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The effect of Savitzky-Golay smoothing filter on the performance of a vehicular dynamic spectrum access method

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Abstract – **Modern Intelligent Transportation System in order to guarantee safety and road efficiency has to implement efficient and reliable communication techniques. Traditional techniques are based on a client–server paradigm, needing the installation of base stations and the allocation of frequency bands to be implemented. These solutions would require the allocation of a band in several countries in order to give a reliable service to long–distance traveling vehicles, without considering that nowadays the radio spectrum resource is overcrowded. To overcome these limits the interest for Vehicular Dynamic Spectrum Access (VDSA) is arising. In order to accomplish this goal spectrum sensing plays a very important role. A good spectrum sensing technique makes use of smoothing filters.These filters shows different features in terms of de-noising effectiveness, computational burden, shape preserving to cite a few. In this framework, aim of the paper is to analyze the use of the Savitzky-Golay filter which has rarely been employed to smooth data in spectrum sensing technique. The performance of such a filter is compared with one attained by a much popular filter, well–known and overused in smoothing techniques, i.e. the Moving Average linear filter. The comparison is made by considering suitable figures of merit typical of cognitive radio.**

I. INTRODUCTION

Traditional transportation network in several countries is outdated and only few new roads have been recently constructed. Traditional roads were designed to meet the traffic characteristics requirements typical of the period in which they were constructed. Unfortunately, those characteristics are very different from the present ones, and those roads could be not adequated to support high speed modern vehicles and large volume of passenger vehicles. As a consequence, safety and road efficiency are issues to be accurately accomplished.

To this aim, the development of Intelligent Transportation Systems (ITS) is supported by several national governments. The European Council in the directive 2010/40/EU [1] defines them as advanced applications of information and communication technologies to the road transport sector in order to improve environmental performance, energy efficiency, safety and security of road transport, including the transport of dangerous goods, public security and passenger and freight mobility. Consequently, in this context communications between vehicles and infrastructure and between vehicles themselves play a very important role.

Focusing the attention to the inter–vehicle communications, to be reliable, they need short delays due to the high traveling speeds of vehicles [2]. Furthermore, this extremely mobile context does not allow the use of a traditional communication infrastructure based on base stations, but it is more suitable to adopt a peer–to–peer ad hoc network topology.

Several national and international standard authorities have carried out many attempts in order to develop a wireless communication standard especially designed for vehicles. The most important developed standard is the IEEE 802.11p, also known as Dedicated Short-Range Communication (DSRC), intended for vehicular ad-hoc networks (VANETs). Currently this is the only standard with support for direct vehicle-to-vehicle (V2V) communication. In USA the Federal Communications Commission has allocated 7 10 MHz-wide channels in the band 5.850-5.925 GHz [3]. At these frequencies the Doppler effect cannot be neglected, especially if the vehicles are traveling at a very high speed. This is the main reason because the research community is investigating the opportunity to use spectrum bands at lower frequency. Moreover this choice allows the extension of the communication range.

The hypothesis of using spectrum bandwidth at lower frequency is difficult to pursue because the spectrum resource at that frequency is overcrowded. In fact, the development in wireless communication is always followed by the increasing demand of spectrum bands and the most requested bands are that located at lower frequencies. Fortunately, many studies have demonstrated that portions of the radio spectrum are not in use for significant periods of time [4], allowing to adopt a more flexible way to manage the radio spectrum resource without the necessity of a statical band allocation.

A possible solution is the development of Vehicular Dynamic Spectrum Access (VDSA) approaches. VDSA combines the advantages of dynamic spectrum access to achieve higher spectrum efficiency and the special mobility pattern of vehicle fleets [2]. In order to successfully reach this goal, the devices that implements VDSA have to be aware of the electromagnetic environment around them. As a consequence they have to be able to use *spectrum sensing* techniques in order to understand the frequency occupation around them, since the principle of non-interference has to be respected towards licensees, who maintain the priority of transmission in their licensed bands.

In literature, there are a lot of well–assessed techniques addressing this issue, such as *energy detection* [5], *cyclostationarity–based detection* [6], *matched–filtered detection* [7] and others.

Stemming from past experience of the authors in the development of power spectrum density (PSD) estimation and frequency agility methods for cognitive radio (CR) devices [8], [9], in this paper, a modified energy detection method [10], based on frequency domain analysis and originally developed for CR applications, is adjusted in order to be also effective in VDSA. It is a wide–band iterative procedure working on PSD of the acquired signal. Despite its good performance in terms of detection, it maintains some critical issues about the precision of the detected bands, in terms of starting and stopping frequencies of the revealed bands. In particular, in this paper, the improvement in detection accuracy due to the employment of a de-noising stage based on the Savitzky–Golay (SG) filter [11], instead of the previous Moving Average (MA) filter [12], whose computational simplicity is generally counterbalanced by a worse capability of keeping the signal edges sharp, is analyzed.

II. PROPOSED SPECTRUM SENSING METHOD

Let *B* the frequency interval of the radio spectrum under analysis and available for supporting several wireless telecommunication systems. Each transmitter, having access to this spectral resource, could use different modulation techniques and operating frequencies, occupy different bandwidths inside this frequency interval.

The proposed method aimed at identifying the portions of the radio spectrum that are currently in use by a *Primary User* (PU) or by another transmitter. The input of this method is the acquired *PSD* whose shape is usually affected by high-frequency noise. Consequently the first task, that it has to accomplish, is to smooth the PSD trace in order to reduce the effect of noise and improve the sensing performance.

This preliminary operation is the subject of this paper. In its first version, to smooth the trace a moving average filter (MA) is applied and in this paper the improvement in detection accuracy due to the employment of a de-noising stage based on the Savitzky–Golay (SG) filter [11], will be studied. Some notes about the characteristics of this kind of filters will be given in the next section.

When the PSD trace has been de–noised, the method proceeds to evaluate the top level T_{lev} and the noise floor N_{fl} of the smoothed trace. After the evaluation of these two parameters it calculates the following ratio:

$$\lambda = 10log_{10}\left(\frac{T_{lev}}{N_{fl}}\right), \quad (1)$$

if λ is greater than a proper threshold λ_{th}, the algorithm proceeds with the next steps, otherwise it stops and does not provide any detected occupied bandwidth because T_{lev} is too close to N_{fl} , thus making the sensing procedure unreliable.

In case of success, the algorithm identifies a suitable threshold T_h for the occupied bandwidth estimation: it is selected as the median value in the $[N_{fl}, T_{lev}]$ interval.

A certain bandwidth (f_{start}, f_{stop}), inside the spectrum of interest, is said to be occupied if :

$$\forall f_i \in [f_{start}, f_{stop}[, S_x(f_i) \geq T_h \quad (2)$$

where $S_x(\cdot)$ is the de-noised *PSD* trace of the received signal.

In the next step the proposed method replaces the *PSD* amplitude in the frequency interval, previously detected as occupied, with an amplitude value equal to N_{fl} in the following way:

$$\forall f_i \in [f_{start} - B_g, f_{stop} + B_g[, S_x(f_i) = N_{fl}; \quad (3)$$

where B_g is a proper guard interval, to be sure that even the signal tails can be neutralized.

Over the modified PSD, the same algorithm still runs for its second iteration, in order to discover new users, whose amplitude was too low to be detected with the threshold T_h, obtained in first iteration.

So a new T_{lev} is evaluated, while N_{fl} can be considered constant in all iterations, (1) is computed again and compared with λ_{th}.

The stop condition for the algorithm is:

$$\lambda \leq \lambda_{th} \quad (4)$$

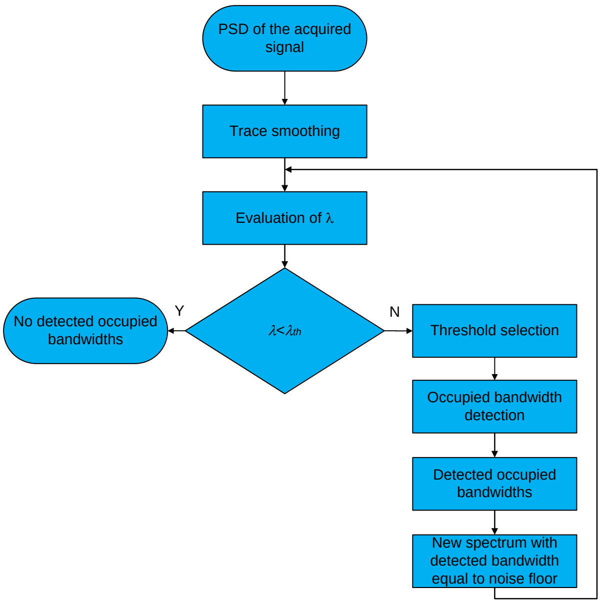

Fig. 1. Flow–chart of the operations executed by the proposed spectrum sensing method

whose meaning is that no further users are present, so T_{lev} is evaluated only on noise values and, consequently, it definitely approaches N_{fl}.

In Fig. 1 a flow-chart of the operation executed by the proposed algorithm is sketched.

III. THEORETICAL BACKGROUND

A. *Moving Average (MA) linear filter*

The MA linear filter [12] is well–known for its simple implementation and low computational cost, well–desired features for low complexity devices as cognitive radios. The filter shows some other important peculiarities: it is able to reduce random noise and to keep a sharp step response. In its linear variant, the only degree of freedom is the window length. It accomplishes two main operations: the average of the points included in the window and the one-bin-right shift to move the window forward and repeat the operation on new points of interest. Because of its procedures, it presents two disadvantages: the resulting array is shorter than the input one and the position of the points is right-shifted by the half of the moving window length. There is a trade–off in using this kind of filter: the wider the length, the more is noise reduction, the less is the sharpness of the edges, which are subjected to be deformed. On the other way around, if a shorter window length is chosen, the sharpness is well–kept while noise is less reduced, such that the effectiveness of the filter is negligible. For VDSA's applications, it is important to keep very sharp edges to be as more precise as possible in detecting the occupied bands in the spectrum portion of interest; at the

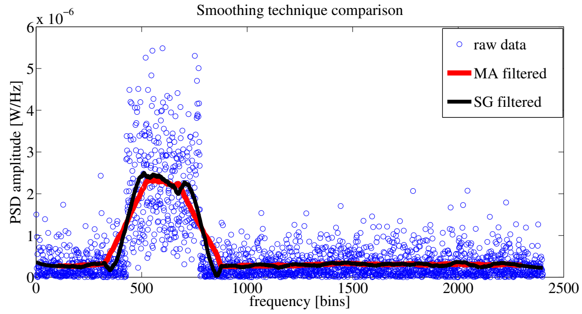

Fig. 2. Comparison between the considered data smoothing methods

same time, a strong noise reduction allows to detect signals even in very low SNRs (signal to noise ratios).

B. *Savitzky–Golay (SG) filter*

The SG filter [11] is a method for data smoothing, based on polynomial approximation of the raw data in a fixed data window. Due to its nature, a SG filter has two degrees of freedom: the polynomial order and the window length. The first parameter allows the smoothed data to best follow the raw data, with the advantage of retaining the edges and the disadvantage to follow noise fluctuations, too. The second degree of freedom, the window length, has the advantage, if wide, to neutralize the high-frequency noise contribution, whose fluctuations are smoothed by the polynomial fitting; on the other hand, a wide window is very risky because of the opportunity to smooth narrowband signals inside the spectrum of interest and, consequently, the impossibility of detecting them. From an analytical point of view, for a given *n*-degree-polynomial, the algorithm looks for the best *n + 1* polynomial coefficients in order to best fit the raw data, and evaluates the result in the window center point. In order to maintain symmetry, window length must be odd, so that the evaluation point has as many points on its left as those ones on its right. The window is then one-bin-right shifted and then the approximation method restarts, by finding new coefficients and still evaluating the resulting polynomial in the center bin. In the choice of best coefficients, a *Least Mean Square* algorithm is applied. It is possible to show that such approach gives the same results than considering a tantamount impulsive response of a proper low pass filter. In such a way, the computational complexity becomes lower, because the impulsive response can be once calculated *a priori*, and just a convolution with the entry data needs to be evaluated. In Fig. 2, M-A and S-G filtered capabilities have been shown. The graphic shows the major ability to retain edges by S-G, while M-A is able to keep more flattened levels.

Table 1. Testing scenarios

No. of scenario	No. of users	f_{C_1} [bins]	B_1 [bins]	f_{C_2} [bins]	B_2 [bins]
1	1	300	50	-	-
2	1	600	350	-	-
3	1	900	650	-	-
4	1	1200	950	-	-
5	2	250	100	2000	200
6	2	300	200	1800	400
7	2	350	300	1600	600
8	2	400	400	1400	800

IV. EXPERIMENTAL RESULTS

A. Simulation environment

Here just simulation tests have been performed and the relative results are discussed. As simulation software, MATLAB™ has been employed: some test scenarios have been realized and the iterative spectrum sensing algorithm has been tested over them, by employing both M-A and S-G filters, in order to make a comparison between the obtained performances.

B. Scenarios' description

To perform tests, 8 different scenarios have been realized, each one characterized by 6 different SNRs, ranging from -20 dB to 5 dB, with a 5dB–step. An Additive White Gaussian Noise (AWGN) has been considered. The aim of the authors is to simulate real scenarios, by taking into consideration many possible users interfering in automotive scenarios. The most common interfering sources to meet are network signals, such as GSM, GPRS, UMTS, DVB–T, and wireless microphones signals. Moreover, as Table 1 shows, testing scenarios differ also for the number of user present in the available spectrum: one user (from 1 to 4) and two users (from 5 to 8). f_{C_1} is the carrier frequency of the first user and f_{C_2} is the carrier frequency of the second user. B_1 are B_2 the signal bandwidth of the first and second user, respectively.

C. Figures of merit

The evaluation of performances is based on four figures of merit:

1. ***Correlation coefficient** (ρ)* : it is described, for two given vectors X and Y, as follows:

$$\rho(X, Y) = \frac{\mathbf{Cov}(X, Y)}{\sqrt{\mathbf{Var}(X)\mathbf{Var}(Y)}}. \quad (5)$$

   It is useful to test and give a numerical value to likelihood between two different vectors: in this work, it is tested to estimate the goodness of filtering over a noisy signal, as it will be described in simulation results.

2. ***No Detection Bandwidth** (Γ)*: evaluated as the percentage ratio between the number of times the sensing method is not be able to detect an occupied bandwidth and the total number of tests. This figure of merit has been designed to verify the ability of the sensing method to detect signals also in very noisy environment.

3. ***False Detection** (Δ)*:

$$\Delta = \frac{1}{N_d} \sum_{i=1}^{N_d} \frac{B_i}{B_{free}} 100\% \quad (6)$$

   where N_d is the number of times the sensing method has detected at least one occupied bandwidth, B_{free} is the frequency interval that is not currently occupied by a PU and B_i is the sum of the frequency bins overcoming in B_{free}. This figure of merit has been designed to test the ability of the sensing method to detect only the bandwidth really occupied by users.

4. ***Edge Detection Error** (ε)*: evaluated as the difference between the estimated start and stop frequencies of the user bandwidth and the true edges, as imposed in scenarios' generation.

D. Numerical results

As first step in comparison procedure between SG and MA filters, it has been implemented filtering procedure with both methods in which their key parameters, described in Section B, were variable in a particular range, as described in Table 2:

Table 2. Parameter variability for filtering simulation

Filter type	Parameters	Min Value	Max Value	Step Value
MA	Window length	40	1200	30
SG	Window length	41	1201	30
	Polynomial order	1	5	1

To evaluate the goodness of the filtering procedure, the first figure of merit has been evaluated. In particular, for each scenario and each SNR, the correlation coefficient between the filtered spectrum and the original signal, with no AWGN added, has been evaluated. As an example, in Fig. 3, two different scenarios have been considered aiming to analyze the behaviour of filters in various conditions. In order to allow a coherent comparison, the same SNR (-5 dB) has been considered for both scenarios (2 and 6, respectively).

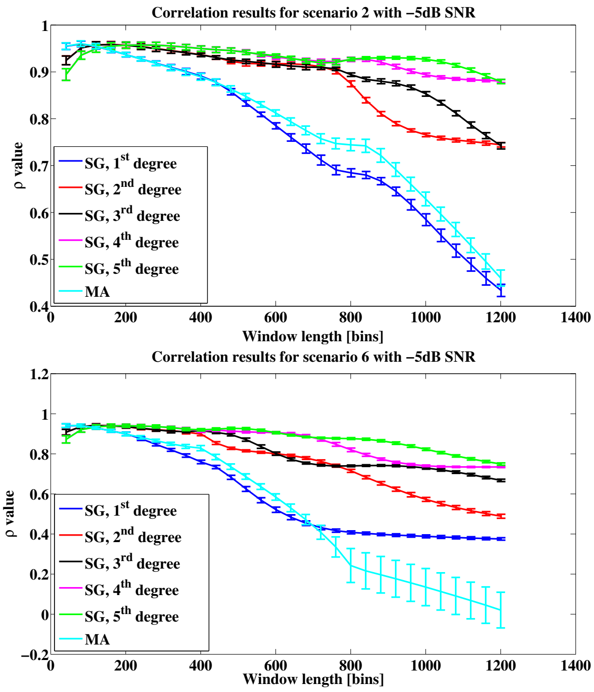

Fig. 3. Correlation results for filtering simulation

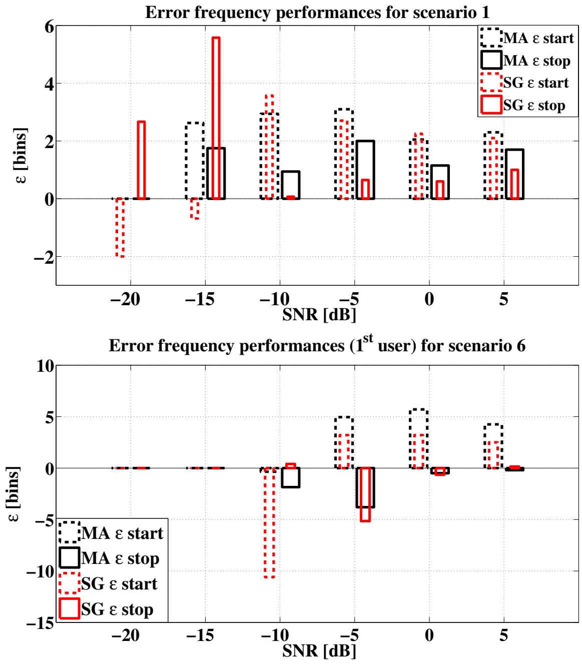

Fig. 4. ε results for first user in some scenarios

The above figures show that, for a short window length (less than 100 bins) all filter configurations report high correlation coefficients, very close to 1 while, for wider windows, only higher degree polynomial still show good performances, with a correlation coefficient greater than 0.8. The standard deviation for each values is still plotted, as vertical bar over the average value: it is possible to highlight that MA filter is less stable than SG approach, especially for wide window lengths, in scenarios with more than one user.

E. Performance assessment

The sensing algorithm works with the best combination of window length and polynomial order, for SG approach, and with the most valuable window length for M-A filter, both obtained from correlation analysis, as shown before. So, for every scenario, the spectrum sensing is accomplished by filtering the PSD of the acquired signal with the described filters. Please note that the best values are obtained scenario by scenario, SNR by SNR, so they are not general for all possible spectrum conditions.

In the following figures, results are shown for two scenarios characterized by a different number of users. In particular, they show the ε figure of merit, whose improvement is the main aim of this work.

As you can see, generally, SG improves the performances in terms of frequency error, especially in higher SNR, from -5 dB to 5 dB. This is an interesting consideration because when we are in situations characterized by lower SNR, the main goal is to detect the presence of a user, while the accuracy in starting and stopping frequency is less critical because of the major difficulty in detecting user in a strong noisy environment. On the other hand, for higher SNRs, when detection is an easier operation, it is fundamental to correctly estimate the edges of the detected bands, in order not to interfere with licensed users. According to this statement, SG seems to follow this direction, as shown in Fig. 4 and in Fig. 5. It is important to highlight that, in Fig. 5, for low SNRs, the M-A approach does not provide any detection of the weaker user while S-G aided method does. That is the cause of 0-error in M-A for some SNRs, since error cannot be evaluated if detection is not provided. So, in such cases, not only we have an improvement in terms of correct detection but, also, the possibility to detect users, otherwise undetectable for their high noise corruption level.

V. CONCLUSIONS

In this paper, the authors aimed to analyze the employment of the Savitzky–Golay as smoothing filter in cognitive radio. Even if widely used in biomedical analysis, it is quite new in cognitive radio's field, such that very few literary references are present about it. The results attained highlight that, compared with the popular Moving Average linear filter, the Savitzky–Golay could improve the performances in cognitive radio spectrum sensing with respect to the capability of detect signal edges with the minimum frequency error. By using the best combination for each scenario and every SNR, the spectrum sensing algorithm

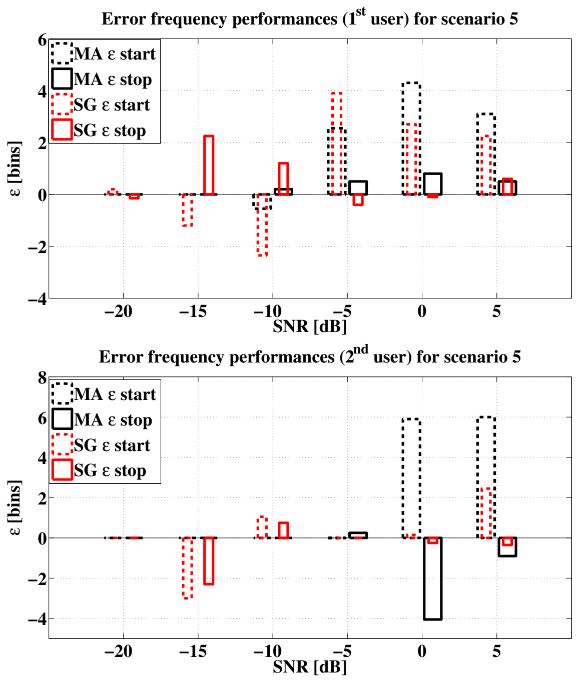

Fig. 5. ε results for first and second user in scenario 5

has been run with both filtering methods. Performances give evidence about the goodness of Savitzky–Golay filter in such applications.

REFERENCES

[1] European Parliament and Council of the European Union, "Directive 2010/40/EU – on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport," Brussels, pp. 1–13, July 2010.

[2] S. Chen, "Vehicular Dynamic Spectrum Access: Using Cognitive Radio for Automobile Networks," Ph.D. dissertation, Worcester Polytechnic Institute, 2012.

[3] D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments," in *proc. of IEEE Vehicular Technology Conference, 2008. VTC Spring 2008.*, May 2008, pp. 2036–2040.

[4] T. Taher, R. Bacchus, K. Zdunek, and D. Roberson, "Long-term spectral occupancy findings in Chicago," in *proc. of 2011 IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN)*, May 2011, pp. 100–107.

[5] S. Srinu, S. Sabat, and S. Udgata, "Wideband spectrum sensing based on energy detection for cognitive radio network," in *proc. of 2011 World Congress on Information and Communication Technologies (WICT)*, Dec 2011, pp. 651–656.

[6] S. Narieda and T. Kageyama, "Simple spectrum sensing techniques based on cyclostationarity detection in cognitive radio networks," *Electronics Letters*, vol. 49, no. 17, pp. 1108–1109, August 2013.

[7] C. Jiang, Y. Li, W. Bai, Y. Yang, and J. Hu, "Statistical matched filter based robust spectrum sensing in noise uncertainty environment," in *2012 IEEE 14th International Conference on Communication Technology (ICCT)*, Nov 2012, pp. 1209–1213.

[8] L. Angrisani, D. Capriglione, L. Ferrigno, and G. Miele, "PSD estimation in cognitive radio systems: a performance analysis," in *proc. of 19th IMEKO TC-4 Symposium Measurements of Electrical Quantities*, July 2013, pp. 543–548.

[9] ——, "A measurement algorithm for frequency agility in cognitive radio," in *proc. of 2013 IEEE International Instrumentation and Measurement Technology Conference*, May 2013, pp. 371–376.

[10] L. Angrisani, G. Betta, D. Capriglione, G. Cerro, L. Ferrigno, and G. Miele, "Proposal and analysis of new algorithms for wideband spectrum sensing in cognitive radio," in *proc. of 2014 IEEE International Instrumentation and Measurement Technology Conference*, May 2014, pp. 701–706.

[11] R. Schafer, "What Is a Savitzky-Golay Filter? [Lecture Notes]," *Signal Processing Magazine, IEEE*, vol. 28, no. 4, pp. 111–117, July 2011.

[12] S. Smith, *The Scientist and Engineer's Guide to Digital Signal Processing*, 1997, ch. Moving Average filters. [Online]. Available: `www.dspguide.com`