Understanding the perception of Sharpness by increasing the Loudness of a Sound

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Introduction

Psychoacoustics is a field of acoustics dealing with the human perception of Sound. Sounds in everyday life can be analyzed with FFT (Fast Fourier Transform) [1] based analysis, however, these analyses do not take into account the human hearing capability and hence cannot paint a clear picture on sound perception. Psychoacoustic analysis [2] aims to consider all aspects of human hearing and hence is very useful to present the perceptional results. Loudness of a sound emphasizes the overall perception of sound volume whereas Sharpness emphasizes the perception of high frequency components in a sound.

Scope of Research

Let us consider a situation where a machine is operating at a lower speed and radiates sound. When the operating speed of the machine is increased, there is a natural increase in loudness of the sound since the machine is doing more work. However, the corresponding frequency distribution of the sound at higher speed need not be a linear increase from the sound at lower speed as one has to take into account the non-linearities of the machine and its operating conditions. As a second situation, let us consider a linear increase in the sound pressure level of a sound by digital amplification, which results in a controlled increase in amplitude. In this case, the frequency distribution of the amplified sound is a linear increase from the original sound assuming no clipping in the amplification process. In both these situations, how the new frequency distribution of the louder sound affects the perception of sharpness is a question to be answered. Sharpness is chosen as a parameter as it highlights the presence of high frequencies in a sound. To study these two situations in detail, two types of Experiments were performed namely:

- Recording technical sounds generated by a washing machine at different rotational speeds.
- Digitally amplifying a piece of piano music.

Experimental Setup and Test conditions

Experiment 1

A typical integrated front loading washing machine is chosen as the test object. The spinning cycle in a typical wash cycle of this washing machine is chosen as the test condition as this is the only operation where the loudness is naturally perceived different based on the spin RPM (Rotations per minute) compared to other operations. Three different spin RPMs were chosen for this experiment namely 400RPM, 600RPM and 800RPM. The total run time of the wash cycle including spinning cycle was around 20 minutes and care was taken to load the same amount of clothes and detergent for every test. Measurements were acquired once per day for each spin RPM at 1m distance from the center of the washing machine door. All measurements were monaural and were repeated after one week to check for repeatability. The recorded sounds of various spin RPMs also contained water drain noises in addition to spinning cycle noises as water is constantly drained during the spin cycle. For analysis of all spin RPMs, only spinning cycle noises spanning a duration of 5 second were considered.

Experiment 2

A piece of piano music with a duration of 5 second is chosen for this experiment. This music is analyzed in its original form and later in an amplified form. Amplification of music is accomplished with a suitable DAW (Digital Audio Workstation) software. A linear 10dB amplification is performed on the original music. Care is taken to ensure that this amplification operation does not introduce clipping.

Analysis and Interpretation of Results

For both experiments, a preliminary 1/3 Octave band analysis was performed to understand the frequency distribution in general. This analysis was used to calculate Specific Loudness [3] and further Aures Sharpness [4] for all experiments. Aures Sharpness method is chosen for sharpness calculation as it considers the influence of absolute loudness of the sound.

Experiment 1 Results

The unweighted 1/3 Octave band analysis as shown in Figure 1 reveals the frequency distribution for different spin RPMs. The spin cycle sounds for all RPMs are in general broadband in nature. The higher the spin RPM, the higher the amplitude but the net amplitude gain or loss within each 1/3 Octave band is not linear. Although all spin RPMs have broad band spectra, each spin RPM has different dominant frequency regions which will alter the sound perception.

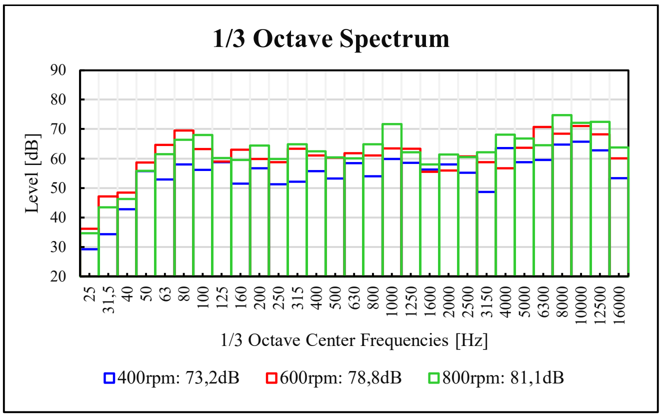

Figure 1: 1/3 Octave Spectrum of Washing machine Spinning cycle for operational RPMs 400, 600 and 800.

The Specific Loudness as shown in Figure 2 exhibits the distribution of loudness across the critical bands. For Spinning cycle of 400RPM, critical band 18 is dominant, followed by critical band 22 to a small extent. For Spinning cycle of 600RPM, critical bands 20 to 21 are dominant followed by neighboring critical bands. For Spinning cycle of 800RPM, critical bands 18 and 22 are most dominant followed by critical band 9 in mid-frequency region. The specific loudness results are different from results in Figure 1 because the unweighted 1/3 Octave band analysis did not take non-linear human frequency selectivity and sound masking into consideration. A common observation for all 3 RPMs of spinning cycle is, higher critical bands are dominant compared to lower bands, which will certainly influence the sharpness perception. It is interesting to note that although the spinning cycle of 800RPM is twice that of 400RPM, there seems to be no relation between these two RPMs as far as specific loudness is concerned. First, the total loudness single value of 800RPM which is 44 sone is not twice as that of 400RPM which is 28,3 sone. Second, the specific loudness distribution of 800RPM contains different dominant critical bands, some of which were negligible (critical bands 9 and 22) in 400RPM.

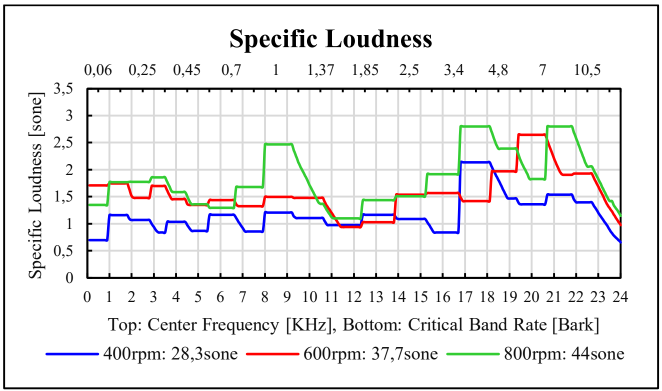

Figure 2: Specific Loudness results of Washing machine Spinning cycle for operational RPMs 400, 600 and 800. The primary X-axis (bottom) is represented as Critical Band Rate in Bark whereas the secondary X-axis (top) is represented as Center frequencies in KHz.

The Aures Sharpness as represented in Figure 3 reveals that sharpness does increase for each spin RPM. The increase in sharpness is attributable to the loudness distribution itself as more high frequency regions are dominant for higher RPMs compared to lower RPMs. The sharpness increase between these 3RPMs is quasi linear.

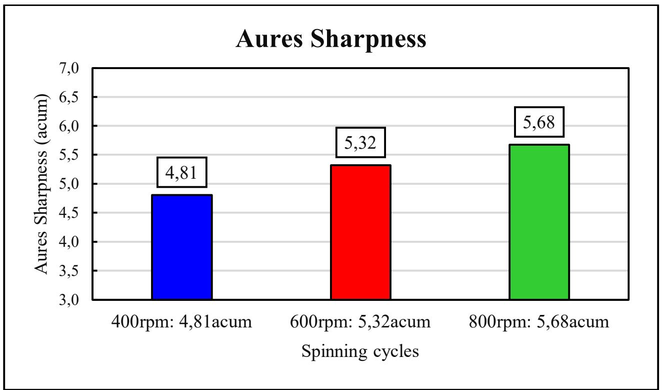

Figure 3: Aures Sharpness results of Washing machine Spinning cycle for operational RPMs 400, 600 and 800.

Experiment 2 Results

The unweighted 1/3 Octave band analysis in Figure 4 reveals the frequency distribution of the original and amplified piano music. As the amplification was accomplished digitally, there is an expected 10dB increase in overall level as well as within each 1/3 Octave band. Spectrally, the piano music is dominant only in low and mid frequencies. Higher frequencies on the other hand appear to be negligible relative to low and mid frequencies.

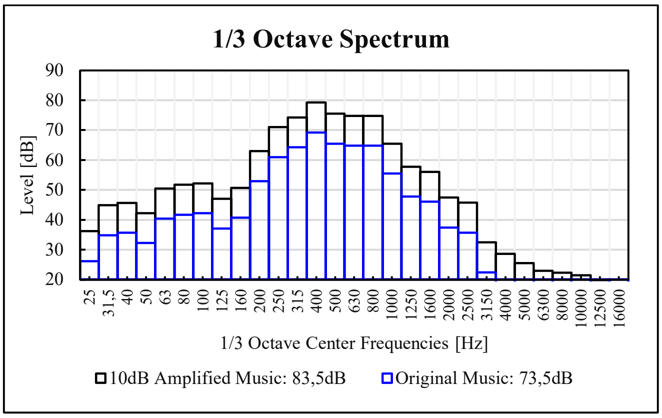

Figure 4: 1/3 Octave Spectrum of piano music in original and in 10dB amplified form.

The Specific loudness of original and amplified piano music in Figure 5 shows dominant critical bands 4 to 5 followed by neighboring critical bands. The lack of high frequencies is reflected in the graph as critical bands beyond 8 show little contribution to the overall loudness. As a result of linear amplification, the specific loudness distribution also shows a linear increase within each critical band. The total loudness single value for amplified music which is 30,9 sone is almost twice that of the original music which is 16,3 sone. Hence it can be said that the amplified music sounds twice as loud as the original music since the sone scale is linear.

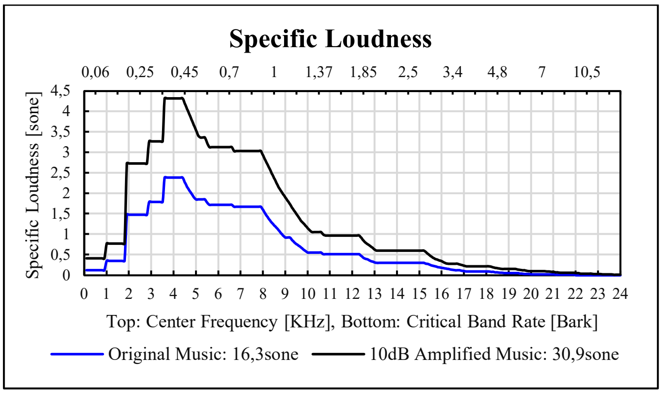

Figure 5: Specific Loudness results of a piece of piano music in original and in 10dB amplified form. The primary X-axis (bottom) is represented as Critical Band Rate in Bark whereas the secondary X-axis (top) is represented as Center frequencies in KHz.

The Aures Sharpness as represented in Figure 6 reveals that there is not an appreciable increase in sharpness due to the lack of high frequencies within the piano music. A 10dB amplification of piano music although resulted in higher loudness, contributed little to overall sharpness.

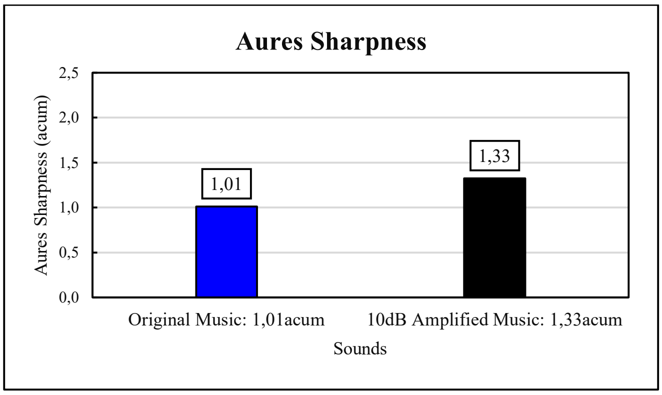

Figure 6: Aures Sharpness results of piano music in original and in 10dB amplified form.

Conclusion

The effect of perception of Sharpness by increasing Loudness is studied for two experiments. Based on the results of both the experiments, it can be concluded that the frequency distribution of sound in question plays a major role in sharpness perception. In the first experiment, the natural way to increase loudness was to operate the machine faster. The frequency distribution was broad band in nature, additionally, higher frequencies were stronger, which in turn contributed to higher sharpness perception. It is also important to note that the frequency distribution of the louder sound is generally not predictable since the behavior of machine at different speeds is not predictable. In the second experiment, however, the loudness was increased by a simple linear amplification without clipping. Due to controlled amplification, the frequency distribution of louder sound can be readily predicted. Since the frequency distribution of original piano music was itself stronger in low and mid frequencies, but weaker in higher frequencies, linear amplification operation resulted in an amplified piano music with the same frequency distribution. Thus, if the original sound lacks high frequency components, a linear amplification would not add more value to sharpness perception.

Literature

[1] Kreyszig, E.; Kreyszig, H.; Norminton, E., Advanced Engineering Mathematics, Tenth edition, Wiley, Hoboken, NJ, 2011.

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[4] Aures, W., „Berechnungsverfahren für den Wohlklang beliebiger Schallsignale, ein Beitrag zur gehörbezogenen Schallanalyse", Doktorarbeit, TU München, 1984.