# Controlling Stiffness with Jamming for Wearable Haptics

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## ABSTRACT
Layer jamming devices enhance wearable technologies by providing haptic feedback through stiffness control. In this paper we present our prototype that demonstrates improved haptic fidelity of a wearable layer jamming device, using computer controlled solenoid to enable fine-grained control of the garments stiffness property. We also explore variable stiffness configurations for virtual UI components. An evaluation was conducted to validate the methodology, demonstrating dynamic stiffness control with a two waveforms.

### Author Keywords
Jamming; haptic; variable stiffness; wearable haptics.

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

## INTRODUCTION
In this paper, we present a wearable layer jamming device developed and constructed to support dynamic control of stiffness to enhance haptic fidelity. We achieve a richer modality than just 'jamming on' and 'jamming off', by employing a solenoid to rapidly activate an air valve, allowing the stiffness parameter to be controlled by regulating the vacuum pressure in the jamming device. Our goal is the advancement of the layer jamming control method to support a new set of haptic interactions by improving the wearable haptic feedback fidelity using variable stiffness. We are able to model a range of dynamic pressure-time waveforms to develop modes of dynamic stiffness, and apply these modes to a common user interface control. Our work is the first example of a wearable, layer jamming technology that uses dynamic stiffness control to support a range of haptic feedback techniques. We present three contributions to the wearable and haptic communities:

1. A proposed set of variable stiffness configurations for wearable devices,
2. An improved implementation of a novel jamming device that is capable of controllable variable stiffnesses, and
3. Empirical measurements that validate our prototypes ability to produce repeatable variable stiffnesses.


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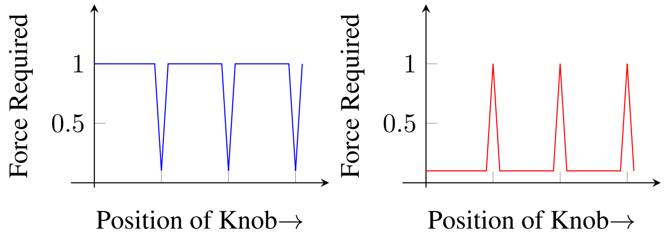
## BACKGROUND
Layer jamming is an emerging technique that offers favourable characteristics within the wearable haptic domain: light weight, a low profile suitable for garment integration, and only requires power when changing state [4]. Several notable layer jamming implementations have been demonstrated. Ou et al. [1] presented dynamic furniture and jamming footwear. Yong-Jae et al. used layer jamming as the basis for a device intended for keyhole surgery [6]. However, layer jamming has not received significant attention as a wearable haptic technology to date. Simon et al. [4] presented a wearable layer jamming mitten that had limited modality: the jamming was either off or on; simulation of a hard object was possible, but first simulating a hard object and then transforming to a sponge is not possible.

## DYNAMIC STIFFNESS FOR WEARABLE UI CONTROLS
We aim to provide haptic feedback for interactions with common virtual user interface (UI) components. Valuators fundamentally underpin many user interfaces [5], making them suitable for our investigation. We consider the motion of pinching between thumb and finger, which replicates that of a slider action where the distance between the thumb and finger indicates the current position of the slider. Wearable systems have previously explored interaction devices that use the action of touching a thumb and finger together for menu selection [3, 2]. Adding variable stiffness mechanisms to such devices could providing a range of haptic feedback configurations, such as requiring the user to apply a constant force to bend their finger, changing the stiffness of the gloves during the sliding action in a gradient fashion, or with rapid momentary changes. The combination of these dynamic stiffness modalities allows for the creation of different virtual UI controls. We examine two modalities: *clicks* and *detents*.

To provide a user with a clicking sensation, the force required to move the slider may be varied in the manner depicted in Figure 1a (the minimum and maximum usable physical forces for a UI control have been mapped from 0 to 1, respectively). Figure 1b depicts a detent — a configuration in which the slider becomes harder to move when it is about to move over predetermined value locations. This may be applied to a slider as a selector from a discrete range of options, such as pre-set radio stations. The haptic feedback requires a conscious, additional action by the user to move the slider. This additional cognitive load can be used, for example, to prevent accidental changes to the current selected radio station.

## IMPLEMENTATION AND PERFORMANCE EVALUATION
We designed and constructed an improved version of the bladder presented by Simon et al. [4]. We improved the




(a) (b)

**Figure 1: Slider force configurations. a) Momentary 'clicks' to alert the user towards discrete values. b) 'Detents' at discrete values.**

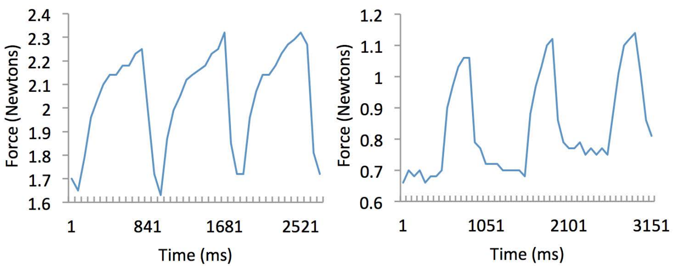



**Figure 2: Experimental results for two haptic configurations.**

design by constructing an new pressure regulation system, comprised of a pneumatic system comprised of a vacuum source connected to a jamming bladder (120 x 210mm) via a solenoid valve, which could be opened and closed under computer control. The wearable haptic device we constructed was evaluated to validate the ability of our improved system to create variable stiffness haptic feedback configurations. We explored waveforms encompassing two types of momentary changes in force: the 'click' and 'detent' configurations.

### Procedure

Evaluations were were conducted by bending the jamming device with the computer controlled apparatus shown in Figure 3 between 'not bent' and 37° (fully bent) over a period of approximately one minute (900 ticks of approximately 70ms). The force required to bend was measured using a digital force gauge, and the force-vs-time graph compared to the intended waveform for the haptic configuration.

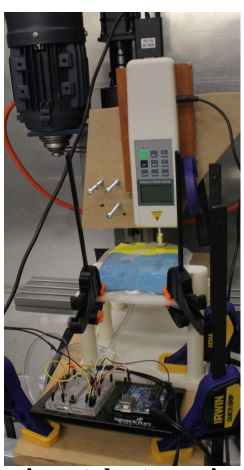


**Figure 3: Experimental setup using our improved wearable bladder attached to a CNC machine.**

### Results and Discussion

We evaluated the haptic response for the 'click' configuration, shown in Figure 2 (left), and for the 'detent' configuration, shown in Figure 2 (right). The results demonstrate that the force required can be manipulated to create the expected haptic response of the input signal. Both graphs depict the approximately expected results. Several sources of noise exist: the gauge must take up any relaxation in the jamming system (between layers, for example), and the test stand itself has some level of flexibility. Another factor is the natural increase in stiffness as the jamming device bends, reflecting the material properties of the layers and bladder material.

## CONCLUSION

Three contributions are presented to the wearable and haptic fields. First, a definition of two haptic configurations that can be incorporated into physical and virtual user interface controls. Secondly, an improved controllable wearable jamming device capable of dynamically providing *variable* haptic configurations, and thirdly a validation of the jamming device. Our prototype is the first demonstration of a variable wearable layer jamming device capable of providing dynamic *variable stiffness* feedback sensations to a user.

## REFERENCES


1. Ou, J., Yao, L., Tauber, D., Steimle, J., Niiyama, R., and Ishii, H. jamsheets: Thin interfaces with tunable stiffness enabled by layer jamming. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI)*, ACM (2014), 65–72.
2. Piekarski, W., Smith, R., Wigley, G., Thomas, B., and Kearney, D. Mobile hand tracking using fpgas for low powered augmented reality. In *Proceedings of the 2004 International Symposium on Wearable Computers* (2004), 190–191.
3. Piekarski, W., and Thomas, B. Tinmith-hand: Unified user interface technology for mobile outdoor augmented reality and indoor virtual reality. In *Proceedings of Virtual Reality*, IEEE (2002), 287–288.
4. Simon, T. M., Smith, R. T., and Thomas, B. H. Wearable jamming mitten for virtual environment haptics. In *Proceedings of the 2014 ACM International Symposium on Wearable Computers*, ACM (2014), 67–70.
5. Simon, T. M., Thomas, B. H., Smith, R. T., and Smith, M. T. Adding input controls and sensors to RFID tags to support dynamic tangible user interfaces. *Tangible and Embedded Interaction* (2014), 165–172.
6. Yong-Jae, K., Shanbao, C., Sangbae, K., and Iagnemma, K. Design of a tubular snake-like manipulator with stiffening capability by layer jamming. In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (2012), 4251–4256.