



Detection and segmentation of FMCW radar signals based on the chirplet transform



Fabien MILLIOZ and Mike DAVIES

email: {fmillioz,mike.davies}@ed.ac.uk School of Engineering and Electronics
The University of Edinburgh, Kings Buildings, Mayfeld Rd
Edinburgh EH9 3JL - United Kingdom

Objective:

- Detect, identify and analyse signals in the presence of similar signals
- Sparse detection
- Frequency Modulation Continuous Wave radars

I. Signal Model

Frequency Modulation Continuous Wave radar $r(t)$

$$r(t) = \sum_{n=1}^N A_n \cos(2\pi f_n(t)t + \phi_n)$$

$f_n(t)$ a piecewise linear function

$n(t)$ a white Gaussian noise of variance σ^2

$f_n(t)$ may be discontinuous to modelize very high chirprates

II. Discrete Chirplet Transform

$$C(n, k, c) = \sum_{m=-\frac{M_\phi-1}{2}}^{+\frac{M_\phi-1}{2}} x[n+m]\phi[m]e^{j2\pi\frac{c}{2}m^2}e^{-j2\pi m\frac{k}{K}}$$

n and k the time and frequency indices

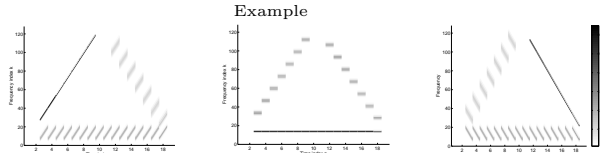
$\phi[m]$ a energy-normalised smoothing window of M_ϕ points

K the number of frequencies

c the chirprate discretized such that $c = \frac{1}{L}c_{max}$

l the chirprate index from $-L$ to L , $2L+1$ different chirprates

Redundancy of the chirplet transform: redundancy of STFT \times number of chirplets



Energy concentrated along the chirps corresponding to the good chirprate, spreaded otherwise

III. Signal Detection

Goal: select the fewest possible relevant chirplets

A simpler time-frequency representation, the maximum chirplet

$$D[n, k] = \max_c |C[n, k, c]|^2$$

associated with the corresponding chirprates $CR[n, k]$

$$CR[n, k] = c : |C[n, k, c]|^2 = D[n, k]$$

III.1. Neyman-Pearson detection

$|C[n, k, c]|^2$ of noise only has a χ^2 distribution

Hypothesis: $Corr(C[n, k, c_i], C[n, k, c_j]) = 0$ if $i \neq j$ (\approx true for long windows ϕ)

Order Statistics \implies PDF of $D_{noise}[n, k]$, parameter σ^2 unknown

Estimate σ^2 [1] \implies PDF of $D_{noise}[n, k]$ of noise only fully known

Detection threshold t leading to a given probability of false alarm p_{fa} :

$$t : Prob(D_{noise}[n, k] > t) = p_{fa} \implies t = \sigma^2 \ln \left(1 - (1 - p_{fa}^{-1})^{\frac{1}{2L+1}} \right)$$

Set of detected chirplets $\mathcal{S} = \{[n, k] : D[n, k] > t\}$

III.2. Local maxima

Set of local maxima along the frequencies \mathcal{M}

$$\mathcal{M} = \{[n, k] : D[n, k] \geq D[n, k']\}, k' = [k-10, k-9, \dots, k+9, k+10]$$

Avoid too many local maxima but selects different chirps at close frequencies

Selected chirplets $\mathcal{P} = \mathcal{S} \cap \mathcal{M}$

IV. Chirps Estimation

Goal: merge the selected chirplets into linear chirps

Algorithm:

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for all selected chirplet coefficients do
  for all created chirps do
    if current chirplet  $\in$  current chirp then
      Associate the time-frequency location of the chirplet coefficient to the chirp;
      Estimate the chirp's parameters with a linear regression from all associated time-frequency locations;
    else
      Create a new chirp of parameters the chirplet's;
    end if
  end for
end for
end for

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chirplet centred on $[n, k]$ of chirprate $c \in$ chirp centred on $[n_c, k_c]$ of chirprate c_c ?

- time condition: $|n - n_c| \leq \delta_t$
- frequency condition: $|k - k_c| \leq \delta_f$
- chirp condition: $|c - c_c| \leq \delta_c$

Parameters in regard to the chirplet transform's parameters

$$\delta_t = M_\phi, \delta_c = \frac{1}{L}c_{max}, \delta_f = \max(1, K\frac{1}{L}c_{max}\frac{M_\phi}{2})$$

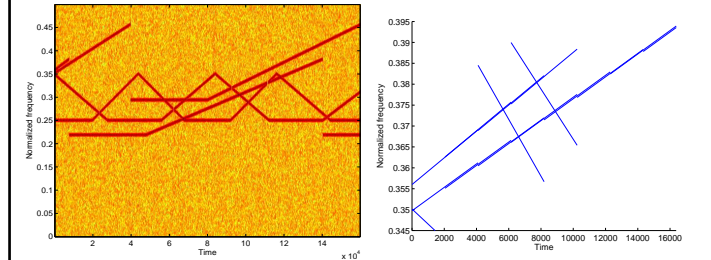
Post-processing:

Wrongly selected chirplets \implies false alarm chirps

Remove estimated chirps with length equal to a single chirplet's length

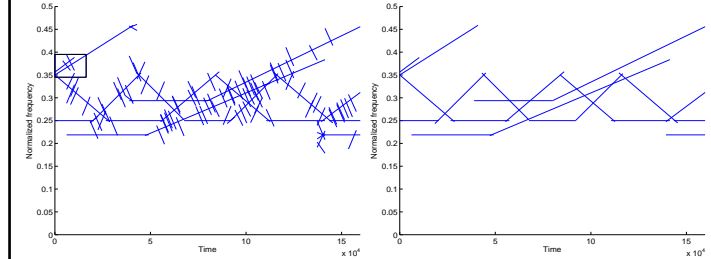
V. Results

Result on a synthetic signal of 160001 points, Hanning window of 4095 points, 50% of overlap, 4096 frequency bins, 51 different chirprates



Spectrogram of the signal

Selected chirplets, zoom



Estimated chirps

Estimated chirps after post-processing

- 379 chirplet coefficients are selected;
- 98 chirps are created;
- 78 false alarm chirps are discarded.

Conclusion:

- Detect and estimate linear chirps
- Real time algorithm

Ongoing Research:

- Replaced the detection step by a iterative windowing step
- Classify the linear chirps in radar signal
- Compressed Sensing for acquisition and detection

[1] F. Millioz, and N. Martin, "Estimation of a white Gaussian noise in the Short Time Fourier Transform based on the spectral kurtosis of the minimal statistics: application to underwater noise," in *Proceedings of IEEE Conference on Acoustics, Speech and Signal Processing*, Dallas, Texas, USA, Mar. 2010.