Using Audio Recordings to Characterise a Soft Haptic Joystick

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Abstract. The principle of particle jamming, a physical effect where fluids can be made to change their hardness at will, has many applications in engineering. Previous research has investigated combining this change of hardness with other haptic effects, resulting in a technology that can render vibration, hardness/softness and shape. This paper proceeds to describe the application of this technology to a soft haptic joystick handle for use in interactive games and telerobotics scenarios. Dynamically generated sound waveforms are used to drive vibrations inside the handle, and a microphone records these as they reach the tip of the handle under different jamming conditions. Audio frequency analysis is then used to analyse the behaviour of the resulting vibrations.
This analysis shows that vibration is lowest under a strong vacuum, confirming previous observations that increasing the hardness of the particle fluid has the effect of restricting the displacement of the source vibrations. Moreover, frequency of vibration remained broadly stable in both hard and soft states again confirming previous observations. These results, obtained with a fundamentally different haptic device and sound-based instrumentation, necessitate the conclusion that the behaviour of particle jamming controlled vibration is repeatable and controllable regardless of the physical configuration in which it is used.

Keywords: soft haptics · particle jamming · vibration.

1 Introduction

Particle jamming refers to the principle of using controlled air pressure to affect the viscosity of a granular fluid inside a soft, sealed container [2]. This can be used to create shape-changing [6], shape-memory [8] and hardness changing [7] haptic interfaces.

These previously complex haptic sensations have applications in a variety of fields. In virtual reality, soft hatic devices can be worn to provide haptic feedback naturally to different parts of the body [11, 9, 1]. In telerobotics, particle jamming can be integrated into interactive devices [3] where changes of hardness have been shown to be useful to relay environmental information to users of remote robots [10].

Previous work has added rendering of vibrotactile sensations to a haptic surface based on particle jamming [5, 4]. This design is now extended and expanded with the intention of creating a haptic system that can be retrofitted to a computer joystick or other interactive devices to render a wide variety of haptic sensations whilst controlling a remote mobile robot.

In what follows, particle jamming technology is employed to create a joystick handle which offers three distinct modes of haptic sensation - vibration, hardness/softness change and shape change. The behaviour of this device is then characterised using an electret microphone to determine how hardness and vibration interact in order to inform the design of haptic feedback delivered through the handle.

2 Soft Haptic Joystick based on Particle Jamming

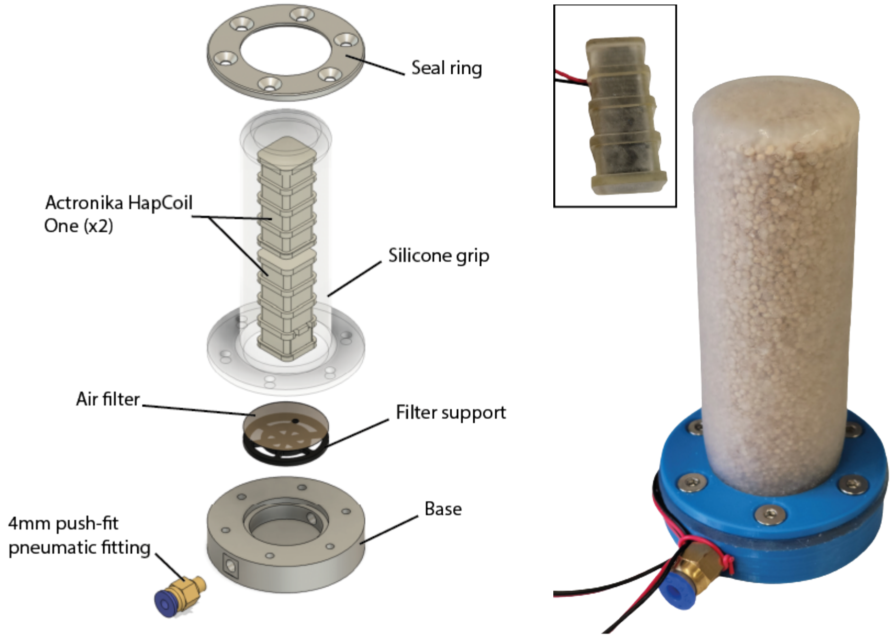
An obvious target for integrating the particle jamming system is a computer joystick. This is already a ubiquitous interface in many HCI and HRI contexts such as computer gaming and robot teleoperation, which will accelerate the process of evaluating the benefits of multimodal haptic feedback in a variety of application domains. A prototype multimodal haptic joystick handle was therefore created to demonstrate and allow experimental evaluation of these applications (Fig. 1b). The simple handle shape associated with a joystick also allows the prototype device to serve as a template for integrating the underlying technology into other devices, thus speeding up prototyping.

2.1 Functional design

The hardness or softness of the handle are controlled by the particle jamming effect. Here, negative air pressure can be used to deform the silicone handle causing the particle fluid to jam. The lower the pressure, the stronger this effect and the harder the handle is to the touch. As the handle contains two solid LRAs, there is a limit to the softness that can be achieved. Unlike in some soft-haptic devices however, this is actually beneficial as it preserves the device's straight, handle shape which is important when the joystick is used as an input device and has to be pushed in a specific direction.

Vibrotactile sensations are generated by a pair of Actronika HapCoil One Linear Resonant Actuators (LRAs), controlled by an Actronika HSD mk.1 high current sound card. Previous research has shown that the vibrotactile effect can be modulated by the particle jamming system as well as by direct signal control of the actuators [5].

Finally, air pressure above atmospheric levels can be used to inflate the device, causing the handle to change shape. In the user's hand, this will cause the device to exert a force on the inside of the palm. The handle geometry is designed to increase in diameter more readily than length during inflation, as this is more likely to be felt during conventional, one-handed operation. Alternative geometries could promote expansion in other directions, such as in length but not diameter to lift the thumb if it were to be left resting on the top of the handle, or to inflate the whole of the handle uniformly. These effects can be achieved by thickening the silicone in different areas of the handle wall.



(a) (b)

Fig. 1: (a) Exploded CAD model showing the construction of the multimodal haptic joystick. (b) Figure: The prototype joystick. Insert: The Actronika HapCoil One LRA with ribbed enclosure.

2.2 Physical design

The joystick consists of a 3D printed silicone handle (Formlabs Elastic resin, 50A shore durometer) which is clamped to a 3D printed plastic base. The base provides access for pneumatic hoses via a 4mm push-fit connector and electrical cables as well as allowing the joystick handle to be mounted to other devices, such as a flight stick base or force feedback interface. The silicone handle measures 100mm in length, 35mm in diameter and has a wall thickness of 1mm which is sufficiently thick to mask the texture of the particle fluid whilst still being thin enough to deform and exert pressure to jam the particles under vacuum. The top wall of the grip is much thicker (3mm) in order to maintain the overall cylindrical shape of the handle under changing air pressure.

The handle is filled with the particle fluid for jamming (quinoa seeds of approx 1mm dia) and the two LRAs. The LRAs are themselves encapsulated within ribbed sleeves (Fig. 1b insert) which serve to both prevent seeds from entering the actuators and agitate the particles during vibration (Fig. 1a). A cotton filter, reinforced with a plastic frame, keeps the particle fluid contained within the handle and provides a pass-through for four wires which control the two LRAs. The complete assembly (not including the particle fluid) is shown in Fig. 1a.

There are four threaded holes on the underside of the base to allow the joystick to be attached to a variety of interactive computer input and force feedback devices.

2.3 Operation

The joystick handle is controlled by a Raspberry Pi 3 Model B+. This dynamically generates audio signals in real time, allowing any sound waveform to be manipulated and played through the LRAs. These audio samples are output to an Actronika HSD mk.1 20-channel, high current sound card to control vibration. Air pressure is controlled via two MCP4725 DAC modules which are then amplified by op-amp circuits to achieve a range from 0-10VDC and sent as input to pneumatic regulators. Negative pressure is controlled by an SMC Pneumatics ITV0090-3BS regulator, whilst positive pressure is controlled by an ITV0050-3BS regulator (not used in this study). Feedback from the pressure sensors is collected by a Texas Instruments ADS1263 10-channel ADC.

3 Experimental characterisation

Whilst the behaviour of the underlying particle jamming technology has previously been explored, it is useful to verify that the behaviour demonstrated in 2020 [5] remains valid in a device with a fundamentally different configuraton. Here, vibration is provided in one direction using a linear resonant actuator, whilst previous characterisation of the technology has used a two dimensional ERM (Eccentric Rotating Mass) motor. Moreover, the particle volume in this device is significantly lower, and the particle fluid is contained within an almost entirely soft enclosure, rather than the predominantly rigid enclosure used in the aforementioned study.

3.1 Experiment design and apparatus

An experiment has been designed to explore the effect of pressure control on vibration propagation up the soft handle. The joystick was placed on a foam pad and a highly sensitive electret condenser microphone (Knowles VEK-H-30108-000) was glued to the top of the joystick handle to measure on-axis vibration (the only axis in which vibrations are expected to be felt). A 1μF capacitor was connected in series with the optput to correct for DC bias. The microphone signal was then recorded at 48KHz on an Apple MacBook Pro. The LRAs were driven with a 15Hz sine wave and the vibration was recorded in both the hard state (-100KPa vacuum) and soft state (atmospheric pressure). In each state, vibrations were also recorded with and without a user's hand gently grasping the joystick. In each trial, the whole surface of the user's palm and fingers gripped the shaft of the joystick firmly, but not so hard as to change the shape of the shaft to conform to the user's fist. This gives rise to 4 experimental conditions:

- S: Soft state
- SG: Soft state, one hand grasping the joystick
- H: Hard state
- HG: Hard state, one hand grasping the joystick

Each condition was recorded for 10 seconds and the outputs checked for anomalies or decay in amplitude, frequency and shape, which were not present in any of the recordings. After recording, a Fourier analysis was conducted on each recording to determine the frequency of vibrations passed up the handle and whether this was affected by the particle jamming. Several cycles of vibration in each condition were also extracted to provide an understanding of the shape of the output vibration.

Additionally, two recordings of ambient noise were made for comparison with the vibration recordings - one with and one without the vacuum pump operating. These additional recordings were analysed in the same way as the conditions described above. The noteworthy results are presented below.

3.2 Ambient noise

Ambient noise was measured with a maximum peak-peak signal amplitude (digital sound level) of ±4e16 (Fig. 2). Powering on the vacuum pump increased this by almost a factor of 5 to a much more uniform level of ±1.9e17 (Fig. 2).

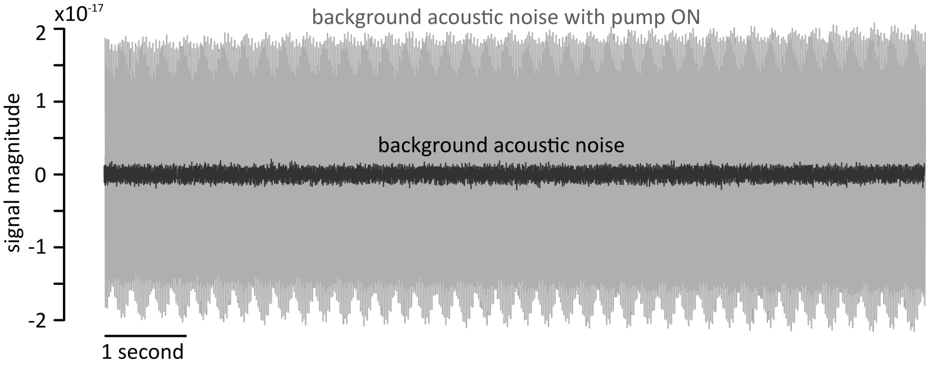
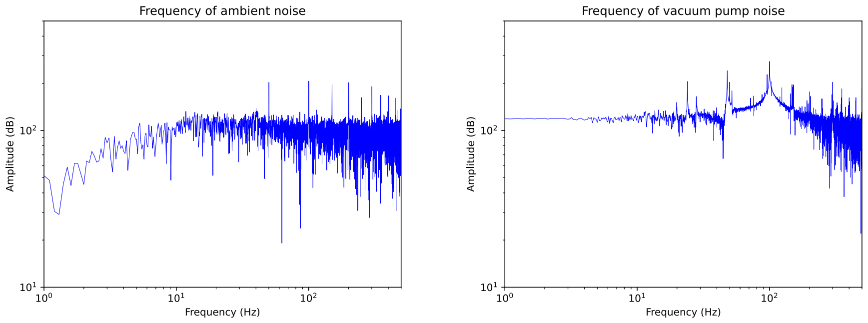


Fig. 2: Ambient noise recorded during the experiment with and without the vacuum pump operating.

Fourier analysis showed that there is no significant periodicity to the ambient noise, meaning that the joystick was sufficiently well isolated from background vibrations during the experiment (Fig. 3a). The vacuum pump introduced a peak of 100Hz (Fig. 3b), which can be disregarded from the results for the hard conditions.



(a) (b)

Fig. 3: (a) Frequency of ambient noise during the experiment. (b) Frequency of vacuum pump noise during the experiment.

3.3 Soft state vibration (conditions S and SG)

The S and SG conditions will be analysed together since it is useful to explore how the hardness state of the particle fluid affects the vibration response both with and without a user grasping the handle.

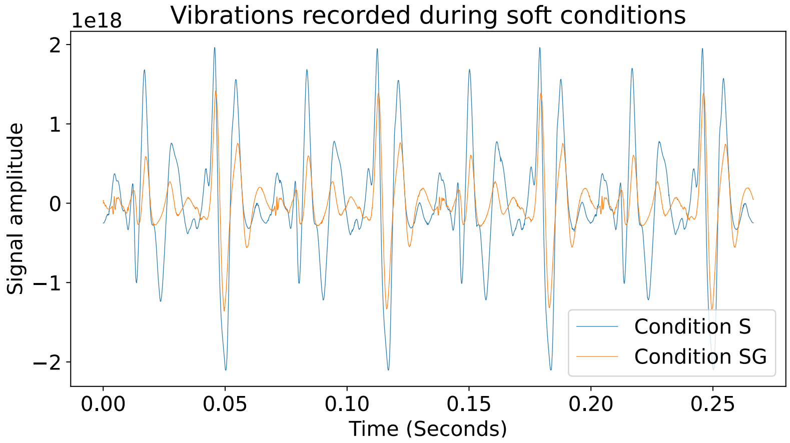


Fig. 4: Several vibration cycles recorded under soft jamming conditions S and SG.

In the S condition, the vibrations were recorded with a peak signal amplitude of approximately 2e18. This is two orders of magnitude above the ambient level shown above. A close-up view of the recorded signal shows a broadly periodic pattern of high and low amplitude oscillations (Fig. 4). The changes in amplitude have a period of approximately 0.07 seconds, corresponding to the 15Hz source vibrations. There is significant distortion to this signal which corresponds to harmonics of the 15Hz input vibration. We hypothesize that the joystick design resonates close to or betwen 75Hz to 90Hz. These frequencies are dominant in all the proceeding frequency spectra. The SG condition differs in magnitude, with a maximum signal amplitude of ±1.5e18.

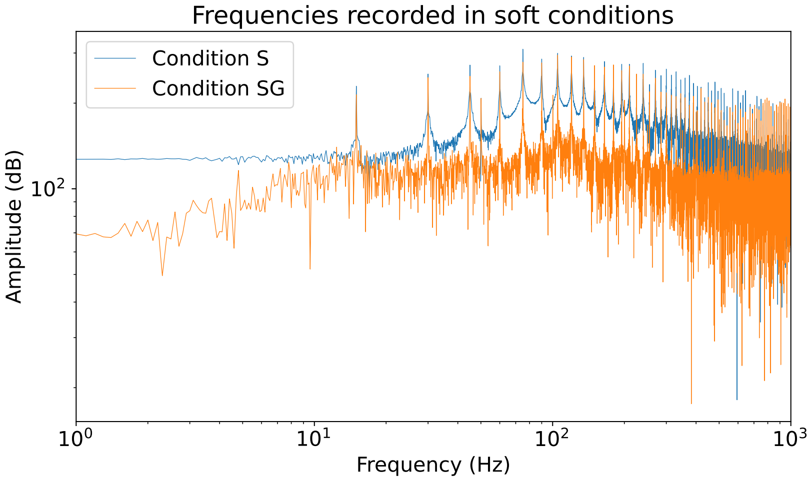


Fig. 5: Frequencies recorded under soft jamming conditions S and SG.

Fourier analysis of the whole of each recording goes further, demonstrating a frequency shift between the two conditions. Condition S records a peak frequency of around 75Hz, whereas the peak component of the SG condition was 105Hz. This is in fact much higher than the 15Hz source vibration, suggesting that transmission through the particle fluid caused very significant distortion of the original vibration pattern (Fig. 5).

3.4 Hard state vibration (conditions H and HG)

In the H condition, vibration was measured with a maximum signal amplitude of ±1.3e18. The signal recorded is a relatively smooth sinusoid with periodically decreasing amplitude. This amplitude decrease shows strong periodicity with frequency 15Hz, which matches the source vibrations. The recording from condition HG has a maximum signal amplitude of 6.5e17, which is approximately half the amplitude of vibrations when not gripped. There is considerable distortion to the signal, as was observed in condition SG. The reduction in signal amplitude has the same overall frequency as in the H condition (Fig. 6).

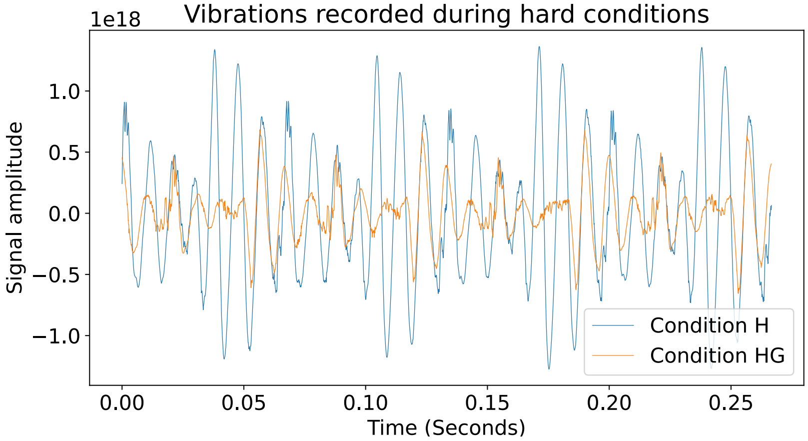


Fig. 6: Several vibration cycles recorded under hard jamming conditions H and HG.

The frequency spectrum shows that both hard conditions H and HG peak at 105Hz, with similar second peaks at 90Hz. The amplitude of components for HG are expectedly much lower than for H (Fig. 7).

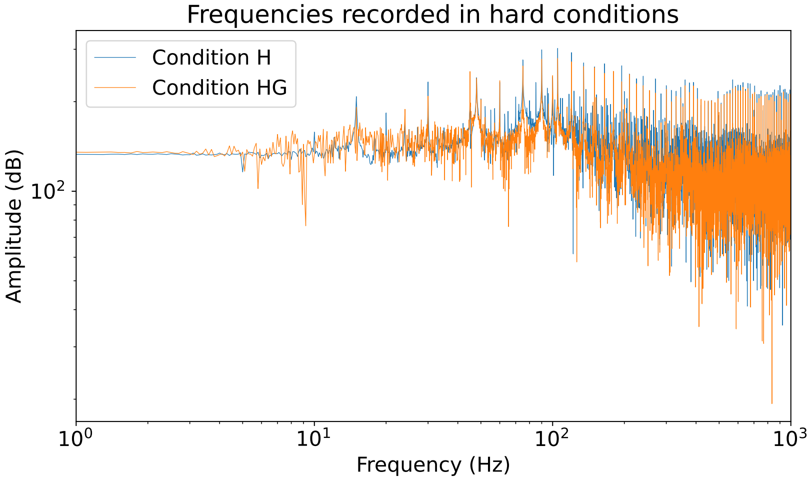


Fig. 7: Frequencies recorded under hard jamming conditions H and HG.

4 Summary, Discussion and Future Work

From these results, a number of conclusions can be drawn. Firstly, vibration amplitude was highest in the soft conditions, indicating that a harder particle fluid limits the displacement of the actuators, damping the vibrations passed to the touch surface. Secondly, it was shown that a hand grasping the handle reduced the vibration amplitude further still, which is an important consideration for interactive devices which must be designed to be touched and manipulated by users. Finally, frequency of vibrations remained broadly in the range of 90-105Hz in all conditions.

These results confirm prior research into the effect of particle jamming on vibration. This is an important outcome, since the configuration of the joystick handle is fundamentally different to the experimental setup that has been used for characterisation in the past. This means that the behaviours described above and in the previous study can be confidently attributed to the underlying technology rather than any feature of the specific implementation.

Future research will investigate the pshcyophysical effects of the different sensations generated by the handle, both alone and in combination. In the immediate term, vibration will be used to try to create a sensation of movement of the user's hand, as this effect has clear applications to telerobotics and VR. Additionally, it is hoped that the change of hardness may serve to strengthen the effect of force feedback against the user's hand or wrist and this interaction will be studied.

The handle will also be incorporated into existing HCI devices such as a computer joystick (Logitech 3D Pro joystick) or force feedback device (Human Robotix HRX-1 wrist interface) in order to enable a broader range of sensory studies, as well as application testing in telerobotics and computer gaming scenarios.

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