Wearable Jamming Mitten for Virtual Environment Haptics

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ABSTRACT
This paper presents a new mitten incorporating vacuum layer jamming technology to provide haptic feedback to a user. We demonstrate that layer jamming technology can be successfully applied to a mitten, and discuss advantages layer jamming provides as a wearable technology through its low profile form factor. Jamming differs from traditional wearable haptic systems by restricting a user's movement, rather than applying an actuation force on the user's body. Restricting the user's movement is achieved by varying the stiffness of wearable items, such as gloves. We performed a pilot study where the qualitative results showed users found the haptic sensation of the jamming mitten similar to grasping the physical counterpart.

Author Keywords
Wearable Glove; Haptics; Jamming

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation: User Interfaces: Haptic I/O

INTRODUCTION
This paper presents a new haptic mitten employing vacuum based layer jamming [11] to change material stiffness under computer control. Our investigation is exploring how haptic technologies can be incorporated into wearable computing forms such as garments and gloves [2]. The goal is to provide computer controlled haptic stimulus to user movement.

The sense of touch is associated with many aspects of life and is a primary sense used to examine the physical world. Touch is most perceptible in the hand, and the hand is an ideal interaction tool [15] supporting both fine-grained and large-scale manipulations with high degrees of dexterity. A glove is an ideal platform to provide haptic feedback to a user when engaging in grasping operations in virtual environments (VEs). We incorporate layer jamming into a mitten to emulate the haptic sensation of clenching gestures, such as operating bicycle brakes, holding shopping bags or grasping a safety rail.

ISWC'14, September 13 - 17 2014, Seattle, WA, USA

http://dx.doi.org/10.1145/2634317.2634342

(a) Open mitten configuration **(b) Closed mitten configuration**

Figure 1: Open and closed mitten postures

Traditional hand-based haptic feedback systems have exerted a force on a user's hand by employing actuators. For wearable systems where mobility is important, creating slim, portable haptic feedback systems is challenging. We are exploring the use of layer jamming to overcome these size limitations. Layer jamming [3] uses air-tight volumes containing sheets layered on top of each other. When a vacuum is applied to the layers the stiffness of the volume increases. Jamming is currently employed in robotics to control the flexibility of joints and malleable exoskeletons [14]. In Human Computer Interaction (HCI), jamming has potential for shape displays [5]. One example is jamSheets which demonstrated a multi-modal flexible display capable of emulating materials such as foam or timber [11]. Projected texture information is used with a particular stiffness to change the appearance and feel.

In this paper, we demonstrate new applications and present a layer jamming mitten for haptic feedback within VEs. Our system provides a locking mechanism to the user's hand for a clenching action with a low profile design suitable for wearable integration. Our implementation places the jamming layer against the user's palm. When the mitten is jammed, the user is prevented from opening or closing their hand, resulting in haptic sensations. As an example, Figure 1 depicts a standard oven mitten in open and closed configurations. The clenching of the user's four fingers is the action of interest; jamming of the thumb is not considered. We present three contributions to the wearable computer research field: 1) the development of new wearable haptic device that employs low profile layer jamming, 2) a performance evaluation of the device indicating repeatable performance and positive user feedback, 3) the discussion of wearable applications that layer jamming may be applied for haptics in future systems.

RELATED WORK
Haptic feedback refers to the combination of kinesthesia and tactile feedback. Developing haptic feedback to improve re-

alism in virtual environments has been an area of intense research, as haptics is a crucial aspect of interactions in the physical world [13] where the hand plays a central role in many interactions. The following sections provide an overview of two related domains: gloves for VEs and jamming technologies.

Gloves for Virtual Environments

A glove provides a foundation both for user input (hand tracking and glove-based sensors) and system output (haptic feedback). One approach to support user input for command entry tasks, such as menu selection, is pinch gloves [12] which sense when finger tips come in contact with either the tip of the thumb or the user's palm. Supporting system output through haptic feedback is required for improving user performance in VEs [1]. There are a number of commercial active haptic glove systems. CyberGrasp gloves employ actuators and wires attached to the user's digits to provide computer controlled haptic stimulus. Active actuation systems continuously create sensations on a user to guide the user's body in a direction. For example, when a user pinches a virtual object, CyberGrasp exerts a pressure on the user's fingers, emulating the experience a user would have when interacting with a physical object.

Jamming Technologies

Jamming differs from traditional haptic technologies as it creates haptic feedback through restriction, rather than actuation, of a user's body. As previously mentioned, jamming can change the viscosity of a volume along a continuum between a fluid-like and a solid-like state. This transition is reversible — when the volume is released from the pressure it reverts back to its fluid-like state [7]. This technique is particularly useful for robotic joints where the constraints of flexibility, strength and size compete. Particle jamming — jamming a bladder containing particles, such as sawdust or coffee grounds — has been used to control joints flexibility in multiple degrees of freedom under computer control [6, 4]. The changeable rigidity of jamming technology has also been demonstrated to create robotic skins to allow robots to squeeze through small spaces [14]. Jamming has been used for tangible user interface applications [9] and flexible interactive surfaces [8]. Particle jamming systems like the Particle Mechanical Constraint system [10] have demonstrated wearable haptic systems attached to the users arm and wrist, allowing the user to feel as though they were moving through water. However, particle jamming systems are much bulkier than layer jamming systems, and are not as well suited to garment integration.

JAMMING APPLICATION DOMAINS

Layer jamming haptic devices are suitable for VEs as the low profile of the bladder means it can fit tightly against the user's body. While we are primarily investigating jamming applications for hand-based wearable computer interaction devices, the techniques used here are suitable to many other regions of the human body to provide a computer controlled rigidity parameter for the joints on a human body [10]. Medical therapy applications are another exciting area for wearable

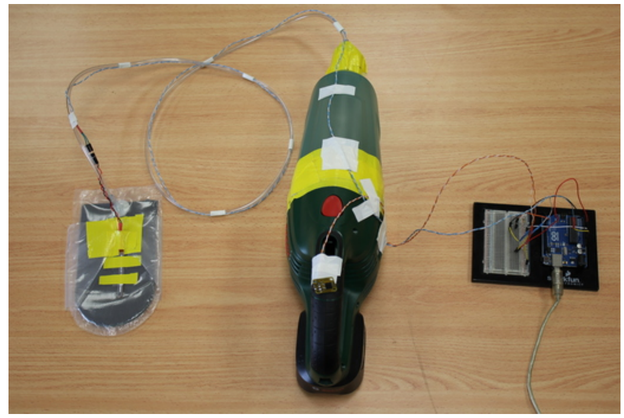

Figure 2: Jamming system components: the jamming mitten, a vacuum pump and an Arduino microcontroller connected to a personal computer (not shown)

jamming technologies. One example is the use of a garment and gloves to assist with tremor reduction. By sensing movement in real time with an accelerometer we can employ the jamming technology to adjust the stiffness to assist a user in manual tasks, such as pressing closely located buttons on a number pad. A potential application for wearable jamming technologies is posture training for musical instruments such as piano or violin, where the user's wrist and hand must be kept aligned. By tracking the user's wrist orientation in real time and adjusting the stiffness of a wrist guard, we can employ the jamming technology to guide the user's posture when it lapses. Further developing exoskeletons are another motivating avenue for wearable jamming technology research. For example jamming-based gloves and exoskeleton might work together to assist a user engage in manual tasks, such as carrying shopping bags. Our implementation has focused on the idea of advancing wearable haptic systems through the use of jamming technologies. This is realized through our mitten implementation. The above applications further motivate the need to explore jamming technology in wearable computing.

IMPLEMENTATION

The layer jamming mitten implementation consists of three subsystems: the jamming bladder, the vacuum pump, and a computer-control mechanism for the vacuum pump (shown in Figure 2).

Jamming Bladder Implementation

The jamming bladder is constructed from polyethylene with a nylon outer layer. The bladder measures 21cm by 12cm (see Figure 3.a). The layers are constructed from 1200 grit wet-dry sandpaper. The layers measure 17cm by 10cm (see Figure 3.b). Eleven layers are used, orientated with the grit on the top side of each layer. A 3D printed nozzle was attached, and 3mm vinyl piping used to connect the bladder to the vacuum pump. To seal the bladder, a heat gun was used to melt the two halves of the bladder together, and two part epoxy used to seal the nozzle and piping connections. A flex sensor (Spectra Symbol FS7548) was attached to the mitten. Finally, a sheath for the user's hand was attached to the

(a) Jamming bladder (b) Single jamming layer (c) Completed mitten

Figure 3: Components of the layer jamming mitten during construction

back of the mitten. When worn, the jamming bladder is on the palm side of the users hand, with the vacuum tubing and electrical cables terminating near the user's wrist (shown in Figure 3.c). The prototype mitten has a low profile, with the overall thickness of the bladder being 2.1mm.

A Bosch hand-held vacuum (model PAS 18LI) was used. A MOSFET (NTD5867NL) was retrofitted to the vacuums switch allowing computer control. An Ardunio Uno is connected to both the vacuum's on/off switch via the MOSFET, and the flex sensor. When the flex sensor reading reaches a pre-configured value, the Arduino switches on the vacuum. The rigidity of the mitten bladder increases through the jamming of the sandpaper layers.

PILOT STUDY

A qualitative pilot study was performed to better understand how users experienced the haptic sensation. The participants consisted of five research students and an administrative worker. The mean age of the participants was 31.33 years (SD = 10.54), with four male and two female participants. All participants were right handed. Participants were asked to compare the sensation of touching a physical object and virtual object whilst wearing the layer jamming mitten.

Procedure

Participants donned the mitten on their dominant hand. They were asked to slowly close their hand until they felt the presence of an object. Nine cycles were performed with three conditions. For the first condition the jamming technology was disabled and a 30mm metal pole was placed so the participant's hand closed around the pole. In the second condition participant were asked to grasp a pole with the layer jamming technology. With the third condition the jamming technology was enabled and no pole was placed near the hand. Users performed trials alternating between the three conditions in a randomized order. After each cycle, the user was asked to open their eyes and verbally indicate a response to "it felt like there was a physical object in my hand" using a scale from one to ten (one indicating strong disagreement and ten indicated strong agreement). On completion users were asked to response to the statement, "the presence felt the same each time" by noting their response on a line printed with a five level Likert scale ranging from 0% 'strongly disagree' to 100% 'strongly agree'. The response was determined by physically measuring the length from strongly disagree to the indicated marked position with a digital caliper. Participants were then asked to close their hand four times, twice grasping a physical object without the layer jamming technology, and twice with layer jamming and no physical object. Participants were allowed to visually examine their actions during this phase of the evaluation. Finally, participants respond to "the haptic response was realistic each time", by marking a line with a five level Likert scale ranging from 0% 'strongly disagree' to 100% 'strongly agree'.

Qualitative Results

Figure 4 shows the participant's mean responses to question 1, "It felt like there was a physical object in my hand". Figure 5 shows the responses for the second and third questions, "The response felt similar each time" and "The haptic response was realistic".

The participants' response to question 1 clearly indicates for all three conditions there was distinct detectable haptic sensation, determined from all the mean responses above six. The qualitative sensation of repeatability and consistently was measured in question 2. Five participants out of six responded in the positive to the question, and indicate this sensation to be true. Question 3 asked the participants if the haptic response was realistic each time, and all participants responded above 69%, supporting the second hypothesis (a user is able to perceive a haptic sensation from the layer jamming haptic system). A number of positive responses from participants also supported these results including: "Wow! It really felt like there was something in my hand." "It feels much more realistic than I'd expected." "It feels very real."

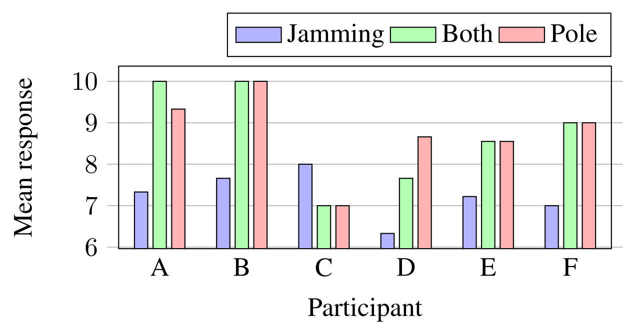

Figure 4: Mean responses to Q1

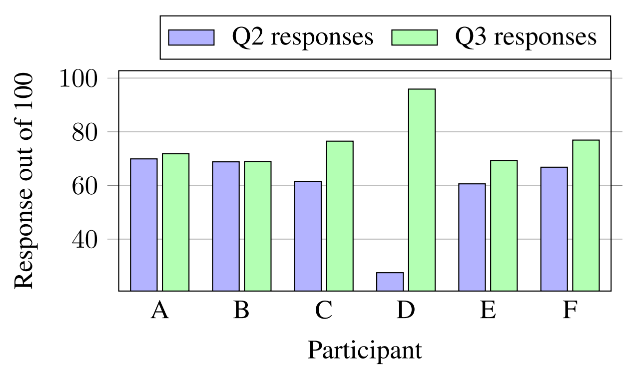

Figure 5: Responses from Q2 and Q3

LIMITATIONS

We have identified several limitations of the current prototype and areas for technological improvement. Firstly the size and power requirements of the vacuum pump represent a significant limitation for wearable applications. The vacuum pump is a hand-held vacuum cleaner, designed to be carried by a user. Although this form-factor is mobile it still represents a significant size and weight compared to clothing items. Two possible avenues of improvement: micro vacuum pumps, and hydraulic cylinders to displace air for jamming activation. Hydraulic cylinders would have the additional benefit of maintaining pressure without requiring constant power. The noise generated by the vacuum pump when in operation is a small limitation of the prototype. The hydraulic cylinder approach we envision would allow maintaining a lower pressure within the bladder to be silent. An important factor is the tensile strength that can be created using jamming. Higher tensile strengths create a more rigid volume, which 'locks' the users hand in place. The tensile strength of the jamming system is related to the surface area of the layers [11]. For small jamming areas, such as individual digits for jamming gloves, this indicates the maximum stiffness achievable is limited.

CONCLUSION

This paper has explored haptic technologies for wearable systems such as garments and gloves. We employed layer jamming to instrument a mitten that has computer controlled stiffness for clenching gesture support. The prototype mitten has a low profile, with a thickness of 2.1mm. A qualitative evaluation also revealed positive outcomes with all participants indicating there was a detectable haptic sensation that felt realistic.

Further investigation of mitten prototype applications in VEs is necessary. Instrumenting each of the fingers digits would greatly improve the potential haptic effect that is aligned with the virtual environment. With such a glove we envisage it would be possible to emulate more complicated interaction tasks such as typing on a keyboard or playing a musical instrument such as the piano.

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