Laboratory of Autowave Processes of The Institute of Applied Physics of RAS

team AWP IAP RAS

Methods of analysis of autowave solutions in the models of distributed non-equilibrium, neuron-like media are developed. The patterns of collective activity (autowave processes) in homogeneous non-equilibrium media are investigated.

A research system for control of the effeciency of image recognition algorithms is carried out.

Applications: a) variants of biometric systems;

b) comparison of the experimental data on the specific features of sensor signal transformation with the results of computer simulation.

Application of Neuron-Like algorithms for extraction and recognition of model gravitational wave

Institute of Applied Physics RAS
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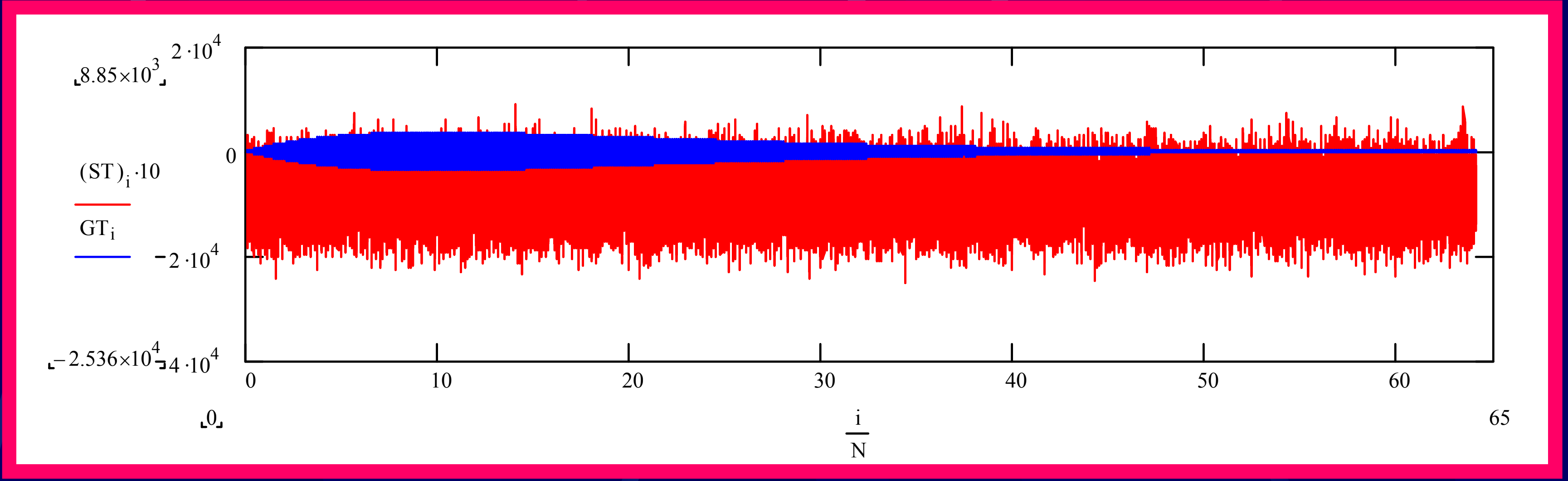
LIGO-G020114-00-Z

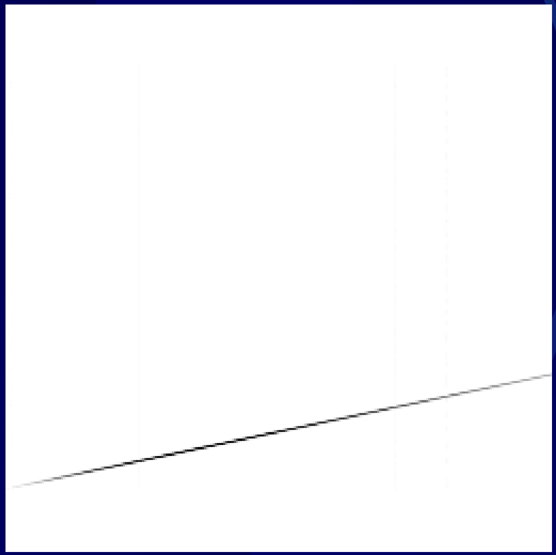
Examples of a model gravitational wave *Wave(t)*, and noise in a LIGO detector *Noise(t)*



Results of computation of the efficiency of model gravitational signal extraction against the background of LIGO detector noise

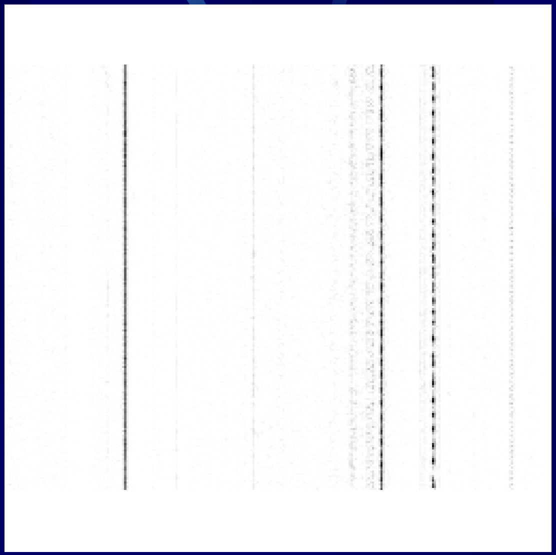
$$S = 1 \cdot Wave + K \cdot Noise$$

- K=0



$Noise(t)$

- K=100



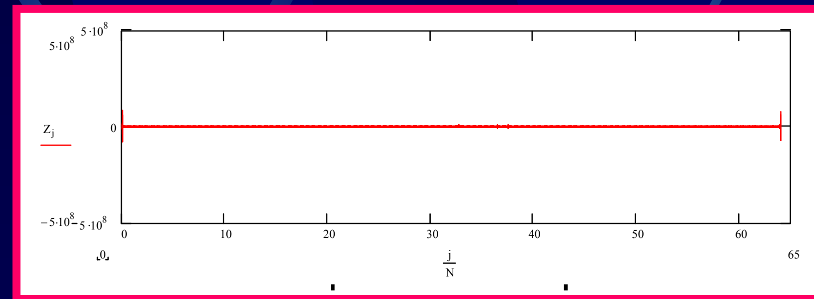
Signal dynamics spectra

Covariation spectral analysis

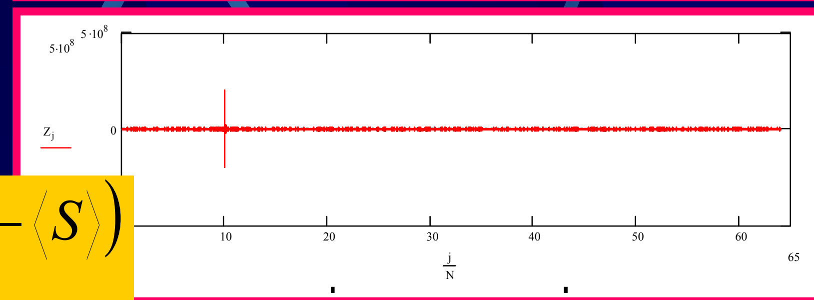
$$S(t) = 1 \cdot Wave(t) + K \cdot Noise(t)$$

K=10

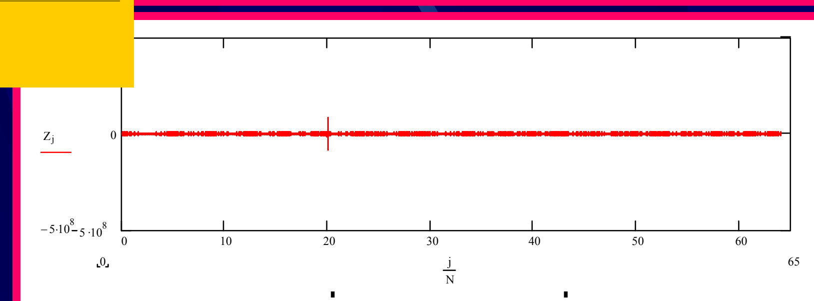
Time 0-6 sec



Time 10-16 sec

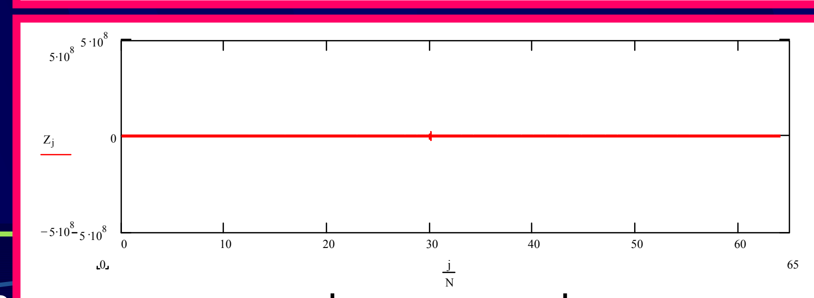


$$\mathrm{cov}(\tau) = \frac{\sum_i \left(Wave(t) - \langle Wave \rangle\right) \cdot \left(S(t-\tau) - \langle S \rangle\right)}{\delta_{Wave} \cdot \delta_S}$$

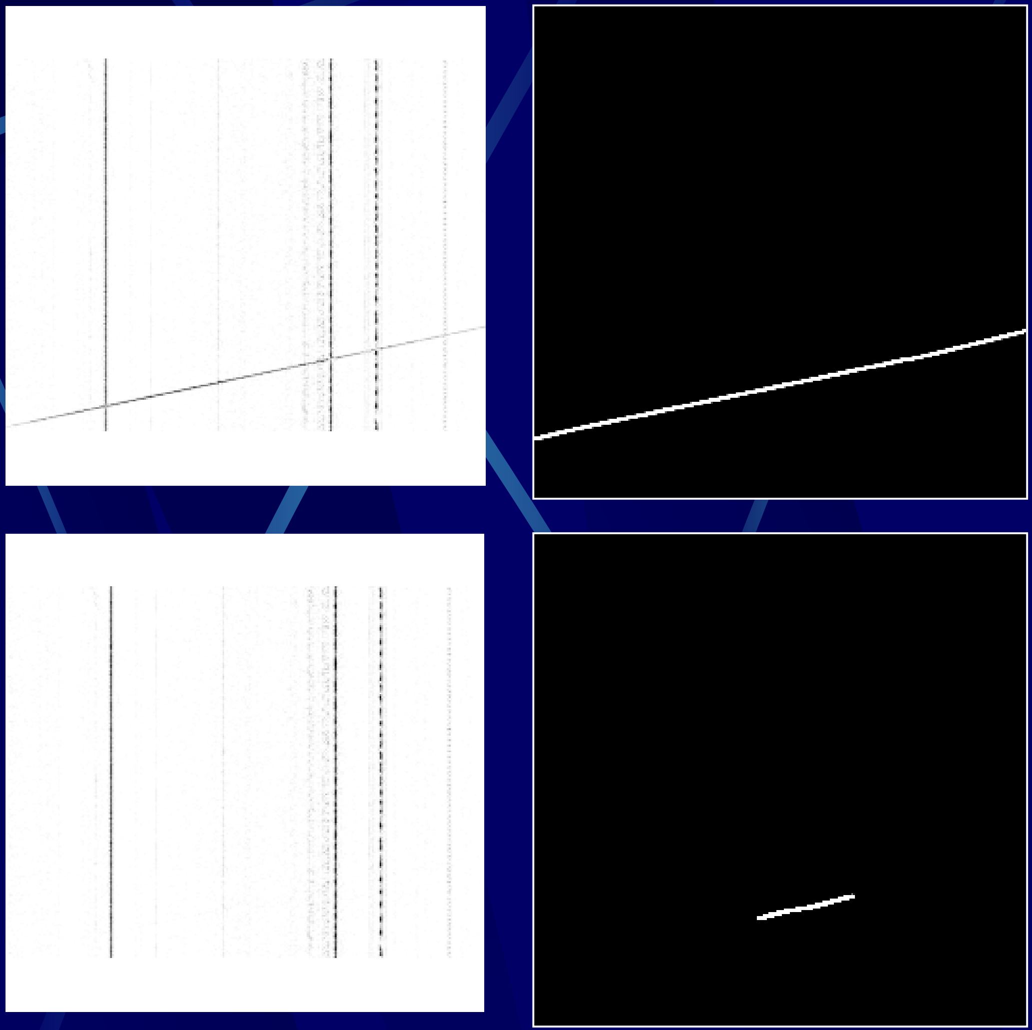


Time 20-26 sec

Time 30-36 sec



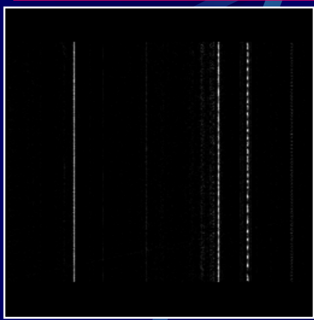
- K=10
- K=100

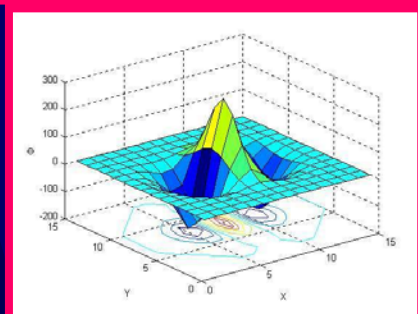


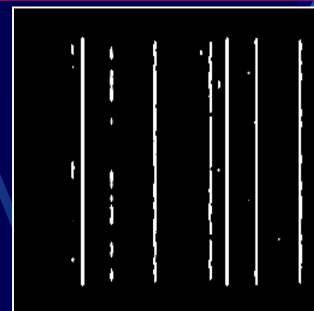
Initial signal and the results of gravitational signal extraction (the size of the spatial “frequency – time” filter is 15*15 pixels or ~15Hz*6 sec)

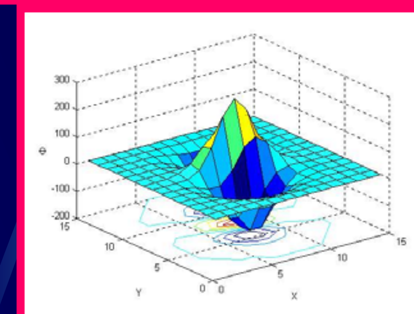
A nonlinear spatial-frequency filter is used as a homogeneous neuron-type medium

$$U_{n+1}(i,j) = (1-\tau_u)\cdot U_n(i,j) + \tau_u F\left[-\mathrm{T}_0 + \sum_{\kappa,\lambda=-n_x,-n_y}^{n_x,n_y} \Phi(k,l)U_n(i-k,j-l)\right]$$

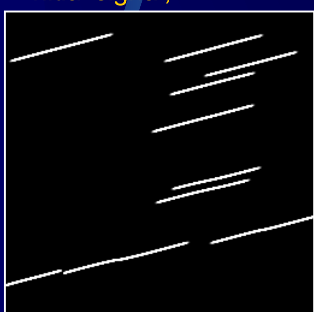


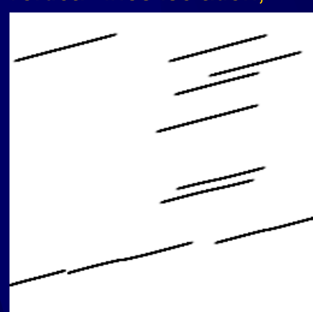


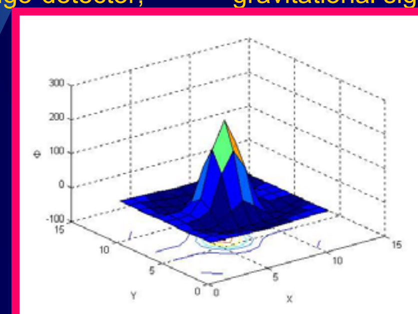


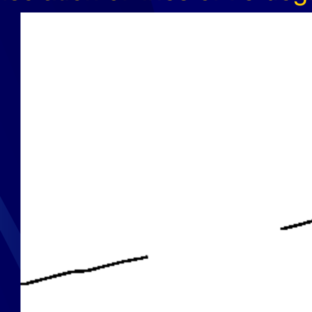


Initial signal; Φ(k,l) – vertical lines isolation; noise of ligo-detector; gravitational signal; Φ(k,l) – isolation of lines of 75 degrees.

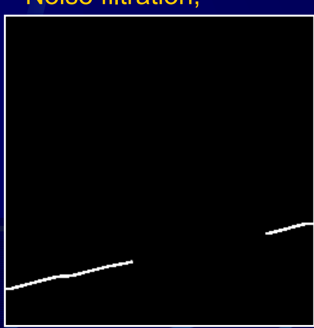


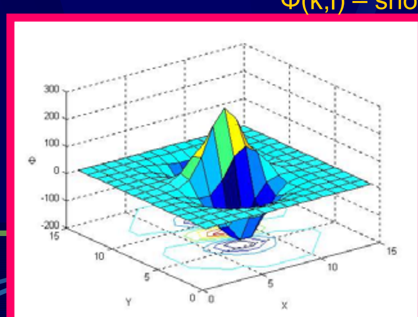


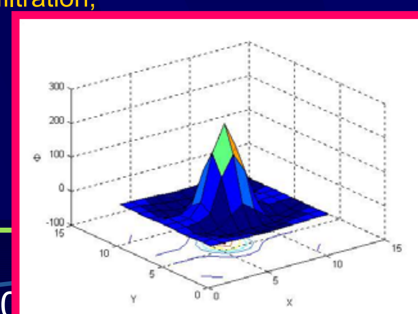


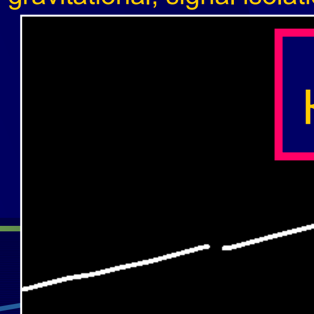


Noise filtration; Φ(k,l) – short lines filtration; gravitational; signal isolation





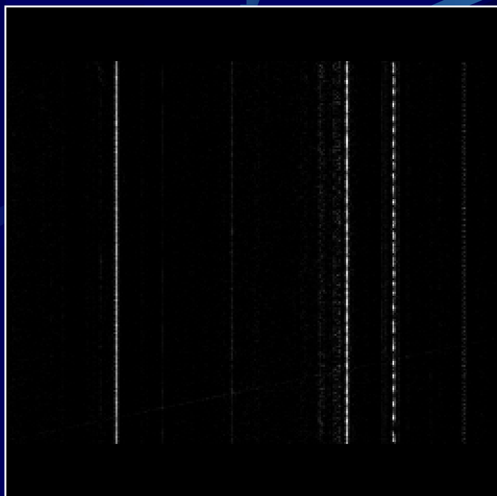




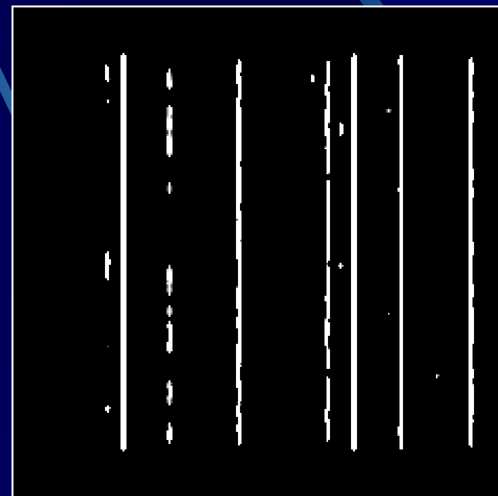
K=70

A nonlinear spatial-frequency filter is used as a homogeneous neuron-type medium

K=50

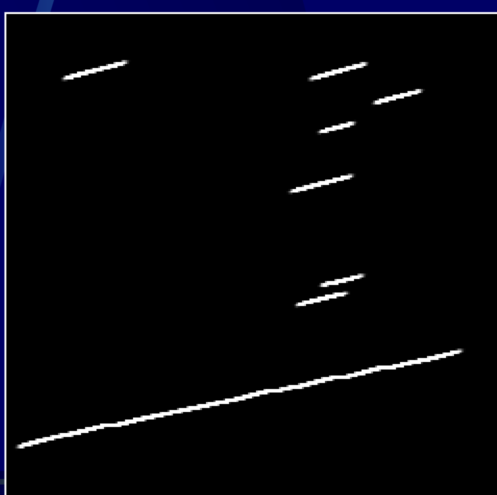


Initial signal;



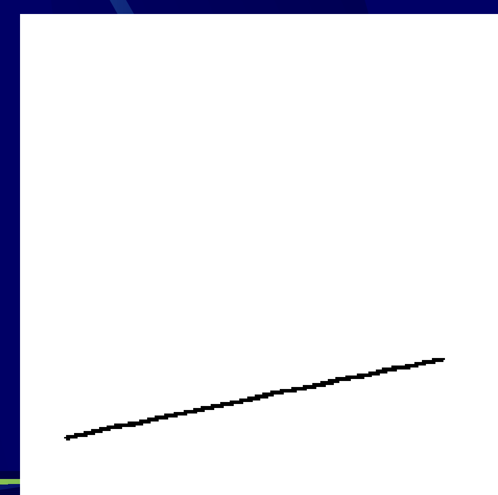
noise of LIGO detector;

gravitational signal;



Result of processing;

noise filtration;



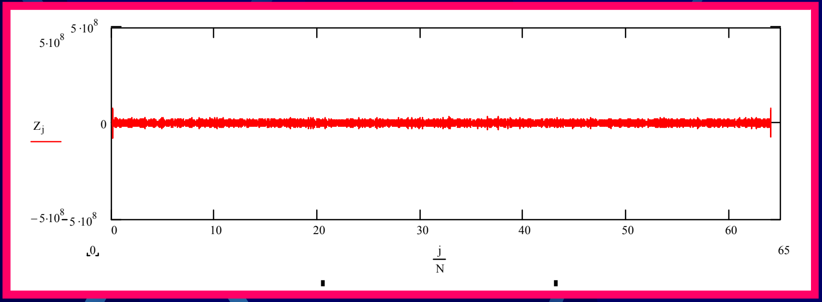
extraction of gravitational signal

Covariation spectral analysis

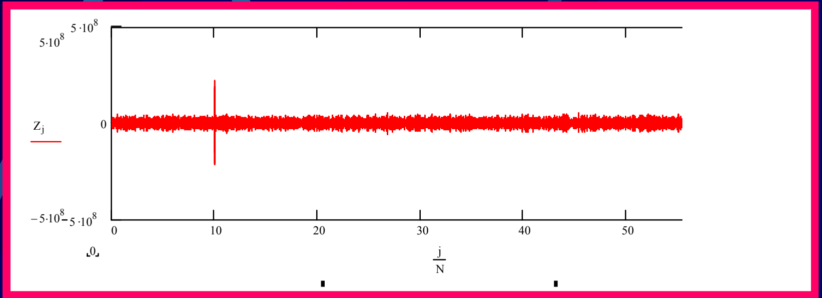
$$S = 1 \cdot Wave + K \cdot Noise$$

K=50

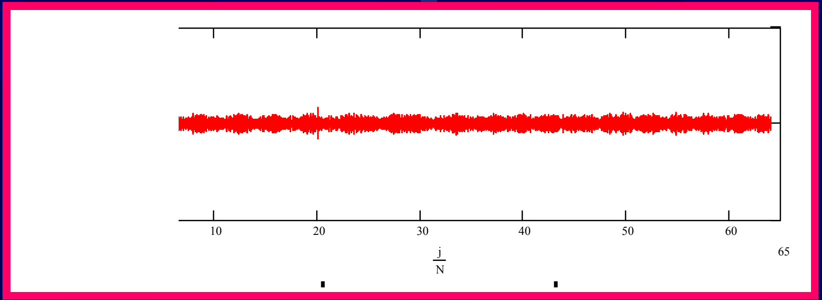
Time 0-6 sec



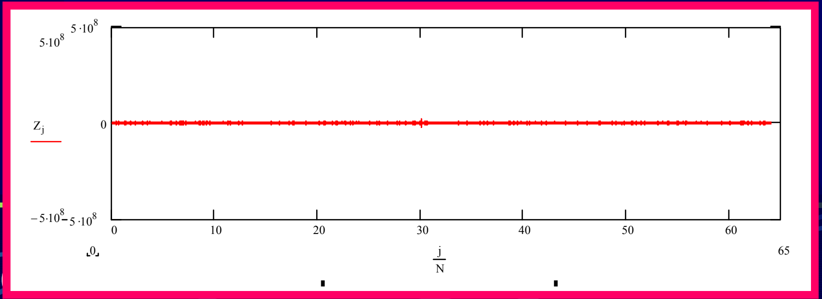
Time 10-16 sec



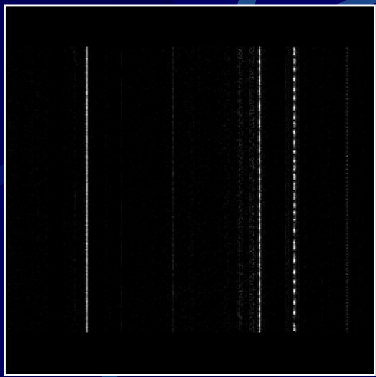
Time 20-26 sec



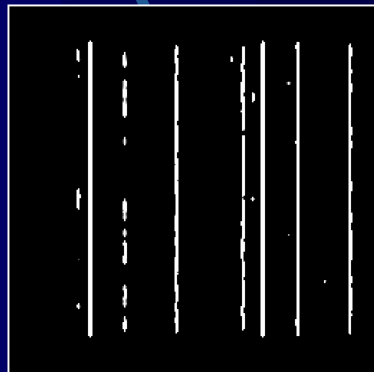
Time 30-36 sec



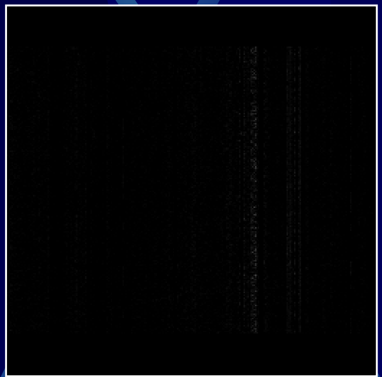
A nonlinear spatial-frequency filter is used as a homogeneous neuron-type medium



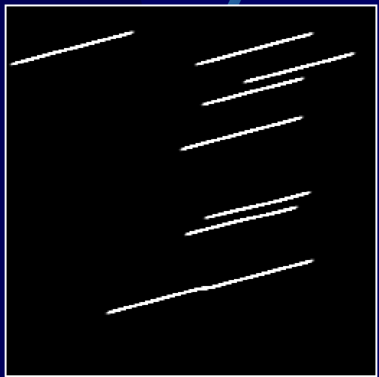
Initial signal;



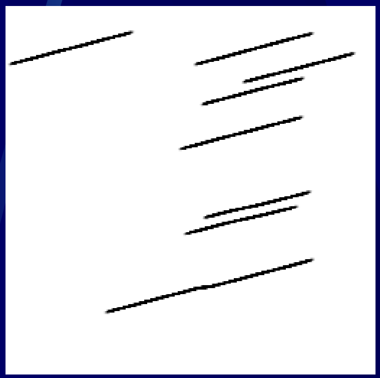
noise of LIGO-detector;



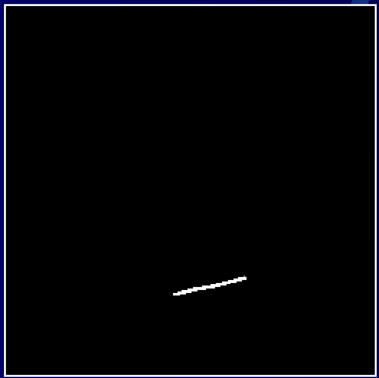
gravitational signal;



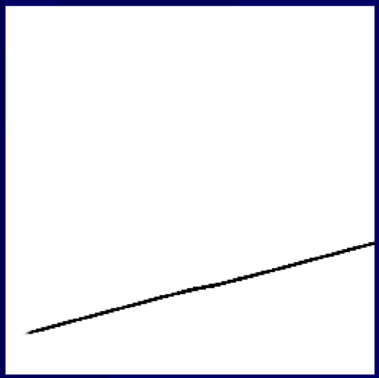
result of processing;



noise filtration;



isolation of gravitational signal.



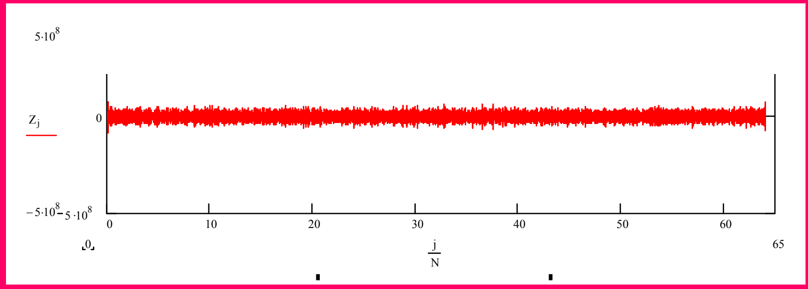
K=100

FAR (K) ; FRR (K)

Covariation spectral analysis

$$S = 1 \cdot Wave + K \cdot Noise$$

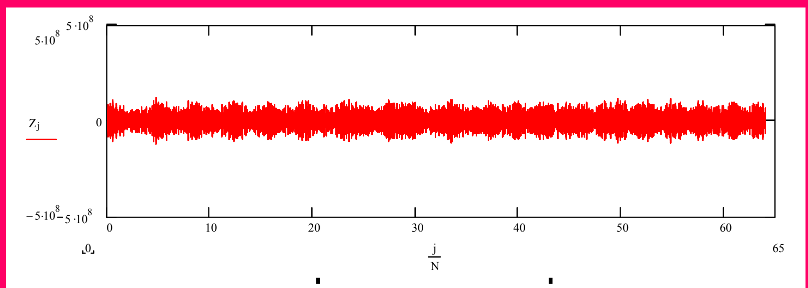
Time 0-6 sec



Time 10-16 sec

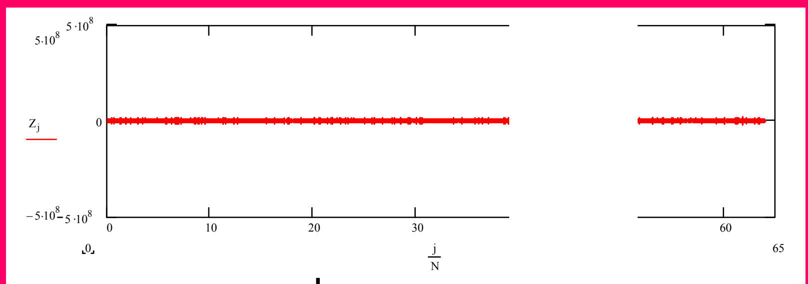
K=100

Time 20-26 sec



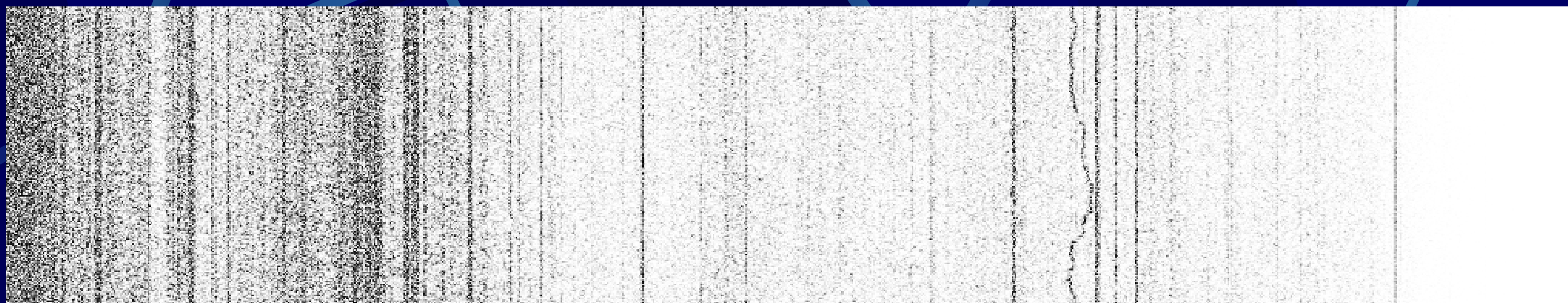
FAR (K) ; FRR (K)

Time 30-36 sec



Results of analysis and processing of images of a 100-sec signal from a LIGO detector.

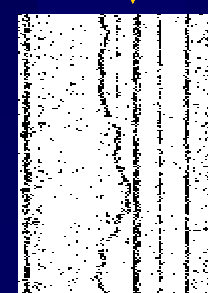
«Initial dynamic spectrum of the signal». (2048 points)



The *x* axis shows frequency from 1 to 1024 Hz; the *y* axis – time from 1 to 100 sec.

The changes in the spectral component in the range from 690 Hz to 704 Hz reveal a moving source of signal near the detector.

We used a program for extracting and recording frequency of maximum signal and its amplitude within the frequency range of 650 – 750 Hz.



A source for such a signal was apparently an object that changed its velocity in the direction towards the detector in the range from 0 to ~25km/h.

Variants of models for a homogeneous neuron-like medium to transform an initial image, were used.

That is example of signal processing in the time-frequency domain with variants of "wavelet"-like functions of filtering

The model is given by the following equation:

$$\tau_u \, \partial u / \partial t = -u + F\left[-T + \alpha \int_{-\infty}^{+\infty} \Phi_u(\vec{\xi} - \vec{r}) \cdot u(\vec{\xi}, t) \cdot d\vec{\xi} + u_{ex}(\vec{r}, t) \right]$$

where $u(\vec{r}, t) = u(x, y, t)$ - the distribution of excitation in the form of space-time structures in a 2D distributed neuron-like system.

T determines threshold of system's actuation in response to the summed signal.

The spatial coupling function $\Phi_u(\vec{r})$ is chosen of the type of lateral inhibition with positive center and negative wings.

α is the normalizing constant for the coupling function.

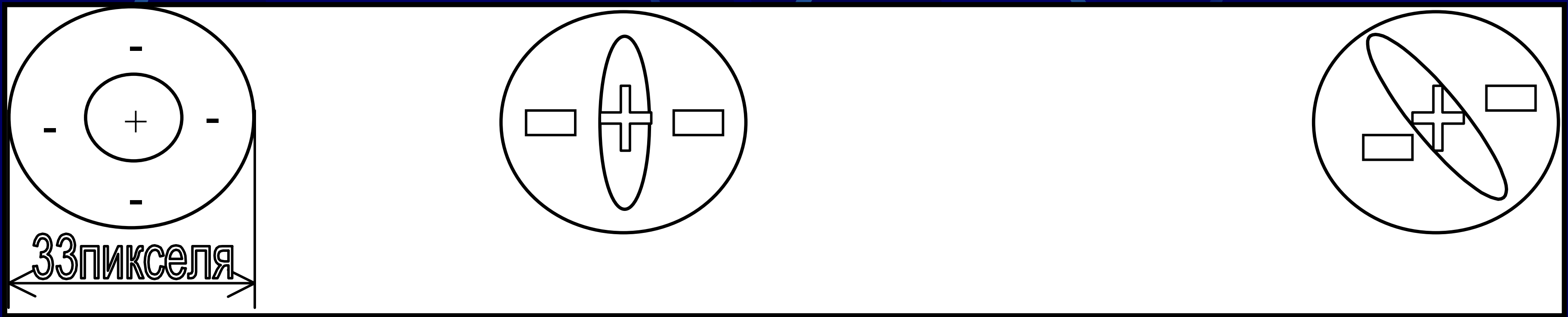
In the absence of second term in the right-hand side of the equation, the initial condition decays during the time τ_u .

Coupling functions are taken in the form of Gabor functions

$$\Phi(\vec{r}-\vec{r}_0) = cos(2\pi \cdot kx + \phi_0)\, exp\left(\frac{-\vec{r}^{\,2}}{2 \cdot l^2}\right),$$

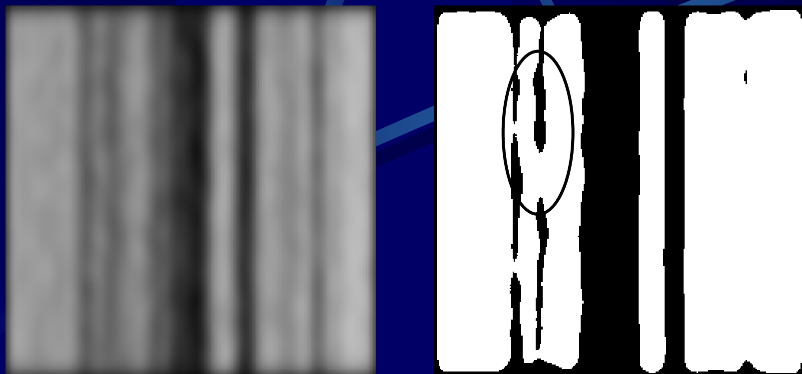
$$\vec{r} = (x, y)$$

In this case, at given ***l*,φ** the element coupling function of the lateral inhibition type is realized, where l is standard deviation in Gaussian distribution.

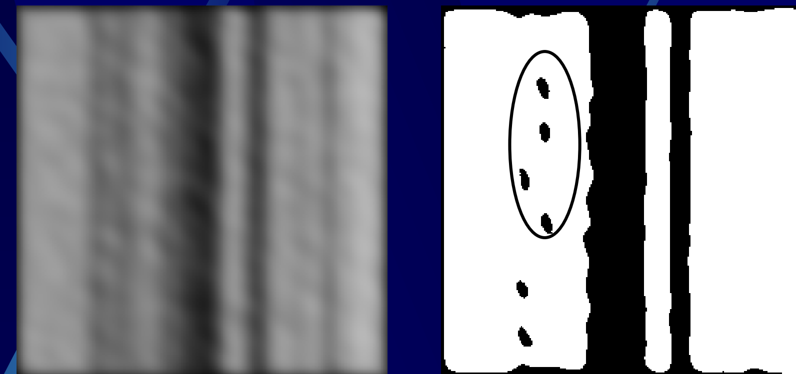


Coupling functions for extracting lines in different directions (vertical lines and lines at a -45° angle) .

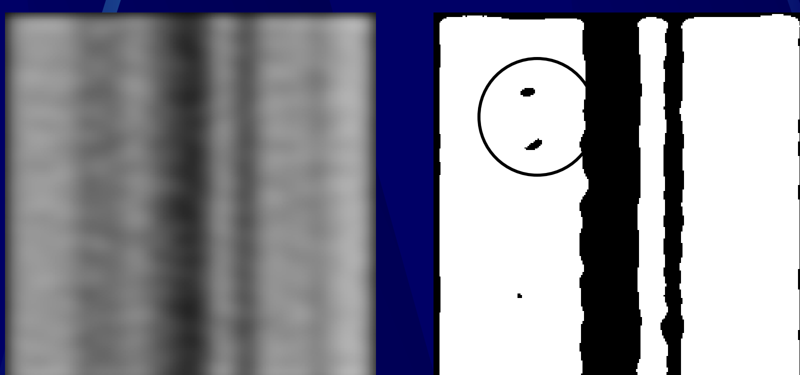
Matrix of couplings of 33*33 element



Extraction of vertical lines. Threshold T=100



Extraction of inclined lines (at a -45° angle)



Extraction of horizontal lines. Threshold T=100

Extraction of inclined lines (at a 45° angle)

Conclusions

1. The algorithm for image analysis of the signal dynamics spectrum seems to be more convenient for apprehension by an operator-researcher and more efficient, in particular, for extracting **signals with different, a priori unknown dependences of the frequency** filling in the sought gravitational waves.

2. It is very interesting to develop a version of an automated system enabling one to seek the fragments of recorded signal that resemble the signals from gravitational waves or the pre-extracted or pre-examined “signals” (with the calculating of the probability of coincidence and statistics of recording such fragments on the experimental records being analyzed).

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