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Authors: Hang Yang, Liang Dong, Lesheng He, Lesheng He

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Abstract

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Full Text

Preamble

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Article

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Assessment of Radio Observatory Sites Using a Multi-Threshold Algorithm

Hang Yang¹, Liang Dong^{2,3}, Lesheng He^{1*}

¹Yunnan University, Kunming 650500, China

²Yunnan Province China-Malaysia HF-VHF Advance Radio Astronomy Technology International Joint Laboratory, Yunnan Observatories, Chinese Academy of Sciences, Kunming 650216, China

³Yunnan Observatories, Chinese Academy of Sciences, Kunming 650216, China

*Correspondence: he_{lesheng}@263.net

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Abstract: The radio environment plays a crucial role in radio astronomy observations. Further analysis is needed on the time and intensity distributions of interference signals for long-term radio environment monitoring. Sample variance is an important metric for determining the interference signal decision threshold. Here, we propose an improved algorithm for calculating data sample variance that relies on four established statistical methods: the variance of trimmed data, winsorized sample variance, median absolute deviation, and median of trimmed data pairwise averaged squares. The variance and decision threshold in the protected section of the radio astronomy L-band are calculated. Among the four methods, the improved median of trimmed data pairwise averaged squares algorithm demonstrates higher accuracy, but in a comparison of overall experimental results, the cleanliness rate of all algorithms exceeds 96%. In a comparison between the improved algorithm and the four baseline methods, the cleanliness rate of the improved algorithm exceeds 98%, verifying its feasibility. The time-intensity interference distribution in the radio protection band is also obtained. Finally, we use comprehensive monitoring data from radio astronomy protection bands, radio interference bands, and interfered frequency bands to establish a comprehensive evaluation system for radio observatory sites, including the observable time proportion in the radio astronomy protection band, the occasional time-intensity distribution in the radio interference frequency band, and the intensity distribution of the interfered frequency band.

Keywords: Radio astronomy; Electromagnetic environment; Threshold algorithm; Cleanliness rate

1. INTRODUCTION

Radio astronomy studies and analyzes electromagnetic waves emitted by cosmic objects to obtain information about them, operating at frequencies far lower than the visible light band. Celestial bodies vary in the electromagnetic waves they emit across different bands, with these emissions corresponding to distinct physical mechanisms in their progenitors. Through the analysis and study of these physical mechanisms, radio astronomy has discovered many previously unknown cosmic phenomena and produced numerous important theories that explain various physical processes. So far, there have been several major discoveries related to radio astronomy, such as research on the mechanism behind interstellar molecular line emission, which won the Nobel Prize in Physics in 1964; the discovery of pulsars and integrated aperture radio telescopes, which won the 1974 Nobel Prize in Physics; the discovery of cosmic microwave background radiation, which won the Nobel Prize in Physics in 1978; and the detection of cosmic microwave background anisotropy, which was awarded the 2006 Nobel Prize in Physics.

Because radio telescopes observe weak radio signals from the universe, radio astronomy observations are vulnerable to electromagnetic interference, both from the telescope itself and the surrounding environment. There are several key considerations to ensure normal operation of radio telescopes: managing frequency allocation in the spectrum in accordance with International Telecommunication Union (ITU) regulations; building observatories in sparsely populated areas to avoid interference; delimiting electromagnetic environmental protection areas to reduce interference sources; and using interference reduction methods to separate observed and interfering signals. Combined, these measures can ensure stable operation of telescopes and support radio astronomy research.

Electromagnetic interference is any electromagnetic signal that causes the performance of radio telescope equipment to decline, reducing the signal-to-noise ratio of observations and contaminating the observed data. Typically, observations that contain unwanted signals must be abandoned and the contaminated data deleted, which, according to ITU Recommendation ITU-R RA.1513, effectively results in the loss of observation time. For interference estimation and determination of time loss rate between different industries, the ITU provides a series of recommendations. For radio astronomy services, among others, ITU-R RA.1031 proposes that observation time loss should not exceed 2% of the ITU-R RA.769 limit value, and ITU-R RA.1513 proposes that the time loss rate caused by lumped interference of multiple active services should not exceed 5%.

The 40-m radio telescope of the Yunnan Observatories, Chinese Academy of Sciences (YNAO), is an important radio astronomy observation instrument in China. Radio telescopes are susceptible to radio frequency interference (RFI) be-

cause of their technical and operational characteristics, both from the telescope's own equipment and from the surrounding environment. To ensure proper operation of the telescope, it is possible to implement a “quiet area” free of electromagnetic waves, analyze the observation data, identify RFI patterns, and avoid or remove interference during observations. Sample variance can be an indication of an RFI anomaly. In this study, four statistical methods—variance of trimmed data (VTD), winsorized sample variance (WSV), median absolute deviation (MAD), and median of trimmed data pairwise averaged squares (MPAS)—are used to calculate variance estimates and decision thresholds for different frequency bands. These algorithms help mitigate RFI issues in radio astronomy and enable real-time processing. Considering that there may be outliers in the data, an improved algorithm labeled New Variance Estimation (NVE) is also proposed. The purpose of this study is to find a stable variance estimation method with the help of these algorithms and then characterize the interference distribution in the radio protection frequency bands.

2.1. System Composition

The hardware in our system comprises an HL050 antenna, a low-noise amplifier, a voltage regulator power supply, an FSU26 spectrometer, and a computer (see [Figure 1: see original paper]). The signal collected by the HL050 antenna is amplified by the low-noise amplifier and then transmitted to the FSU26 spectrometer for conversion into a spectrum. The data are then transmitted to the computer for display and storage. The stabilized power supply provides stable voltage to the amplifier to ensure the accuracy of the data.

The frequency range and polarization mode are controlled using the LabView software package that displays information such as observation direction, polarization information, integration time, starting frequency band, scanning point, and storage data format. During the process, the real-time average value and the maximum value are set for the spectrum analyzer, which are essential for subsequent data processing. On the operator side, the system uses the LabView graphical programming software and common interface bus control protocol for system control, test data reception, and data storage. The main user interface ([Figure 2: see original paper]) of the computer software contains three displays showing real-time observational data and can be divided into three sections from top to bottom. The upper right section (“Basic Parameter Setting”) displays—and allows the user to define—input parameters for reading data. The middle section is the real-time “waterfall chart” display area, separated into the “Average value” waterfall chart (left) and “Maximum value” waterfall chart (right). The third section, at the bottom, is the real-time spectrum display area, in which the red spectrum line is the maximum value spectrum (“Maximum spectrum”), and the blue spectrum line is the average value spectrum (“Average spectrum”). After setting the basic parameters, the user clicks on the “Start” button to start observation and data recording.

In the LabView software, the starting frequency of the test band, polarization

mode, resolution bandwidth, integration time, and execution times can be adjusted, and the collected signal can be saved as a preset for data processing and analysis. Technical specifications of the testing equipment are given in .

**** Test equipment and parameters

Equipment	Model	Frequency range	Technical specifications
R&S logarithmic periodic antenna	HL050	20 Hz–26.5 GHz	Standing VSWR*: \$ \$2.5, gain/dBi: 8–8.5
B&Z low noise amplifier	BZ-0218-201030-202525	-	Standing VSWR*: \$ \$2.5, gain/dBi: 30
R&S FSU26 spectrometer	RS- HL050	-	Phase noise: 137 dBc/Hz

*Voltage Standing Wave Ratio

2.2. Monitoring Process

The test site was that of the YNAO, located east of Kunming on Fenghuang Mountain (25°01 48.538 N, 102°48 14.180 E), Yunnan Province, mainly for the L-band test. The system frequency range was 1–2 GHz and the frequency sweep width of the spectrometer was set to 5,000 MHz. The display bandwidth and resolution bandwidth of the spectrometer were set to 300 kHz, and the scanning time was 30 s. This test was divided into two parts: a day test and a night test. The first part took place between 10 a.m. and 8 p.m., and the second part was from 10 p.m. to 8 a.m. A total of 16 datasets were recorded, each lasting for 10 hours.

3. ALGORITHM ELABORATION

This section describes the selection of variance estimates in the VTD algorithm, the WSV algorithm, the MAD algorithm, and the MPAS algorithm and introduces our original algorithm for improved variance stability estimation. There are different ways to judge the stability of variance estimates. Assuming a distribution function $F(x)$ and a population X determined by this distribution function, then the estimated value $T(x, F)$ is a function related to $F(x)$. If the estimated value X is moderately affected by $F(x)$ variations within a certain range, then $T(x, F)$ will not fluctuate markedly. From the perspective of the functional relationship, if the dependence of $F(x)$ on $T(x, F)$ variations is continuous and smooth, then this estimated value $T(x, F)$ is usually labeled

as “relatively robust” in theoretical analysis. Because the variance estimation is used to judge the threshold value, the Friedman test and two additional stability metrics are used for the calculations.

3.1. VTD Algorithm

The VTD algorithm sets the test data samples as random samples and sorts them in ascending order. The sample pruning variance is calculated by shifting the data by the difference between the maximum and minimum values (i.e., index translation by $2k$) and using the remaining data samples. The variance estimate of the trimmed data sample in the VTD algorithm is given by:

$$T_1 = K_{\text{trim}} \frac{1}{N - 2k} \sum_{n=k}^{N-k} (x_n - d_{\text{trim}})^2$$

where

$$d_{\text{trim}} = \frac{1}{N - 2k} \sum_{n=k}^{N-k} x_n$$

Here, d_{trim} is the sample average of the trimmed data. Trimming reduces the variance of the data. N is the selected data set dimension. Coefficients provide a consistent estimator of normally distributed data. In the field of communication, signal loss refers to the weakening of signal strength during transmission. The loss estimator (LOSS) is a metric that frequently needs to be monitored and minimized to improve system efficiency and performance.

3.2. WSV Algorithm

The WSV algorithm sorts the test data samples in ascending order. The ordering of the data is set to ascending order, sample data from values of x_k , sample data between unchanged, and sample data with values greater than are set to mean and variance are estimated using the mean defined, yielding a modified sample. Even if the data sample is already sorted correctly, its variance estimate T_2 is defined as:

$$T_2 = \frac{1}{n - 1} \sum_{i=1}^n (W_i - \bar{W})^2$$

where W_i represents the winsorized data values.

3.3. MAD Algorithm

The MAD algorithm sorts the samples in ascending order of their observed values without additional processing of the data samples. The calculation of the mean in the MAD algorithm is a standard mean calculation. In the Simple Thresholding algorithm, the MAD serves as the variance estimate and its calculation method is given by:

$$T_3 = \text{MAD} = 1.4286 \times \text{med}_{1 \leq i \leq n} \{|x_i - \text{med}(x_i)|\}$$

The calculation process is described as follows: (1) Calculate the median of the original population array, with the original population array defined as X_i and the median of this array defined as med ; (2) Construct a new sample array by subtracting the median med obtained in step 1 from each element in the original population array X_i , i.e., for each element X_j ($j = 1, 2, \dots, n$, where n is the number of elements in the array) in the original population array, calculate $X_j - \text{med}$, and thus construct a new sample array Y_i ; (3) Calculate the median of the newly constructed sample array Y_i , denoted $\text{med}Y$; (4) Obtain the final MAD value by multiplying the median $\text{med}Y$ of the new sample array obtained in step 3 by a constant proportionality factor of 1.4286. The purpose of this operation is to make the finally obtained MAD value consistent with the expected Gaussian distribution.

3.4. MPAS Algorithm

The MPAS algorithm uses the test data samples in ascending order, adds dislocation, and finds the mean as shown in:

$$M_i = \frac{x_i + x_j}{2}, \quad 1 \leq i \leq j \leq n$$

The median of a new sample in the MPAS algorithm is the test sample mean, given by:

$$\bar{b}_n = \text{med} \left(\frac{x_i + x_j}{2} \right), \quad 1 \leq i \leq j \leq n$$

The variance of the test sample is given by:

$$T_4 = 1.4286 \times \text{med}_{1 \leq i \leq j \leq n} \left[\frac{x_i^2 + x_j^2}{2} \right]$$

The calculation process is described hereafter. First, arrange the original data samples in ascending order and then square the data values in each sample successively. Perform a staggered addition on these squared data (for example,

add the first squared value to the second squared value, then add the second squared value to the third squared value, and proceed similarly until the last two values in the sample) and ultimately calculate the mean of the sums obtained. Through such an operation, a set of data samples can be created, with the number of data samples in this new set lower by one group than the original number of data samples. Subsequently, the median of this new set of data samples will be calculated and multiplied by a constant proportionality factor of 1.4286. The value finally obtained is the variance estimate value T_4 for this algorithm.

3.5. Algorithm Improvement

Combined with the analysis of the four algorithms described in the previous sections, the experimental results for the test data show that the MAD algorithm is a robust measurement of sample deviation for univariate numerical data, i.e., a standard used to describe the variability of univariate samples in quantitative data. The MAD is a robust statistic that adapts better to outliers in a dataset than the standard deviation. The standard deviation is calculated from the square of the distance from the data to the mean. Larger deviations have larger weights, so that the influence of outliers on the results cannot be ignored. For the MAD, a small number of outliers will not affect the outcome of the experiment. Because the median is less sensitive to outliers than the mean, it is also preferable for similar reasons that motivate choosing the MAD over the traditional standard deviation. If the data distribution is Gaussian, then the MAD value becomes similar to the standard deviation and the median similar to the mean.

Friedman emphasized that the type and intensity of radio frequency interference (RFI), together with the observation type and implementation method, are important factors in determining what to estimate. Therefore, in our experimental test, the variance estimates of the VTD algorithm, WSV algorithm, and MPAS algorithm exhibit large deviations from the mean value, resulting in large discrepancies between the algorithms in terms of outlier detection accuracy and number of detected outliers. Combined with the experimental data observed in the L-band, we propose an improved variance estimation algorithm derived from these four algorithms. Using the VTD algorithm, WSV algorithm, and MPAS algorithm to create new data samples from the original data, we then apply the MAD algorithm to estimate variance between the new datasets created by the other three algorithms. The advantage of such improvement is that the obtained variance estimate does not have a large deviation from the mean value of the algorithm, allowing the sensitivity to outliers to be better characterized. In the process of analyzing and comparing different experimental results, the optimal variance estimate for the experimental data is selected and the optimal threshold is obtained.

The specific improvement method is as follows: first, use the original VTD algorithm, WSV algorithm, and MPAS algorithm to process the test data samples.

After the processing is completed, calculate the mean value of the processing results from these three algorithms. In addition, in the VTD algorithm, WSV algorithm, and MPAS algorithm, the original variance calculation methods will be adjusted. For the calculations of the variance estimation values T_1 , T_2 , and T_4 in these three algorithms, we adopt the method of the MAD algorithm for selecting the variance estimation value. Finally, the improved NVE algorithm is obtained and yields:

$$T_1 = T_2 = T_4 = \text{MAD} = 1.4286 \times \text{med}_{1 \leq i \leq n} \{|x_i - \text{med}(x_i)|\}$$

4.1. Data Introduction

When carrying out data monitoring work, considering the actual storage capacity and the need to record a large amount of data, if the conventional linear data recording mode is adopted, there may be problems such as insufficient storage space to store the considerable amount of acquired data. To record larger volumes of data more efficiently, we decided to adopt a non-linear data recording mode. Specifically, this mode optimizes the amount of data by reducing the dynamic range of absolute data values. During the data collection process, the acquired data, expressed in dBi units, are recorded as text (ASCII) using the TXT file format. This format has strong compatibility and is easy to read and process with a variety of devices and software, which can better meet the requirements of data recording and subsequent analysis. Because the spectrometer output comprises two spectra during the test process ([Figure 3: see original paper]), we record each test dataset into two columns. The first column is the maximum retention value of the collected data, and the second column is the average data value over the scan time, which reflects the stability effect of the test system during each test. The data are stored in a logarithmic format derived from the relation $x_i = (1 \times 10^{-3}) \times 10^{\text{dBmV}/10}$, where the subsequent data processing requires linear transformation of the data.

4.2. Data Processing Procedure

The intensity of the interference signal received by a radio telescope is often stronger than that of the signal being observed, i.e., most of the observed signal can be regarded as noise; thus, when a signal strength value exceeds a certain threshold, it is regarded as RFI.

The purpose of this test is to calculate the variance and decision threshold in the radio astronomy protection band located within the radio L-band using the improved algorithm and to further characterize the temporal variations of the interference intensity distribution in the radio protection band using the following process: (1) Select a dataset from each of the 16 groups of L-band nighttime and daytime data tested, and then select a narrow spectral band with a width of 1 MHz in relatively clean regions of the radio protection band (1,400–1,427 MHz and 1,660–1,670 MHz). (2) Calculate the variance and decision threshold

of the selected 1-MHz sample of data using the improved algorithm described in Section 3. (3) After obtaining the variance and decision threshold of the data samples, compare the sensitivity to outliers of the improved algorithm with that of the original statistical methods and obtain the interference distribution in the narrow spectral band according to the decision threshold. (4) Conditioned on the completion of the previous steps, carry out further in-depth investigation using the improved algorithm on the temporal distribution of interference intensity over the full bandwidth of the radio protection band.

Subsequently, comprehensive monitoring data of the radio astronomy protection frequency band, the radio interference frequency band, and the interfered frequency band are integrated. On this basis, a comprehensive evaluation system for radio observatory sites has been successfully established. This system covers multiple key components, including the proportion of observable time in the radio astronomy protection frequency band, the distribution characteristics of occasional time-intensity in the frequency band without radio interference, and the detailed intensity distribution in the interfered frequency band.

4.3. Calculation of Variance Estimates

The variance of the sample is an important statistical estimate of RFI. The 1-MHz band selected here is centered at 1,665 MHz in the radio protection band. To process the monitored data, the initial step is a logarithmic operation. A logarithmic transform offers key advantages: it preserves data properties and correlations and compresses the variable scale (i.e., distance between extreme values or dynamic range) to stabilize data for better subsequent analysis. Notably, when constructing data analysis models, the logarithmic transform mitigates common issues such as collinearity and heteroscedasticity, enhancing model reliability and effectiveness. Therefore, it is necessary to linearize the data when calculating the variance estimate, as shown in:

$$x_i = (1 \times 10^{-3}) \times 10^{\text{dBmV}/10}$$

After the data are linearized, the variance estimate of the frequency band can be obtained using the improved algorithm defined in Equation (11). The results are shown in .

4.4. Calculation of the Decision Threshold

At present, there is no clear regulation on interference thresholds in astronomy, but the common method for outlier detection is that if any data point exceeds a value corresponding to the dataset mean + α times its variance estimate (where $0.0 < \alpha < 5.0$, with a default value of $\alpha = 3.0$), then the data (time or frequency) are considered an outlier and this value is taken as the threshold. The threshold is expressed as:

$$\text{Th} = \bar{b} + \alpha T, \quad \alpha = 3$$

where \bar{b} is the data mean, T is the data variance estimate obtained with the improved algorithm, and Th is the threshold value. While three data sample means are obtained using the VTD algorithm, WSV algorithm, and MPAS algorithm, the linear threshold of the improved algorithm is then derived (results shown in).

After calculating the linear threshold Th , it is necessary to apply its value to the monitored logarithmic data to calculate the cleanliness rate in the selected 1,665 MHz band, as defined in:

$$\text{Th}^* = 10^{-3} \log_{10}(\text{Th})$$

and obtain the final threshold result. The improved algorithm block diagram and algorithm pseudocode are displayed in [Figure 4: see original paper].

5. MEASURED RESULTS AND ANALYSIS

In this section, we discuss the results for, first, the variance values obtained with the improved variance estimation algorithm and the algorithm decision threshold selected for the data measured in the radio protection band of the L-band; then, the temporal variations of the interference intensity distribution at different frequencies in the radio protection band; and, finally, the observable time proportion in the radio astronomy protection band, the occasional time-intensity distribution in the frequency band without radio interference, and the intensity distribution in the interference bands.

First, we selected the 1-MHz radio protection band at 1,665 MHz from the 8 groups of data tested. Using our improved algorithm, we calculated the variance estimate in this frequency band and its decision threshold and derived both the cleanliness rate and the interference distribution. summarizes the variance estimates, decision thresholds, and cleanliness rates of the first two data groups in the 1,665 MHz radio protection band, during day and night, in the test data (a detailed comparison table with results from all groups is provided in the Supplementary Material). The analysis of the data in indicates that, among the new improved algorithms, compared with the VTD algorithm and the WSV algorithm, the MPAS algorithm was more sensitive to changes of relevant factors. Moreover, the sensitivity of these three algorithms was enhanced step by step from the VTD algorithm to the WSV algorithm and then to the MPAS algorithm. We found that the VTD algorithm removed the maximum and minimum data of the k group and modified the number of groups; that the WSV algorithm did not change the number of groups but modified the maximum and minimum data values of the k group; and in the WSV algorithm, the average value was calculated by dislocation addition. After comparison, the accuracy

of the MPAS algorithm was highest in an overall comparison of experimental results. The cleanliness rate of the three improved algorithms exceeded 98%, making them suitable for use.

[Figure 5: see original paper] shows the interference distribution in this band for daytime test data. It can be clearly seen from [Figure 5: see original paper] that there are additional interference points in the MPAS algorithm that are not present in the VTD algorithm and the WSV algorithm. However, some interference points that appear at the same time account for 98%. In addition, during the time periods from 10:35 to 10:56, from 14:31 to 14:54, from 18:22 to 18:42, and from 19:50 to 20:00, there was no RFI in the radio protection frequency band at 1,665 MHz in the 8 groups of daytime test data. This is of great importance for the subsequent establishment of a comprehensive evaluation system for radio astronomy observatory sites and can serve as an important evaluation criterion. Although this is only an estimation for a narrow (1 MHz width) frequency band within the radio protection frequency band, it also proves the availability of the algorithm and its high sensitivity to outliers.

shows the variance estimates, decision thresholds, and corresponding cleanliness rates for the radio protection band (1,400–1,427 MHz, 1,660–1,670 MHz). The sensitivity of the MPAS algorithm is higher than that of the VTD and WSV algorithms, but compared with the overall experimental results, the cleanliness rate of all three improved algorithms is above 98%. The results of the comparison of variance and decision threshold showed that all three algorithms were available.

[Figure 6: see original paper] shows interference distributions for the first data group within the radio protection band (1,400–1,427 MHz, 1,660–1,670 MHz) during daytime and nighttime. [Figure 6: see original paper]A–B show the results for the 1,400–1,427 MHz and 1,660–1,670 MHz subbands, respectively, during daytime. [Figure 6: see original paper]C–D show the interference distribution in both subbands, but at night. We found that within the frequency band 1,400–1,427 MHz, there were no remaining unidentified interference points when the MPAS algorithm was used to analyze the interference distribution during daytime. It was found in [Figure 6: see original paper]B–D that there are still some other interferences in the MPAS algorithm. The sensitivity of this algorithm remained better than that of the VTD and WSV algorithms, but there was not much difference overall. Moreover, since the frequency band of 1,660–1,670 MHz was less than the frequency band of 1,400–1,427 MHz, the interference in the interference distribution map seemed to be less. However, it was not difficult to find from that, in fact, the cleanliness rates of the two radio protection frequency bands were above 98%, so the interference in the two frequency bands was similar, not less in the frequency band of 1,660–1,670 MHz.

6. CONCLUSIONS

We introduced an algorithm, on the basis of the VTD algorithm, WSV algorithm, MAD algorithm, and MPAS algorithm, to estimate the variance of a sample of data and determine the RFI decision threshold in a specified frequency band, with the aim of mitigating RFI in radio astronomical observations. Firstly, the specific contents of the VTD algorithm, WSV algorithm, MAD algorithm, and MPAS algorithm are understood, and based on these four algorithms, an algorithm to determine the new variance estimate was obtained. In addition, through the above description of the improved algorithm, this paper calculated the variance and decision threshold in the L-band radio astronomical protection band, and further obtained the time-intensity interference distribution in the radio protection band, which verifies the calculation flow and feasibility of this algorithm and has certain application value. Finally, we used comprehensive monitoring data in the radio astronomy protection band, radio interference band, and interfered frequency band to establish a comprehensive evaluation system for radio observatory sites, including the observable time proportion in the radio astronomy protection band, the occasional time-intensity distribution of the radio interference frequency band, and the intensity distribution of the interfered frequency band. In future work, we intend to use the Monte Carlo algorithm to estimate the time used for observation within the radio astronomical protection band.

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AI DISCLOSURE STATEMENT

AI-assisted technology is not used in the preparation of this work.

AUTHOR CONTRIBUTIONS

Hang Yang wrote most of the manuscript, conceived the idea of the algorithm, and conducted the experiments. Liang Dong conceived the idea of the project, initiated the project, and revised the paper. Lesheng He revised the paper. All authors read and approved the final manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. Wang, S. G. 1960. *Radio astronomy*. Scientific Notification, 11(15): 458–459. (in Chinese)
2. Li, Y. 2001. Astronomical “Stars” in the Nobel Prizes. *Knowledge is power*, 8(12): 10–11. (in Chinese)
3. Lou, Y. Q. 2007. Nobel Prize in Physics 2006—Black body spectrum and anisotropy of microwave background radiation in the universe. *Physics and Engineering*, 17(1): 10–21. (in Chinese)
4. Nan, R. D., Zhang, H. Y., Zhang, Y., et al. 2016. FAST engineering construction progress. *Acta Astronomica Sinica*, 57(6): 623–630. (in Chinese)
5. Deboer, D. R., Cruz-Pol, S. L., Davis, M. M., et al. 2015. Radio frequencies: policy and management. *Transactions on Geoscience & Remote Sensing*, 51(10): 4918–4927.
6. International Telecommunications Union. 2021. RECOMMENDATION ITU-R RA. 1513-2—Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis.
7. International Telecommunications Union. 2015. RECOMMENDATION ITU-R RA. 1031-3—Protection of the radio astronomy service in frequency bands shared with other services.
8. Fridman, P. 2008. Statistically stable estimates of variance in radioastronomical mitigation. *The Astronomical Journal*, 135(5): 1810.
9. Liu, Q., Wang, K., Wang, Y., et al. 2014. Measurements of radiation characteristics of a set of electronic backend devices for radio astronomy. *Astronomical Research and Technology*, 11(3): 218–223. (in Chinese)
10. Li, S. Y., Dong, L., Le, L. Z. 2017. An automatic radio environment test platform based on LabVIEW and third-party drivers. *Electronic Test*, 34(13): 75–76. (in Chinese)

11. Rauscher, C. 2001. *Fundamentals of spectrum analysis*. München: Rohde & Schwarz GmbH & Co. KG.
12. Schoemaker, R. 2011. Removing radio frequency interference in the LO-FAR using GPUs. Amsterdam: Vrije Universiteit Amsterdam.
13. Offringa, A. R., de Bruyn, A. G., Biehl, M., et al. 2017. Post-correlation radio frequency interference classification methods. *Monthly Notices of the Royal Astronomical Society*, 405(1): 155–167.
14. Yuan, H. R. 1992. Radio astrometry of small antenna gain. *Radio Engineering*, 22(4): 50–53. (in Chinese)
15. Yuan, H. R. 1995. Measurement techniques for microwave antenna gain in radio astrometry. *Publication of Yunnan Observatory*, 33(2): 26–35. (in Chinese)

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