Supplementary material for TFSAP book Section 13.5: "Time-Frequency Estimation of Radio Signal Modulation Parameters"[1]

The additional material[2] in this file is provided by Prof Boashash to assist the reader to better understand Section 13.5 of the TFSAP book. The material was collected from the first author and then edited and standardized by Prof. Boashash. The MATLAB functions and scripts listed below can be used to reproduce some of the illustrative figures found in Section 13.5.

Theoretical Overview:

Signal Generation:

Two signals that are used to validate time-frequency distributions (TFDs): binary Frequency Shift-Keying (BFSK) and 4FSK. The difference between the two signals is that the BFSK transmits one bit per symbol (represented by a combination of two frequencies) while the 4FSK signal transmits two bits per symbol (represented by a combination of four frequencies). Besides the BFSK and 4FSK signals, a captured FSK recorded in a file *FSK_captured.wav* at sampling frequency of 8000 Hz is included to demonstrate the practicality of using the TFDs in a real radio monitoring environment.

Time-Frequency Distributions:

The two TFDs that are described in this Section are the adaptive windowed Wigner-Ville distribution (AWVD) and the extended modified B-distribution (EMBD). The AWVD features the procedure of estimating the time and lag windows adaptively, based on the signal characteristics, which allows an accurate *(t, f)* representation of the signal under analysis. The peak of the power spectrum is used to estimate the time window while the global adaptive procedure is used to estimate the lag window. For comparison purposes, the EMBD which is a well establish TFD with fixed windows, used in biomedical applications, is included.

MATLAB Functions:

- *BFSK*: It generates a BFSK signal.
- *M4FSK*: It generates a 4-FSK signal.
- *swwvd0*: It computes the smooth-windowed Wigner-Ville distribution (s-WVD) of a time domain signal.
- *rt_tau2*: It computes the bilinear product to be used in *swwvd0*.
- *lagwn1*: It generates a generalized Hamming lag window to be used in *swwvd0*.
- *tsmoth*: It generates a time window to be used in *swwvd0*.

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[1] A.Z. Sha'ameri and B. Boashash, "Time-Frequency Estimation of Radio Signal Modulation Parameters", Chapter 13.5; in B. Boashash (ed.), *Time-Frequency Signal Analysis and Processing*, 2nd Edition (London: Elsevier / Academic Press, pages 777-789, December 2015); ISBN 978-0-12-398499-9.

[2] All of the book supplementary materials can be found here.

- *Rz_to_Pz*: It calculates a TFD from its time-dependent autocorrelation function, to be used in *swwvd0*.
- *AWVD*: It computes the AWVD of an input time domain signal.
- *kernelParameters*: It estimates the kernel parameters, i.e. time and lag windows, which are used in *AWVD*.
- *time_window_estm*: It estimates the frequency components in a power spectrum and determines the time window to be used in *kernelParameters*.
- *EMBD*: It computes the EMBD of an input time domain signal.
- *embd_2dfilter*: It computes the kernel parameters, and performs 2D filtering in the ambiguity domain which is used in *EMBD*.
- *IF_estimate*: It estimates the instantaneous frequency (IF) from a computed quadratic TFD.

MATLAB Scripts:

Fig_13_5_2.m

- Description: This script reproduces the results depicted in Fig. 13.5.2, on page 781 of the book.
- Process: It generates a BFSK signal, using the *BFSK* MATLAB function, and computes its ambiguity domain representation.
- Note: TFSAP Toolbox[3] should be installed.

Fig_13_5_3.m

- Description: This script reproduces the results depicted in Fig. 13.5.3, on page 782 of the book.
- Process: It generates a BFSK signal, using the *BFSK* MATLAB function, and computes two EMBDs of the generated signal with different kernel parameters, using the *EMBD* MATLAB function, and their ambiguity domain representations. Furthermore, additional results are generated by estimating the IF of the BFSK signal, using the *IF_estimate* MATLAB function, from the computed EMBDs.
- Note: TFSAP Toolbox should be installed.

Fig_13_5_4.m

- Description: This script produces the results depicted in Fig. 13.5.4, on page 783 of the book.
- Process: It generates a 4-FSK signal, using the *M4FSK* MATLAB function, and computes its EMBD, using the *EMBD* MATLAB function. Furthermore, additional results are generated by estimating the IF of the 4-FSK signal, using the *IF_estimate* MATLAB function, from the computed EMBD.
- Note: TFSAP Toolbox should be installed.

Fig_13_5_6.m

- Description: This script produces the results depicted in Fig. 13.5.6, on page 785 of the book.

[3] TFSAP Toolbox can be found here.

- Process: It regenerates the BFSK and 4-FSK signals, that were used in *Fig_13_5_3.m* and *Fig_13_5_4*.m, and then computes their AWVD, using the *AWVD* MATLAB function. Furthermore, additional results are generated by estimating the IF of the generated signals, using the *IF_estimate* MATLAB function, from their computed AWVDs.

Fig_13_5_8.m

- Description: This script produces the results depicted in Fig. 13.5.8, on page 787 of the book.
- Process: It generates a BFSK signal, using the *BFSK* MATLAB function, and corrupts it with white Gaussian noise to produce a noisy signal with an SNR of 14 dB. After that, it computes the AWVD of the noisy signal, using the *AWVD* MATLAB function, and estimates its IF, using the *IF_estimate* MATLAB function, from the computed AWVD.

Additional Folders:

- *Supporting functions*: It holds all the required functions needed to run all the aforementioned scripts (listed on page 1).

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