DETECTION AND DISCRIMINATION OF X-RAY RADIATION SOURCES

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Summary. While studying radiation sources in X-ray range by devices, carried to the near-Earth orbit, there appears some problems, called by the necessity of uninterrupted scanning of the sky sphere and high speed of canals’ test, which leads, consequently, to a considerable volume of data.

Side by side with strong sources of radiation one shows great interest to the weak ones which may turn out to be unknown to the science stars. On detecting the source, it is necessary to get a number of parameters, characterizing its structure.

Devices of the space station “Saljut 4”, carried an enormous deposit into the study of sources in X-ray range. The analyses of results shows, that beside useful signal from X-ray telescopes, a considerable number of superfluous references enters the radioline.

Highly effective algorithm of detection and discrimination of useful signals, allowing to raise the informational capability of radioline is represented in the work. Superfluous references, which are stipulated by a galactic background are excluded from the whole data stream.

The use of this kind of algorithm allows to discriminate more legible the sources of radiation in on-board and on-Earth use. The effectiveness of this algorithm is shown in adaptation of experimental data, got from X-ray telescopes of the space station “Saljut-4”.

Introduction. The latest times in astrophysics of high energies the most important results are got in X-ray astronomy. More than 150 sources of X-ray radiation are discovered. The process in this field is connected with the experiment beyond the atmosphere of the Earth.

The researches in the field of X-ray astronomy consist of the following stages: detection of the sources of radiation, study of energy spectres and time related sources, localization of sources on the sky sphere.
For fulfilling this task X-ray telescopes are made with larger effective square of particles’ registration, lower the apparatus background of devices and etc.

On finding energy dependence the whole range of registration is divided into some subranges, and for getting information about the time relationship of sources one must raise frequency of canals’ test.

Measurements, conducted on Earth’s satellite in the scanning range, give a large volume of information, more than 90%, which compose the background, and that makes Earth’s adaptation of experimental data slow and overloads the radioline by superfluous information.

The state can be very much improved if one puts a computer on board the satellite, which will show presence or absence of the source in the field of view of the device.

Thus, one may exclude background parts (excessive data) from the whole mass of data and raise the share of informational reference. For fulfilling the task it is necessary to develop algorhythm of detection and evaluation of scientific data, received from X-ray telescopes, which will satisfy such conditions:

- detection and discrimination with the assigned exactness not only of the signals, which exceed the background level for $3\sigma$, but also the signals with smaller ranges of energy (weak sources);

- transmission in the radioline only those meanings of reference, which carry information about the sources.

Many methods of compression of data are known, for example, aperture. To them one can refer extrapolators and interpolators of N-orders.

Both the methods use the criteria of exactness, therefore it is not expedient to carry out the treatment of X-ray messages, because one can loose the information about weak sources.

Let’s discuss the typical kind of measurements from X-ray telescope, sent by on-board system of spacecraft, where data from the 4 canals is shown (figure 1). They characterize the intensity of energy onbranges $E_{\xi}/\xi = E + \Delta / \xi$ in dependence from the time of watch.

Parts with the sign “⊗” show the changes in the intensity of radiation. The interconnection between indications of different detectors, in coinsiding time moments.
But the character of detector’s indications is that the classification (detection and discrimination of radiation parameters) for this very case may be made by a comparatively simple way, using any measurement algorithm of the moment of statistic characteristics of the process, watched.

The results of the statistic treatment of experimental data allow to suppose the following:

1) the signal and the noise are independent processes;

2) the signal \( S(t, \bar{a}) \) is a determined process with the following vector of parameters

\[ \bar{a} = (a_1, \ldots, a_n) \]

3) the noise \( n(t) \) is an incidental process with independent meanings and common one-dimensional distribution;

4) the signal and the noise are additional;

5) correlation between energy subranges without the signal is -0, with the signal is -1.

It is clear that the task of detection of the signal may be represented in the following traditional for the theory of communication treating.

Mixture enters the device:

\[ x_i(t) = Q \cdot S_i(t_i, \bar{a}) + n_i(t_i) \quad /1/ \]

where \( Q \) is an incidental magnitude with the distribution:

\[ F(Q) = \begin{cases} P \delta(Q-1), & Q = 1 \\
(1-P) \delta(Q), & Q = 0 
\end{cases} \]

\( \delta(x) \) - \( \delta \) function, \( t_i \) - discretion time,

\( i \) - number of the canal, \( i = 1, \ldots, \infty \)

The noise \( n(t) \) is every moment \( t \) is a whole magnitude with the discrete distribution of probability \( \{ p_n \} \), enveloping of which is wonderfully described by Hans-curve.

Evaluation \( Q \) and \( \bar{n} \) leads to a well-known task of parameters detection of determination signal on the background of non-stational “white” noise with unknown parameters. The system of detection and measuring of parameters switches on the subsystems, working in the interval of watch with the condition that \( Q = 1 \) and the parameters \( \bar{a}_b \) are known quite well.
The subsystem of watch functions independently from the difference of b vector, describing the statistic structure of normal process n (t).

We may consider \( \tilde{a}_b \) as hipervektor:

\[
\tilde{a}_b = (\tilde{a}. \ b)
\]

Scheme-block of detector measurement is shown at figure 2. The criterion of evaluation of such systems’ quality is very specific, because it is necessary to use this criterion for detection of discrete parameter ( \( Q = \{0, 1\} \)). The most suitable for fulfilling the task seems to be Neiman-Pirson’s criterion, minimizing the probability of signals, missing in the given meaning of false alarm.

Let’s research the process of detection-evaluation, allowing to get the optimal variant of detector, with the help of some additional suppositions.

We shall take real characteristics, got from X-ray telescopes (figure 1, 3 - for energy subranges) as a basis of the signal kind. Let \( S_i (t_i, \tilde{a}) = S(t, a) \), then, the signals in all N-canals are identical. Let a parameter be two-dimensional \( \tilde{a} = (a_1, a_2) \) where \( a_1 \) - amplitude, \( a_2 \) - time delay. Let’s describe the structure of detector, realizing the principle of storage “Horizontal and vertical”, that is producing the storage for N-canals and for the time (weight storage for every \( S_i (t, \tilde{a}) \) signal) (figure 2). Such principle of storage is just in the light of supposition about correlations of sources of different energy subranges,

Entering data \( \{x_i\}_{i=0}^n \) are subjected to normalizing in the interval \( T_N \). In every moment of interrogation \( t_i = i \cdot \Delta t \), where \( \Delta t \) -interval of interrogation, frame \( x_i (x_{i1} \ldots \ldots x_{iN}) \) representing peg-vector, components \( x_{ik} \) of which are signals of detectors from the \( k \)-canal ( \( k = \overline{1, N} \)), transformed with the help of orthogonal matrice \( P \) in vector \( \bar{Y}_i = P \bar{X}_i \). The necessary condition of optimity of such a matrice is the presence of line (or peg)

\[
\{ P_m \}_{m=1}^N
\]

which has the form \( \{ S_k (t_i, \tilde{a}) \}_{k=1}^N \) that is quite the contrary to the selection on the signals in every canal.
Thus, K-line of the matrice P must be coinsided with the selection of the signal vector in N-canals.

In the case of $S_{\kappa}(t, \bar{a}) = S(t, \bar{a})$ that is when the signals in all the canals have the same form, matrice P must have the line from constant elements.

It is clear that every known types of ortogonal matrice (Furje, Haar, Wolsh, etc.) can satisfy this condition.

Element $y_{ik}$ of vector $\bar{Y}_k = PX_k$ is subjected to further change in the storage-block "6" in accordance with the algorithm of consistent filtration

$$Z_k = \sum_{i=1}^{K} \rho_i Y_{ik}$$

where weight in neccession $\{\rho_i\}_{i=1}^{K}$ is chosen from the condition of consistency of the kind of weight function with the signal. As it is seen from the figure 1 and 3 the signal can form the kind of Haus-curve, triangle, trapezium and etc.

Accordingly, weight function must have discrete meanings in the interval $T_\kappa$ near to the mentioned kinds.

The result of such treatment in the moment $t_k = k \Delta t$ is compared with the threshold D, which is chosen from the condition of detection and evaluation of the signal. The threshold of detection is chosen from the condition of exceeding of the signal above the noise that is $D_{11} = 1/\sqrt{\kappa}$, where L-numbers of storing references in the time interval. Threshold of evaluation is chosen from Neiman-Pirson criteria and basically depends from the given meaning of probability of false alarm ($\varepsilon$). Threshold $D_{12}$ can be found from the equation:

$$\varepsilon_1 = \frac{1}{2} \left[ 1 - \Phi \left( \sqrt{\frac{1}{2} \cdot \frac{\rho_c}{\rho_w} \cdot \frac{D_{12}}{\alpha}} \right) \right]$$

where $\Phi(x)$-interval of probability, $\rho_c/\rho_w$ -relation signal/noise, $\alpha$ - signal amplitude. When $Z_i > D_{11}$, there is a signal, when $Z_i \gg D_{12}$ the fact of the signals' existence is evaluated.
In the threshold selection block "3" delay (memory) of vector $Y_i$ must be forseen before its treatment for the time of signals' duration $S_i(t, \tilde{t})$.

Let's examine the effectiveness of detection when there are some limitations in the form of a signal in every canal and taking into account the statistics of the process of noise.

Let $S(t)$ be fully determined in the form. However we consider that at the interval $T_H$ it may be transferred in time to any point of the interval or even its part only overlaps by the interval $T_H$. We consider that in all the canals the signals are identical as to the form. In this case transition from vector $\bar{x}_i$ to $\bar{y}_i$ is equivalent to enlarging of the signals' amplitude to $N$.

We consider the displacement $t_{\tilde{t}}$ as an incidental magnitude, proportionally distributed in the interval $T_H$. If $T_{\tilde{t}} \ll T$ stay, one may consider that the evaluation $\bar{x}_i$ and $\sigma_i^2$ have smaller mistakes and in the first approach may be taken equal to truly meanings $M\{x_i\}$; $\sigma_i^2 = M\{(x_i - M\{x_i\})^2\}$. If one considers that $T_H = T_s$, where $T_s$ - duration of a signal, when $Q = 1$, it is more probable, that part of the signal will hit into the interval of watch.

This is equivalent to diminition of the signal two times. That's why signal/noise correlation will have the form;

$$\beta = \frac{N}{2} \cdot \frac{E_i}{N_0 \cdot F \cdot T_H}$$

where $E_i$ - energy of a signal, $N_0$ - spectral solidity of noise, $F = F_\phi / 2 = 1 / 2 \Delta t$.

While multiplying in succession of every reference of signal $Y_i$ to the weight function $f_i$ (correlational method) one may more successfully combine them. Then the meaning $N/2$ in the formula (4) is transformed to $N$. The results of treatment for zones (according to the formula (4)) are shown at the 4-th figure and for correlational method at the figure 3.
Correlation signal/noise fully characterize in those conditions the effectiveness of such method of detection.

At figure 1 one sees the result of discharge and evaluation of strong source of radiation, got while treating the data, taken from X-ray telescope of the station “Saljut 4”.

The data of the fig. 1a, b, c, show the graphic notes of the four canals (energy subranges) of X-ray telescope. At the figure 1c one sees the result of treatment of the signals by the block 6 (Figure 2).

At the same figure threshold meanings $D_{11}$ and $D_{12}$ are shown. The number of points, analyzed was 50. Multiplied function (triangle) is divided into 50 points.

At the 3-d figure the most interesting case is shown the result of the treatment of weak source of radiation.

At the figure 3a, b, c and d TM references from the 4 canals of X-ray telescope but on the other coil of the satellite are shown.

After normalizing voltage of the canals by block “I” and block “2”, vertical summarizing was carried on. The result of this treatment is shown on the figure 3e.

On the figure 3 g the result of multiplying of the signal (3e) and the weight function $\sin x$ where $x$ is discreetly changed from 0 to 180 is shown.

More compact the same result with taking into account threshold levels $D_{11}$ and $D_{12}$ is shown on fig. 3g. As a result of such treatment there was detected and discharged with a great state of truth (90%) two useful signals of X-ray source, concealed in the noise.

Thus, this algorythm turned out to be effective while detecting not only strong, but also rather weak sources.

Time zone, marked by the algorythm is the most informational part, which is transmisseted by a radioline from the whole mass of data, treated.
Fig. 1
Fig. 2

- Entering N-channel data
- Calculation of trend or average meaning
- Calculation of dispersion
- Normalisation
  \[ \hat{x}_i = \frac{1}{n} \sum_{j=1}^{n} (x_j - \bar{x}) \]
- The block of transformation with matrix \( P \)
- The block of compression (threshold choice) threshold \( \Delta \)
- Quantum and addressing block
- Choice of K-component to vector \( Y_k \)
- The block of matching filtration (storage)
- Threshold device (Threshold \( \Delta_a \))
- Fixation of detection moment
- The signal of detection
  - Yes
  - No
  - Threshold regulation
  - To memory or the candle