

Demo Report: Dark Velvet Noise

1 Introduction

For the demo we implemented convolution-based reverberation using modulated dark velvet noise as the impulse response.

1.1 Background

An impulse response IR, specifically a room impulse response RIR, between two points in a space is generated by a loudspeaker at one location playing a full frequency signal and recorded by a microphone in a second location. The resulting recorded signal is essentially an acoustic fingerprint of the surrounding physical environment, and it typically contains three components: direct sound, early reflections, and a reverberation tail. These three components carry spatial information about the room, such as size, surface material, and location of sound source and receiver. Thus the generation of RIRs are important for auditory rendering of virtual spaces and adding room effects to dry signals in music production. Most simply, any dry signal convolved with an RIR will synthesize how that signal would sound if played and recorded from the source-receiver position within the RIR room.

RIR generation is a well researched area in acoustics and signal processing. Many methods for IR generation exist, such as the ray-based image source method, finite element wave-based methods, convolution-based FIR filters, modal reverb [1], feedback delay networks FDNs [2][3] and more.

Velvet Noise Reverb

Noise based reverberation is a rich class of abstract algorithms that synthesize a RIR, which can then be used in convolution, as mentioned above. Noise based reverberation methods are generally not physically informed, but are tunable to capture important characteristics of RIRs. Velvet noise [4] based reverberation is the topic of this demo. Original (or white) velvet noise OVN is sparse pseudo-random noise that consists of samples with -1, 0, 1 values [4]. The advantages of OVN is that the sparseness and unity and negative unity values allow for a fast convolution with the OVN; instead of multiplying input samples with the OVN, convolution can be equivalent to simple addition and subtraction by taps at the nonzero samples, "pulses", in the OVN along a delay line [5].

A specific type of velvet noise is dark velvet noise DVN with a low pass spectrum which can be controlled by minimum/maximum pulse width and pulse density parameters [6]. In DVN, the pulses can have sample length greater than 1 which leads to its low pass quality. For this reason, and that pulse width and pulse density parameters can be changed over time, DVN is a great flexible candidate for RIR modelling since physical room reverberation is also a lowpass filter.

1.2 Scope of work

This demo project synthesized RIRs from dark velvet noise to be applied in convolution-based reverberation. We first explore the properties of white velvet noise and dark velvet noise. Then we experiment with time-modulating the parameters of DVN, pulse width and pulse density. We find that parametrically time-modulated DVNs can generate a rich and controllable range of RIRs.

2 Implementation

The following velvet noise algorithms were implemented in MATLAB using equations given in [6].

2.1 White Velvet Noise

OVN is generated by first dividing the time domain into evenly sized bins of length T_d and then replacing a single randomly chosen sample in each bin with a unit impulse with a randomly chosen sign. This results in a sparse ternary sequence of values in $\{-1, 0, 1\}$ as shown in Figure 1a. When plotting the power spectral density (PSD) of the implemented OVN sequence, we get the flat spectrum shown in Figure 1b as expected.

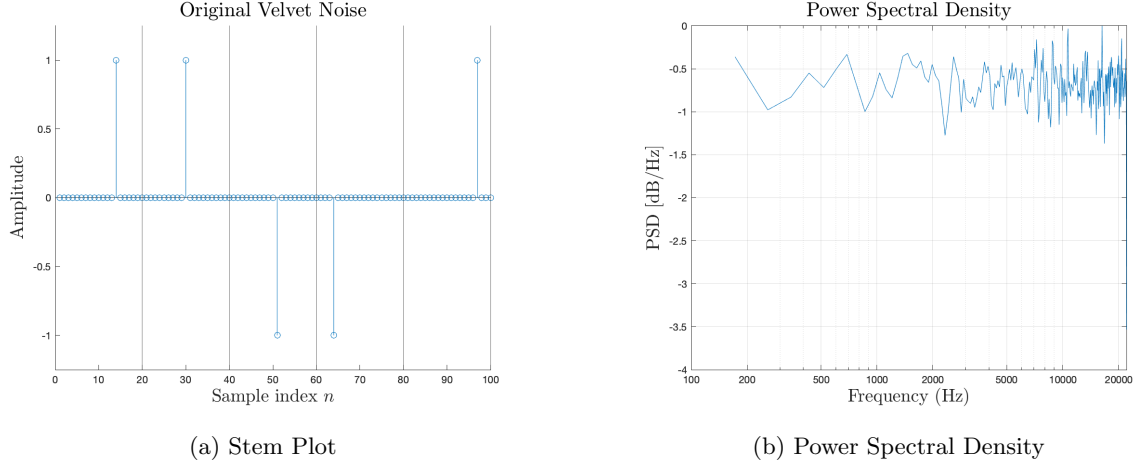


Figure 1: OVN generated with $T_d = 20$

While the OVN produces a smooth noise signal, it cannot be used as is to produce physically accurate reverberation due to its white spectrum. In real life room reverberation, higher frequencies decay at a faster rate than low frequency components.

2.2 Dark Velvet Noise

Dark velvet noise is a variation OVN where unit impulses are replaced with rectangular pulses resulting in a low-pass spectrum. The width of the rectangular pulse in each bin is randomly chosen in the range $[1, T_d w_{\max}]$, where $w_{\max}$ is the maximum width of the rectangular pulse in proportion to the width of the sample bin. From Figure 2 we can see that as $w_{\max}$ is increased, the average width of the pulses increases as well. The corresponding PSDs are plotted in Figure 3. We notice that the low-pass bandwidth of the DVN sequence decreases as $w_{\max}$ is increased, as described in [6].

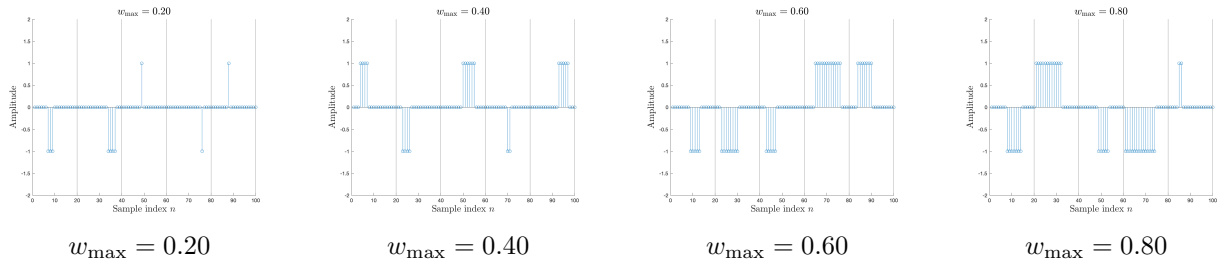


Figure 2: DVN stem plots

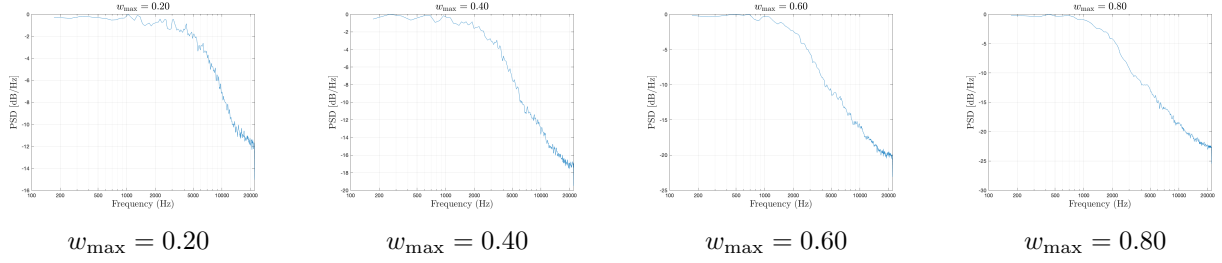
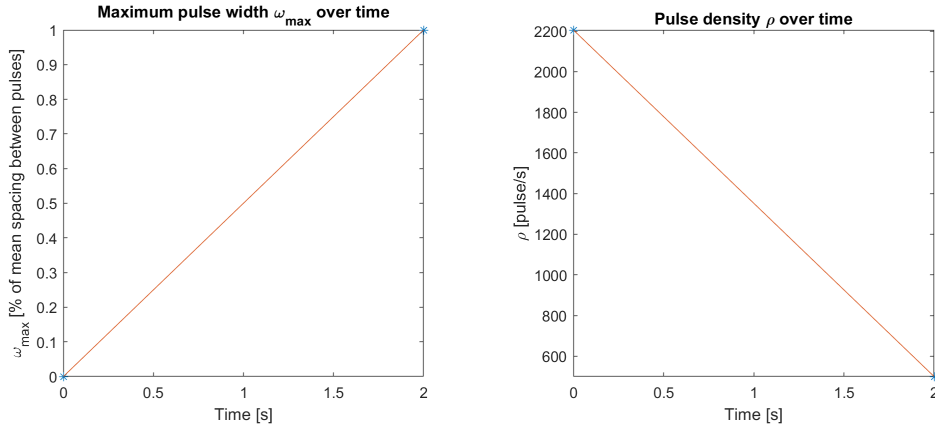


Figure 3: DVN power spectral density plots

2.3 Time Modulated Dark Velvet Noise

As discussed above, the controlling parameters of DVN are maximum pulse width $\omega_{\max}$ and pulse density $\rho = f_s/T_d$, which can be changed over time to modulate a DVN sequence's spectral density to mimic the STFT of measured RIRs. Figure 4(a) shows $\omega_{\max}$ increasing and ρ decreasing from 2200 to 500 pulses/s over two seconds. 4(b) shows the resulting DVN sequence, and (c) shows the energy normalized DVN which is necessary to keep constant energy over the DVN sequence, where an increase in pulse width increases signal energy. Lastly, an exponential decay curve with $RT60 = 2$ s was applied to (c) to generate the final time-modulated DVN sequence for room reverberation purposes.



(a) Example of time-varying functions controlling DVN parameters. On the left: maximum pulse width $\omega_{\max}$ as a proportion of pulse density. On the right: pulse density ρ pulses per second.

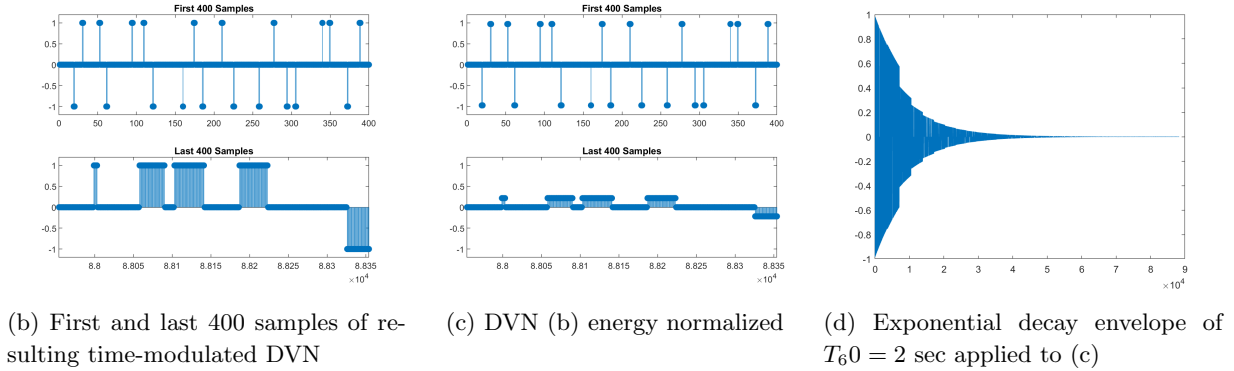


Figure 4: Time-modulated parameters controlling DVN sequence

The STFT 5 of the energy normalized DVN sequence in 4(c) shows typical RIR spectral characteristics, where the early part of the DVN is full spectrum and gradually changes to low pass in the late part.

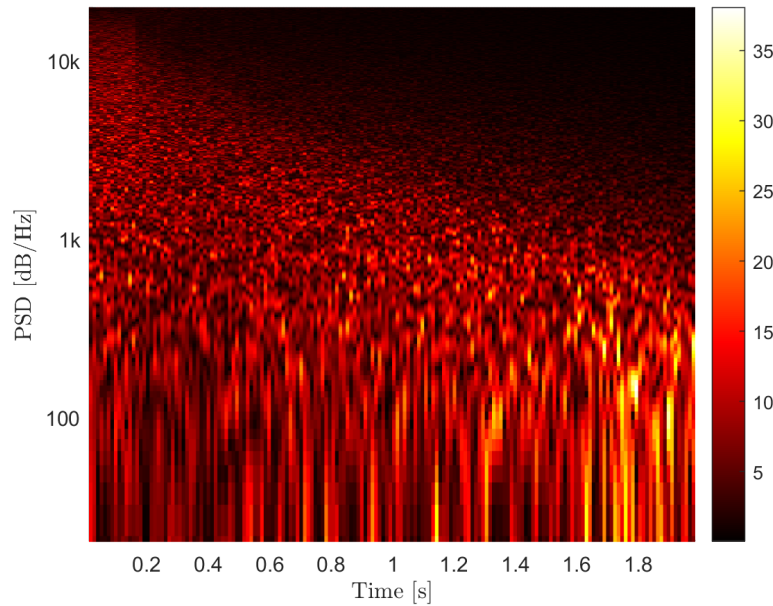


Figure 5: Spectrogram of energy normalized DVN w.r.t. time, before exponential decay envelope has been applied.

3 DVN Experiments and Results

We experimented with changing the shape of the parameter curves to achieve DVN sequences with different spectral characteristics. Figure 6 shows a comparison of the spectrograms of DVN sequences. A comparison between the first (baseline) DVN and the second DVN shows that ω_{max} has a large impact on the spectral quality. This is reasonable – as ω_{max} is small, DVN is the same as OVN and has a white spectrum. Row 4 shows the opposite effect of rapidly increasing ω_{max} , which shows an almost constant lowpass characteristic over the duration of the sequence, matching 3. Row 3 compared to baseline shows that though the spectral envelope is very similar, the granularity in the frequency domain is finer as pulse density is larger. We didn't explore the perceptual differences between the baseline and row 3. Lastly row 5 shows that the spectrograms of the DVNs depend solely on the parameters and can create unnatural results. This shows that the methods explored can be used creatively to create synthetic filters for music production.

We convolved these five different DVN sequences with speech, guitar, music, and gunshot audio samples to add reverberation. The perceptual results were convincing to us, but a rigorous perceptual study is needed to fully understand how well DVN is for reverberation.

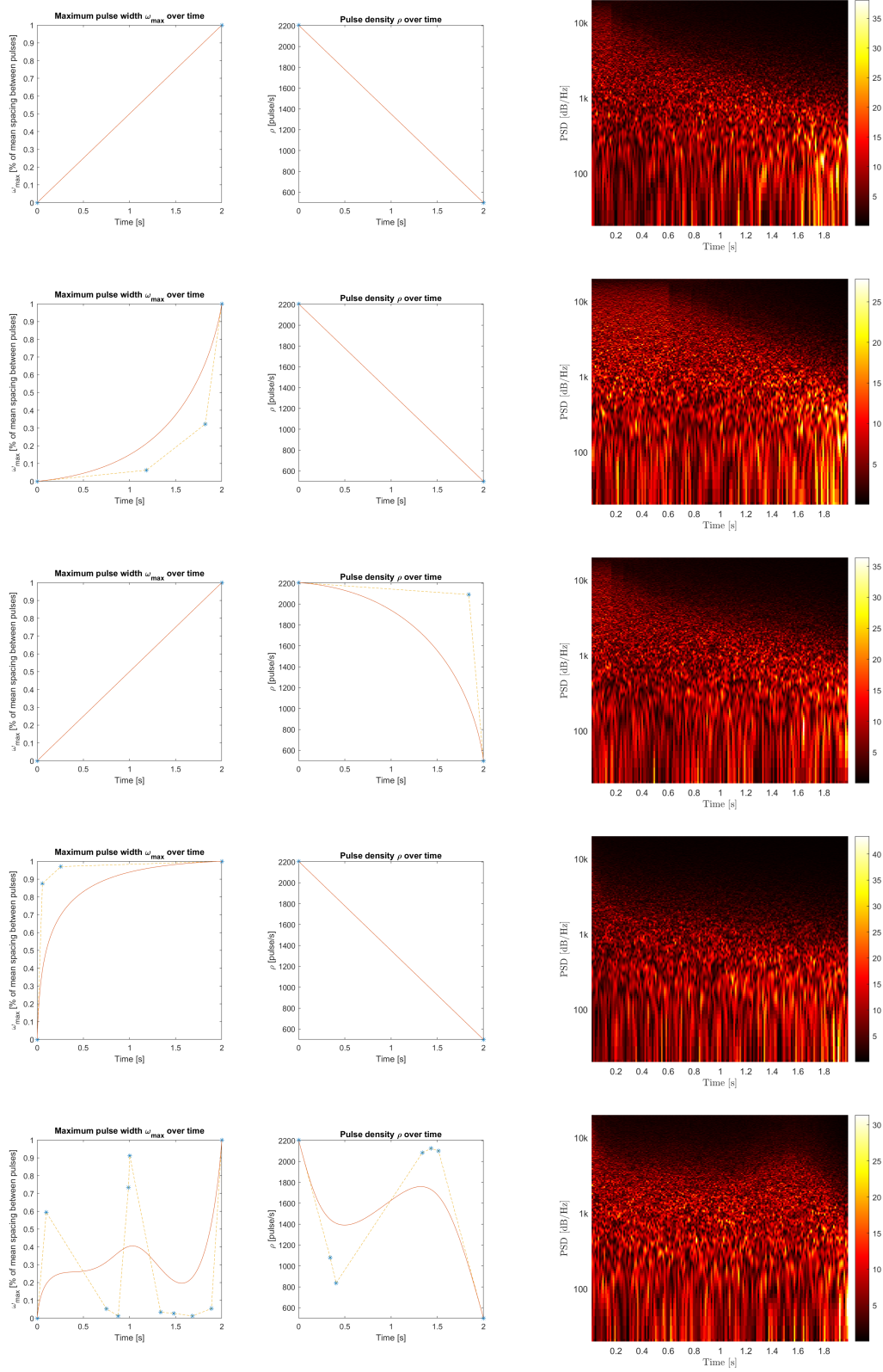


Figure 6: Comparison of five different 2-second DVN sequences. The left hand column are the time-modulated controlling parameters, right is resulting energy normalized DVN spectrogram.

3.1 Individual contributions

Jackie

Implemented MATLAB functions for generating velvet noise sequences. Convolved velvet noise sequences with audio for the demo presentation. Wrote the introduction section, section 2.3 and section 3 and generated the corresponding plots.

- Implemented initial OVN and non-time-modulated DVN
- Generated the parameter plots on as seen in the left column in 6 which took user mouseclick input to set control points of a Bezier curve.
- Translated the user inputted parameters into a time-modulated DVN sequence.
- Convolved time-modulated DVn sequences with audio samples for the presentation.

Verner

Implemented MATLAB functions for generating and visualizing DVN waveforms with different parameters:

- Plotting the power spectral density and spectrogram of a given audio signal.
- Loudness normalization.

These functions were used to produce the plots shown in the demo slides and in this report.

I also implemented a Recursive Running Sum filter to be used in a real-time version of the reverb. Unfortunately we ran out of time before we could finish a full real-time version of the reverb.

4 Conclusion

Modulated DVN is a promising method for synthesizing convincing sounding room reverberation effects and for unreal reverberation for music production.

References

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