Perception-Aware Design of Digital Drawing Tools

Supplementary Materials

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This supplemental material provides details on our measurement setups and validation of our simulation. We also include all the measurements performed for the purpose of the paper.

1 ABREVIATIONS

In the following text and figures, we use these abbreviations: 2H pencil (p2h), 8B pencil (p8b), ballpoint pen (pen), Stabilo point 88 fine-liner (fine), Stabilo pen 68 (stab), charcoal (charc), 80 g office paper (office), rough artistic paper (rough), smooth stone paper (stone).

2 VIBRATION MEASUREMENTS

Vibration measurements were executed on our setup in the vibration measurement configuration (Figure 1). In this configuration, we use a shorter arm to reduce the vibrations coming from our setup. The arm has attached weight which exerts 2.2 N of force on the turntable. Additionally an ADXL335 accelerometer is attached onto the drawing tool that provides us with real-time vibration capture at 1000 Hz.

The vibration test aims to capture the velocity dependent spectrogram of response. To this end, we turn the turntable from 0 to 350 mm/s in 1% increments (Figure 3). Each increment is maintained for 1.5 second to gather enough data for Fourier analysis. One experiment trial takes 2.5 minutes. Since our measurements show bands with no frequency shifts to accelerate the data collection for 3D printed tools, we modify the experiment and use 10% increments (Figure 4), which shortens one trial to 15 seconds. Finally, to reduce the impact of measurement noise, we repeat each measurement three times. To get the final results, we average the amplitudes of each signal in frequency domain.

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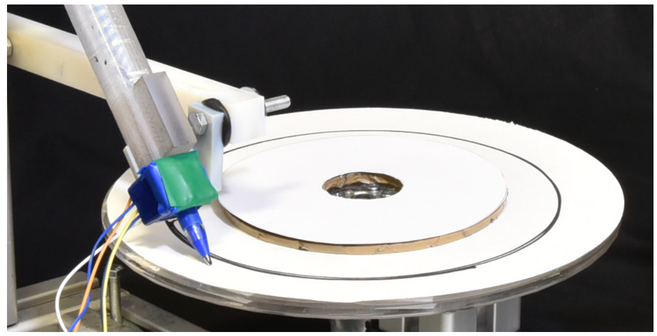

Fig. 1. Acceleration measurement setup. The arm holds a drawing instrument, and the drawing substrate is attached via a magnetic plate. The vibrational response of the drawing tool is captured using an accelerometer.

3 FRICTION MEASUREMENTS

For friction measurements, we reconfigure our setup. Instead of an accelerometer we attach a force sensor OptoForce OMD-10-SE-10N (Figure 2). To increase the sensitivity of the sensor, we attach the drawing tool on a 3D printed lever which provides us ten-fold amplification of frictional force. Similarly to the previous experiment, we attach an additional weight to the so it applies 2.2 N of force on the turntable.

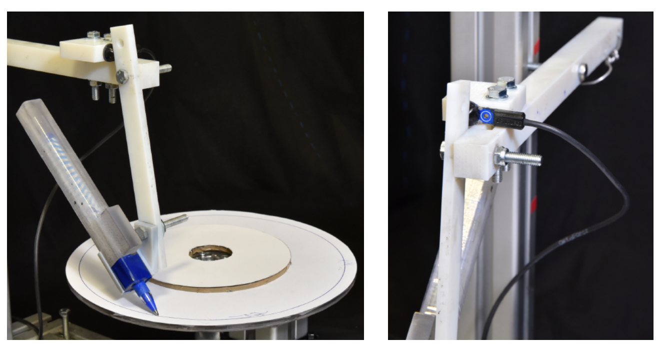

Fig. 2. Friction measurement setup. The arm is enhanced with a lever that amplifies the frictional force excreted on the force sensor.

The turntable is set to move from 17 to 250 mm/s in smooth increments. The frictional force is captured at 1000 Hz during this motion. The recovered measurements are in Figure 6.

4 SIMULATION VALIDATION

We have 3D printed nine different material-shape combinations using the Objet260 printer to train our data-driven forcing term. We used three base materials: VeroClear, DM95, and DM85. The shape variation consisted of dome-shaped tips with varying diameter: 1,2, and 4 mm. Each of these tools was measured on our surfaces: glass, screen protector, office paper, rough paper, and stone paper. Captured vibration is shown in Figure 4, and Figure 5 and friction in Figure 7.

We run a leave-one-out cross-validation of our simulation. We consider our 3D printed designs on our three paper substrates and a fixed velocity giving us a total of 27 optimizations. In each optimization, one sample was left out and then reconstructed using data optimized for other samples. These left out samples are collected in Figure 8.

5 SPECTROGRAM INTERPOLATION

We validated our spectrogram interpolation by 3D printing two surfaces. Each surface was measured at various velocities and then reconstructed using our full data-driven exponential Euler pipeline. We consider two cases. In the first case, we interpolate a mixture of 25% VeroClear and 75% DM85 on office paper with a tip size of 1 mm (Figure 9 top). In the second case, we simulate a mixture of 50% VeroClear and 50% DM85 with a tip size of 4 mm (Figure 9 bottom). Both mixtures were measured on our turntable on an office paper (Figure 9 blue lines) and are compared to our simulator (Figure 9 red lines). We also compare to not interpolated forcing terms (Figure 9 gray lines).

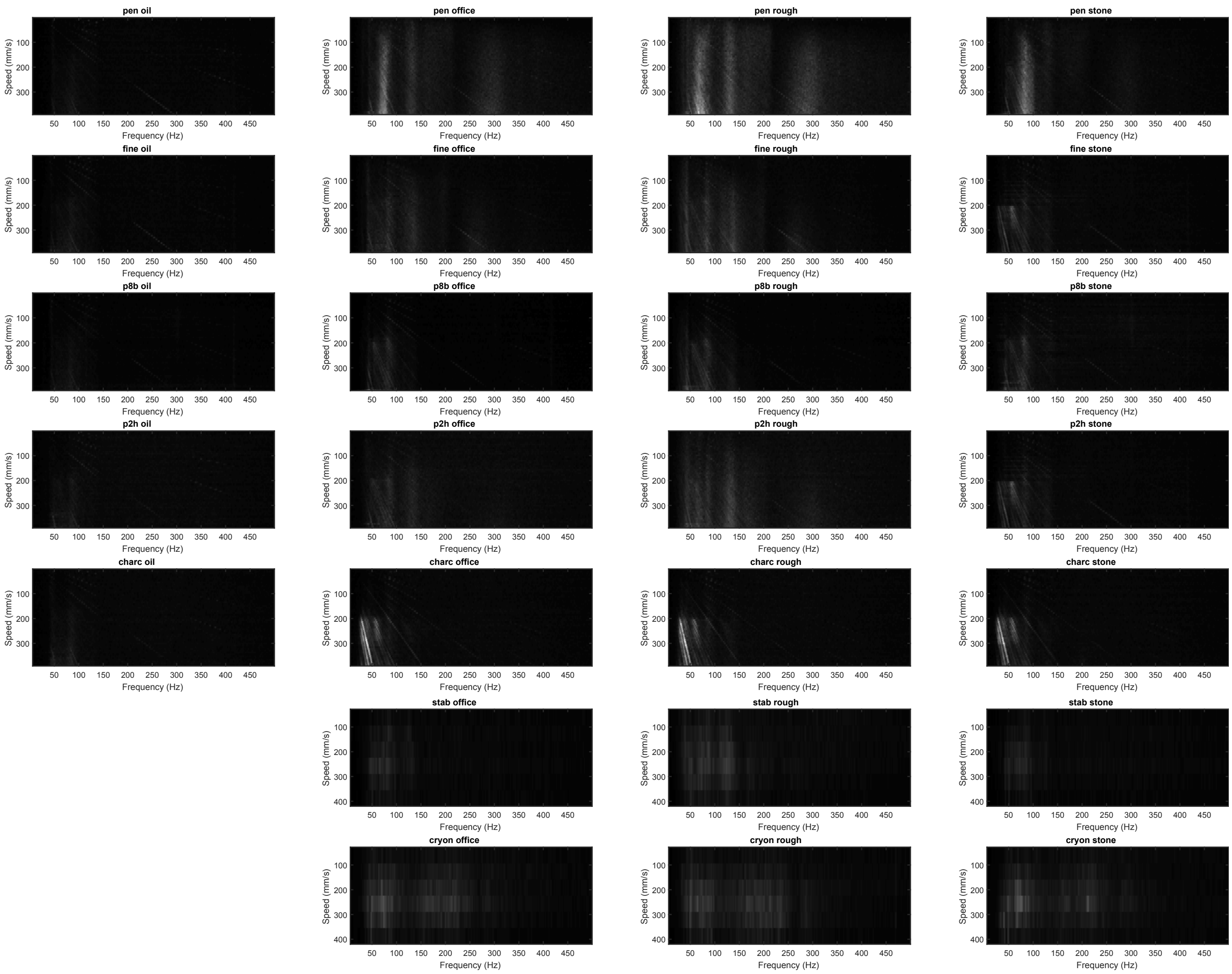

Fig. 3. Vibration spectrograms of real tools recorded using our setup. Each title of the plot consist of name of the tool and the surface. The first column provides measurements of the tools on oiled surface in order to demonstrate the lack of vibrations coming from the measurement setup.

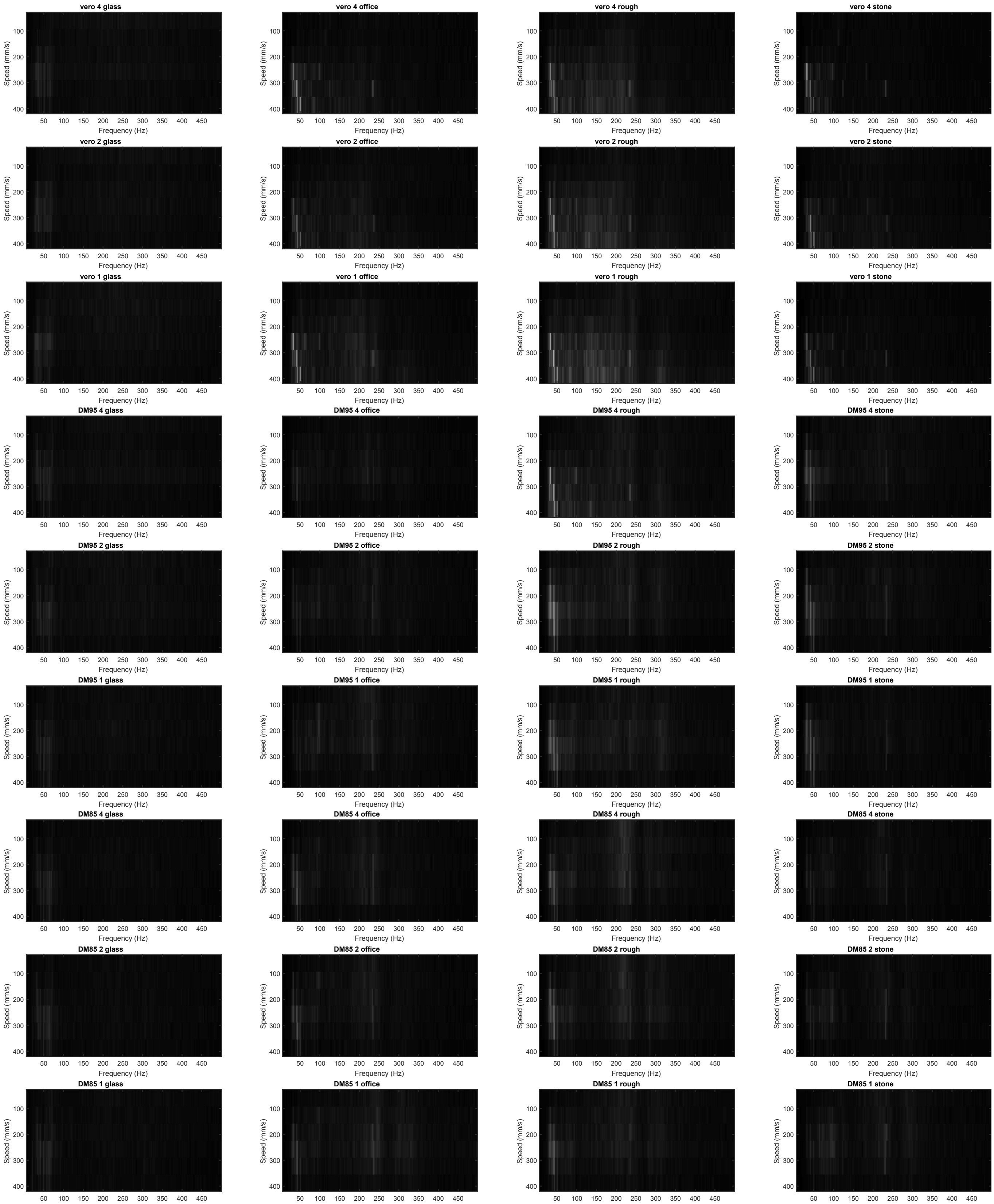

Fig. 4. Vibration spectrograms of 3D printed tools recorded using our setup. The titles of the plots consist of the name of the material, size of the tip, and the name of the surface.

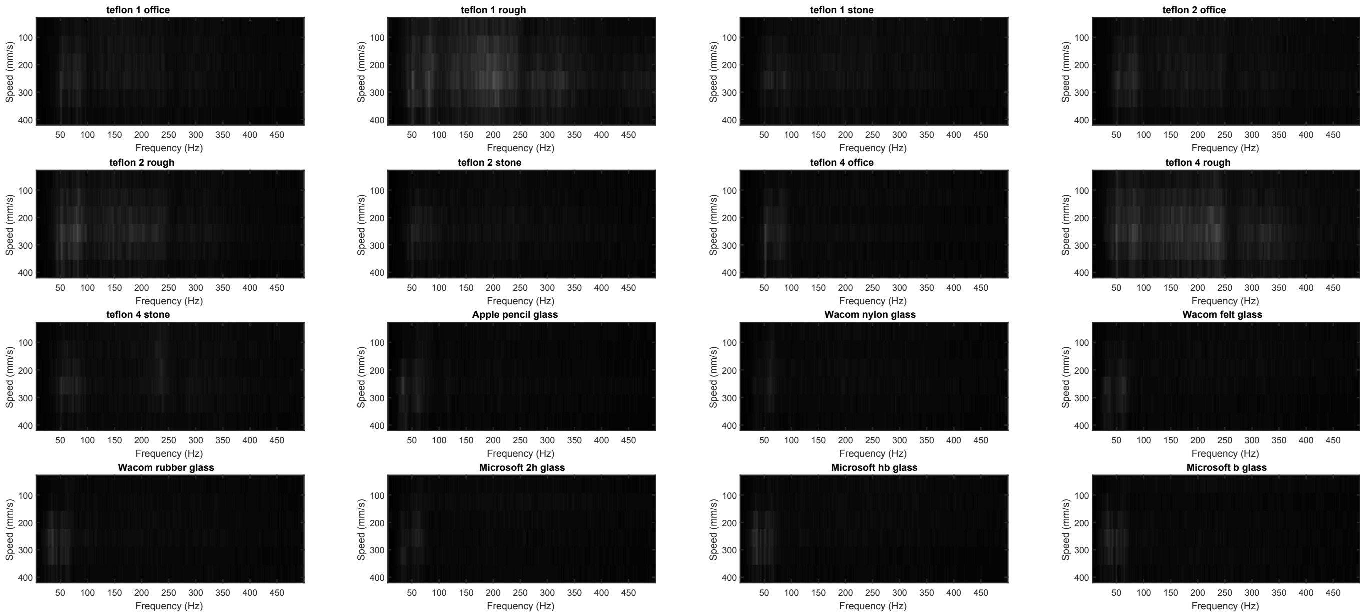

Fig. 5. Vibration spectrograms of 3D printed and commercial tools recorded using our setup. The titles of the plots consist of the name of the material/tool (for commercial products), size/type of the tip, and the name of the surface.

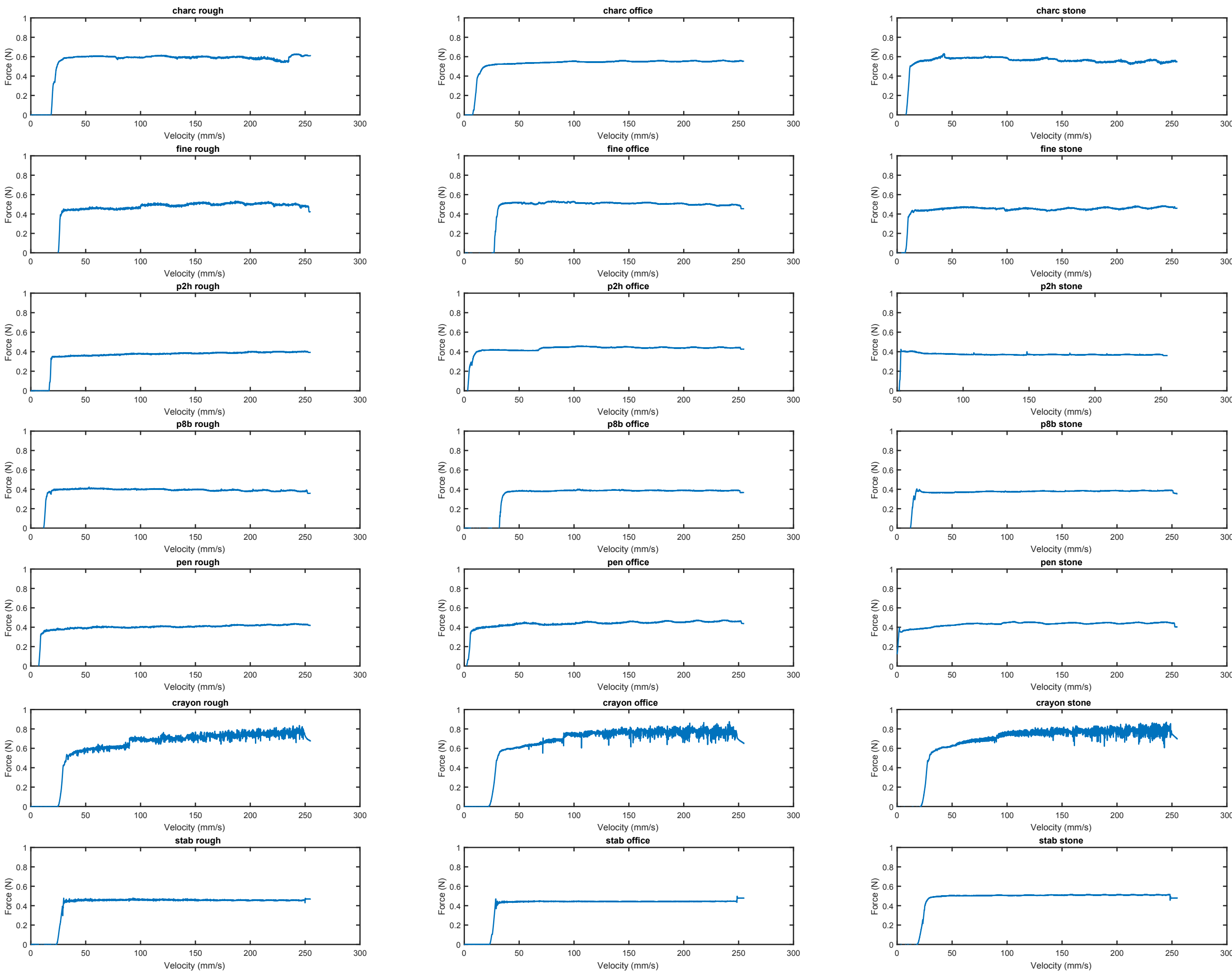

Fig. 6. Friction measurement of drawing tools on various kinds of paper recorded using our setup.

Fig. 7. Friction measurement of 3D printed and commercial styli recorded using our setup.

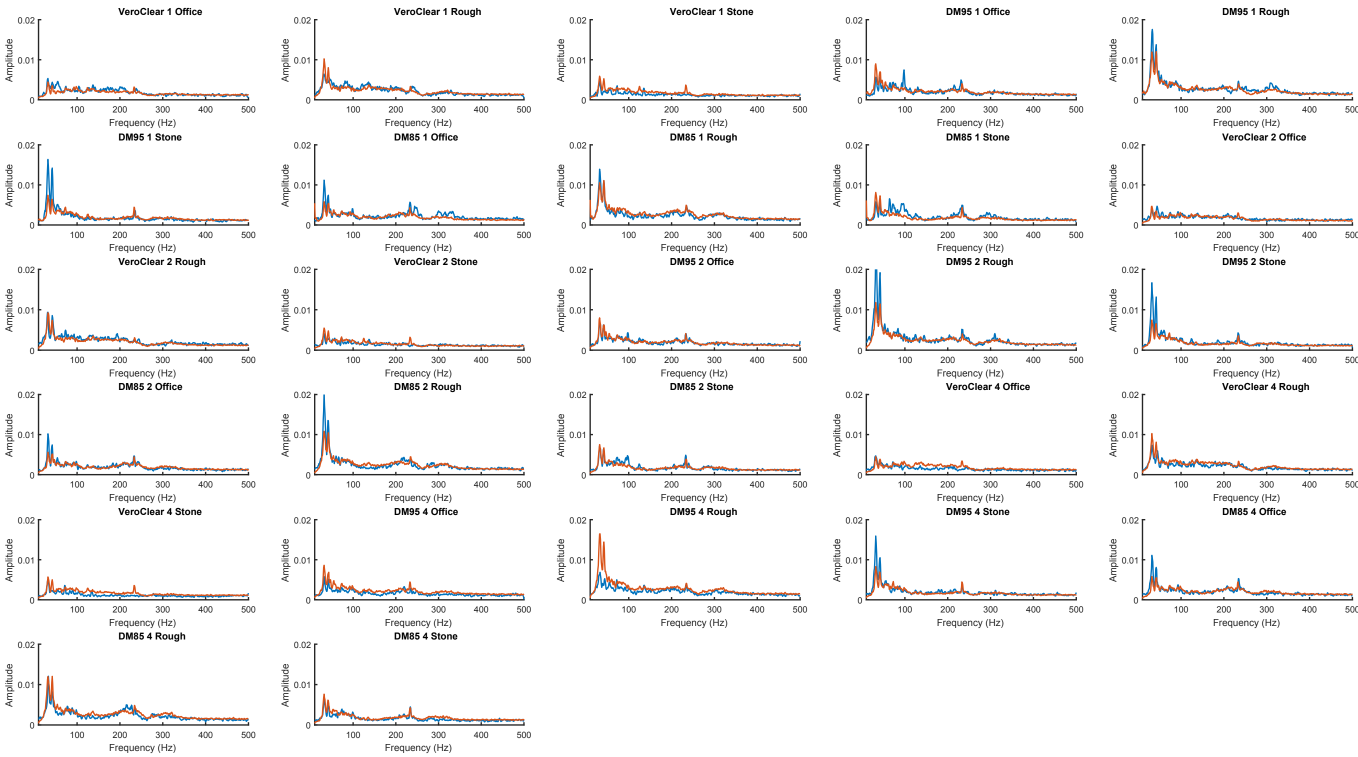

Fig. 8. Full leave-one-out cross-validation of our data-driven forcing term.

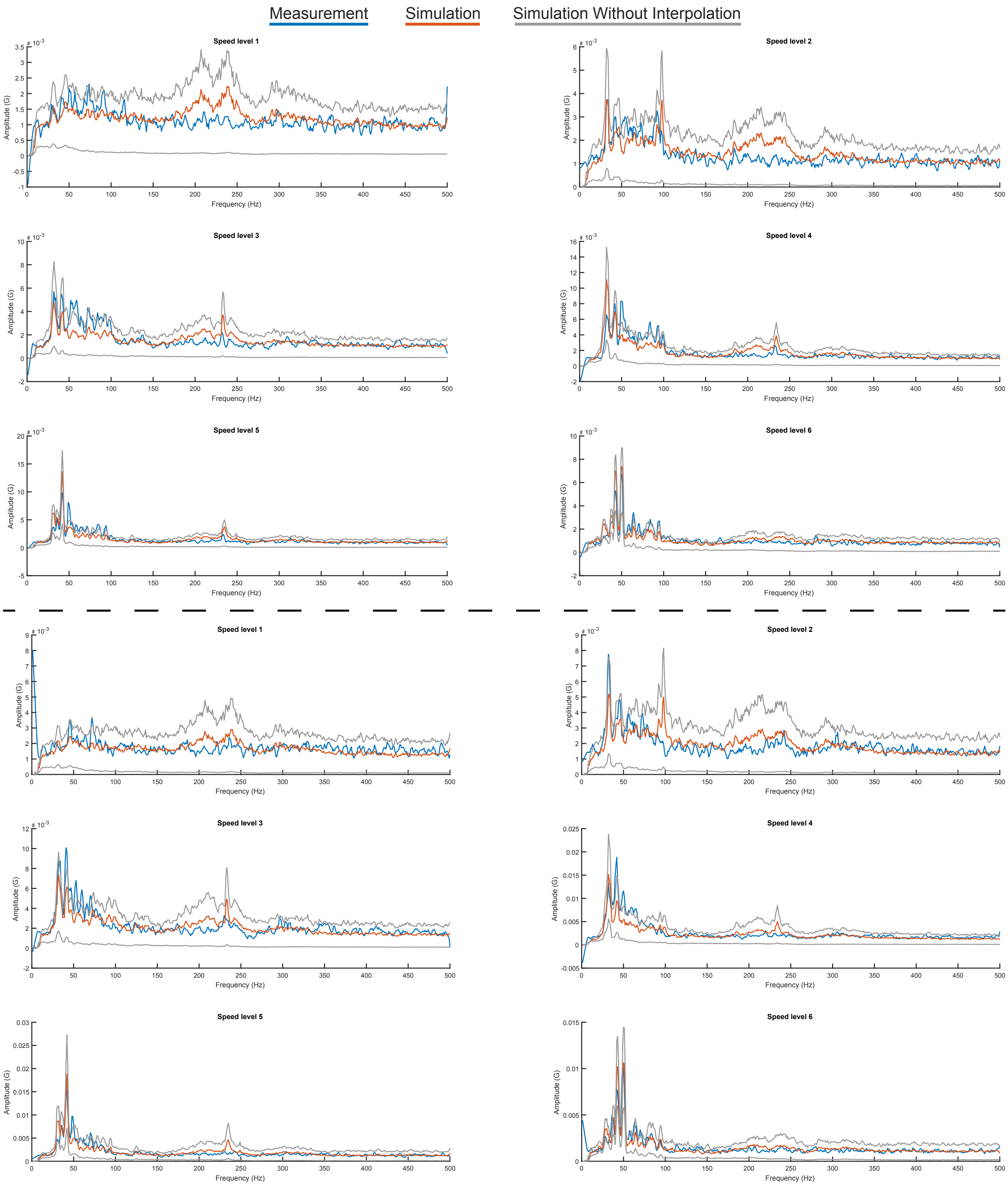

Fig. 9. Interpolated forcing term evaluation. We predicted the vibration response of an interpolated forcing term using our simulator (red line) and compare it to measurements on our turn-table (blue line). We also compare it to the simulations without interpolation of forcing terms (gray lines).