SPACE RESEARCH AND TECHNOLOGY INSTITUTE, BULGARIAN ACADEMY OF SCIENCES

Department of Aerospace Control Systems

NATIONAL SCIENCE FUND

БАН ИКИТ

SCIENTIFIC POSTER

ESTIMATING AN UAV OPERATOR'S COGNITIVE WORKLOAD BY MEASURING PUPIL DILATION

Author: Konstantin Metodiev, PhD

e-mail: komet@space.bas.bg

URL: http://www.space.bas.bg/acsu/easier-web/Metodiev.html

01 INTRODUCTION

Task of measuring pupil dilation comes down to setting apart two reflexes of the visual analyzer muscles, which often occur simultaneously. Two muscle groups control the pupil dilation: the circular muscles surrounding the pupil and the radial muscles extending from the pupil to the iris periphery. Under the influence of a light stimulus, the circular muscles are activated and the radial ones are suppressed, thus causing the pupil to contract. On the contrary, under the influence of a cognitive stimulus, the radial muscles are activated and the circular ones are inhibited, which provokes an abrupt dilation of the pupil diameter.

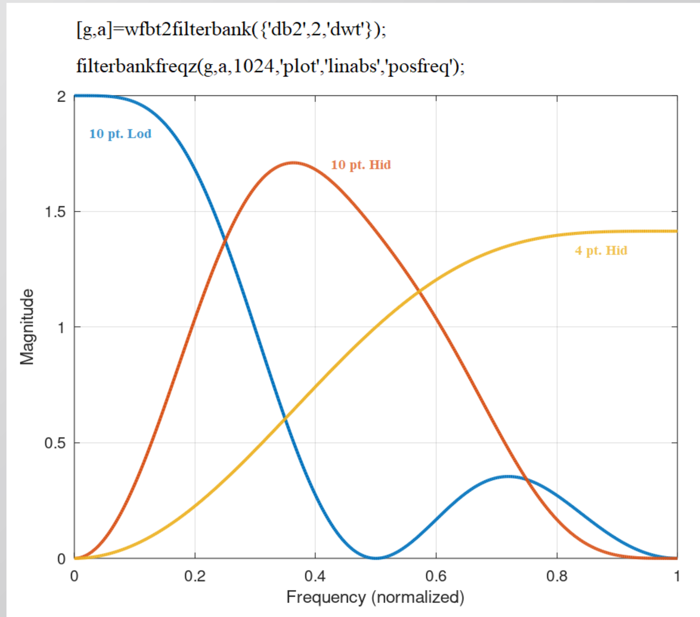
The study hereby aims at identifying events of high cognitive workload during flight task performed on RC flight simulator. The research methodology has adopted to some extent what is described in patent [1] by Sandra P. Marshall. All credits are due to the respectful inventor.

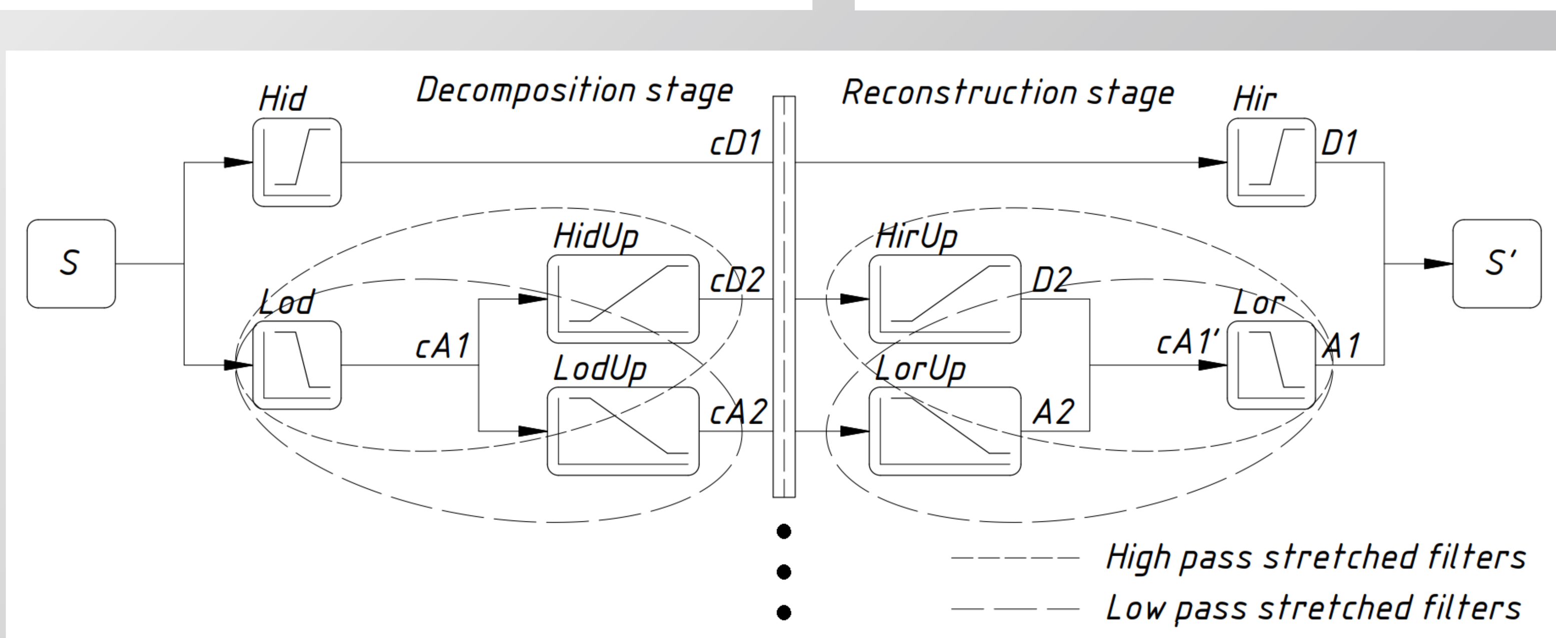
The presented study is tied down to purely mathematical processing of raw data. Psychological interpretation of obtained results is beyond the presentation scope.

02a MATERIALS AND METHODS

The experiment setup consists of a PC, Gazepoint GP3 HD eye tracker, [2], Taranis X9D+ radio transmitter, [3], RC to USB KSim dongle, Phoenix RC 6.0.i RC flight simulator, [4], and a RC helicopter. A trainee is told to perform take off, basic flight manoeuvres, and land within two minutes. During flight session, the eye tracker is gathering data about pupil diameter variations and blinks at sampling rate of 150 Hz. The ambient light conditions are set constant.

The undecimated discrete wavelet transformation (UDWT) has been chosen to separate frequency components of the pupil diameter signal. The flowchart below comprises two nested single-level UDWTs. Two stages are recognizably different during transformation, i.e. decomposition and reconstruction stage, hence the indices **d** and **r**. After filtering, low (**cA**, approximations) and high (**cD**, details) frequency components are split up. In present study, Daubeches **Db2** wavelet has been chosen. Low order (of two) makes it feasible for the wavelet to extract high frequencies obtainable from the input signal. Frequency responses of both basic and stretched filters used at decomposition stage, in case of two-level UDWT, might be depicted in GNU Octave environment by means of LtFat library, [8], [9], freely available in the Internet.





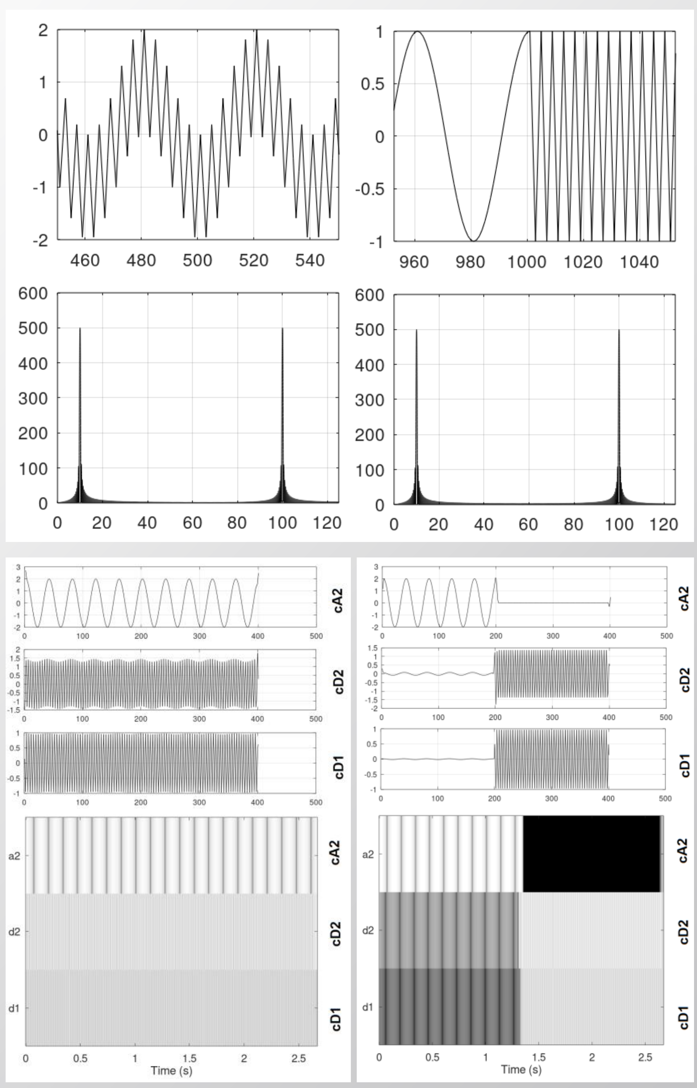
02b MATERIALS AND METHODS cont.

Time Frequency Localization

The proposed algorithm has been put to the test by means of two exact signals with frequency components of $\mathbf{f_1}$ = 10 Hz and $\mathbf{f_2}$ = 100 Hz. The wave equations are

$$x_1 = \cos(2\pi f_1 t) + \cos(2\pi f_2 t) \quad t \in [0;1]$$

$$x_2 = \begin{cases} \cos(2\pi f_1 t) & t \in [0;1] \\ \cos(2\pi f_2 t) & t \in (1;2] \end{cases}$$



Signal denoising

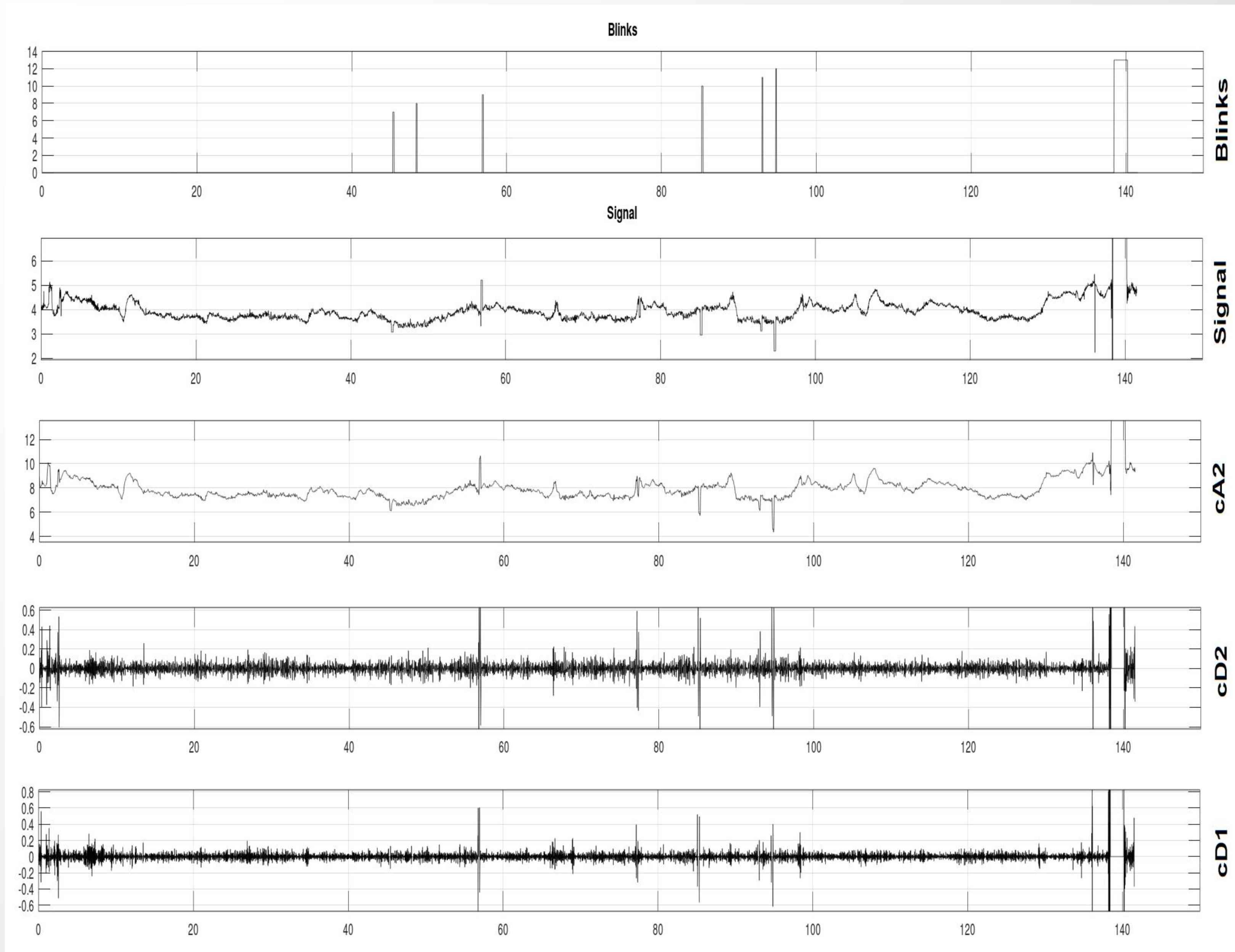
The high frequency signal **cD1** is believed to have been corrupted by noise. Threshold according to paper [10]:

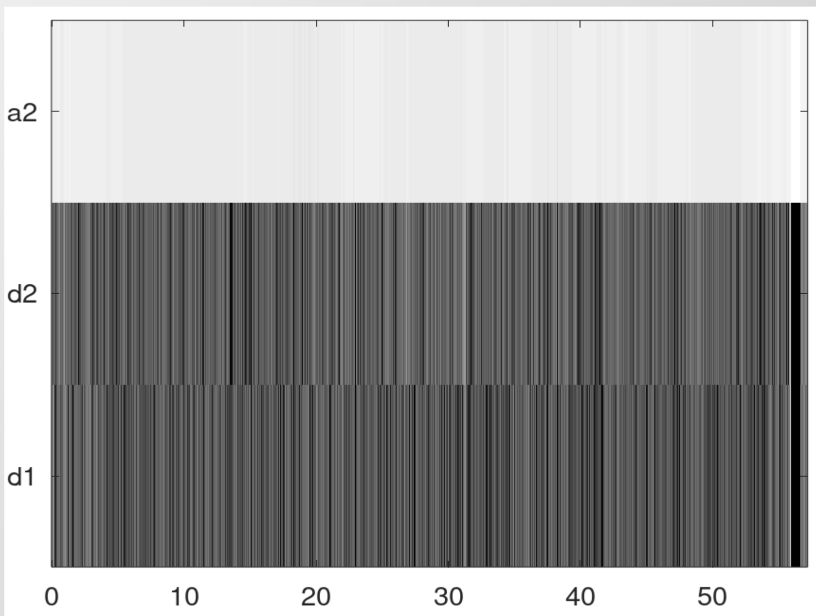
$$\lambda^U = \sigma\sqrt{2\ln(N)} \qquad \sigma \approx \frac{median(|x_i|)}{0.67449}$$

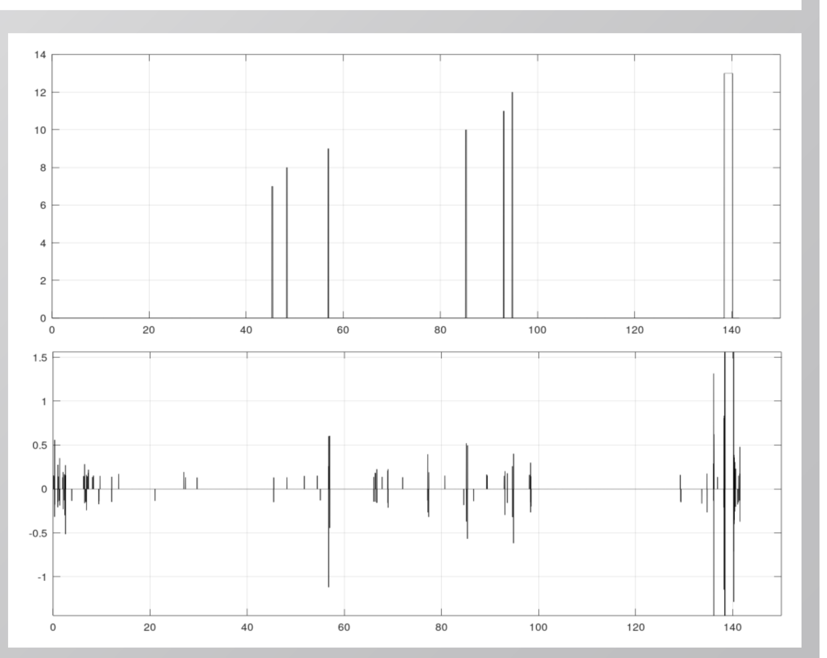
Hard thresholding of the signal

$$x_i = \begin{cases} 0 & if\ |x_i| \le \lambda^U \\ x_i & if\ |x_i| > \lambda^U \end{cases}$$

03 RESULTS







The computed threshold level is λ^U = 0.1289. The hard thresholding method preserved 161 samples out of 8584 in total. Sample onsets coinciding with blinks (7 in total) are to be neglected. Remaining samples are identified as events during which the cognitive load has risen. In order to localize these events, one may look up in the video stream.

04 DISCOURSE

A binary vector might be defined subsequently within limited interval of interest. The vector length depends upon the eye tracker sampling frequency. Gazepoint GP3 HD eye tracker gathers data at rate of 150 Hz. Therefore, the vector is `floor(150 times seconds)` elements long. An expected time period between two consecutive samples is 6.7 ms. Whenever non-zero samples are encountered in denoised **cD1** signal, the vector takes non-zero elements. In this way, the vector might indicate a noticeably different pupil activity, [1], attributed to increasing cognitive workload.

Choice of basic wavelet number of coefficients (i.e. order) appears to be essential. Daubeches wavelets are suitable for solving signal self-similarity properties at separate scales as well as signal discontinuities. To extract information from the signal is based on number of zero moments equal to half the number of wavelet coefficients. The higher number of the zero moments, the better ability of wavelet to delineate a polynomial behaviour of the input signal. It is highly up to an experienced researcher to make a definitive decision. In addition, decomposition might be repeated to keep on dividing frequency band to sub-bands (further increase frequency resolution of the coefficient signal). Last but not the least, the obtained results might be enhanced by EEG measurements carried out simultaneously. In addition, some physiologic data might be gathered, for example galvanic skin response and pulse. Gazepoint GP3 HD eye tracker provides for tools to measure with during gaze point reading. Results from measurements carried out repeatedly might be merged and used to estimate the UAV operator's cognitive workload in a truthful way.

05 REFERENCES

[1] Marshall, Sandra P., Method and Apparatus for Eye Tracking and Monitoring Pupil Dilation to Evaluate Cognitive Activity, patent US006090051A, 18th of July, 2000

[2] https://www.gazept.com

[3] https://www.frsky-rc.com/

[4] https://www.rc-thoughts.com/phoenix-sim/

[5] Mallat, S. G. "A Theory for Multiresolution Signal Decomposition: The Wavelet Representation," IEEE Transactions on Pattern Analysis and Machine Intelligence. Vol. 11, Issue 7, July 1989, pp. 674–693.

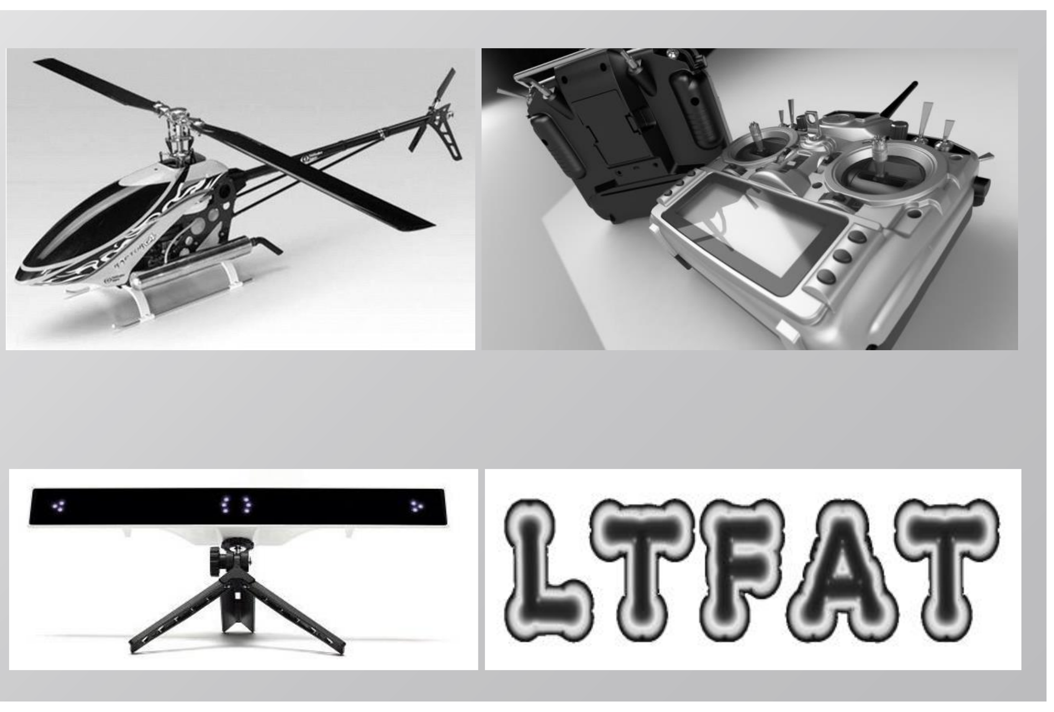
[6] Fugal, D. Lee, Conceptual Wavelets in Digital Signal Processing, an In-Depth Practical Approach for the Non-Mathematician, Space & Signals Technical Publishing, San Diego, California, 2009, p.p. 120, 134 http://www.conceptualwavelets.com/, ISBN: 978-0-9821994-5-9

[7] Eaton, John W., David Bateman, Søren Hauberg, Rik Wehbring (2020). GNU Octave version 6.1.0 manual: a high-level interactive language for numerical computations. https://www.gnu.org/software/octave/doc/v6.1.0/

[8] Průša, Zdeněk, Peter L. Søndergaard, Nicki Holighaus, Christoph Wiesmeyr, Peter Balazs, The Large Time-Frequency Analysis Toolbox 2.0. Sound, Music, and Motion, Lecture Notes in Computer Science 2014, pp 419-442

[9] Søndergaard, Peter L., Bruno Torrésani, Peter Balazs. The Linear Time-Frequency Analysis Toolbox. International Journal of Wavelets, Multiresolution Analysis and Information Processing, 10(4), 2012

[10] Donoho, D. L., in Proceedings of Symposia in Applied Mathematics: Different Perspectives on Wavelets; Daubechies, I., Ed.; American Mathematical Society: Providence, RI, 1993; Nonlinear Wavelet Methods for Recovery of Signals, Densities, and Spectra from Indirect and Noisy Data pp 173-205



06 ACKNOWLEDGEMENTS

The Bulgarian National Science Fund at the Republic of Bulgaria has been supporting the research hereby since 11th of December, 2018, according to contract № КП-06/Н27-10. The project title is "Human Factor in Remotely Controlled Aerial Systems – Analysis, Estimation, and Control."