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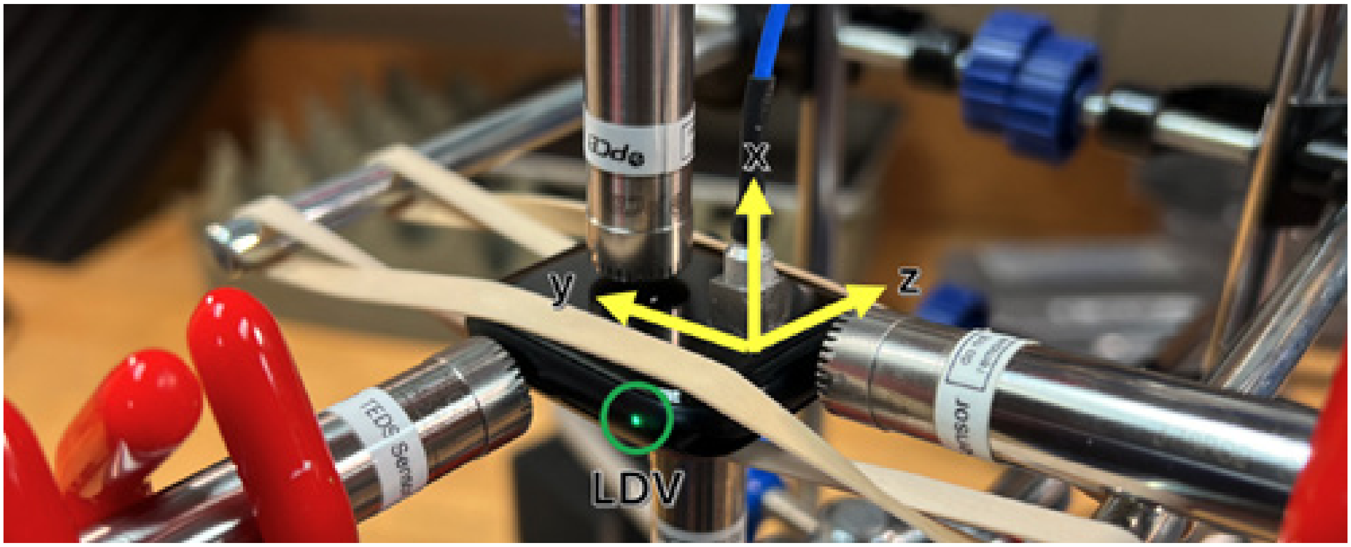

Rethinking Haptic Testing: The Microphone Solution

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Comparing Haptic Testing Techniques

Haptic technology, which you experience when your smartphone vibrates in response to a notification, when a video game controller rumbles during intense action, or when a smartwatch taps your wrist with a gentle reminder, is all about bringing a sense of touch into the digital world. Products typically employ haptics along with audio and visual feedback to create a more immersive and intuitive user experience, adding a new dimension to how we connect with devices and digital content. Parameters like vibration intensity, duration, count, and location drastically affect the final perception of the effect [1, 2]. However, ensuring consistent haptic performance across devices poses a significant challenge for manufacturers, requiring reliable and cost-effective testing methods during production.

Traditionally, testing has relied on either non-contact or contact-based approaches. Laser Doppler Vibrometry (LDV), a non-contact method, offers fast, repeatable data but comes at a high cost for instrumentation and fixturing and is sensitive to environmental factors such as surface reflectivity and roughness. On the other hand, contact-based testing typically uses accelerometers that must be physically attached to the device under test. While accelerometers provide accurate data, the need for custom fixtures and invasive mounting methods, such as glue or mechanical linkages, can complicate the testing process and increase costs.

Microphone-based testing offers an appealing alternative by balancing cost and performance. This method, which measures the particle velocity of the vibrating surface without physical contact, provides reliable results while avoiding the complications of fixture design and environmental sensitivity. As a result, microphones are becoming an attractive solution for testing haptic components, particularly in production environments where efficiency and affordability are key concerns.

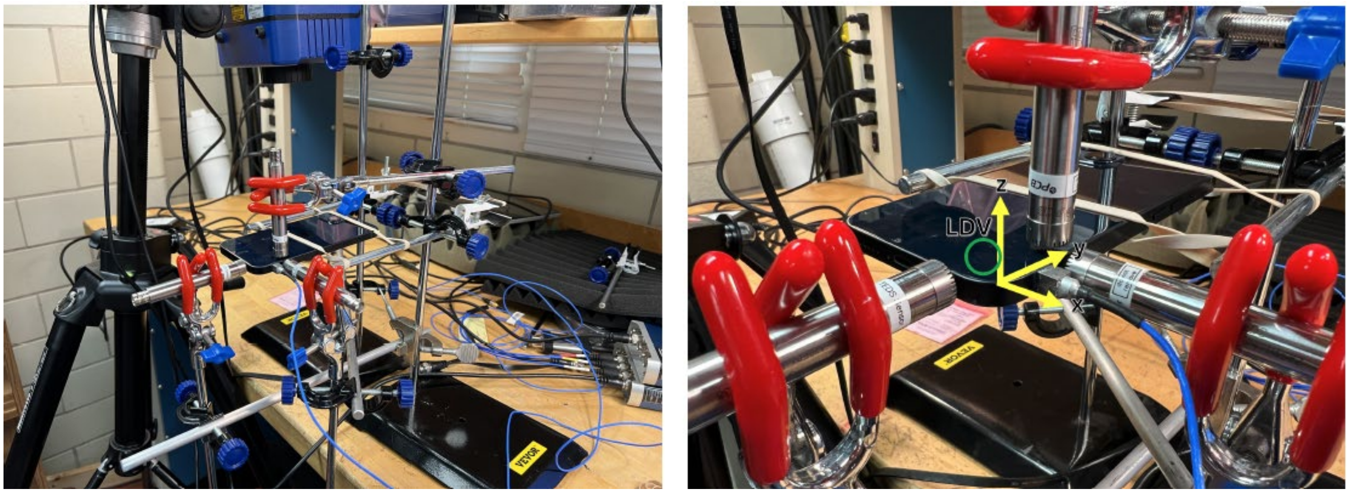
Real-World Testing: Smartphones, Smartwatches, and Fitness Watches

To evaluate haptic feedback across different devices, we conducted a series of experiments using a Crystal Instruments Spider 20HE 4-channel unit, synchronized via a Spider-HUB Ethernet switch connected to a computer running Crystal Instruments Digital Signal Analyzer software [3]. The microphones used were PCB Piezotronics model 378B02, while a PCB Piezotronics model 356A03 triaxial accelerometer was employed for measuring acceleration. The Laser Doppler Vibrometer (LDV) in use was an Optomet Nova single-point system. All collected data were processed with a 4th-order IIR filter, set between 50 Hz and 300 Hz, to focus on the expected haptic motion and to eliminate unwanted low-frequency noise from HVAC systems and high-frequency interference.

The tests involved simultaneously measuring haptic events using the LDV, microphones, and accelerometer, with three devices: a smartphone, a smartwatch, and a smart fitness watch. Each device was suspended using rubber bands to ensure a free boundary condition. The haptic motors of these devices were wirelessly triggered, ensuring that no physical contact interfered with the data collection.

Smartphone Testing

For the smartphone test, a triaxial accelerometer was mounted near the edge of the phone, close to the haptic motor, using cyanoacrylate glue to ensure a secure connection and wide bandwidth. Microphones were positioned approximately 1 cm from the phone's surface on three sides, as close as possible to the accelerometer and LDV measurement points, with their diaphragms parallel to the phone's surface.

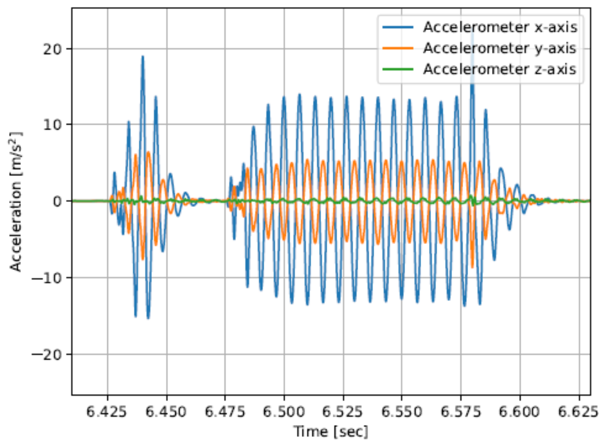


(a) (b)

Figure 1- Test Setup Overview. (a) The blue LDV is positioned at the top with the three microphones shown in an array around the phone. (b) (The accelerometer is mounted to the side of the phone near the haptic motor.

The coordinate system used for sensor placement: x is normal to the mounting axis of the accelerometer, y is normal to the long dimension of the device, and z is normal to the large plane of the device.

To determine the primary direction of the haptic motor's movement, a text message was sent to the phone, and the resulting haptic feedback was recorded by all five sensors. The data showed that the highest amplitude occurred in the y-axis (normal to the long edge of the phone), indicating that the haptic motor primarily moved in this direction. The lower amplitude detected in the other directions further supported this conclusion. Alignment between the LDV and accelerometer data in both phase and magnitude confirmed these results.



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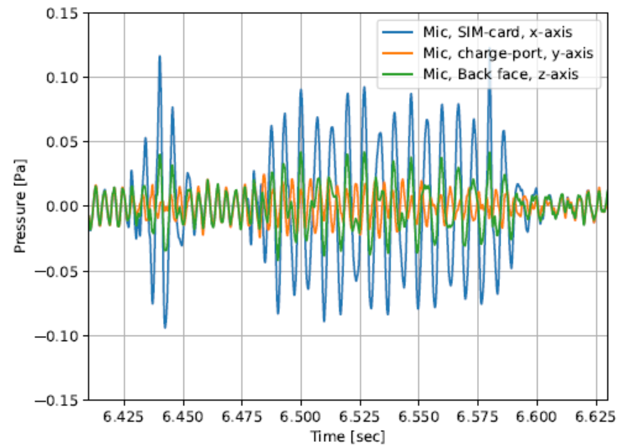

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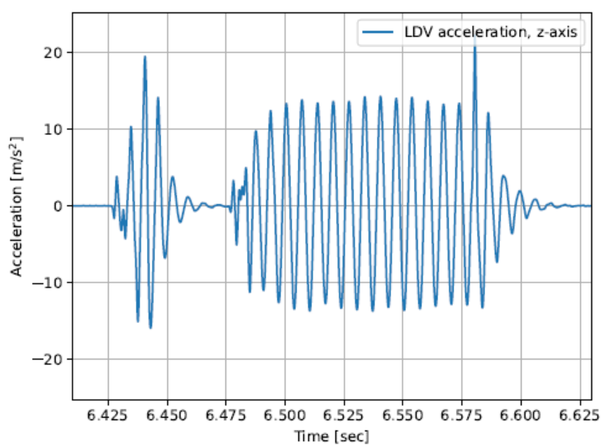
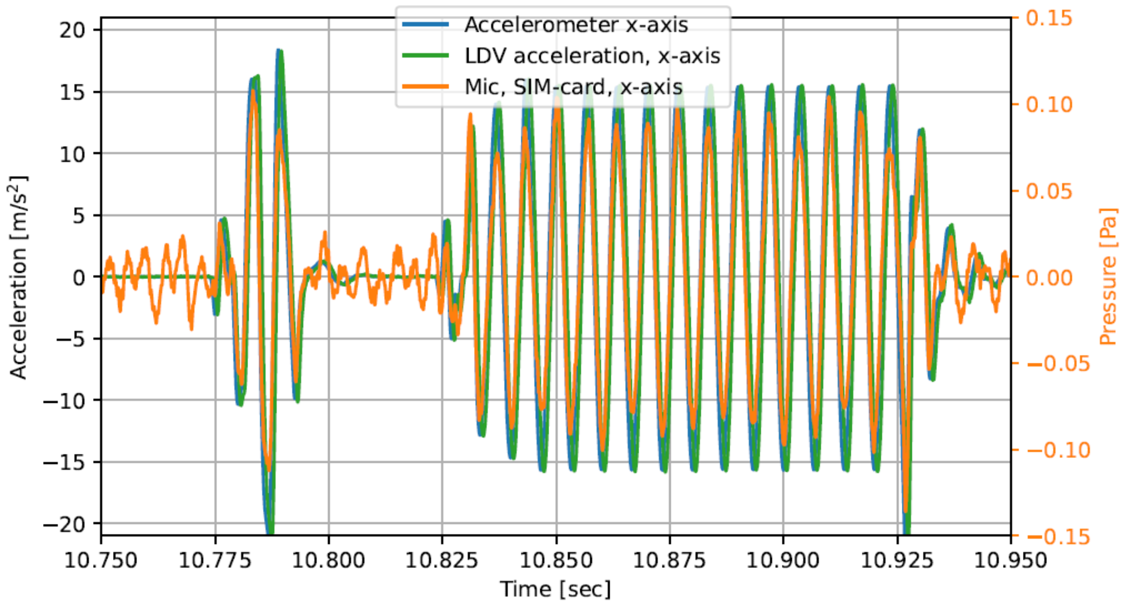


(c)

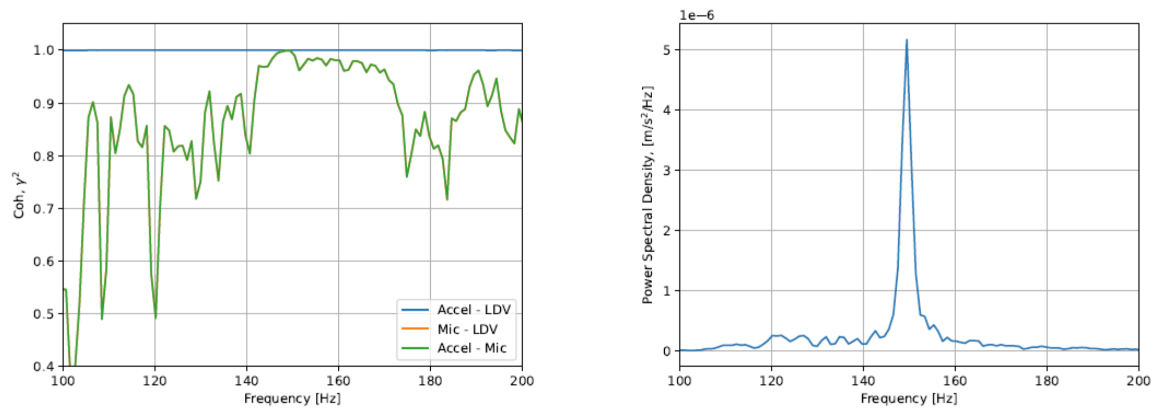
Figure 2- Time series data for the smartphone measurements. (a) Accelerometer time series. (b) Microphone time series. (c) LDV time series (z-axis).

With the direction of the haptic motor's movement identified, the LDV was then positioned to target the side of the phone, as close as possible to the accelerometer. The test was repeated, and the resulting time series are shown in Figures 3 and 4. While there may be slight timing differences (phase offsets) between the signals from each sensor—due to factors like their spacing or sensor phase response—these differences were expected. Ultimately, the results showed strong coherence at the main haptic frequency across all three sensors, confirming that they were accurately capturing the same haptic event.



(a)

Figure 3- Smartphone results. (a) Time series for the LDV, accelerometer, and microphone on the long edge of the phone near the haptic motor.



(b) (c)

Figure 4- (b) Coherence between each sensor pair. (c) Accelerometer averaged power spectrum showing the primary haptic frequency peak.

Smartwatch Testing

A similar testing approach was applied to the smartwatch. The watch was suspended using rubber bands to create a free boundary condition. Four PCB Piezotronics 378B02 microphones were oriented on all unique faces of the watch. Due to the lack of flat surfaces on the sides and back of the watch, the PCB Piezotronics 356A03 triaxial accelerometer was fixed to the watch face with beeswax. The LDV was aimed at the side of the watch.

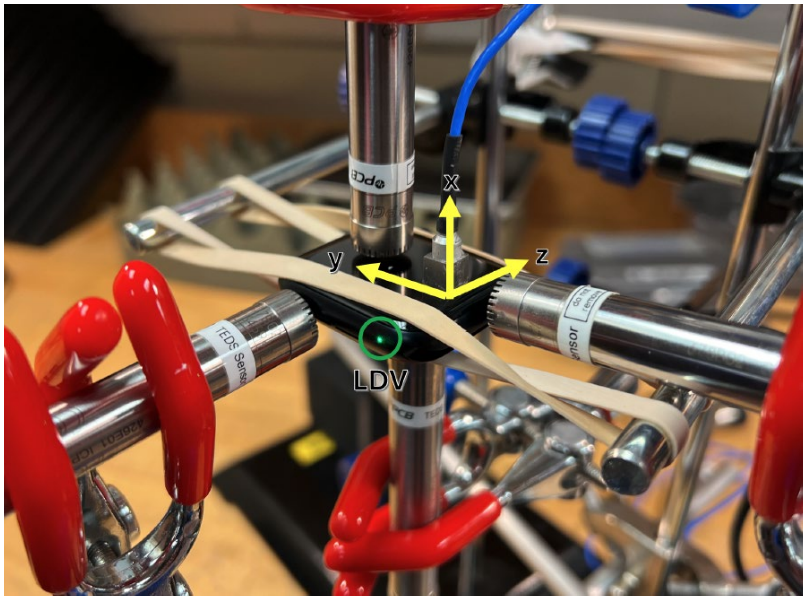
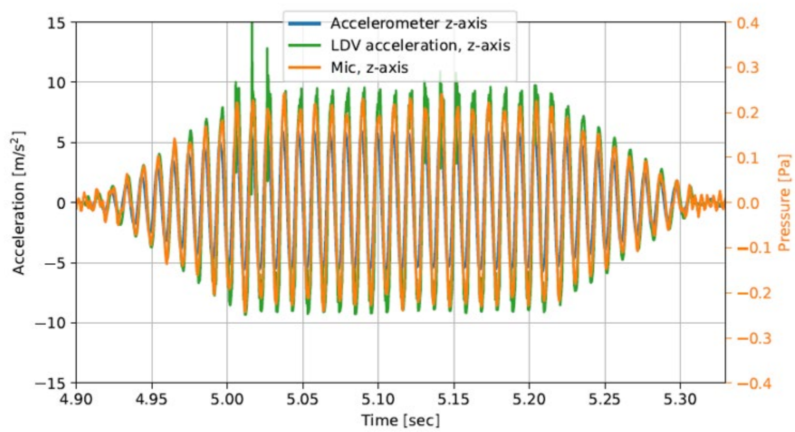


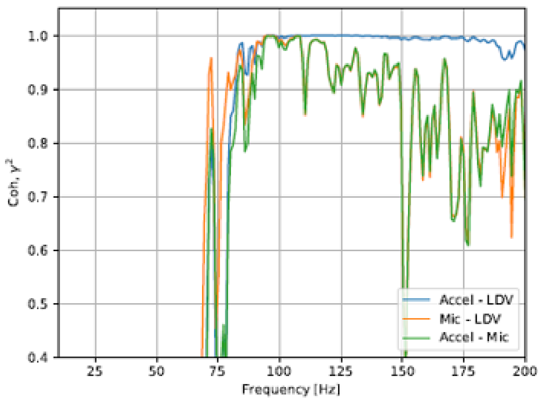
Figure 5- Measurement apparatus for the smartwatch. The green aiming laser is visible on the edge of the watch (circled in green), with the accelerometer mounted on the screen and microphones positioned on all faces.

When the smartwatch received a text message, the haptic feedback was captured by the sensors, revealing a primary vibration frequency of 98 Hz. As with the smartphone, the microphone was able to accurately detect the haptic response, with a coherence of unity at the primary haptic frequency and poor coherence at all other frequencies.



(a)

Figure 6- Smartwatch results. (a) Time series from the LDV, accelerometer, and microphone. Acceleration is shown on the left y-axis, and pressure is on the right x-axis.



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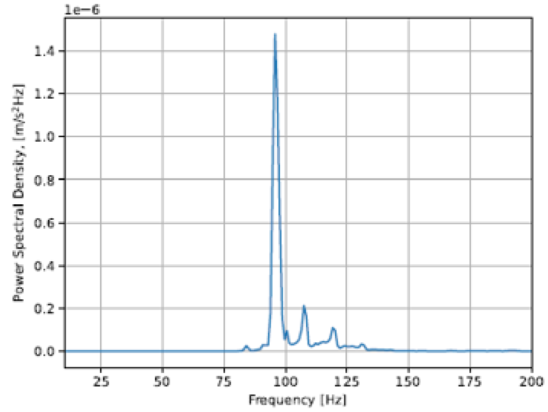


(c)

Figure 7- Smartwatch results. (b) Coherence between each sensor pair. (c) Accelerometer averaged power spectrum showing the primary haptic frequency peak.

Fitness Watch Testing

The same testing setup and methodology was used on a smart fitness watch. The results are illustrated below, with the watch suspended and the instruments set up similarly to the previous tests. (Note that no accelerometer was used due to the lack of suitable mounting locations.) Haptic feedback was recorded after sending text messages to a connected phone.

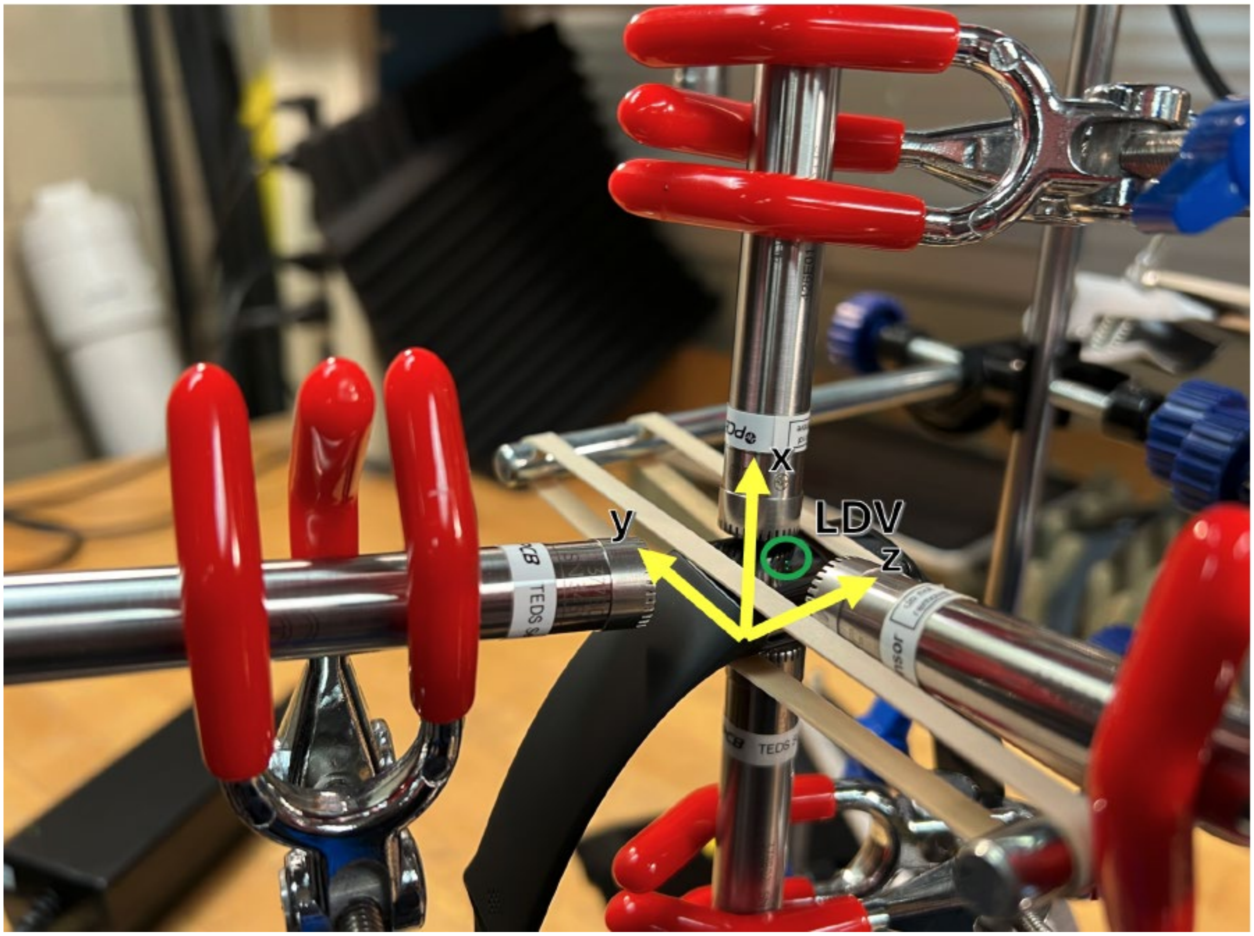
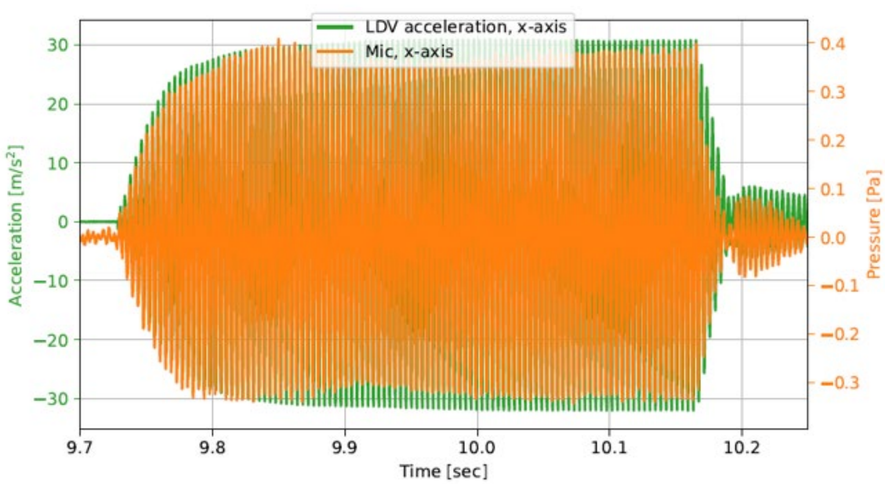
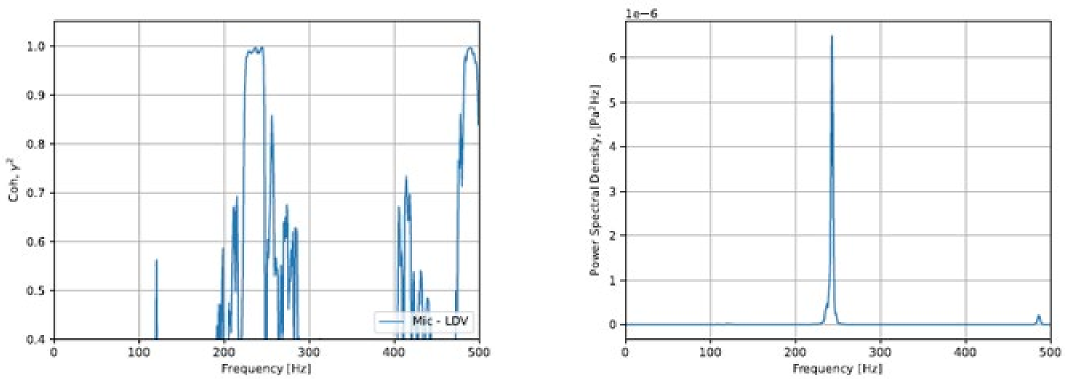


Figure 8- Measurement apparatus for the fitness watch. Of the microphones pictures, only the microphone normal to the watch face was used, with the LDV aimed at a nearby point on the face (circled in green).



(a)

Figure 9- Smart fitness watch results. (a) Time series from the LDV and microphone. Acceleration is shown on the left y-axis, and pressure is on the right x-axis.



(b) (c)

Figure 10- Smart fitness watch results. (b) Coherence between each sensor pair. (c) Averaged microphone power spectrum showing the primary haptic frequency peak.

The tests on the fitness watch were also successful, with excellent coherence between the microphone and LDV at the primary haptic frequency of 240 Hz. The smart fitness watch did differ from the smart watch and smartphone testing as this device had the primary haptic movement normal to the screen.

Critical Insights

Our haptic measurement tests demonstrate exciting potential for non-contact microphone-based haptics testing. This is particularly true for applications where speed, cost, and relatively simple test setups are critical, such as in end of line and production assembly tests. Results show that microphone-based testing can effectively capture haptic feedback across different devices with the same accuracy as traditional methods like LDVs and accelerometers, while offering a cost-savings and non-invasive alternative. With microphones emerging as a promising solution, manufacturers can ensure their smart devices deliver the high-quality haptic feedback that today's consumers expect.

References

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