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Improving Radio Signal from Baghdad University Radio Telescope Using the Savitzky-Golay Filter

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Abstract

Astronomical radio observations from a small radio telescope suffer from various types of noise. Hence, astronomers continuously search for new techniques to eliminate or reduce such noise and obtain more accurate results. This research investigates the impact of implementing the Savitzky-Golay filter on enhancing radio observation signals retrieved from the Baghdad University radio telescope (BURT). Observations from BURT were carried out for different Galactic coordinates, and then a MATLAB code was written and used to implement the Savitzky-Golay filter for the collected data. This process provides an assessment of the ability of the filter to reduce noise and improve the quality of the signal. The results of this research clearly showed that applying the Savitzky-Golay filter reduces the noise and enhances the signal of astronomical radio observations. However, the filter should be used appropriately to preserve the original features of the signal. In conclusion, the filter is considered an efficient tool for enhancing the radio signal by reducing the noise and smoothing the signal. Therefore, the filter provides a substantial contribution and improvement to the field of radio astronomy.

Article Info.

Keywords:
Baghdad University Radio Telescope BURT, Data Smoothing, Radio Astronomy, Savitzky Golay Filter, Signal Processing.

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1. Introduction

Radio astronomy has revolutionized our understanding of the Universe by capturing and analysing electromagnetic radiation emitted by celestial objects [1]. The Baghdad University Radio Telescope (BURT) is a small radio telescope [2, 3] with a diameter 3 m, a focal length of (f=1.18 m) and an f/D ratio = 0.39. Feed is designed to operate within L band frequency from (f = 1.3 to 1.5) GHz [3, 4]. Its advanced technology and precise measurements [5] play a crucial role in unravelling the mysteries of the cosmos [6, 7]. However, the acquired radio signals are often contaminated by various sources of noise, including atmospheric disturbances, instrumental imperfections, and cosmic background radiation [8]. These noise components degrade the signal quality [9], limiting the accuracy of data analysis and the extraction of meaningful scientific information. To overcome these challenges and improve the quality of radio signals, sophisticated signal processing techniques have been developed [10, 11]. One such technique is the Savitzky-Golay filter, a digital signal technique used for smoothing or noise reduction in time series data [12]. It was developed by Abraham Savitzky and Marcel J. E. Golay in the 1960s and is widely used in various scientific and engineering fields [13]; it offers a powerful means to enhance the received radio signals [14, 15]. The filter employs polynomial regression and convolutional filtering to simultaneously reduce noise [16] and preserve important signal features, providing an optimal balance between noise suppression and signal fidelity [17]. The application of the Savitzky-Golay filter to the radio signals received by the Baghdad University radio telescope holds great promise for enhancing their quality and enabling more precise scientific investigations.

2. Methodology

The digital signal processing (DSP) Savitzky-Golay filter is a technique used for smoothing and differentiating data [18, 19]. It has various applications in various fields, such as data analysis [20], image processing, and spectroscopy [21]. The filter is named after its developers, Abraham Savitzky and Marcel J. E. Golay, who introduced it in 1964 [14, 22]. The general filter equation, as defined by Savitzky and Golay, allows for the generation of various types of filters [23], including the moving average filter [24], polynomial fit, and smoothed derivatives. The behavior of the filter can be adjusted by choosing appropriate filter coefficients [25]. The equation is as follows:

$$Y_j = \frac{\sum_{i=-m}^{i=m} C_i Y_{j+i}}{N} \quad \textbf{(1)}$$

The data consists of a set of points in this equation $[X_j, Y_j]$, j = 1, ..., n, where Xj is a variable that is independent and Y_j is the observation value. They are treated with m convolution coefficients Ci according to the expression and N represents the number of convoluting integers [14, 26].

The Savitzky-Golay filter operates on a sliding window of data points and performs convolution to compute the filtered output [27, 28]. Unlike traditional smoothing filters like moving averages, it employs a least squares polynomial fitting approach to estimate the smoothed values. The polynomial fitting is done using the least squares method [29-31], which minimizes the sum of the squared differences between the actual data points and the fitted polynomial curve [32]. Increasing the window size considers more neighboring data points, resulting in better smoothing but with a potential loss of fine details [33]. Similarly, increasing the polynomial order allows for a more flexible fitting, but excessive order selection can lead to overfitting or signal distortion.

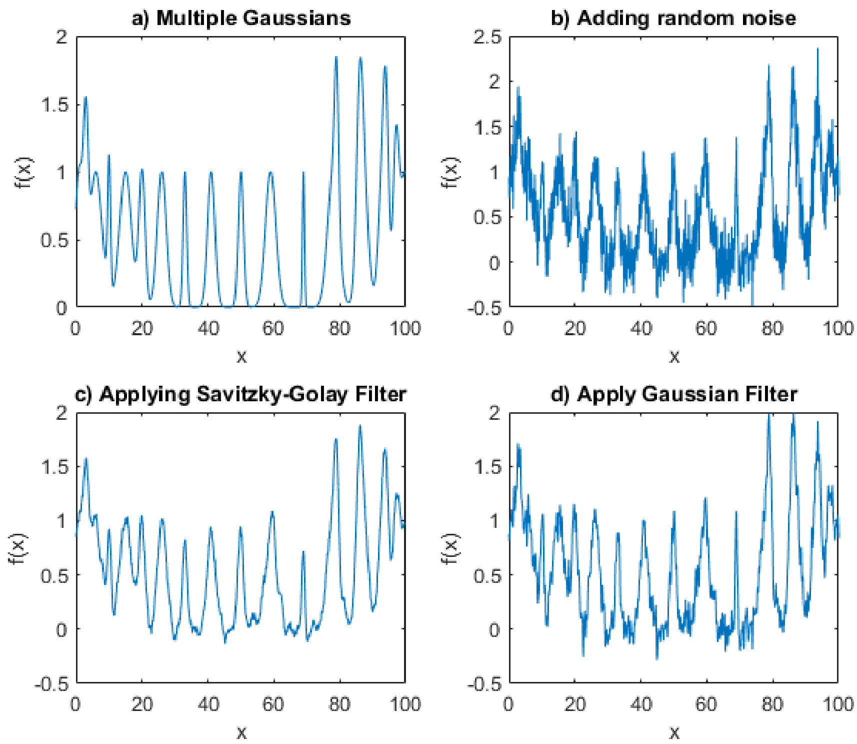

Figure 1: Applying the Savitzky Golay filter and the Gaussian filter to multiple Gaussians.

Before applying the filter to the observations obtained from BURT, the filter was applied for a multiple Gaussian function, which is given by the following formula:

$$f(x) = \sum_{i}^{n} A_i e^{-\left(\frac{(x-B_i)^2}{2C_i^2}\right)} \quad (2)$$

where: n is the number of peaks (Gaussians) and A_i, B_i, and C_i are the amplitude, the position on the horizontal axis and Full Width at Half Maximum, respectively, of each individual peak (Gaussian), as shown in the upper left panel of Fig. 1.

Random noise was added to the original function, as one can notice in the upper right panel of Fig. 1. Finally, the Savitzky-Golay and Gaussian filters were implemented for the noisy function; the results are presented in the lower panels of Fig. 1, and the noise was removed successfully. When the filter was used, there still was a difference between them, although they have the same window size for each; it is noticeable the signal-to-noise ratio (SNR) for the Savitzky-Golay filtered signal was (0.01 dB), and the SNR for the Gaussian filtered signal was (-0.18 dB) for this small compare can the Savitzky Golay more effusion.

3. Results and Discussion

This study aimed at improving the radio signal obtained from the BURT in the first three months of 2023 (January, February, March, and April), which are the most suitable time for observation at Galactic coordinates ($0 \leq l \leq 90$) and ($b = 0$) [34] where b and l are the galactic latitude and longitude, respectively. The spectrometer parameters of optimum values of the radio telescope used in this work are frequency sweep time, Video Band Width (VBW) span, and center Resolution Band Width (RBW). The values of those parameters are listed in Table 1.

Table1: Selecting spectrometer parameters values.

Center frequency	Sweep time(s)	Vbw	Span	Sweep perc n=0 a=1	Rbw	Atten(dbm)	Preamp on=1 off=0
1.42e+09	30	1000	1e+07	0	1000	0	1

To achieve the goal of this research, a function in MATLAB called "sgolayfilt" [35, 36] was used [37]. This function represents the Savitzky-Golay filter tool to smooth the collected data [38]. The purpose was to evaluate the effectiveness of the filter in enhancing signal quality while also considering its potential disadvantages [39, 40]. This digital signal processing technique is known for its ability to smooth time series data by fitting a polynomial within a moving window [41, 42]. The choice of the window length significantly impacts the performance of the filter. Experiments were conducted with window lengths ranging from 5 to 15 data points. After careful visual inspection and quantitative analysis, it was found that shorter window lengths tended to over smooth the data, blurring important signal features, while longer window lengths failed to suppress noise adequately; following a thorough evaluation, it was determined that a window length of 11 provided the optimal compromise, effectively attenuating noise without sacrificing crucial signal details. The polynomial degree determines the complexity of the polynomial fitted within each window; a higher degree offers greater flexibility in capturing intricate signal variations but increases the risk of overfitting noise. Conversely, a lower degree may fail to capture the nuances of the signal. To address this, polynomial degrees ranging from 1 to 3 were explored, while higher

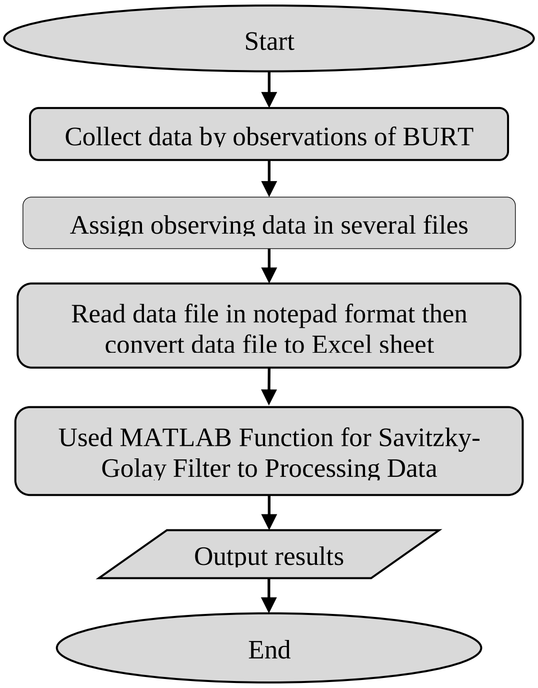

Figure 2: Block diagram represents the processing by the Savitzky-Golay Filter.

degree polynomials initially seemed promising in capturing fine-scale features; they often introduce unwanted oscillations, particularly near sharp transitions in the signal. Ultimately, a second-degree polynomial struck the ideal balance, effectively smoothing the data while preserving signal integrity.

The application of the Savitzky-Golay filter to the radio signal data resulted in noticeable improvements. The observation and processing steps are illustrated in Fig. 2.

Firstly, the filter reduced high frequency noise components present in the data [43]. A smoother signal the noise reduction is evident in visual inspection of the data as the fluctuations and random difference were obviously reduced, as shown in Fig. 3.

Secondly, the Savitzky-Golay filter saves the essential features and characteristics of the original signal while reducing noise [44]. This is crucial in radio astronomy during the smoothing process. The filter achieved a good balance between them, as seen in Fig. 4. Moreover, applying the Savitzky-Golay filter resulted in an improvement in the SNR [45, 46]. The reduced noise allowed for the detection of weaker signals from the data, as seen in Fig. 5. This enhancement in the SNR is particularly valuable in radio astronomy, where faint signals from celestial sources need to be distinguished from the background noise.

However, it is important to note some potential disadvantages of the Savitzky-Golay filter. One limitation is the trade-off between noise reduction and signal distortion depending on the choice of filter parameters [47], such as the window size and polynomial order [48]. There is a possibility of smoothing the data, which can lead to the loss of important signal features or the introduction of artificial artefacts; therefore, careful selection of these parameters is essential to strike the right balance between noise reduction and signal fidelity. Another consideration is the computational complexity of the Savitzky-Golay filter, particularly for large datasets [49]. The filter requires a substantial computational resource [50], which can be time-consuming especially when processing extensive radio signal data. Efficient implementation strategies and optimization techniques may be necessary to mitigate these computational challenges. Utilizing the Savitzky-Golay filter on extensive datasets, particularly in radio astronomy, requires careful computational planning to streamline the process techniques, such as parallel processing, optimized parameter selection, preprocessing incremental filtering, and hardware acceleration can be employed. These methods effectively handle the computational workload, rendering the filter suitable for large-scale applications in radio astronomy.

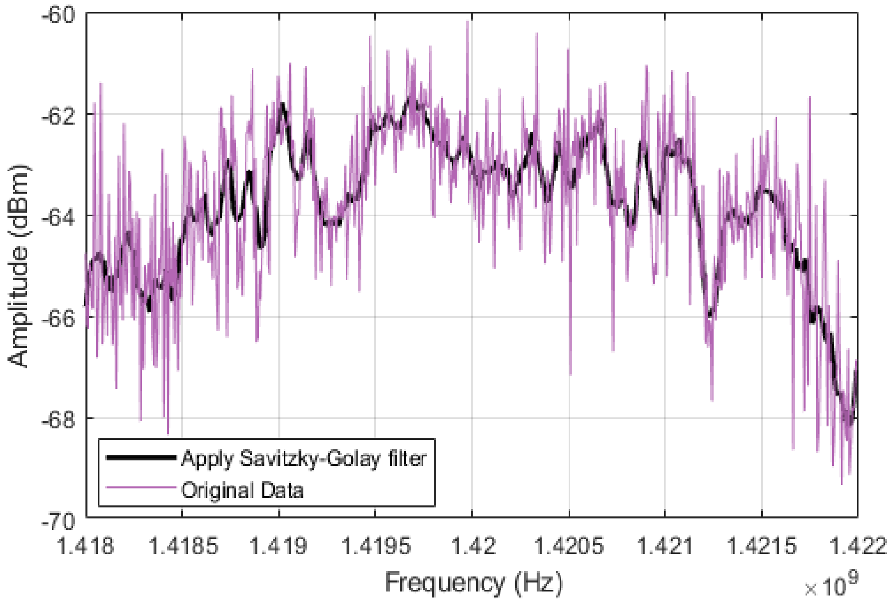

Figure 3: BURT Data at b = 0^o and l = 20^o.

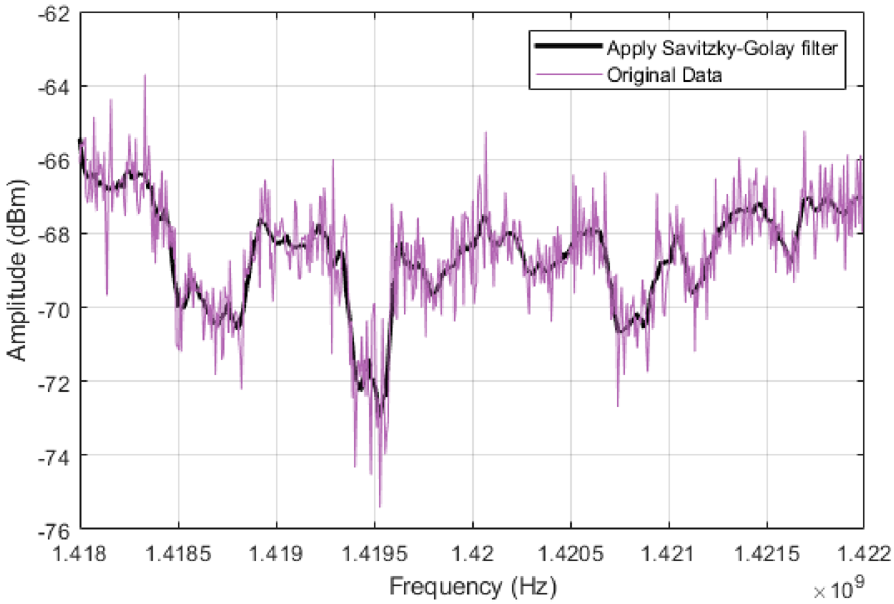

Figure4: The data at b = 0^o and l = 50^o.

4. Conclusions

The fundamental goal of this research was to examine the ability of the Savitzky-Golay filter to improve the radio signal from BURT. Before applying the filter to the astronomical observations from BURT, an experiment using a MATLAB code was performed to demonstrate the filter's ability to eliminate noise. A function of multiple Gaussians was defined, random noise was added to the original function, and finally, the filter was applied to the noisy function. The filter successfully eliminated the noise in this experiment, which was encouraging. Then the Savitzky-Golay filter was implemented on observational data from BURT, and the results showed that the filter successfully refined the data by decreasing noise and enhancing signal quality. Despite its user-friendly and adaptable nature, it is essential to meticulously select parameters to achieve a harmonious balance between noise reduction and preserving intricate details. Ultimately, the Savitzky-Golay filter proved to be a valuable asset for elevating data analysis and interpretation within the field of radio astronomy. In conclusion, the implementation of the Savitzky-Golay filter to enhance the radio signal from the BURT yielded promising outcomes.

Conflict of interest

Authors declare that they have no conflict of interest.

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تحسين إشارة الراديو من تلسكوب جامعة بغداد الراديوي باستخدام مرشح سافيتسكي-غولاي

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الخلاصة

تعاني بيانات الرصد من تلسكوب راديوي صغير من أنواع مختلفة من الضوضاء. لذلك، يبحث علماء الفلك الراديوي بصورة مستمرة عن تقنيات جديدة لغرض إزالة هذه الضوضاء أو تقليلها من أجل ضمان الحصول على نتائج أكثر دقة. يتضمن هذا البحث التحقق في تأثير تطبيق مرشح سافيتسكي-غولاي على تحسين اشارة الارصادات الراديوية المستحصلة من تلسكوب جامعة بغداد الراديوي (BURT). وبالتحديد، تم اجراء الارصادات باستخدام BURT لاحداثيات مجرية مختلفة ومن ثم تم كتابة برنامج ماتلاب واستخدم لتطبيق مرشح سافيتسكي-غولاي على البيانات التي تم جمعها. هذه العملية تعطي تقييم على مقدرة المرشح لتقليل الضوضاء وتحسين جودة الاشارة. نتائج هذا البحث بينت بصورة جلية ان تطبيق مرشح سافيتسكي-غولاي يقلل من الضوضاء ويحسن اشارة الارصادات الراديوية الفلكية. على اية حال، المرشح يجب ان يستخدم بطريقة مناسبة من اجل المحافظة على الخصائص الاصلية للاشارة الراديوية. يستنتج من هذا البحث ان مرشح سافيتسكي-غولاي هو اداة فعالة لتحسين الاشارة الراديوية. لذلك فهو يضيف مساهمة وتطوير فعالين لتخصص الفلك الراديوي.

الكلمات المفتاحية: تلسكوب جامعة بغداد الراديوي (BURT)، تنعيم البيانات، علم الفلك الراديوي، مرشح سافيتسكي جولاي، معالجة الإشارات، التلسكوب الراديوي.