Hand-Controller for Combined Tactile Control and Motion Tracking

Laurel S. Pardue
Queen Mary University of London
Mile End Road
London, England
lpls3@eecs.qmul.ac.uk

Bill Sebastian
Visual Music Systems
80 Summer St.
Boston, Massachusetts 02111
bill@visualmusicsystems.com

ABSTRACT

The Hand-Controller is a new interface designed to enable a performer to achieve detailed control of audio and visual parameters through a tangible interface combined with motion tracking of the hands to capture large scale physical movement. Such movement empowers an expressive dynamic for both performer and audience. However movement in free space is notoriously difficult for virtuosic performance that requires spacially exact, repetitive placement. The lack of tactile feedback leads to difficulty learning the repeated muscle movements required for precise reliable control. In comparison, the hands have shown an impressive ability to master complex motor tasks through feel. The Hand-Controller uses both modes of interaction. Electro-magnetic field tracking enables 6D hand motion tracking while two options provide tactile interaction- a set of tracks that provide linear positioning and applied finger pressure, or a set of trumpet like slider keys that provide continuous data describing key depth. Thumbs actuate additional pressure sensitive buttons. The two haptic interfaces are mounted to a comfortable hand grip that allows a significant range of reach, and pressure to be applied without restricting hand movement highly desirable in expressive motion.

Keywords

hand, interface, free gesture, force sensitive resistor, new musical instrument, tactile feedback, position tracking

1. INTRODUCTION

Performance interfaces often focus on one of two main interaction syles: unrestricted large-scale expressive motion or precise, detailed control of smaller motions. The focus on one interaction mode is frequently detrimental to the other. The Hand-Controller is an interface designed to enable an optimal balance between both of these desires. It provides the hand up to 12 degrees of freedom with precise tangible feedback and adds another six degrees through motion tracking which enable larger scale physically expressive arm and hand movements.

The origination of the Hand-Controllers was spawned by the development of a visual performance system intended to enable a visual artist to perform live similarly to a musician. Bill Sebastian's early version of such an instrument was the Outerspace Visual Communicator [12]. Sebastian developed the OVC in the 1970s with performances around New England with the Sun Ra Arkestra and others. Central to the idea was that the artist is immersed in the visuals and is an expressive part of the performance. This requires all interactions be understandable and navigable without menus, or text overlays generally relied upon in visual editing. It also means that similar to music, reliance on mouse, keyboard, and knobs is insufficiently expressive for the performance experience and presentation.

Thus the interaction is similar to music not only in the live aspect of the performance, but also in that the design of an appropriate interface follows many of the requirements for designing a musical instrument. The system is understood to be complex, and any accompanying interface must have a potential for virtuosity through considerable practice. The visuals, rendered through computers graphics engines, are thoroughly complex with a vast range of parameters and outcomes. Some of outcomes, such as instant selection of a particular hue, may require fine control for which haptics are highly appropriate. Some outcomes, for instance, moving a particular object, may make more sense through a visible gesticulation.

Based on these goals, the Hand-Controller design requirements were: 1) utilize the ability of the wrist, arm, and other body muscles to make large intuitive gestures, while simultaneously providing a stable platform for finger input, 2) provide each finger with intuitive precision control of independent parameters with tactile feedback complementary to motor learning, 3) does not require significant visual attention for operation, and 4) does not use external cameras or other technologies with sensitivity to lighting conditions. The fourth requirement is a technical issue due to the primary intended performance arrangements using complete full field visual projection.

2. PREVIOUS SYSTEMS

Finding a balance between precise control and physical freedom has been a persistent challenge throughout the development of new digital interfaces. The use of technology to enable no-touch physically expressive control goes back to some of the earliest electronic interfaces including the Theremin and Max Matthews' Radio Drum [13]. Full body gestural expression was explored by David Rokeby using video cameras with the "Very Nervous System" [10]. While these instruments succeed at bringing physicality into a performance, they lack tactile feedback. This makes reliable performance and learning highly difficult.

Gloves have provided a useful option for retaining high freedom in motion while enabling more direct feedback. One of the earlier examples is Laetitia Sonami's "Lady Gloves" [11] which used a combination of Hall effect, bend, and pressure sensors to detect hand actuation and ultrasonic trans-

NIME'13, May 27 – 30, 2013, KAIST, Daejeon, Korea.

mitters to track distance between the hands. The Bokowiecs have demonstrated engaging performances such as the "Suicided Voice" and "V'Oct" [2, 1] based on a version of the Bodycoder system making prominent use of gloves. The SoundGrasp led by Tom Mitchell and Imogen Heap [9] is similarly engaging. Flex and abduction of the hand is measured using fiber optic bend sensors. Hand orientation is detected using an inertial measurement (IMU) system with body tracking accomplished using the Microsoft Kinect [3].

While gloves can be successful in performance and offer expressive yet understandable gesture control, they still suffer from a failure to provide optimal haptics. In part, this is because the majority of glove systems fail to take full advantage of one of the dominant means of task learning, finger touch. Most glove based design, including those referenced above, has tended to focus on hand posture with only simple touch interactions.

Michel Waisvisz's "The Hands" [6], and the subsequent "Midi-Conductor" [4] do use touch. "The Hands" and "The Midi-Conductor" are both worn on the hands and feature a number of buttons and pressure sensors for manipulation by the fingers and thumbs. Additionally, each hand was equipped with tilt sensors and ultrasound to determine distance between the hands.

3. THE HAND-CONTROLLER

Although "The Hands" were not a direct inspiration for our work, the Hand-Controller similarly features controllers for both hands. The Hand-Controller offers two options for touch control: a platform with four dual pressure and linear position sensing tracks, or a set of four continuous input trumpet-like slider keys. A separate plate hosts multiple pressure sensitive buttons for manipulation by the thumbs. 6D hand motion tracking is robustly enabled through the use of the electro-magnetically based Razer Hydra[1] and a secondary IMU system based on the combination of a gyro, magnetometer, and accelerometer that provides independent orientation information. In order to exploit the full reach of the finger and the application of pressure throughout the full reach, both the tracks and the trumpet keys attach to a molded palm grip that is strapped to the hand.

Figure 1: A complete Hand-Controller System with Track Platform, Slider Keys, boxed electronics, and the Razer Hydra

The Hand-Controller might be seen as an evolution from Waisvisz's work. While the platform may appear to offer a limited number of input options with only four tracks, in practice it increases capability with a substantial range of continuous control through two understandable interactions-finger pressure and finger position. A large number of discrete options could be made available using mappings to break up of the continuous space into separate sections.

3.1 Tactile Sensors

The primary tactile sensors are the finger tracks. Each finger has an independent track surrounded by a bumper to help intuitively guide the finger. Each track is a single sensor which is acts as a force sensitive linear potentiometer (FSLP) providing two degrees of freedom by tracking both pressure and finger location. This is achieved by hacking a standard commercial strip force sensitive resistor (FSR) per Adrian Freed's discussion of the DuoTouch [5].

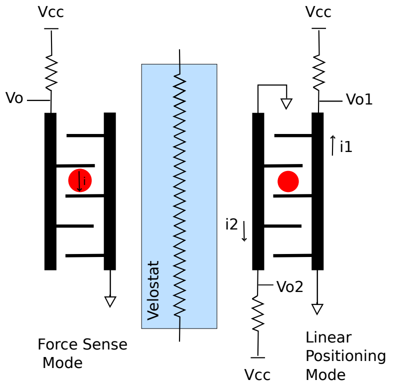

Figure 2: The two operational modes of a FSLP

A typical strip FSR is composed of a length of velostat, a conductive material whose conductance increases as pressure is applied, and two physically separated circuits at different electro-potentials. As the velostat's conductance changes with pressure, the amount of current flow between the circuits will be proportional to applied pressure. Velostat can also be used for linear positioning. Typical velostat resistances have been measured at 400-500 Ω/cm. With one end of the velostats tied high, and one end to Gnd, the voltage at any given physical point is the proportional to the distance between the measurement point and each end.

The FSLP makes use of both these operating modes. Pressure is determined using the force sense mode in Figure 2. Position is determined by the creation of variable length resistors. Commercial FSRs are built with an air gap so that normally no contact is made between the circuits and the velostat. When pressure is applied to the strip, the circuits contact the velostat at the point where pressure is applied. The resistance between the contact point and the end of the FSR is determined by the contact location. As illustrated in Figure 2, by connecting to both of the opposite ends of the circuit, and both of the opposite ends of the Velostat, it is possible to measure the contact from either direction.

With DuoTouch, Freed used measurement from either end as independent sources of data. The Hand-Controller only needs to measure one point of contact per track. With the FSLP, force applied to the velostat will also affect the resistance of the strip in linear positioning mode altering the measured distance. By comparing the contact location measured from one end of the FSLP, to the contact location measured from the other end, a far more stable and exact single contact output can be determined than when the contact points are considered independently. Digital potentiometers are included in the hardware to automatically calibrate for any environmentally induced change in velostat resistance. Tests have found that the FSLPs have a stable resolution down to 0.2mm. This is excellent con-

---

[1] `http://sixense.com/razerhydrapage`

sidering the smallest distance increment a finger can sense is 0.1mm [7]. For the typical strip of 40mm, that offers 200 identifiable positions.

There are four FSLPs per platform. The FSLPs are constructed in three different lengths in order to match finger sizes. As visible in Figure 3, around each FSLP is a plastic bumper to help guide the user's finger along the correct axis of measurement. Different bumpers also have notches to provide additional tactile guides for positioning. As different users have different finger lengths, additional nubs are placed to delineate a users range. Output can be calibrated in software to match the user's finger length.

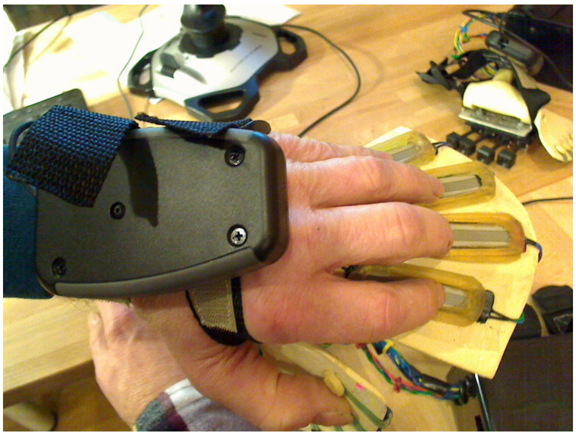

Figure 3: Hand-Controller with Track Platform

The thumb pressure sensors are straight-forward FSRs with button covers for improved feel. The present hardware supports up to four thumb sensors, but there is plenty of space for more. The alternate platform pictured in Figure 4 uses slide keys made from BEI Duncan spring return linear position sensors. Electrically, they function as a standard potentiometer and are modified through the addition of a plastic cap for comfortable use.

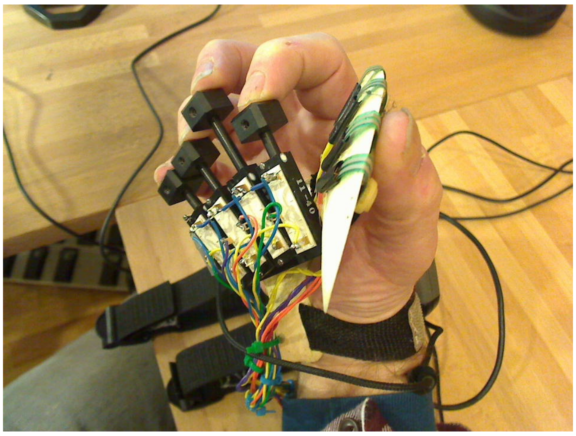

Figure 4: Hand-Controller with Trumpet Key Sliders

3.2 Mechancial Design

Both platforms and thumb plates are mounted on a palm grip. The grip extends across the 4 finger metacarpals and down to the carpals in order to distribute pressure across the hand while providing sufficient clearance of joints to allow independent finger motion and wrist movement. An adjustable strap extends across the back of the hand to keep the controller in place. Both the right and left hand grips have been designed keeping comfort and ergonomics in mind and have been successfully tested with a wide range of hand sizes. The thumb plate is shaped to follow natural thumb reach and can be rotated for optimal comfort. Similarly, the track platform is formed to the natural curvature of the hand. The height of the finger platform can be adjusted and it can be rotated towards the palm to match individual preferences. The angle of the trumpet keys is also adjustable to suit different hand shapes. All plates have sufficient space to accomodate a non-interactive rest position.

They layout of sensors is highly customizable to suit user preference. The thumb buttons are covered by a Smooth-On[2] foam for improved tactual feel. Bumps on the covers allow the finger to quickly disambiguate between neighboring buttons without visual reference. The tracks, and their accompanying bumpers can also be placed per user preference. The Hand-Controller parts are molded using Smooth-On plastics and machined aluminum. They are easily reproducible and five sets have been made so far.

3.3 Tracking Hand Movements

Due to the projection environment intended for the complete visual music system, the use of optical tracking for motion capture was rejected. Instead, hand tracking is primarily done using the Razer Hydra developed by Sixsense. The Hydra is a low cost electromagnetic field (EMF) tracking system based on the same principles as the Polhemus Liberty[3] system used in motion tracking scenarios such as string instrument bow tracking [8]. However while the Liberty system costs over $5000, the Razer costs only $79. Sixsense provide a regular SDK and a MIDI SDK. Although the accuracy and range is reduced in comparison to more costly systems, our tests suggest it still remains accurate within 2mm and 2 degrees of rotation within a range of about 70 cm from the sensor.

The Hydra is sold as a game controller with a base station and two joysticks. Along with EMF tracking, it features buttons and inputs for gaming. As our goal was strictly to use the tracking capabilities, we have separated the inductor array used for the EMF tracking from the rest of the controller. The Hydra joystick comes separated into two boards- one that conditions the EMF circuit and one with an ARM processor to deal with the traditional joystick capabilities. The otherwise unnecessary ARM board is required for the Hydra libraries to run and the EMF board is much larger than useful for mounting on the hand. We have built an extension board (see Figure 5) that replaces the commercially produced Hydra EMF board with one that is much smaller but retains full capability and compatibility.

One drawback of the Hydra is that stable reliable EMF tracking requires electrical connection between the base station and the end sensors. As a future goal for the Hand-Controllers is to support wireless performance and considering a user may explore space beyond the Hydra's stable performance range, the Hand-Controller is also equipped with a 9 degree of freedom inertial measurment sensor stick from SparkFun[4]. This board has an ADXL345 accelerometer, ITG-3200 gyro, and a HMC5883L magnetometer. Combined, these sensors are sufficient for orientation tracking and some gesture recognition.

3.4 Processing Electronics

Apart from the Hydra, the hardware for the system is composed of two boards pictured below: the processor core,

---

[2] `http://www.smooth-on.com`

[3] `http://www.polhemus.com/?page=Motion_Liberty`

[4] `https://www.sparkfun.com/products/10724`

and an analog conditioning board. The separation into two boards was done to support the different analog conditioning required for the two finger actuation options, but it has the added benefit that the analog systems can be revised or enhanced without impacting the core module. In fact the core has turned out to be a highly useful alternative to the Arduino in various rapid prototyping senarios.

The core is based on the new Atmel AVR32UC3C. The UC3C has a highly configurable 12 bit 16 channel ADC, single cycle multiply, native USB and floating point support. Besides completing the necessary analog readings to track the various finger actuations, the UC3C also does most of the computation for tracking orientation using the 9DOF board. The code computes full fusion of all three sensors including the use of Kalman filtering to improve results. The entire sensor fusion computations including matrix multiplications runs in less than 5ms, entirely sufficient for human response times. The complete hardware code including 2 times oversampling of the analog inputs and USB communication runs at 100Hz.

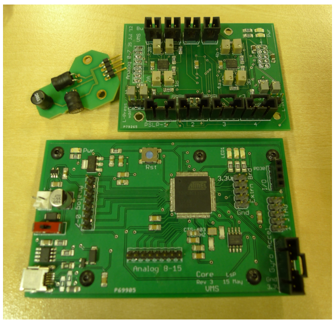

Figure 5: Electronic boards used for the Hand-Controller. The upper left is the Hydra extension board. Upper right is the FSLP board that mounts on the core controller at the bottom.

4. MAPPINGS AND USE

In depth discussion of the Visual Music Systems visualizations and the means to control these visualizations is both beyond the scope of this paper and very much still in development. The Hand-Controller is fully integrated into the on-going visual performance system and there is a Hand-Controller test bench. The Test bench provides useful visualizations for what inputs the Hand-Controller is receiving and provides entry to test and calibration software.

The Hand-Controller has also been used to create a new musical instrument using a single controller with the track platform. Serial data sent from the Hand-Controller is received into MAX where it can either be passed along to control a MAX for Live instrument, or an MSP instrument. Whether controlling MAX for Live or MSP, the mappings remain the same, but MAX for Live provides quick and easy access to a variety of preset sounds.

The present mapping is inspired by stringed instruments. Finger position on each track selects pitch and, like a stringed instrument, pitch is continuous. Each track controls an octave range and they are set a fifth apart. The pressure applied to the track changes timbre through vibrato like effects. Lastly, four thumb buttons are paired to each track to control the volume of the linked track. Present free gesture mappings are quite simple, triggering additional timbre changes to the sound. The mappings were inspired by the violin and should provide a good test of the range of control achievable through the primary tangible interface.

5. ONGOING WORK AND CONCLUSIONS

So far, we have built an interface that meets our design goals- It includes hand tracking to capture expansive physical motion without relying on vision based systems. The interface also provides tangible detailed, reliable, and learnable means for the fine control required to fully explore virtuosic performance. While the hardware is fairly stable, there are eventual plans to scale parts down so that the hardware can fit behind the palm grip for less intrusive mounting. There are also plans to eventually make a wireless version with reduced free gesture capture using the introduced IMU solution.

However work with the Hand-Controllers has only just begun. The next major phase is to develop a rich vocabulary of gesture that can be used to in conjunction with the tactile systems for more expansive and wide ranging expressive performance for both the visual and audio spheres. We have already introduced one audio instrument. Work on the visual instrument continues.

6. ACKNOWLEDGMENTS

I would like to thank Marina Porter, Andy Cavatora, Andrew McPherson, C4DM, and all at Visual Music Systems who have contributed to and supported this work.

7. REFERENCES

[1] M. Bokowiec. V'Oct (ritual): An interactive vocal work for bodycoder system and 8 channel spatialization. In *Proc. New Interfaces For Musical Expression*, pages 40–43, 2011.

[2] M. Bokowiec and J. Wilson-Bokowiec. The Suicided Voice, Etch. In *Proc. New Interfaces For Musical Expression*, pages 388–389, 2008.

[3] D. Cornish. Watch Imogen Heap's full Wired 2012 glove demo and performance, January 2013. http://www.wired.co.uk/news/archive/2012-10/29/imogen-heap.

[4] R. Dean. *Hyperimprovisation: Computer-interactive sound improvisation.* AR Editions, Inc., 2003.

[5] A. Freed. Novel and forgotten current-steering techniques for resistive multitouch, duotouch, and polytouch position sensing with pressure. In *Proc. New Interfaces For Musical Expression*, 2009.

[6] V. Krefeld and M. Waisvisz. The hand in the web: An interview with michel waisvisz. *Computer Music Journal*, 14(2):28–33, 1990.

[7] S. Lederman. Skin and touch. *Encyclopedia of Human Biology*, 7:51–63, 1991.

[8] E. Maestre, J. Bonada, M. Blaauw, A. Perez, and E. Guaus. Acquisition of violin instrumental gestures using a commercial emf tracking device. In *Proc. International Computer Music Conference*, volume 1, pages 386–393, 2007.

[9] T. Mitchell, S. Madgwick, and I. Heap. Musical interaction with hand posture and orientation: A toolbox of gestural control mechanisms. In *Proc. New Interfaces For Musical Expression*, 2012.

[10] D. Rokeby. Very nervous system. *Arte, technologia e informatica, Venice biennale*, 1986.

[11] L. Sonami. The lady's glove, a brief history, January 2013. http://www.sonami.net/works/ladys-glove/.

[12] B. Stewart. Fliz. *Heavy Metal*, 4(6):79–83, September 1980.

[13] T. Winkler. Making motion musical: Gesture mapping strategies for interactive computer music. In *ICMC Proceedings*, pages 261–264, 1995.