could influence the subjective quality of material textures.

Best Compression Method: The three compression methods are compared in terms of compression rates and subjective quality. The method of truncating data beneath the shifted threshold is clearly inferior to the other two quantization methods (Figs. 6 and 7). For the wood texture, the performances of the linear and log quantization methods are almost equal except at the compression level $L = 6$. For $L = 6$, linear quantization is superior to log quantization, since the subjective dissimilarities for linear quantization were smaller than those for log quantization (t-test, $t_0(7) = 6.03$, $p = 5.27\text{E}-4$, two-tailed). For the sandpaper texture, for $L = 10$ (t-test, $t_0(7) = 3.21$, $p = 0.015$, two-tailed) and $L = 8$ (t-test, $t_0(7) = 3.08$, $p = 0.018$, two-tailed), the linear quantization method was better than the log quantization method, and no significant differences were observed at the other compression levels. Overall, considering the above comparison, the best of the three methods is linear quantization, followed by log quantization and truncation of data beneath the threshold curve.

Nonlinear Effects of Quantization: The experimental results showed that the subjective dissimilarities in the compressed textures did not change monotonically with the compression rates for either the wood or the sandpaper textures. For example, for linear quantization of the wood texture, the dissimilarity at $L = 8$ was unexpectedly small. Also, for log quantization of the sandpaper texture, the dissimilarity at $L = 6$ was not larger than those for $L = 8$ and $L = 10$. On the other hand, for the method of truncating data beneath the shifted threshold curve, the dissimilarities changed monotonically with the compression ratio. In the truncation method, the energy of the stimuli decreases with the compression rate, but this does not hold for the quantization methods; quantization can increase the energy of the stimuli. The relationships between the stimuli energy and the subjective quality of the compressed textures are unknown. However, non-monotonic changes in the energy might produce a texture that happens to be subjectively similar to the uncompressed texture.

VI. Conclusions

The objectives of this study was to investigate the human perceptual properties of vibrotactile material textures. In particular, we experimentally investigated the effects of sub-threshold vibrotactile amplitudes and of changes in the amplitudes on perception. Conventional psychophysical approaches are not suitable for material textures that have many independent variables. We adopted lossy data compression of textures. Data compression manipulates many variables simultaneously while maintaining subjective quality, which is a suitable approach for stimuli in the real world. We applied three lossy data compression methods to the surface textures of a wood board and sandpaper: linear and log quantization of vibratory amplitudes in frequency space and truncation of data beneath the shifted detection threshold curve. Participants in the experiments rated the subjective similarities of these compressed textures compared to the uncompressed original textures. No significant differences in the ratings were observed until the number of quantization steps reached 12. Compression ratios reached 23.8% and 22.4% for the wood and the sandpaper, respectively, while maitaining the quality, which represents that the data size of the material textures can be reduced by up to approximately 75%. Furthermore, the we showed that vibratory amplitudes smaller than detection thresholds could influence the perception of material textures. We conclude that the lossy data compression approach can reveal perceptual properties of vibrotactile material textures.

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