Wrist Compression Feedback by Pneumatic Actuation

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Abstract

Most common forms of haptic feedback use vibration, which immediately captures the user's attention, yet is limited in the range of strengths it can achieve. Vibration feedback over extended periods also tends to be annoying. We present *compression feedback*, a form of haptic feedback that scales from very subtle to very strong and is able to provide sustained stimuli and pressure patterns. The demonstration may serve as an inspiration for further work in this area, applying compression feedback to generate subtle, intimate, as well as intense feedback.

Author Keywords

Pressure feedback, wearable, compressive feedback, blood pressure, pneumatics

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces—*Haptic I/O*.

Introduction

Most haptic feedback today uses vibration—often in the form of a small eccentric mass attached to a motor inside a mobile device. However, vibration feedback captures much of a user's attention and can be disruptive [7], e.g., prohibiting feedback over longer time periods. It is also rather limited in the acceptable stimulus strength. Pressure feedback, on the other hand, enables less attention-demanding feedback [15].

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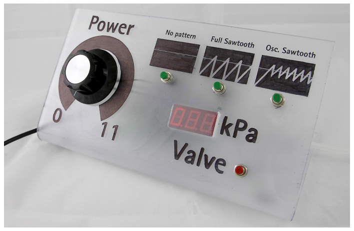

Figure 1: We use a modified blood pressure monitor to generate compression feedback on a user's wrist. Such feedback ranges from very subtle to very intense and is well suited for intimate communication and background feedback. All electronic components are placed in the shown control panel and connect via a silicone tube to the wristband. Users can adjust the pressure level and chose between three different pressure profiles.

We present *compression feedback*, a new form of pressure feedback. Instead of applying point pressure, we inflate a strap around the wrist to generate uniform pressure on users' arms. This pressure can be a sustained sensation, or oscillate around a pressure level for a pulsating sensation. We believe this kind of feedback would integrate well with workout armbands (used, e.g., when running, cycling, or in gyms), smart clothing, or smartwatches/jewelry (requires further miniaturization).

This type of feedback has a number of advantages: (1) It works over a wide range of attention capture—from very subtle to very inhibiting and forceful, demanding instant attention. (2) It provides a pressure continuum—the resolution is finer than discernible pressure differences. (3) It can provide constant background feedback (prolonged vibration would be too disturbing) which can ramp up to slowly bring something to the user's attention (e.g., an approaching bus). This is similar to wake-up lights—a stimulus level slowly increases and is noticed at some point after the detection threshold is crossed. (4) It can feel similar to human attention grabbing behavior—making it potentially useful for intimate communication scenarios. A slight compression on the wrist, e.g., can feel similar to another person grabbing it. (5) In the extreme, it can constrict the arm to an extent that it disables the user from using it (e.g., stopping her from continuing weight lifting exercises). (6) Possible attachment positions (arms, legs, waist, fingers, hands) align well with good locations for wearables (i.e., many people already wear items of clothing there).

Traditional high-frequency vibration feedback is mainly detected by Pacinian corpuscles which have optimal sensitivity at 250 Hz. This receptor, however, is only one of four mechanoreceptors (responding to pressure and vibration) types in the human skin [10]. Meissner corpuscles (sensitive to pressure change at 10–50 Hz), or Merkel and Ruffini cells (responding to sustained pressure and stretching) are not stimulated equally. In contrast, our proposed compressive feedback is able to stimulate these slow-adapting receptors. Pneumatic compression not only provides sustained pressure over a wide range but can also be easily designed to create skin stretch for directional pressure feedback.

Related Work

Our paper ties in with previous work on pneumatics and haptics in HCI. Most commonly, air pressure has been used to inflate small pockets, to move structures or create point pressure.

Pneumatic Actuation

Pumping air into devices has been used to create dynamic buttons [8], actuate tangibles [6, 11, 13], provide haptics for increased alertness [4], simulate virtual buttons [9], or give pressure feedback at surgeons' fingertips [3]. We use a similar principle, but inflate a strap around a user's arm.

Pressure Feedback

Several papers have investigated point pressure actuators (pactors) [1, 2, 14, 15]. Compared to vibration feedback, pactors are less attention-grabbing and are less agitating. Instead of point pressure, *ServoSqueeze* tightens a band around the wrist [1]. In contrast to our system, *ServoSqueeze* is rigid and cuts into the arm instead of applying uniform contraction. A set of balloon actuators around the leg was used for feedback by Fan et al. [5]. However, this was used for discrete point feedback instead of overall compression.

Figure 2: Users only wear the bare wristband from the blood pressure monitor on their arm. All electronic components are moved to an external controller.

Apparatus

We built our prototype around an off-the-shelf *AEG BMG 5610* blood pressure monitor. This wrist-worn medical device comes with an inflatable belt (adjustable from 14–19.5 cm length) and is designed for belt pressures of up to 300 mmHg ($\approx$40 kPa). It also contains an air pump, a safety valve, an air pressure sensor, and a solenoid valve, allowing for controlled in- and deflation of the belt.

For our desired usage as a feedback prototype, we had to modify the device. We removed all parts from the strap and consolidated the control circuitry in an external box (shown in Figure 1). The remaining strap, to be worn by the users, is shown in Figure 2. It is connected to the pump, valves, and sensors via a $\approx$1 m long silicone tube.

Instead of the included pressure sensor, we use a *Freescale MPXV5010 series* sensor, which is designed for the 0–10 kPa range.While this is far from the belt's maximum pressure, this lower pressure range is more appropriate for feedback. The pressure sensor is attached to an *Arduino Nano* which samples pressure values at 100 Hz with the built-in 10 bit ADC for a data resolution of 0.01 kPa.

Users can set desired air flow via a dial which controls the supply voltage to the pump. A valve can be activated to start inflation of the strap, or shut down to allow all air to escape. An additional safety valve triggers, should air pressure ever exceed planned for levels. While this allows users to manually experience a range of pressure levels, they can also activate two additional modes. In those modes, a controller takes over and generates a sawtooth pressure signal, either (1) over the full pressure range, or (2) oscillating around the target pressure. In both cases, pressure will increase up to the set pressure level (the pressure at which the mode was activated). Once the level is reached, some or all air is removed from the strap (depending on the mode) by opening the valve. Afterwards, the valve is closed and the process starts anew.

Conclusion

We have presented the novel form of *compressive feedback*. We think this is but a first step in the exploration of compressive feedback. For example, acceptability of sustained pressure feedback, attention capture quality when distractions are present, or differences of strap placement all require further investigation.

Where we have included three operating modes—holding a pressure level and pulsating—many other ones are possible. For example, with internal valves between adjacent chambers, a sensation of spreading pressure in a wave pattern could be achieved. Composite layers with cut patterns [13], could be used to further distinguish different pressure levels. Straps could stay rigid in some places, adding a displacement force to the feedback.

One challenging aspect for pneumatic feedback is energy use and size. While we use a small pump from a blood pressure monitor, it would still be too large for, e.g., a watch. Micropumps, such as the *mp6*[1] from *Bartels*, could be used for this device class. The power required for pump operation could in future devices, e.g., be collected from user motion. When a reservoir is added to the system this can relieve the pump, which now does not need to deliver peak flow levels. Energy could also be recaptured from airflow when releasing pressure.

Finally, the strap is not just a means for output. The same pressure sensors used to control pump operation can

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[1] http://www.bartels-mikrotechnik.de/content/view/9/15/lang,english/

Figure 3: Internals of blood pressure monitor before disassembly.

also detect external forces on the strap (similar to [12]). When a user presses on the strap or flexes the muscles under the strap, this causes a short peak in pressure level which is easily detectable. Pressing into the strap could also be used as a query gesture: press resistance directly relates to internal pressure level. When a user's press on the strap is detected, the strap can deflate to acknowledge the interaction.

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