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Mathematical processing and computer analysis of data from numerical modeling of radiothermometric medical examinations

Maxim Polyakov
Volgograd State University

m.v.polyakov@volsu.ru

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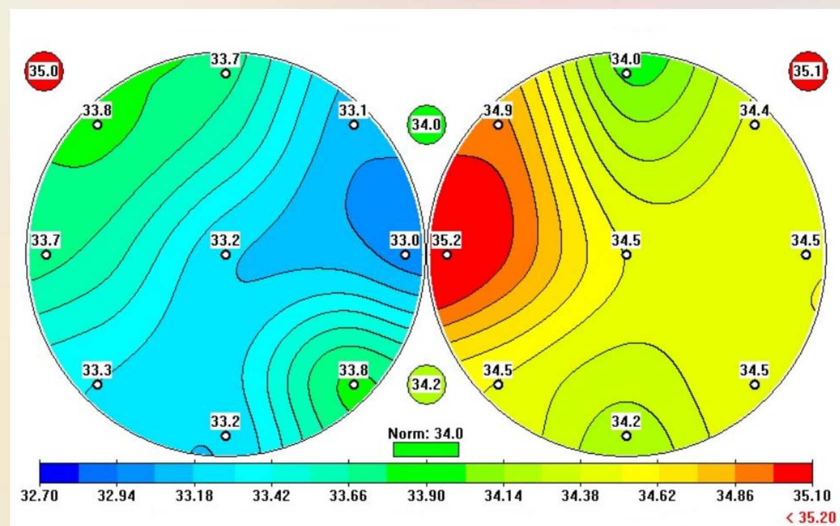
Microwave radiothermometry

Microwave radiometry is a biophysical method of non-invasive examination, which consists in measuring the internal and surface temperatures of tissues in accordance with the intensity of their thermal radiation.

The main task is to develop a method for computer modeling of radiothermometric measurements of biological tissues.
We create a dataset for checking the results of computer modeling by the method of binary classification.
This dataset allows investigating the applicability of the radiothermometry method for the problem of tumor localization and for the problem of determining the minimum radius of a tumor that can be diagnosed.



Mathematical model

To construct a stationary distribution of electric field, it is convenient to use a calculation to establish, solving the Maxwell's equations for non-stationary electric and magnetic fields:

$$\boxed{\frac{\partial \vec{B}}{\partial t} + rot(\vec{E}) = 0, \frac{\partial \vec{D}}{\partial t} - rot(\vec{H}) = 0, \vec{B} = \mu\vec{H}, \vec{D} = \varepsilon\vec{E},} \quad (1)$$

where $\vec{B}$ is magnetic induction, $\vec{E}$ is electric field strength, $\vec{D}$ is electric induction, $\vec{H}$ is magnetic field strength, $\mu(\vec{r})$ is magnetic permeability, $\varepsilon(\vec{r})$ is dielectric constant.

Temperature change is determined by the heat transfer equation

$$\boxed{\rho(\vec{r})c_p(\vec{r})\frac{\partial T(\vec{r},t)}{\partial t} = \nabla(\delta(\vec{r})\nabla T(\vec{r},t) + Q_{bl}(\vec{r},t) + Q_{met}(\vec{r},t) - Q_{rad}(\vec{r},t)} \quad (2)$$

where $\rho(\vec{r})$ is density, $c_p(\vec{r})$ is coefficient of heat capacity, $T(\vec{r},t)$ is simulated temperature, $\delta(\vec{r})$ is coefficient of thermal conductivity, $Q_i(\vec{r},t)$ is heat source functions.

Border conditions $q = \alpha(T - T_{air})$ is heat flux on the surface of biological tissue. Value α is thermal diffusivity, T_{air} is air temperature.

Modeling of brightness temperature

The brightness temperature is determined by the integral ratio of the form:

$$T_{br} = \int\limits_V W(\vec{r}, f) T(\vec{r}, f) dV, \qquad (3)$$

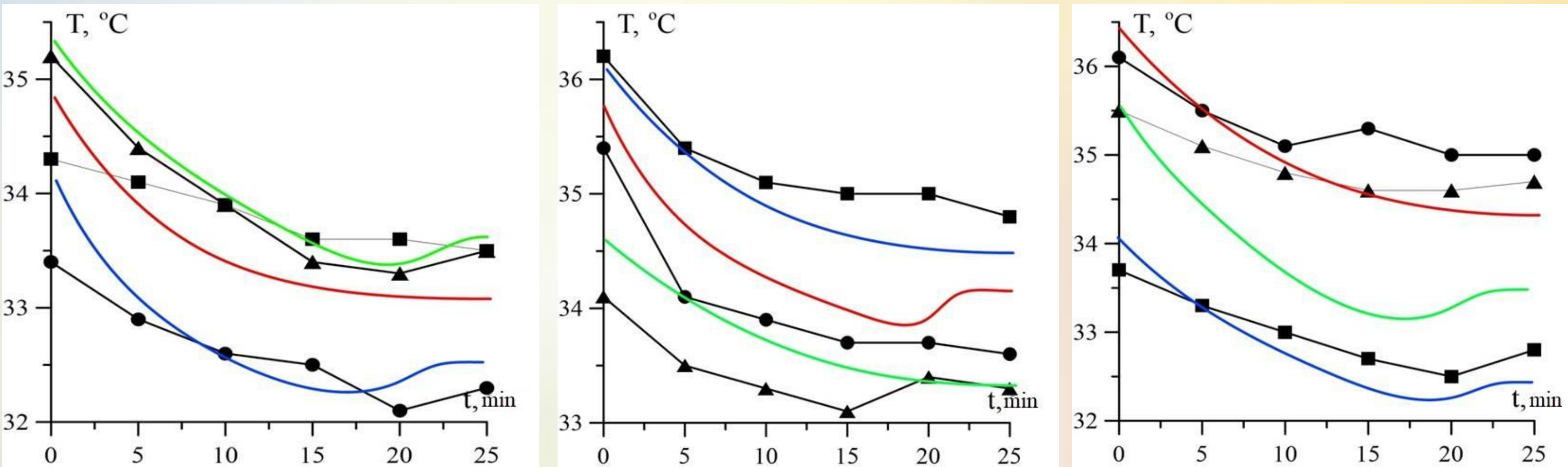
with weight function

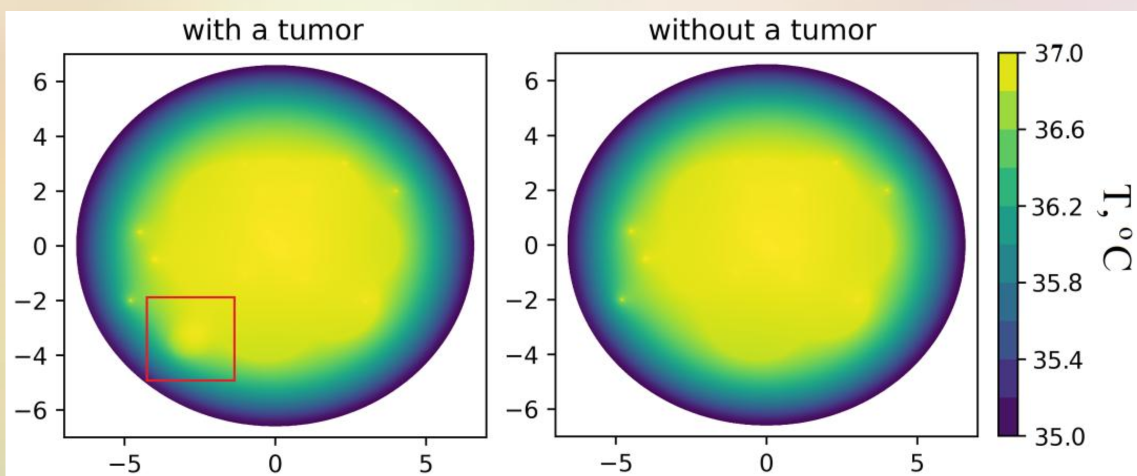
$$W(\vec{r}, f) = \frac{F(\vec{r}, f)}{\int_V F(\vec{r}, f) dV}, \int\limits_V W(\vec{r}, f) dV = 1, \qquad (4)$$

$$F(\vec{r}, f) = \frac{1}{2} \sigma(\vec{r}, f) |E(\vec{r}, f)|^2. \qquad (5)$$

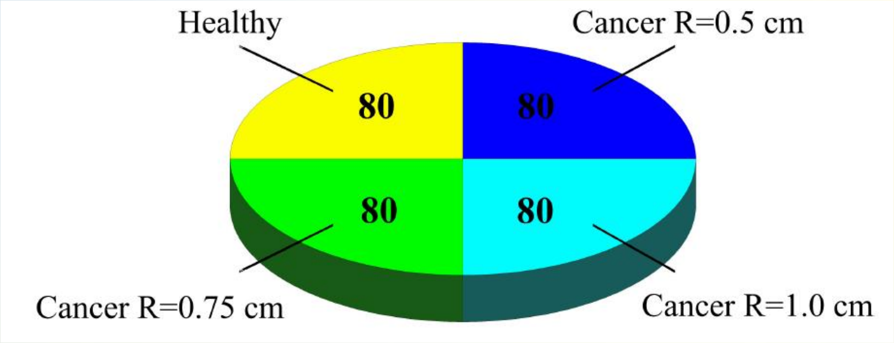
where *f* is operating frequency of the radiothermometer antenna.

Numerical simulation results for thermal dynamics



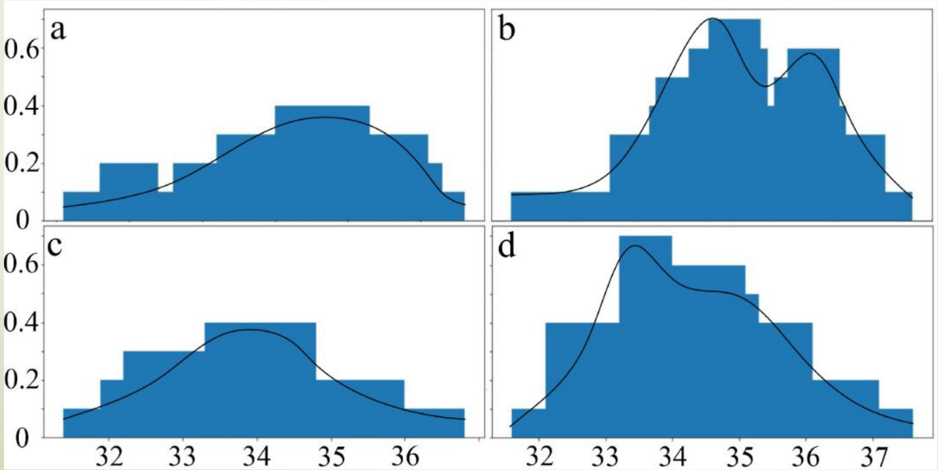


Structure of data set and classification methods



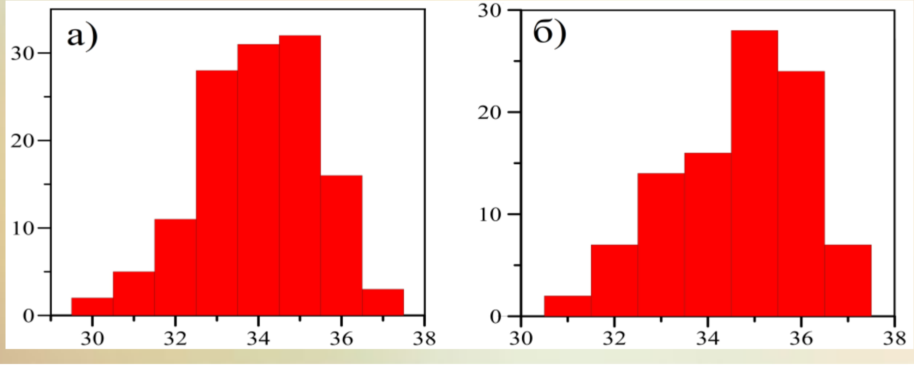
The following methods are used for binary classification of computer modeling data:

1) Support vector machines (SVM);
2) k-nearest neighbors (KNN);
3) Naive Bayesian classifier (NBC).



Frequency distribution of internal temperature data for

a) points «0» of the model without a tumor;
b) points «0» of the model with a tumor R=0.75 cm;
c) points «3» models without a tumor;
d) points «3» models with a tumor R =0.75 cm.



Statistical temperature distribution for

a) models without a tumor,
b) b) models with a tumor.

Classification results

$G = \sqrt{L \cdot S}$, where $L = \frac{TP}{TN + FN}, S = \frac{TN}{TN + FP},$ *TP* is proportion of correctly classified glands class «Cancer», *FN* is proportion of misclassified glands class «Cancer», *TN* is proportion of correctly classified glands class «Healthy», *FN* is proportion of misclassified glands class «Healthy».

EFFECTIVENESS OF DATA CLASSIFICATION METHODS

	NBC	KNN	SVM
R=0.5 cm	0.475	0.525	0.575
R=0.75 cm	0.7	0.675	0.725
R=1 cm	0.74	0.75	0.79

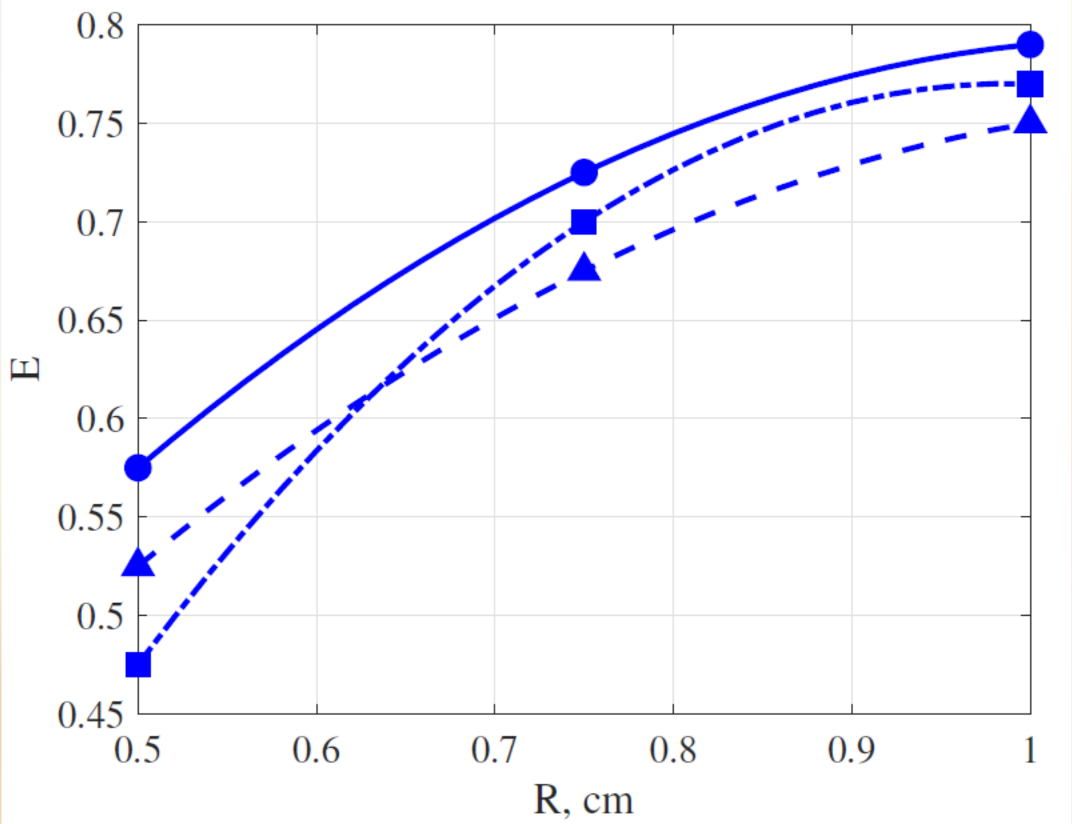
SENSITIVITY, SPECIFICITY, AND EFFECTIVENESS OF THE SVM METHOD FOR VARIOUS DATA SAMPLES

	L	S	G
R=0.5 cm	0.68	0.49	0.577
R=0.75 cm	0.78	0.725	0.75
R=1 cm	0.82	0.76	0.79

RESULTS OF NEURAL NETWORK TESTING FOR VARIOUS PARAMETERS

	Model 1	Model 2	Model 3	Model 4
Number of layers	6	5	4	5
Number of neurons in 1 layer	18	18	18	18
Number of neurons in 2 layer	18	18	18	9
Number of neurons in 3 layer	18	9	3	3
Number of neurons in 4 layer	18	3	2	3
Number of neurons in 5 layer	18	2	–	2
Number of neurons in 6 layer	2	–	–	–
L	0.72	0.62	0.59	0.81
S	0.66	0.59	0.55	0.67
E	0.7	0.67	0.57	0.75

Dependence of quality diagnosis on radius of tumor



Dependence of effectiveness diagnostic method according to microwave radiometry on size of tumor for various machine learning methods (SVM is circles, KNN is triangles and NBC is squares).

Conclusion

- We have carried out computer modeling of thermal fields in biological tissues of the mammary gland.

- Algorithms and machine learning methods were described and applied to process the results of numerical modeling of brightness temperature.

- Presented statistical features of different groups of patients indicate the distinguishing features of models with a tumor from the opposite ones.

- An artificial sample of healthy patients was modeled and used in machine learning for the diagnosis of breast cancer.

- We evaluated dependence of quality diagnosis on radius of tumor.

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