony) rather than just one (pitch) offered by the Musical Ribbon.

early development video feed, showing boundary detection on the red hand

Case Study

The Ultraviolet-Tracker is intended for use by beginner to expert musicians looking for a creative performance tool. I performed my prototype design at the University of Florida School of Music's Unbalanced Connections concert November 19th, 2004 and was fairly successful. Since then I have invited musicians and curious onlookers alike to play with the interface and give me feedback on what they liked and disliked. Ideally, the seasoned musicians should be able to use the interface with the same respect they would give to a trumpet or flute, while anyone who approaches it – regardless of musical background – should be able to intuitively create sound in the same way anyone can hit a note on the piano. I'm interested in learning about the "naturalness" of the interface as well as the long term value for virtuosic play.

I have administered a small case study involving a two-page questionnaire to beta-test users of the system. (see APPENDIX A) The questionnaire consisted of two pages, the first containing musical background questions and the second questions about the experience with the UV-Tracker. The survey consists of only a few key questions with four possible answers, ranging from "1" to "4" (I believe this is beneficial because it omits neutral responses) followed by a free response section to add comments that may improve the interface. The survey needed to account for two major metrics, “naturalness” and virtuosic value.

Measuring “Naturalness” – I define “Naturalness” as how intuitive the instrument feels while playing it – that is, does the sound that is generated by a gesture seem to naturally follow from the aesthetic of performing the gesture; also, does the instrument produce sound easily without technical fuss? This is not a measure of how easy it is to play the instrument, since it is expected to have a learning curve associated with it due to the need for virtuosic value described below. Questions concerning naturalness will be: “How approachable did you find this instrument?”, “Once you understood the basics of producing sound, how well did the sounds you produced match the movements you had to do in order to produce them?”, “Was the experience of playing this instrument enjoyable?”. There is really no numeric way of measuring the naturalness of the system because it is such an object of opinion. Instead measured the playing time each person stayed at the UV-Tracker for, running under the assumption that the longer a new user interacts with the instrument the more enjoyable, and therefore natural, the interaction was. Really though, the only way to see if the instrument plays intuitively is to have a number of people use the system and gather their impressions.

Measuring Virtuosic Value – Virtuosic value is the ability of the instrument to endure use over time and still maintain as a useful artistic device. This in itself requires that there be a level of difficulty inherent in playing the instrument, that there be a learning curve, or else everyone who approaches the interface would already be a master performer. The virtuosic power of an instrument lies in its level of subtlety, the precision of its control, and the number of acoustic variables it can command. It’s important to imbue the user with a strong locus of control. Questions concerning virtuosic value are: “Does this instrument merit practice and further play?”, “How precise was your control over the sounds produced?”, “How satisfied were you with the amount of nuance in the performance of this instrument?” An additional test proved valuable here. While each person used the interface I requested them to play the notes of the major scale “do, rei, me…” and recorded numerically how many notes were missed. This test was a good way to measure precision of the controller when playing the instruments that did not use a continuous pitch control (like the Theremin), in which case the lack of precision would be attributed to a lack of skill in using the instrument.

Results

I surveyed a total of five people, four musicians of varying expertise and one non-musician. In general, those surveyed felt that the interface was “unwieldy but had potential”. Those with previous musical experience were more enthusiastic about future possibilities of the interface and made suggestions for improvement. One issue with video tracking as an interface is that it’s very difficult to get an idea of what you’re doing in the camera’s frame of mind. I had intended the UV-Tracker to be used like any traditional instrument, by Wessel and Wright's model, where the performer makes gestures and changes them based on audio feedback. However it turned out that the meaning of gestures could change depending on slight alterations in the position of the performer's body. To remedy this the performers intuitively looked at the computer monitor where a small window containing the input video could be used to orient themselves. I had originally intended this video monitor as an error checking device for myself, but it turned out to be an essential part of the performance process. In the future I want to improve the computer interface for the UV-Tracker to the point where they are an easily accessible element of the performance.

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APPENDIX A

Case Study Surveys

Musical Background Survey

Name ______________________________

Do you play any musical instruments?
Yes / No

If yes, how many years have you been playing music?
_____

Would you consider music to be one of your primary interests?
Yes / No

Which musical instrument would you say you are most skilled at?
____

How would you rank your skill (on a scale of 1-4) at playing your primary instrument?
(Novice) 1 2 3 4 (Virtuoso)

Please list any other instruments that you play.
____
____

How knowledgeable would you consider yourself in the realm of electronic music?
(Univolved) 1 2 3 4 (Very Knowledgeable)

Have you ever composed or performed electronic music or music utilizing electronic elements?
Yes / No

If so please explain –
____
____
____
____

In electronic music, how important is the development of new controllers?
(Essential) 1 2 3 4 (Trivial)

How interested would you be in trying out new controllers as serious performance instruments?
(Very eager) 1 2 3 4 (Uninterested)

What qualities do look for in a new instrument to play?
____
____
____

When deciding to play a new instrument, would you be more inclined to play an instrument that requires hard work and practice or one that is immediately playable but allows less virtuosity?
(Immediately Playable) 1 2 3 4 (Virtuosity)

Ultraviolet Controller Survey

Name ________________________

How approachable did you find the ultraviolet controller as a musical instrument?
(Intimidating) 1 2 3 4 (Easy to approach)

How enjoyable was the experience of playing this instrument?
(Very enjoyable) 1 2 3 4 (Painful)

Would you ever consider rigorously practicing the ultraviolet controller and playing it as your primary instrument?
Yes / No

Explain –

____
____
____

Once you understood the basics of making sound, how naturally did the sounds produced by the ultraviolet controller follow the gestures you made to create them?
(Unnatural) 1 2 3 4 (Very natural)

Explain –

____
____
____

How satisfied were you with the amount of nuance in the instrument?
(Very satisfied) 1 2 3 4 (It was lacking depth)

How satisfied were you with the precision of control in the instrument?
(Very satisfied) 1 2 3 4 (It was unwieldy)

Please write a few sentences explaining your experience using the ultraviolet controller

____
____
____

What were any problems you had playing the ultraviolet controller? Please describe anything you felt was lacking or could use improvement, also feel free to suggest additions to the interface.

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