A spike immunity method of digital integrating radiometer signals

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Abstract. A spike immunity method of digital integrating radiometer signals in the jamming environment is described. The certain integrating algorithm selection is adaptively made. The purpose of the method is real-time signal processing, and the basic is an alternative selection of the least offset signal estimation using nonparametric "Nearest Neighbor" rule. It is assumed that the signal has a single mode probability distribution, close to normal. The additive spike-like jam makes the "tails" of the distribution "heavier" which leads to different offsets for linear and rank mean estimation on the integrating interval. The integrating interval is chosen significantly less than double bandwidth of antenna system and radiometer. For the given assumption of the sorts of signal and jam the method works faster and delivers better efficiency as compared to well known rank estimations. The extra correlation of the subsequent samples does not exceed 16%. The results of the numerical modeling and experimental method testing are given. The results show the improvement of the radiometer sensitivity by about 20–25%.

1. Introduction

The fast real-time processing of radiometer signals can be successfully implemented because of the existence of modern high performance ADC and data acquisition systems. One can successfully fight therewith the powerful spike jams, using sampling frequency 100–1000 times more than required by sampling theorem. In thas case the powerful spikes could be easily discarded by threshold processing. However things become complicated if the spikes power gets to be comparable to the noise signal variance. Articles (Erukhimov et al. 1988; 1990) hawe shown the reasonability of using robust methods for raw radiometer data compression. Those algorithms are effective also to fight not very powerful spikes as mentioned above. Analyzing articles considered in those algorithms one can see that we deal with some alternative aspects, which are typical for most statistical estimating tasks. On the one hand the trivial meaning average allows us to have the minimum dispersion of mean estimation for the normally distributed noise – like signal. But it is absolutely non robust and mean estimation gets senseless if even the single spike appears. On the other, hand the median-like rank estimation are very robust to spike type contamination (up to 50%), but there is loss in efficiency in case of normally distributed, spike-free signal. The worst case is a median estimation upon the infinite sampling: the efficiency drops to 0.637. The compromise Hodges-Lehmann (Hodges, Lehmann 1957) estimation, which is used for post data processing at RATAN-600, has 0.95-0.98 efficiency, but it is robust just in the case of no more than 25% contamination. Moreover, the calculation of this estimation is quite time consuming, because the sorting of $n \cdot n/2$ values, where n is sampling amount, is involved. It makes some difficulties for using such an estimation in real-time procedures.

However, there is a very promising way of solving this problem if one can formalize some rules to choose different algorithm on-the-fly, during raw data processing. It can be done, based on some general features of signal and spikes. There are hardware dynamic "spike-depression" devices, which are still used in some radiometers at RATAN-600. But because of analog type of these devices, only some sorts of analog threshold criteria could be used. Those criteria are completely unrobust and always need the frequently applied fine tuning, which is very difficult and undesirable for long term observation cycle.

The digital integration method with adaptive selection of the optimal algorithm is given in this article. The method is quite robust and based on some general prior information about signal and spikes.

2. Description of algorithm

The procedure of radiometer signal integration can be considered as a sort of reducing dimension of the initial sampling space, where the samples are the result of analog-to-digital conversion. As a result of this procedure the sampling space within the integrating interval gets reduced to a single sample, which reflects the signal mean estimation.

A variety of circumstances when one needs to select some optimal procedure of the signal estimation is usually splitted into three classical cases.

1. The probability distribution of the signal and spikes is completely known.
2. The probability distribution of the signal and spikes is known only as a function, the parameters are unknown.
3. The probability distribution of the signal and spikes is unknown, however some general features are known.

These cases are well described in the classical statistic literature and lead correspondingly to Bayes, parametric and nonparametric algorithm of the estimation obtaining. The third case is the most frequent if we are interested in getting reliable robust estimation.

Despite the variety of effects, which are responsible for building the radiometer signal statistic (Christiansen, Högbom 1988), the standard radiometer signal processing - low bandwidth filtration - leads to the "normalization" of the end signal statistic (Levin 1974). However the spikes influence disturbers the signal distribution making the "tails" heavier, comparing to normal distribution function.

The model of realization of such a process as a mixture of normal and Poisson processes is considered in Erukhimov's (1988) article. Given calculations, show that the estimation offset strongly depends on the jam intensity and could be very different depending on used estimation algorithm. Thus, there is a way to depress jams having a few sorts of estimation all together and choosing the best one (with the least offset), using some available prior information.

For the given model it seems to be enough to have the mean average and median estimation. The first one is the optimum for the normally distributed noise signal, the second one practically does not have an offset for a reasonable level of spikes contamination.

Thus, the optimal mean estimating procedure takes us to chose one of the two previously obtained estimation, what could be done by testing two hypotheses:

- H_0 – no spikes on estimating interval,
- H_1 – the sample is contaminated with spikes.

The mentioned estimation upon the n – dimensional sample could be obtained like this:

$$\hat{m}_{H_o} = \frac{1}{n}\sum_{i=1}^{n} x_i \ , \qquad \hat{m}_{H_1} = med_n(X)$$

Before choosing the classification algorithm let us make some reasonable assumptions:

- The sampling period is significantly less than the integrating window interval which itself is significantly less than typical non-stationary time period for sky objects and atmospheric trend signals. In such a case we can neglect the non-stationary behavior of the mean in the integrating interval;
- Multidimensional probability distribution of the process is close to the symmetrical one and monotonously falls as it gets away from the means;
- The offset of mean estimation is caused by short spikes and the average time between these spikes is significantly greater than integrating window.

Only the first condition is the main one, the others just lead to some limitation in using the considered algorithm.

Analyzing the above assumptions one can choose the suitable classification algorithm based on p-state measure, such as "Nearest Neighbor" one (Patrick 1972), which, in particular, has been effectively used in real time feedback system (Ulyanov, Chernenkov 1983)

In our particular case the classification algorithm sounds like this: when processing the window number k we choose from alternative[1] mean estimations that one which is closest to one chosen for window k-1.

Applying the mentioned algorithm the following recursive formula can be written:

$$\hat{m}_0 = med_n(X_0), \hat{m}_k = \begin{cases} \frac{1}{n}\sum_{i=1}^{n} x_i & , \quad |d'_k| \le |d''_k| \\ med_n(X_k) & , \quad |d'_k| > |d''_k| , \end{cases}$$

where:

$$d'_k = \frac{1}{n}\sum_{i=1}^{n} x_i - \hat{m}_{k-1},$$
$$d''_k = med_n(X_k) - \hat{m}_{k-1}.$$

The estimation is robust, because there is no dependency from signal distribution parameters, neither from spikes power involved. Because there is no need to increase sample amount for estimation calculation – in opposite to Hodges-Lehmann algorithm, the meaning average and the median can be obtained fast enough.

Let us write down the steps of algorithm

1. Calculation of the median estimation for the initial window and hold it.
2. Calculation of the median estimation and meaning average for the next (moved) window.
3. Calculation of the absolute deviations between the previous estimation and following two.
4. Taking as true estimation the one which has minimum of the mentioned deviation.

[1] If we are talking about non real-time processing, one can move through the record in reverse direction too. In this case the number of alternatives to choose from is doubled.

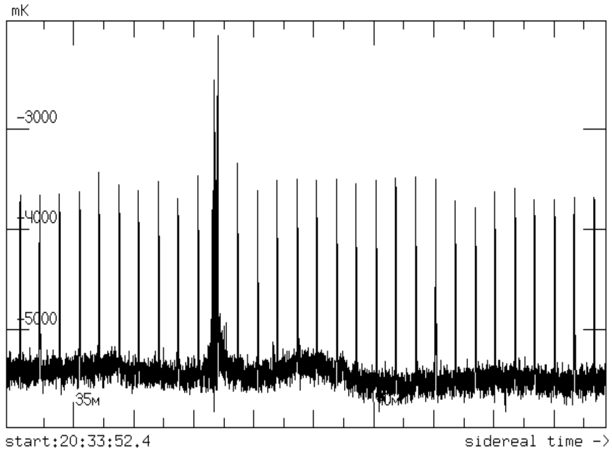

Figure 1: The record, processed by different algorithms.

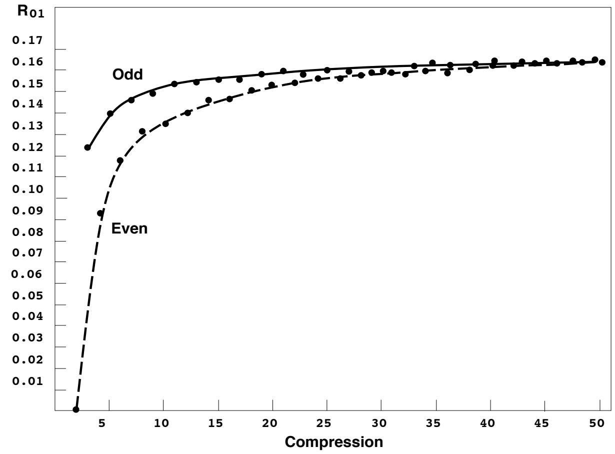

Figure 3: The dependency of subsequent samples correlation coefficient in compression ratio.

5. Go to step 2.

Because of the obvious justifiability of the considered estimation and also continuity of the data acquisition process, for the real-time case one could take off the first step, using zero estimation mean instead.

Tabl.1 contains the comparison of the processing results, obtained by described method on the first cabin "Continuous" data acquisition complex, with the previous ones. The significant performance benefit as compared to best rank estimations could be seen. There is also variance benefit as compared to other algorithm despite the greater spikes power level. The table contains the results of 60000 samples records processing. One of those records is shown in Figure 1. The quality of the considered algorithm could be also illustrated by Figure 2. At the top of the Figure the record containing the source and spike jams is drawn. The results of the different sorts of 5-time compression - of this record - meaning average, Hodges-Lehmann procedure, considered algorithm, - are drawn at the bottom. One could see the considered adaptive algorithm is preferable even by low degree of compression, because all spikes have been depressed.

A disadvantage of the considered algorithm is the appearance of some extra correlation between subsequent samples in the output process. This effect is typical for any feedback algorithm acting as a low bandwidth filter. The dependence of the mentioned extra correlation on the compression factor, which is obtained by numerical modeling, is drawn in Figure 3.

The odd and even compression factor points are drawn as different curves. It could be seen that there is slight increasing of correlation with increasing of the compression ratio up to asymptotic value about ~ 0.16. Perhaps it could be considered as a consequence of well known effect of dropping the efficiency of median estimation to the asymptotic value $2/\pi$ with the increasing the amount of samples (Hodges, Lehmann 1967). Such a kind of relation to the features of median estimation could be also confirmed by different means of the correlation coefficient for the odd and even compression factor values.

Despite the fact the graph is obtained for the initial Gauss distribution of noise process, it actually does not have a strong dependence on the type of initial distribution, if the mentioned above assumptions are justified. That is because the output process gets normalized starting even from small averaging windows.

Thus, if the above mentioned condition are true, the extra correlation effect could be neglected at practical use of considered algorithm.

3. Observational data

In April 1996 the described method was included in the software of automatic data acquisition complex "Continuous". The software was changed after week-long observation at common astrophysical program SAI and SAO. The observer Konnikova V. K. (SAI) observed any discrete sources at West sector of RATAN-600. She was acquired data on the six wide band radiometers of centimeter wavelength. The acquisition frequency was 100 samples per second for each channel with hardware filtering by RC-chain with the value 0.01 sec. At the next step the system made digital integration in real time using data compression with the factor of 10. And the value of the median was calculated as the estimation of medium before change of algorithm. The results of data processing of observations records on the 4–13th of April with respective radiometers are shown in Fig. 4 – 6. Records of discrete sources (up to 53) were written,

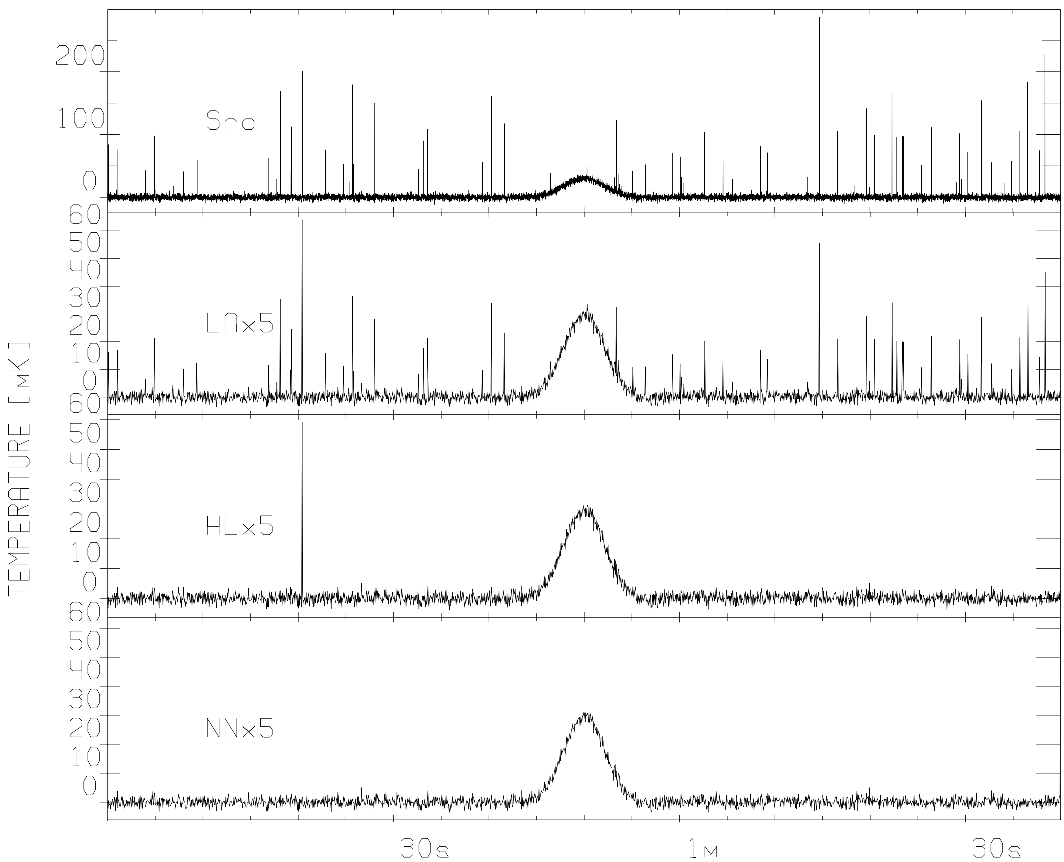

Figure 2: The results of the 5-time compression of the model record by meaning average, Hodges-Lehmann procedure and the considered algorithm.

Table 1: The comparison of the processing results, obtained by described method.

Compression	10			25			50			100		
	t c.	σ	σ_3	t c.	σ	σ_3	t c.	σ	σ_3	t c.	σ	σ_3
Meaning aver.	1.46	26.5	16.4	1.44	22.9	14.6	1.51	20.6	18.0	1.51	17.4	17.2
Median	1.82	27.3	19.0	2.35	21.7	15.3	3.36	18.3	18.3	5.04	13.1	12.3
HL-algorithm	10.1	26.7	17.1	90.1	22.7	15.0	675	19.7	18.7	5556	15.5	16.1
NN-algorithm	1.88	26.4	17.2	2.37	21.4	13.5	3.31	18.4	16.8	5.03	13.3	10.4

and We did not clean records from interferences and sources. More than 400 multifrequency recordings are used in data reduction. Histograms of computed estimates of sensitivities are shown in figures for each wavelength. A shift of histograms picks shows improvement of the real sensitivity of 20–25%. Thit corresponds to the theoretical expectation.

It should be noted that the relatively strong effect of sensitivity improvement for the radiometer of 13cm is due to its engineering tuning and spike depression devices also, which was done in the day of algorithm substitution. This figure shows also that the effect is not visible so obviously at the wavelength of 31 cm, polluted by industrial interferences, apparently caused by low percentage of the general interval of the operation of the linear part of the algorithm.

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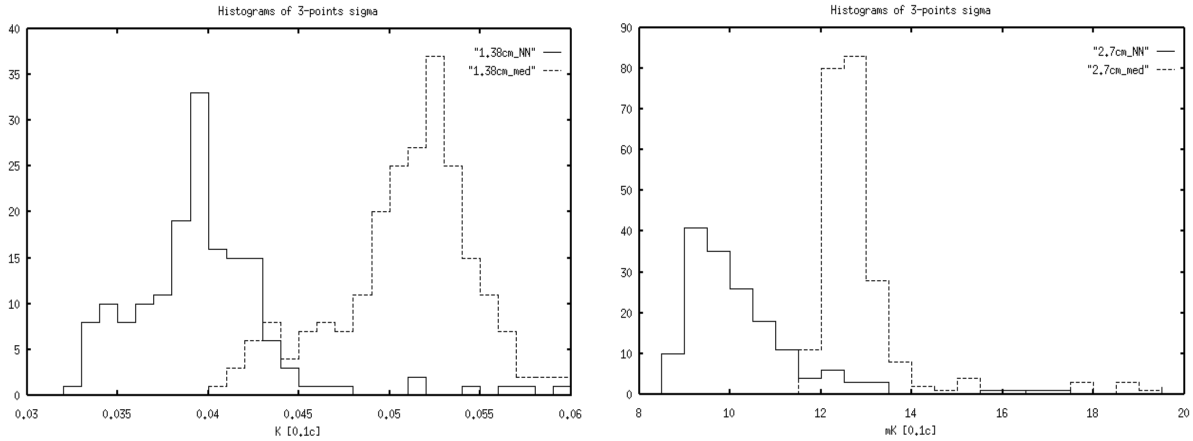

Figure 4: The measuring of sensibility by observing at the wave lengths of 1.38cm and 2.7cm.

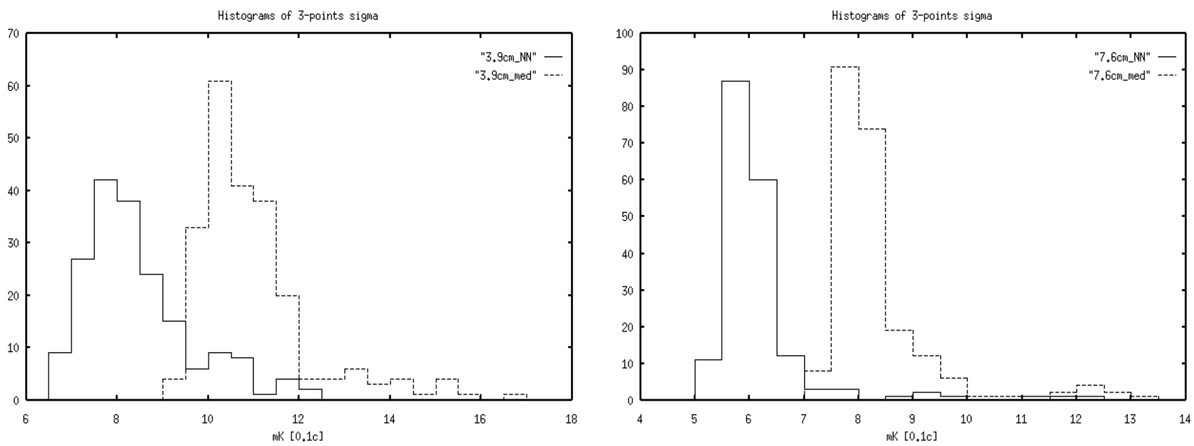

Figure 5: The measuring of sensibility by observing at the wave lengths of 3.9cm and 7.6cm. wave lengths.

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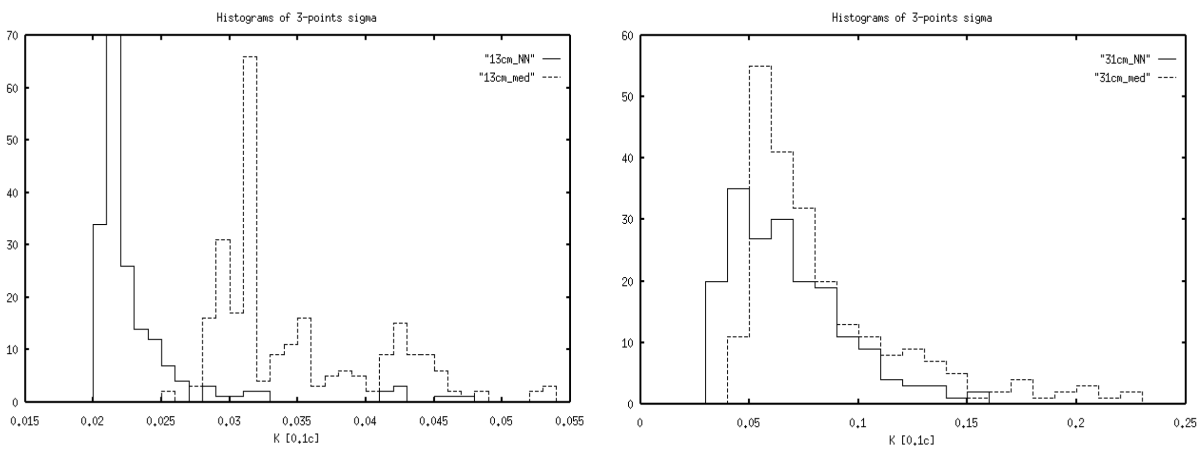

Figure 6: The measuring of sensibility by observing at the wave lengths of 13.0cm and 31cm. wave lengths.