Baseband Version of the Bat-Inspired Spectogram Correlation and Transformation Receiver

Introduction and motivation

Echolocating bats have evolved an excellent ability to detect, resolve and discriminate targets in highly challenging environments. They have had more than 50 million years of evolution to optimise their echolocation system and behavioural experiments have shown their exceptional ability to detect and classify targets even in highly cluttered surroundings.

Behavioural experiments have demonstrated that bats are able to resolve closely located scatterers:

- a two-point resolution of 2÷10 μs with waveforms of a bandwidth of 85 kHz (Eptesicus fuscus)
- discriminate between two phantom target echoes separated by a time-delay of about 1 μs with waveforms of a bandwidth of up to 100 kHz (*Megaderma lyra*)
- higher range resolution performance with respect to the conventional matched filter

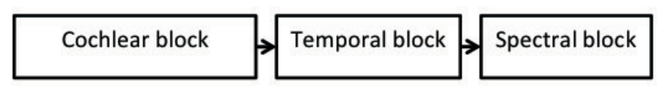
The way bats process target echoes is different from the standard processing techniques used in radar and sonar, and there may be lessons to learn by investigating differences and similarities. The Spectrogram Correlation And Transformation receiver (SCAT) is an existing model of the bat auditory system that takes into account the physiology and underlying neural organisation in bats that emit chirped signals.

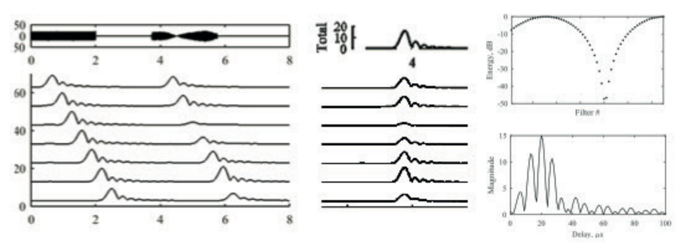
Aims

- Develop a baseband receiver equivalent to the SCAT, called the Baseband Spectrogram Correlation and Transformation (BSCT), to
  - allow the application of biologically inspired signal processing to radar baseband signals
  - enable further theoretical analysis of the key concepts, advantages and limitations of the 'bat signal processing'
- Carry out simulations and experiments to investigate differences and similarities between the output (the frequency interference pattern for two closely located scatterers) of the original SCAT and that of the proposed baseband version

The bat inspired Spectrogram Correlation and Transformation (SCAT) model (Saillant, Simmons, Dear and McMullen, 1993)

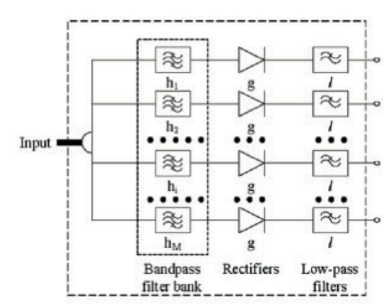
The bat auditory system processes both the emitted call and the received echo through an auditory periphery and then through some higher level brain structures. The auditory periphery includes the outer, the middle and the inner ear and provides a time-frequency representation of the input signal. The frequency content is sampled in a non-linear scale (hyperbolic or logarithmic). The consequent brain processing provides an estimate of the time delay between the call and the echo and provides cues about the structure of each echo.





Cochlear block

- a bank of 81 Butterworth band-pass filters of order 10 and bandwidth B = 4 kHz
- a signal rectifier and a 3 kHz bandwidth low-pass filter after each band-pass filter extracts the envelope of the signal
- the central frequencies f_c of the band-pass filters span the bandwidth between 20 kHz to 100 kHz and are arranged in a hyperbolic scale
- two levels of smoothing



Temporal block

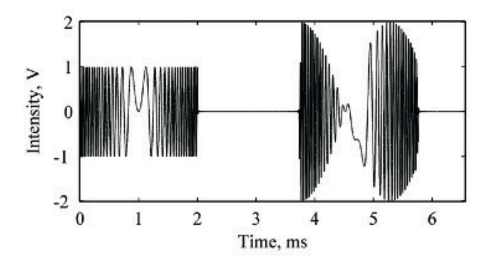
- estimate roughly the time delay between the call and the echo
- 'dechirp' the signal by adding appropriate delays to each frequency channel
- delays are calculated using the emitted signal as a trigger

Spectral block

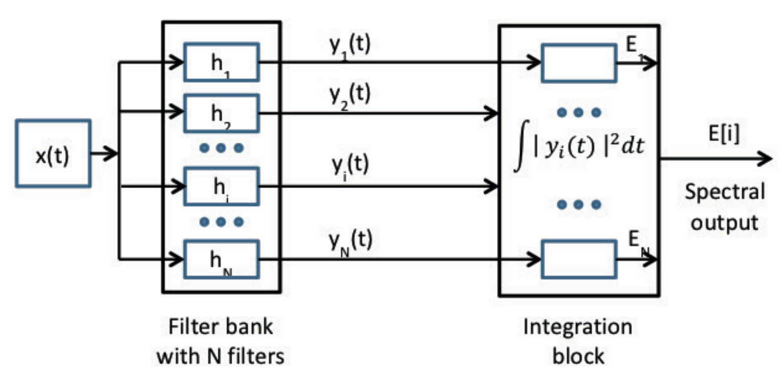
- responsible for extracting the fine structure of the target to detect and measure the delay between highly overlapping echoes
- exploits the interference pattern between overlapping echoes, which results in the suppression or amplification of the power of the output of some of the filters of the cochlear block
- integrates the output signal of each frequency channel for a specific time interval (about 350 μs)
- the output of the integration represents the frequency spectrum of the signal
- a modified inverse cosine transform is then used to convert the frequency spectrum back into the time domain.

The baseband equivalent of the spectrogram transformation

- Input signal $x(t)$ is in baseband



- A filter bank composed of M filters with central frequencies f_i, $i = 1 \ldots M - 1$, bandwidth B and all having the same shape. The impulse response of any filter i is
$$h_i(t) = h(t)e^{j2\pi fit}$$
- The output of each bandpass filter is
$$y_i(t) = x(t) * h_i(t)$$
- We replace the rectifier and the low-pass filter after each bandpass filter with an ideal amplitude extractor. Therefore the envelope of the bandpass filtered signal is $|y_i(t)|$
- The output of the spectral block is:
$$E[i] = \int_{-\infty}^{\infty} |y_i(t)|^2 \, dt$$



Experiment

- The transmission (or 'bat call', $x_c(t)$) was a linear chirp from 100 kHz down to 35 kHz with duration of 2 ms
- Two close-spaced point targets were synthesised by producing two time delayed versions of the emitted calls
- The real measurements were recorded with an ultrasound microphone
- A phantom target was created using an ultrasound loudspeaker at a distance of 1.272 m from the microphone

The filter bank consists of 65 bandpass filters with linear frequency spacing from -32 kHz to 32 kHz for BSCT and from 35.5 kHz to 99.5 kHz for SCAT.

Results

The spectral output of the proposed BSCT is compared with the output of both versions of the original SCAT (with low and high smoothing) for different delays between the glints in the target.

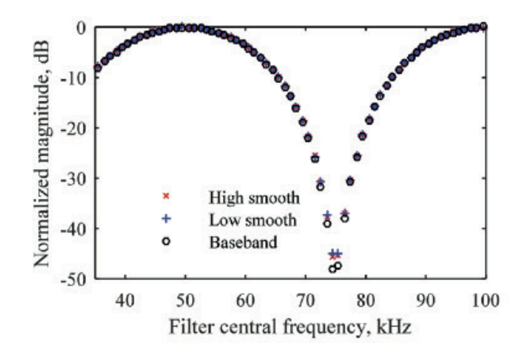
The interference patterns for different relative positions between the scatterers are explored

- The level of smoothing in the original SCAT does not influence the spectral output.

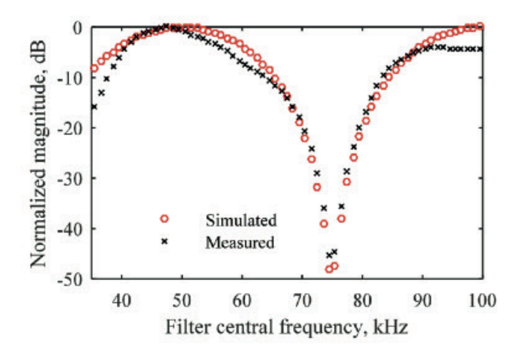
The same is valid for the baseband model which gives practically the same results.

- The general shape and, in particular, the locations of the zeroes, are preserved between the experiments and the simulations.

These features are likely to be significant for any scheme looking at resolving the close-spaced targets. This result indicates that future algorithms, based on the SCAT algorithm, can retain the information which will be needed to resolve the targets.



Spectral output of BSCT (baseband) and SCAT (high and low smoothing), simulated two targets with separation 3.4 mm (delay 20 μs)



Spectral output of BSCT model, simulated vs measured two targets

Conclusion

The proposed baseband spectrogram transformation model gives an output comparable to the output of the original spectrogram correlation and transformation receiver. This implies that

- processing of target echoes with a receiver based on the bat auditory system can be applied to signals that are centred on very high carrier frequencies, such as radar signals
- the output of the spectral block does not depend on the phase information of the carrier signal and is a form of non-coherent signal processing; the spectral block will be more robust to loss of signal coherence than the matched filter

Future work

- further understanding of the model using advanced signal analysis techniques based on complex signal representation
- comparison between the SCAT and the matched filtering

Krasin Georgiev[1], Alessio Balleri[1], Andy Stove[2], Marc Holderied[3]

k.georgiev@cranfield.ac.uk

[1]Centre for Electronic Warfare, Information and Cyber, Cranfield Defence and Security, Defence Academy of the United Kingdom, Shrivenham, Swindon, SN6 8LA

[2]Stove Specialities, Hove, E Sussex, BN3 5NL [3]School of Biological Sciences, Bristol University, Bristol, BS8 1TQ

www.cranfield.ac.uk