A Responsive User Body Suit (RUBS)

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ABSTRACT
We describe the Responsive User Body Suit (RUBS), a tactile instrument worn by performers that allows the generation and manipulation of audio output using touch triggers. The RUBS system is a responsive interface between organic touch and electronic audio, intimately located on the performer's body. This system offers an entry point into a more intuitive method of music performance. A short overview of body instrument philosophy and related work is followed by the development and implementation process of the RUBS as both an interface and performance instrument. Lastly, observations, design challenges and future goals are discussed.

Author Keywords
tactile, haptics, responsive, wearable interface, musical expressivity, intuitive music

ACM Classification
H.5.2 [Information Interfaces and Presentation] User Interfaces–Haptic I/O, D.2.2 [Design Tools and Techniques] User Interfaces, H.5.5 [Information Interfaces and Presentation] Sound and Music Computing.

1. INTRODUCTION
Touch is the primary interface between the human body and the outside world. Through haptics we perceive our environment, objects, and other beings in relation to ourselves in space. The touch sensation creates a relationship between the self and the other - that which lies outside the self. From this relationship comes the synthesis of sensory input, action and perception. Our reality is shaped by our physical movement and interaction. Perception is touch-like in this way, which acquires meaning thanks to our possession of bodily skills [1]. We may intuitively orient ourselves in relation to objects, including instruments. However, learning an instrument is not exactly an intuitive process. "The instrument is very much treated as a difficulty, an obstacle that needs to be overcome in order for it to become one with the performer" [2]. When we create an interface/instrument using the intimate relationship we have with our own body, we are also creating an entry point into a more intuitive musician/instrument relationship. This concept forms the basis of the RUBS system.

The Responsive User Body Suit, or RUBS system, is a tactile interface worn by a performer. This system allows a user to process audio output in real time, simultaneously triggering and manipulating audio samples by controlling fabric strip potentiometers sewn onto the suit. Discrete and continuous audio changes are generated through two different motions of contact; touch and stroking.

The RUBS design is influenced by Lakoff and Johnson's theory of embodied cognition and the primordial touch sensation [3]. The body's influence on the mind necessitates an understanding of our senses, our motor system, and neural mechanisms. As such, the RUBS system acts as an interface between dualisms; the organic (touch) and electronically generated (sound), and the unconscious (thoughts of user) and conscious (thoughts of user and audience). Additionally, the RUBS system makes the previously intangible (thoughts, emotions), perceptible via touch triggers and audio output.

2. RELATED WORK
There are many interfaces that make use of touch, or use the body's awareness of the location of an extended limb or digit. Those involving body contact, such as gloves (e.g. GRASSP [4], mi.mu [5]), can provide a stronger haptic sense in that multiple parts of the body are involved (other digits, arms/legs, or the torso). In these models, multiple signals are being received by the brain which assists in learning and performing.

The DIVA-Fortouch system [6] combines multiple inputs through finger postures and limb location. The positions of fingers in cybergloves provide information for the control of consonants, while the x and z coordinates of a wrist-mounted sensor controls vowel formants and pitch. In this interface, haptic sensing is especially important for creating transitions between consonants, especially liquids and nasals. For liquids, the first finger strokes the extended thumb, with the location of the fingertip controlling the generation of data for the consonant synthesis.

Another example of a multiple input system is the Bodycoder System [7] [8] comprised of switch sensors located on each finger, and flex sensors on the user's limbs. Finger switches on a right hand data glove provide individual sensor activation and deactivation, facilitating on-line and off-line modes of operation. Finger switches mounted on the left hand glove provide utility functions such as Max/MSP patch/preset selection and granular sampling and recording. Bend sensors are located on each elbow and wrist. The mapping and programmed expressivity (sensor scaling) of each sensor element can be changed during the course of a piece of work.

The French singer Émilie Simon performs with the BRAAHS, an arm mounted effects controller designed by Cyrille Brissot [9], that allows her to sample and manipulate her voice and the sound of other accompanying instruments.

The RUBS system expands on these touch interfaces by increasing the surface area of interaction with the body. This is achieved through the interface design, centered on the user's torso, as opposed to localized contact and flex points located on appendages. Centralized design allows for a more theatrical performance style, utilizing gestures from the entire body. There is also an enhanced sensuality to the RUBS system, not found in these previous works. The intimacy between the performer and their own body is central to this system.

In addition, the RUBS system expands the capability for added levels of interactions by involving multiple performers

3. DEVELOPMENT / IMPLEMENTATION
This section describes the approach and materials used to construct the interface, followed by observations dealing with outcomes of the initial testing, rehearsals, and performances.

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3.1 The Interface

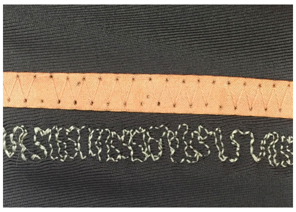

Figure 1. Conductive and resistive fabric traces

The RUBS interface consists of four pairs of parallel tracks constructed of resistive thread patterns and conductive fabric, sewn onto a dance leotard and connected to an Arduino (Fig.1). The initial interface used RJ45 cable to connect the 8 traces to an Arduino, while the current system is wireless, using a pair of APC220 modules and a body-worn Arduino. Each pair of tracks creates a potentiometer, with a copper tape-wrapped or thimble-wearing finger acting as a wiper. The strips are powered by 5 volts supplied by the Arduino, forming the potentiometer in a standard voltage divider circuit. The resulting output voltage is sent to Arduino2Max [10] and from there to the Max/MSP performance patch.

3.2 Tactile Feedback

Prototyping and development was based on the dimensions and reach of a single performer, but the expansion of the project to involve three performers (dancers and vocalist) revealed the differences in reach and flexibility for each performer. Because of the layout of the sensors it was found that cross-body reach was the easiest method of generating data, with the right hand responsible for left side sensors, and vice versa. However, with practice the performers became comfortable using either hand for any sensor. For all performers the initial work with the suit demonstrated the difficulties of sensing the strips while wearing thimbles or copper tape: often, the performer's head would drop while they searched for the location of the appropriate trace. From this experience a performance technique was developed in which a bare finger alongside of the conductive finger provided guidance for the location of the traces, allowing the performer to keep their head up and engage with the audience.

3.3 Data Use

Raw peak and trough values are constantly updated and used to scale the streams of incoming data, giving maximum sensitivity for each trace: each resistive fabric strip is read across its full length to generate data. Due to fabric irregularities and data jitter for audio scrubbing the incoming data is averaged over thirty values and then mapped to the length of its associated buffer.

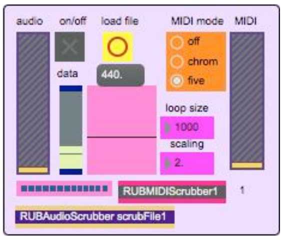

Figure 2. Audio/MIDI input monitor

The performance interface allows for the control of audio scrubbing and sample triggering, and enables on-the-fly changes using matrix presets or realtime repatching. Each data stream controls a particular audio buffer and MIDI stream. For MIDI, the data range of each sensor can be divided to control the desired number of MIDI events. Audio buffers can be reloaded or switched during performance, and MIDI-triggers can be remapped to various samples.

Audio scrubbing uses looping buffer segments (windows), with the incoming data setting the start point in the audio buffer. The size of the loop window is preset, but can be changed using presets or in real-time during performance.

3.4 Types of Touch

In performance, three types of finger contact are used: single touch, flutter, and stroke (Table 1). A single touch can trigger a single, unrepeated MIDI event, or begin a loop at the associated point in the audio buffer. Due to the data averaging being used, audio buffer playback will drift to the start point of the buffer after the finger is released. Flutter touch consists of rapid movement of the fingers to contact different parts of the interface. This type of motion causes the loop window for an audio buffer to move irregularly, creating disjointed audio playback. For MIDI, multiple MIDI events can be triggered, creating cascades of triggered samples.

Table 1. Types of touch

	Single Touch	Flutter	Stroke
Audio	Trigger and Fall-way	Buffer Scrubbing	Buffer Scrubbing
MIDI	Single Event	Multiple Events	Process Control

Finally, stroking controls the start points of audio loops, and can also be used to generate MIDI and audio processing data for the control modules in the UBC Toolbox [11].

4. CREATION OF WORKS

4.1 Voice and RUBS

Bhumber's composition *Touch* for voice, electronics and the RUBS system was performed at the 2016 WAVE EQUATION electronic concert series in Vancouver, Canada. Vocal performance was chosen because it is an organic form of expression and – since vocalization has fewer physical constraints than instrumental performance – it allowed for a wider exploration of the bodysuit.

As mentioned, Rodé's text for the work was developed around Lakoff and Johnson's theory of the embodied mind, in which the same biological mechanisms that inform physical perception also create and affirm our conceptual reality [12]. The text expresses a reliance on tactile validation – "when you touch me / I exist". The performer-as-subject comes into being when impressed upon by external influences, just as the RUBS only "comes alive" (through audio triggering and live processing) when touched by the performer. Fels describes the relation between player and instrument as working towards the "ultimate goal" of embodying the instrument: "As a player learns an instrument, he becomes more intimate with it. The ultimate goal in the process is for the player to have a high degree of intimacy such that he embodies the instrument. When the player embodies the instrument it behaves like an extension of him so that there is a transparent relationship between control and sound. This allows intent and expression to flow through the player to the instrument and then to the sound and, hence, create music" [13]. Because the RUBS system is worn by the performer, they must explore the suit through proprioception. Thus, in practice, rehearsal, and concert the performer is exploring their own body, resulting in a more intimate and expressive method of performance, reflecting Fels' assertion that instrumental embodiment occurs through intimacy and transparency.

Overall, Rodé created her text as a direct response to the development of RUBS. The close fit of the garment, the contoured layout of the sensor strips, and the manner of sensor control provide and promote an intimacy that is directly addressed in the words, subject, and performance of *Touch*.

4.2 Development of *Touch*

Rebelo has stated, "Music performance is dependent on bodily involvement that goes beyond the auditory and the sense of hearing" [14]. As audience members we appreciate gestures that support the musical flow, and vocal works can provide for theatrical possibilities that may not be possible in an instrumental work. In the development of *Touch* this was explored by Marguerite Witvoet whose experience with new music and theatre is an asset to this piece. Her character's opening presentation came to involve discovery, as she becomes aware of her fingers and their metallic wrappings, a union of the organic with the inorganic, foreshadowing the fuller exploration of the instrument.

During the work's development, "gesture painting" became a useful augmentation of traditional word painting. As one example, the character's singing of "configured by the gaze / of your hands across my chest" was accompanied by her hands touching the sensors on the opposite side of the body, physically crossing across the chest to match the text (Fig. 3). This particular gesture points to how creative and practical changes to the work occurred during its development.

Figure 3. Marguerite Witvoet in *Touch* performance

The sonification of bodily experiences emerged throughout the piece's development. Discrete touch gestures evoked feelings of pain by triggered paralanguage audio samples such as sighs, gasps and hums. This intuitive meta-communication gives subconscious nuance and meaning to the live vocals.

4.3 Dance and RUBS

The use of RUBS in dance works proved to be quite theatrical. Each of the dancers involved was intrigued with the interface and enthusiastic in using it, with the ability to control both the triggering and scrubbing of audio being the immediate attraction. As the dancers gained experience with RUBS the ability to use micro gestures for triggering or scrubbing was investigated, since that could be mimicked by small, whole-body movements.

Like *Touch*, the use of RUBS in dance resulted in a new appreciation of how the interface could be used. Part of dance involves an appreciation of how the human body can move, but with RUBS a dancer's movements can emphasize the playing of the sensors or create a distraction, hiding the actual touching of sensors. As a result, in addition to playing the suit, dancers tended to play with the suit in performance, resulting in dance that was a response to the sounds being produced, or dance that was a celebration of the gestures required to produce the sound.

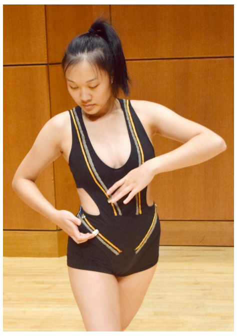

Figure 4. Danielle Lee during performance development

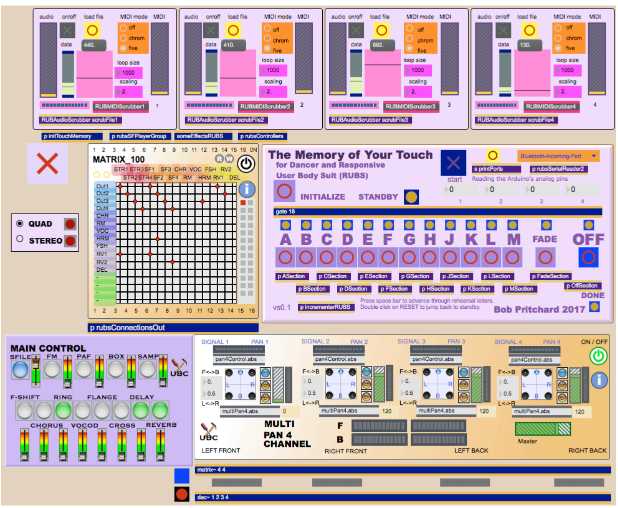

Figure 5. MaxMSP dance interface

As is common with instrument design, initial tests of the interface in performance demanded an expansion of the software. The improvisations of each of the dancers pushed the expansion of the basic system to four audio buffers and four MIDI outputs, allowing the triggering of multiple events in each of the MIDI soundfile players while also supporting four audio buffers that could be reloaded while in progress.

5. OBSERVATIONS / CHALLENGES

5.1 RUBS Design

Various changes were required as the project developed, due to design or performance requirements. In creating the interface we began by investigating various resistive materials including resistive thread, metallic fabrics, and even analog cassette tape. We eventually settled on LessEMF's orange resistive yarn strips (TACRACPS0400OR) which were sewn onto a dance leotard. For aesthetic reasons the orange resistive fabric was complemented with conductive copper plated polyester taffeta to create a strong visual presence of the sensor interface. Originally the performer's fingers were to act as conductive wipers to bridge the two fabrics. However, successful initial trials eventually yielded inconsistent results, so we switched to fingers wearing metal thimbles or adhesive copper tape.

The prototype was quite successful but the manufacturer of the orange yarn strips ceased production, and the replacement strips offered by the supplier were less effective, and compromised the development of the suit and concert works. We tried substituting Softpot potentiometers, attached to the suit in fabric sleeves sewn onto the surface, but these proved to be unworkable, as various movements and the bends around body curves created pressure zones that triggered data in the absence of finger touch.

We then obtained 66 Yarn 22+3ply 110 PET resistive thread, which was used to sew thread patterns directly onto a more robust leotard, and the results were quite acceptable. While this method compromised the high visibility of the original design, it opened up the possibility for more imaginative interface patterns in future.

Following each of the changes in resistive material a change in the second resistor in the voltage divider was required, a somewhat tedious job due to the use of fixed resistors. The use of mini pots would make future adjustments much easier.

One important aspect of sewing the resistive traces was the types of stitch patterns required. Various stitch patterns were tested, and while each fulfilled the resistive requirements of the circuit, we found that the larger, irregular pattern (the last pattern in Fig. 6) gave performers greater confidence in finding and maintaining contact with the strip.

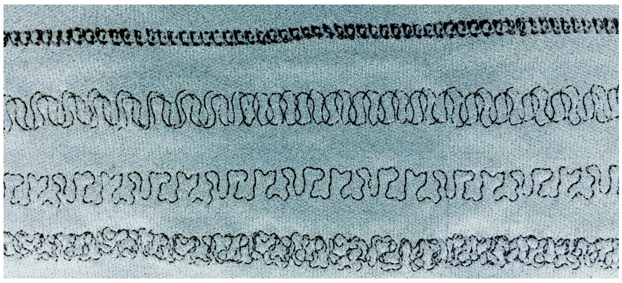

Figure 6. Resistive thread sewing patterns

Throughout the creation of the suits performers participated in the placement of the sensor strips, indicating where they found difficulties in reaching and using sensors, or what worked particularly well. The original hip placement of sensors was found to be constraining and awkward, and performers suggested moving the strips inwards and down to make access easier. An additional suggestion involved changing the stitch pattern on the conductive taffeta, so that there was less friction and snagging of the material by the finger tape

The investigation of dance works advanced the development of a wireless system: for vocal works with little stage movement a tethered system was acceptable, but the same setup is constraining for dancers unless the particular choreography emphasizes the constraint as a motif or theme. At the time of writing we are developing the wireless system using paired APC220 modules, with an on-body Arduino for the dancer. The APC220 system was chosen for its simplicity of implementation, as well as for its relatively modest size.

5.2 Challenges

For performers, the two greatest challenges in learning how to use the suit are in becoming familiar with the sensor locations, and learning what gestures and manipulations are possible and useful for the piece being performed.

The RUBS garments are very close fitting, ensuring that the location of the sensors remains the same from practices through to performance. While this is of benefit to the performer, a problem arises through the insensitivity of the “wiper” fingers. The adhesive copper tape on a finger negates the touch sensitivity of that particular finger so – as mentioned above – a two-fingered technique must be used where a non-taped finger provides guidance as to the location of both the conductive and resistive fabric.

It has been found that each performer develops their own library of gestures that feel natural to them and that create the types of audio manipulations required or desired in the piece. As such, each performer creates a gesture “accent”, so that even if performing with the same audio materials, their own interpretation and performance is unique.

6. FUTURE DESIGN / PERFORMANCE

With the creation of multiple RUBS garments, we are now looking at works with more than one performer. For vocal performance it will be possible to create a small ensemble combining live voice and pre-sampled passages. For dance, multiple performers will be able to perform together, touching their own and others’ instruments, creating an interactive group instrument.

Another area we are interested in pursuing involves combining RUBS with current research using Kinect tracking. This will combine macro and micro gestures in performance, and the combination of data could provide significant control in triggering and processing audio and video.

The RUBS system can also be worked to accommodate diverse body configurations including performers with disabilities.

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8. Appendix I: Video

RUBS dance demonstration video: https://vimeo.com/201567264
RUBS overview video: https://vimeo.com/191104171