Variable Critical Bands

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BACKGROUND

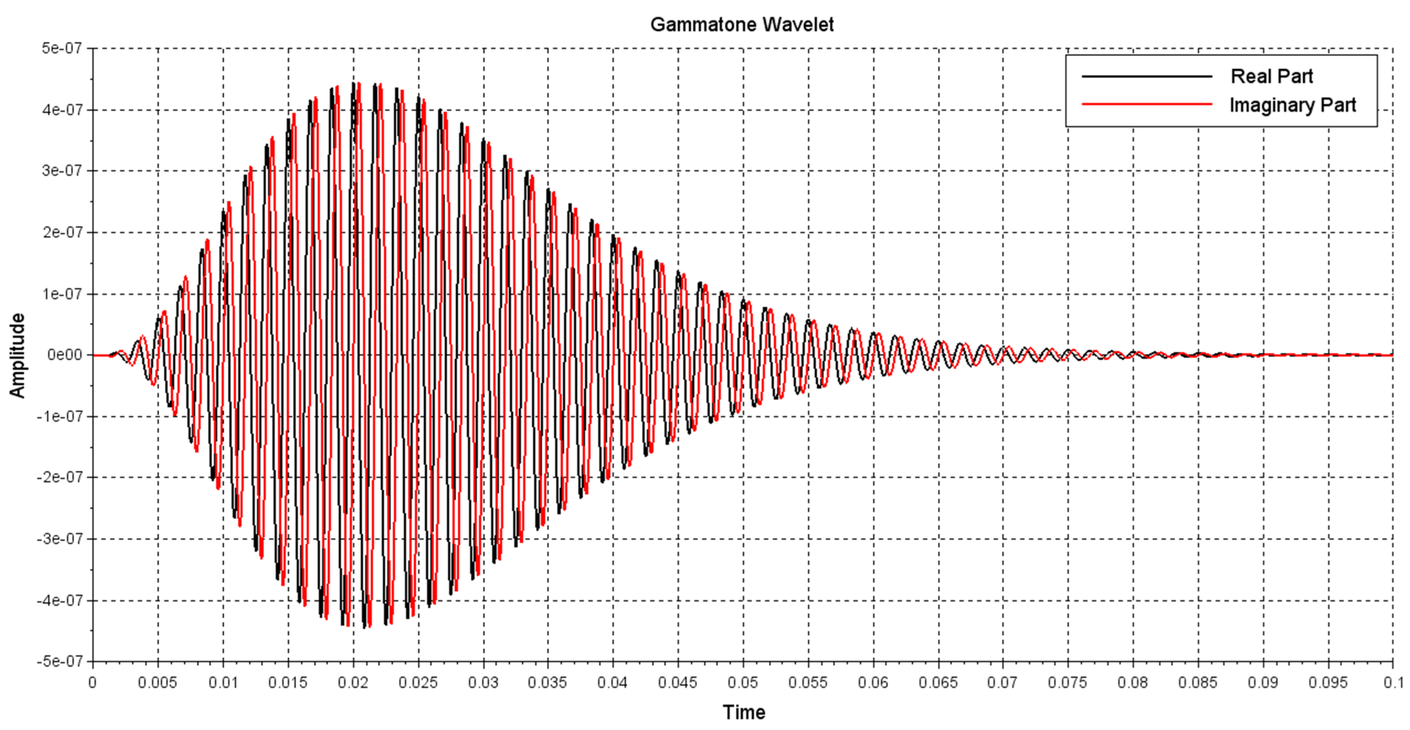
When Fletcher and Munson researched equal loudness contours in 1933, they discovered that tones close to each other are evaluated differently in the ear than tones spread apart. This lead to the investigation of the so called critical bands.
Zwicker, Flottorp and Stevens were able to measure "Frequenzgruppenbreiten" in 1957 and suggested that these were equal to the concept of critical bands. The authors state that Frequenzgruppen are 100Hz wide until a center frequency of 500Hz, above that the Frequenzgruppen are approximatley one third of the center frequency wide.
Center frequencies are again presented by Zwicker and Feldtkeller in 1967. First the authors also state that the center frequencies can occur at any frequency of the human hearing range. Then a division into 24 bands is presented (named the bark scale after Heinrich Barkhausen). This stacking of critical bands is called "willkürlich" (arbitrary) by the authors. They assume based on their measurements, that a broadband noise is divided into these 24 bands, although in one of their measurements the noise was divided into 30 bands.
Spreng also states in 1975 that the center frequencies of critical bands are not fixed. For loudness perception the complete evoked area in the inner ear is decisive. Two evoked areas can only be discriminated if there is a less evoked area between them, i. e. a local minimum is required.
Moore and Glasberg suggested a new formula for critical bands in 1983 based on auditory filters. The authors showed, that the width of critical bands shrinks below 500Hz instead of being constant at 100Hz. Based on empirical data the authors suggested equivalent rectangular bandwidth (ERB) scale, implicating the critical bands are related to

AIMS

Critical bands shall be further explored, specifically their dynamic behaviour. The first phase is to explore their center frequencies if this is continuous or how small possible discrete steps are and if this possible stepwidth changes towards higher frequency regions. For applications it is of interest how dense the sampling of (possibly continuous) critical bands should be.
The second phase will be experiments on the width of critical bands. It is known, that their width changes with temporal effects. This shall be further explored.

METHODS

The simulation uses a wavelet-transform to analyze a time-domain signal in the frequency domain. The frequency resolution of this transform reflects the resolution of the human ear better than a short-time Fourier-transform. Venkitaraman et al. developed a complex gammatone wavelet transform in 2014 extending the gammatone filter to a complex gammatone wavelet. The current implementation uses 56 wavelets and quarters the „Frequenzgruppen" by Zwicker. With the higher resolution dynamic behaviour can be approximated. The filterbank analvzes from 1kHz to 6.3kHz.

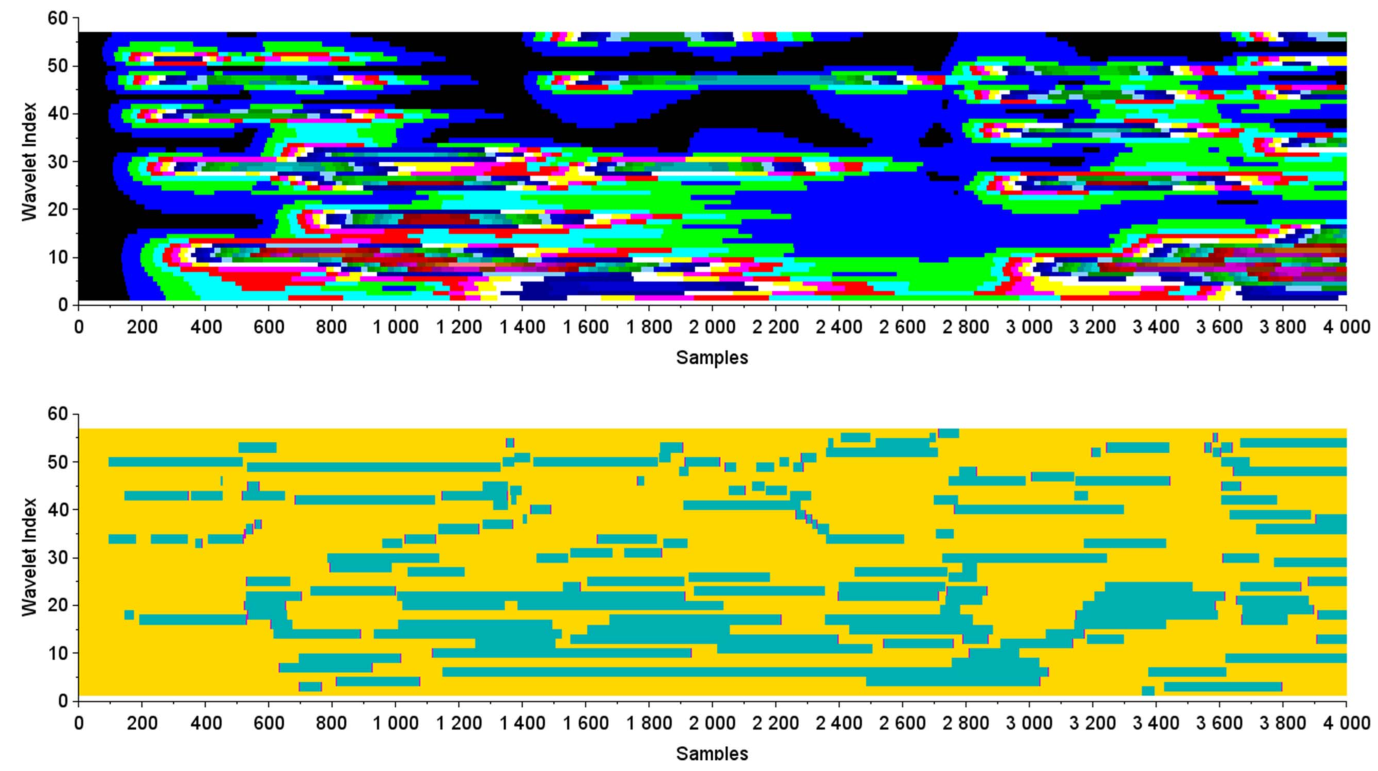


A complex Gammatone-Wavelet.

Psychoacoustic experiments focus on the center frequency and width of critical bands. Utilizing the notched noise method to prevent off-frequency listening, arbitrary center frequencies for critical bands shall be explored. Three center frequencies have been chosen as samples of the human hearing range: 250, 1000 & 8000Hz. For each frequency the ERB is calculated and dissected into 10 segments. These new frequencies are used as center for critical bands. For each of these "fine" frequencies the ERB is calculated and the notch tested with a probe to verify that the critical bands indeed build up at these center frequencies.

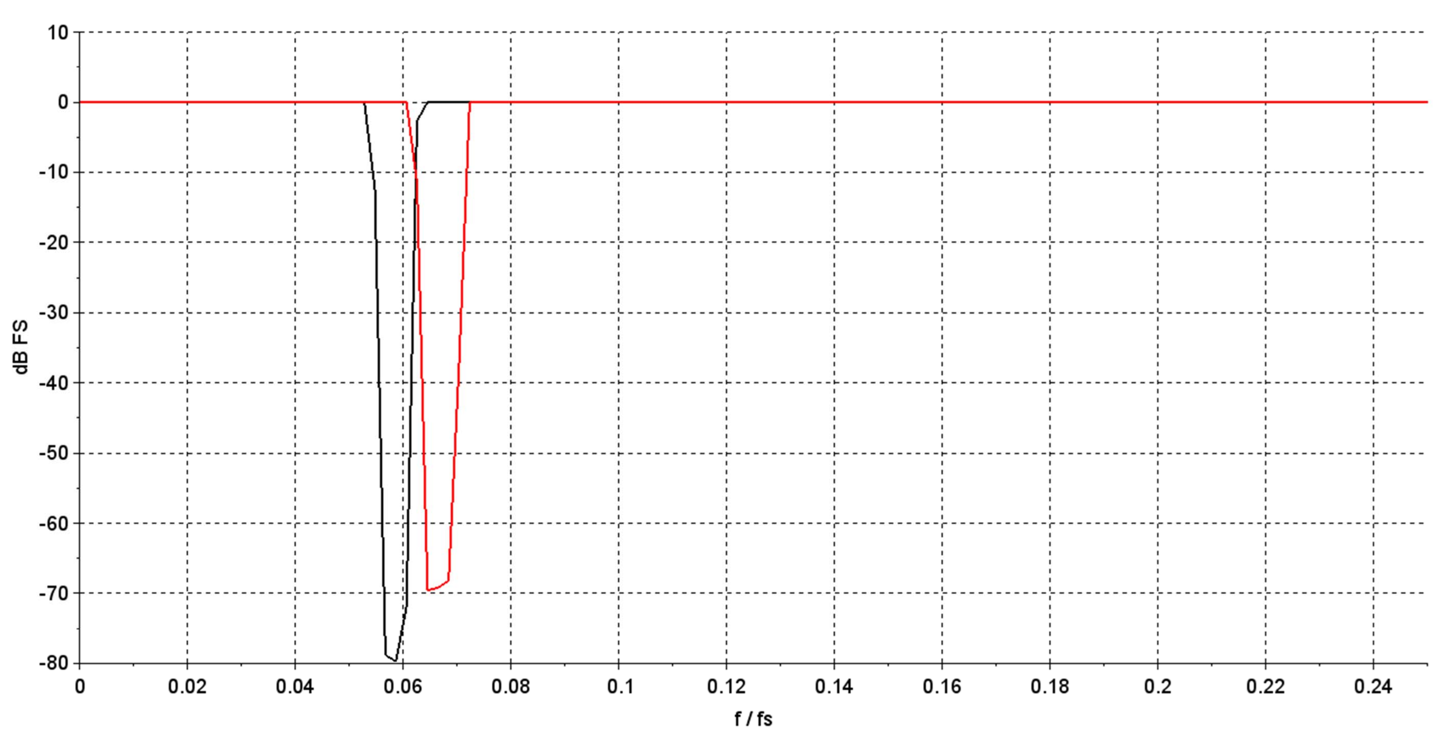
RESULTS

The simulation suggests that matched critical bands will not change loudness perception too much compared to fixed critical bands. The specific loudness changes more with variable width of the bands, hence seems to have more influence.



Top: Spectrogram (wavelet analysis); Bottom: Calculated Critical Bands (yellow).

Psychoacoustic experiments are still in progress, the variable center frequency is the first phase, the next phase will focus on variable bandwidth.It is known that critical bands are narrower in forward masking than in parallel masking. Also Scholl was in 1962 able to produce a critical band three times wider than suggested by Zwickers formula. The figure below shows 2 notch filters: A ERB at 1kHz is 133Hz wide. From 933 to 1066Hz 10 equidistant frequencies are picked and notch filters for the corresponding ERBs calculated. Such the continuous center frequencies shall be tested.



Two notch filters for the notched noise method.

CONCLUSION

Critical bands have been a field of research since the 1930s. The width of critical bands and the shape of auditory filters have been explored by others in detail. The dynamic behavior of critical bands has been pointed out by several researches, for example by Reuter (1995). This work focuses on the continuous center frequencies of critical bands as well as their width depending on temporal effects. Currently the work is in phase 1, which includes a simulation and experiments concerning the center frequencies. The second phase will focus on the width of critical bands. The empirical data gained will be reflected by the simulation. This shall provide a basis for possible future applications like loudness measurement, audio coding and enhancement of audio signals for hearing impaired.

LITERATURE

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