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REFINEMENT OF THREE-LAYER MODEL OF A DAMAGED HUMAN BODY FOR THE CASE OF CHANGING THE MOISTURE OF THE BANDING MATERIAL

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The object of study is a three-layer model of a damaged human body.

In the course of the study, it was found that the generally accepted three-layer model of a damaged human body is built, in particular, on the assumption that the characteristics of dressings remain unchanged over time. Therefore, the vast majority of modern research in the field of passive radiometry requires the removal of such materials from the human body during the measurement or considers their characteristics to be unchanged and insignificant. Questions of a possible change in the results of measuring the radiation of the human body due to the use of plaster casts of varying degrees of humidity remain almost unexplored.

As a result of the study, the mathematical three-layer model of the damaged human body was refined. An element was introduced into the model that describes the dependence of the attenuation of radio wave energy on the relative humidity of the plaster cast. The refined model makes it possible to increase the accuracy of measuring the temperature of the human body, taking into account the time of applying a plaster cast to it. Unlike the existing ones, the proposed model is based on an experimental study that simulates the measurement of the radiation of a human body with a plaster cast of different degrees of humidity. To refine the model, the obtained experimental data were processed by regression analysis methods.

The results of processing the experimental data made it possible to establish the specific type and value of the coefficients of the desired dependence.

The use of the obtained results of the study proves the possibility of remote non-invasive express diagnostics of the state of the human body in the presence of plaster-gauze bandages.

Providing such an opportunity allows disaster medicine workers to increase the ability to fulfill the so-called "golden hour rule", as well as to clarify the requirements for a medical radiothermal mapping system

Keywords: non-invasive diagnostics, plaster cast, radiothermal mapping, regression analysis, quality indicators

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1. Introduction

According to the World Health Organization, the global trends of the first two decades of the 21st century emphasize the need for increased attention in all regions of the world to the following threats [1]:

– cardiovascular diseases;
– cancer;
– diabetes;
– chronic respiratory diseases;
– injury.

The main causes of injuries in the world include the following:

– traffic accidents [2];
– accidents at the workplace and occupational diseases [3].

In addition, natural and man-made disasters, as well as military actions, should be separately mentioned as causes of injuries.

According to the Director-General of the World Health Organization, the results of the assessment of current trends emphasize the urgency of a radical improvement in primary health care in an equitable and integrated manner [1]. The need for comprehensive measures to address the problems of injuries in the workplace is also recognized in [4]. At the same time, it is recommended in [5] to proceed from the assumption that in the event of an accident at the workplace, people can receive injuries of a combined nature. In such cases, the success of treatment is determined, first of all, by timely and effective diagnosis, as well as constant monitoring during therapeutic measures. The economic efficiency of timely diagnostics in the treatment of certain categories of patients was also confirmed in [6].

Modern theoretical and applied research in the field of injury diagnostics is mainly focused on solving two main problems:

– creation and improvement of methods and tools that provide effective primary diagnosis of injuries;

– creation and improvement of models of methods for processing measurement results, which make it possible to improve the accuracy of primary diagnostics.

The solution of the first problem now leads to a gradual abandonment of the methods of radiation diagnostics. These methods are considered traditional in the practice of medical control of the physiological state of the human body [7] and are widely used in countries with very different levels of development [8, 9]. However, these diagnostic methods have a number of features that limit their use. Among these features, it is necessary to highlight the limitation of the frequency of diagnostic sessions in accordance with the individual dose received by the patient, age, gender and a specific type of disease. The manifestation of this limitation in medical practice are the following circumstances:

– unjustified use of radiodiagnostic methods to detect a number of diseases and injuries [10];

– real risk of harm to the patient in case of equipment failure or erroneous actions of a specialist conducting a diagnostic session [11];

– legislative restrictions on the conduct of various types of radiation diagnostics [12].

An additional difficulty in the application of methods of radiation diagnostics should be recognized as the existing global trend of a significant increase in electricity prices.

In recent decades, pyrometry methods and, in particular, infrared thermography have been actively considered as one of the alternatives to traditional methods of radiation diagnostics. However, such methods have a rather significant drawback: the measurement results allow to judge the temperature changes in internal organs only indirectly. Thus, infrared thermography methods give the true temperature of only the uppermost layer of the skin, a fraction of a millimeter thick. This greatly complicates the task of diagnosing internal injuries and pathologies.

Therefore, more and more attention is paid to such an alternative to the methods of radiation diagnostics as microwave radiometry. The first studies on the use of radiometry for cancer diagnosis were carried out as early as the mid 1970s. [13]. However, until the early 2000s such studies, despite promising prospects, were in a relatively infancy [14]. Only in the last decade, a clear trend towards an increase in the interest of specialists in different countries in these diagnostic methods began to appear. However, most research in this area is focused on the study of methods and means of stationary radiometry directly in medical institutions. A number of aspects of the use of microwave radiometry in the course of field diagnostics of injured people remain poorly studied.

In addition, almost all modern methods and tools that are considered as alternatives to radiodiagnosis have a common drawback. This disadvantage lies in the relatively low accuracy of diagnostic results. The generally accepted practice of eliminating this shortcoming is to conduct special studies aimed at clarifying the basic models of damaged areas of the human body used in the course of diagnosis. The results of these studies are used to create special software and hardware modules for the primary correction of the results of direct measurements immediately before they are displayed to the operator of the diagnostic complex.

Therefore, studies that improve the accuracy of microwave radiometry results by refining the basic models of diagnosed areas of a damaged human body should be considered relevant from a theoretical and applied point of view.

2. Literature review and problem statement

The modern increase in interest in radiometry methods is explained by the results of improving the equipment used in these methods. Only in the last decade, as a result of improving the element base of microwave equipment, it became possible to develop new models of medical diagnostic systems. A comparative analysis of the use of radiometry and other methods (both passive and active) of visualization of pathologies was carried out in [15]. The analyzed methods were evaluated according to such characteristics of medical diagnostic equipment as cost, hardware complexity and resolution. Based on the results of this analysis, the following conclusions were made regarding radiometry [16]:

– radiometry does not require large expenditures for the manufacture of equipment;

– training to work on radiometry equipment does not make excessive demands on future specialists;

– the main disadvantage of modern radiometry should be considered the low resolution of the equipment, which generates measurement errors.

A number of studies of radiometry tools for diagnosing the human body consider various approaches to eliminating the main drawback noted in [15], among which two main approaches can be distinguished. The first of these approaches involves the elimination of the noted shortcoming in the course of direct measurement of the characteristics of the human body. As shown in [16], this approach is implemented in measurements from open space in the centimeter and millimeter ranges using a scanning elliptical mirror. The object was located in one focus of this mirror, and the receiving device was located in the other. However, the implementation of this approach proposed in [16] is unacceptably difficult for diagnosing injuries in the workplace, in cases of natural or man-made disasters, as well as in military operations.

The second main approach involves eliminating the disadvantage noted in [15] by processing the results of radiometry measurements performed by contact or non-contact methods. Contact radiometry involves the use of electrodes (applied or implanted in the object of measurement) [16] or special antenna-applicators [17]. However, the use of contact radiometry in the field is difficult due to the high probability of the presence of various layers on the body of a diagnosed person, which distort the measurement results. These overlays include:

– hairline on the human body;

– scraps and remnants of clothing;

– layers of ointments or other drugs applied during primary therapy to the diagnosed area of the body;

– plaster bandages and other dressings.

Therefore, to diagnose injuries directly at the workplace, in cases of natural or man-made disasters, as well as in military operations, non-contact passive microwave radiometry is preferable. It was noted in [18] that microwave radiometers can provide non-contact temperature monitoring of patients in intensive care units in real time at an appropriate distance, reducing the number of contacts between medical workers and patients. In [19], the possibility of using this diagnostic method simultaneously with a therapy session is shown.

However, practically all methods of implementing the second main approach [17–19] have a serious drawback. This disadvantage, as shown in [7], is the lack of an adequate mathematical apparatus that allows describing the state of the diagnosed biosystem with sufficient accuracy.

The desire to eliminate this drawback leads to the need for constant refinement of mathematical models of diagnosed areas of the human body for various special cases of radiometry. Such refinement is carried out, as a rule, according to the results of experimental studies. Thus, in [20], a mathematical coherent model of radiometric contact measurement of the temperature of the human head was proposed. This model assumed the application of the Pennes bioheat equation to a six-layer model of the human head, followed by processing the simulation results using a direct electromagnetic model. However, this model, as shown in [20], turned out to be insufficiently accurate and required tuning based on the statistics of population variations in the population for a wide range of frequencies. Therefore, in [21], corrections were developed based on the results of experimental measurements, which made it possible to correct the coherent model for a particular region of the United States. The introduction of these corrections into the coherent model made it possible to increase the accuracy of measuring the temperature of the human head so that the results of radiometry were within the clinically acceptable error range (±0.5 °C) [21]. However, the authors of [20, 21] cannot guarantee the accuracy of human head temperature measurements using the coherent model refined in this way in other regions of the United States and in other countries of the world. It should also be noted that the coherent model proposed in [20] and refined in [21] is based on the assumption that the aforementioned layers are absent on the human body during diagnostics. Therefore, the use of such models for the diagnosis of injuries in the workplace, in cases of natural or man-made disasters, as well as in military operations.

There are a number of mathematical models that allow processing the results of radiometric measurements, taking into account the presence of such layers on the human body and, in particular, dressings. An example of such models is the three-layer model of a damaged human body, proposed for the first time in [22]. This model takes into account the presence of dressing material on the human body. As shown in [23], a number of types of dressings are permeable to passive radiometry and practically do not affect the measurement results. Therefore, when using this model, it is assumed that the properties of the dressing do not change over time and are taken into account by introducing a constant correction factor into the three-layer model. This assumption was used in [24] when studying the use of a three-layer model of an injured human body for diagnosing burns using passive radiometry.

However, this assumption needs to be verified taking into account the peculiarities of diagnostics in disaster medicine. The use of passive radiometry makes it possible to carry out such diagnostics in parallel or in the first hours after first aid. The use of dressings such as plaster bandages during first aid, which require soaking in water for 5 to 15 minutes, leads to the appearance of plaster bandages on the human body. The moisture content of these dressings changes significantly already during the first hours after application. Therefore, the use of passive radiometry for diagnosing injuries covered by similar plaster casts requires specification of the basic three-layer model.

3. The aim and objectives of the study

The aim of the study is to refine the three-layer model of a damaged human body, allowing to take into account the influence of the absorbency of such a dressing material as plaster casts. This will make it possible to increase the reliability of the results of diagnostics of the human body due to the prompt correction of the results of passive radiometry obtained during the diagnostics in the first hours after the application of a plaster cast.

To achieve the aim, the following objectives were set:

– to conduct an experimental study of the change in the attenuation of electromagnetic waves depending on the change in the humidity degree of the plaster cast;

– to reveal the dependence of the attenuation of radio wave energy on a plaster cast on its relative humidity.

4. Materials and methods of the study

The object of the study is a three-layer model of a damaged human body. The peculiarity is that the process of conducting passive non-contact radiometry takes place in the presence of plaster casts of varying degrees of humidity on the human body during the diagnosis.

As applied to the case of diagnosing burns, the structure of a three-layer model of a damaged human body will look like that shown in Fig. 1 [24]

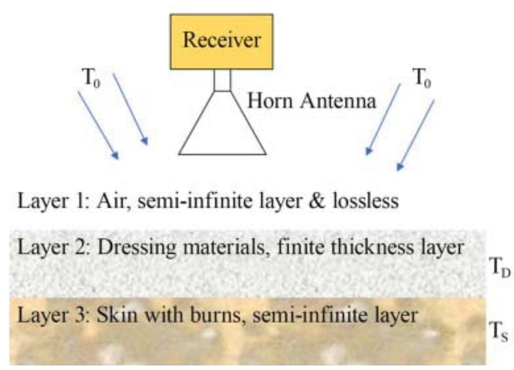

Fig. 1. The structure of a three-layer model of an injured human body for the case of burn diagnostics

In this model, environmental radiation having a radiation temperature T_0 illuminates the dressing, and radiometric skin radiation having a physical temperature T_S illuminates the reverse side. Since the dressing, at physical temperature T_D, has finite absorption, it also radiates. Then the radiation temperature of the human body *Tb*, measured by a passive radiometer, can be described by the following expression [22, 24]:

$$T_b = T_0 R(1-b) + T_N Rb + T_D A + T_S \eta, \quad (1)$$

where T_b is the radiation temperature of the human body; *R* is the reflectance of the bandaged skin; *b* is the fraction of the total radiation blocked from reflection from the sample by the antenna (the value of b depends on the antenna and its proximity to the sample); *A* is the quantitative characteristic of the absorbing capacity of the dressing layer, the heat radiation coefficient of the skin (compared to the heat radiated by a completely black body) [24]; T_N is the noise temperature of the radiometer receiver.

Model (1) is focused on measurements under stable conditions typical of hospital premises. However, these shortcomings, as follows from [20, 21], are characteristic of almost all mathematical models of the human body and its elements used in modern research.

It should be noted that model (1) is generalized and does not take into account a number of parameters that can affect the measurement results. One of such generalizations of model (1) is the assumption of the invariance of the value and the absence of a serious influence of the coefficient A on the results of temperature measurements by passive radiometry. However, these assumptions are incorrect when plaster casts based on standard plaster bandages are used to fix injuries in disaster medicine. In this case, the moisture content of the plaster cast, and hence its absorption capacity, changes significantly during the first hours after such a dressing is applied. Therefore, it is proposed to correct the form of model (1) by clarifying the form of the coefficient of model A based on the results of measurements during the experiment.

5. Results of refinement of the three-layer model of the damaged human body

5. 1. Experimental study of the influence of the humidity degree of a plaster cast on the attenuation of radio waves

To determine the magnitude of the change in the value of the coefficient A of model (1), a special experiment was carried out. This experiment was part of the experimental studies carried out to clarify the medical and technical requirements for radiothermal mapping equipment and described in [16]. In this experiment, a medical radiothermal mapping system (MTRRME) was used to measure the temperature of an injured human body. The basis of MTRRME is a microwave radiometer (JSC Research Institute of Radio Engineering Measurements, Kharkiv, Ukraine) with a wavelength of 8 mm. This microwave radiometer has the following specifications:

– central frequency of the processed signal – 36.6 GHz;
– processed frequency band – 0.4 GHz;
– fluctuation sensitivity of the CRM, reduced to 1 s – 0.126 K;
– noise temperature – 1450 K;
– dynamic range – 37 dB;
– integration time constant – 50 ms;
– decoupling depth between channels – 70 dB;
– beam width at half power: in the azimuthal plane – 6°, in the elevation plane – 5°;
– scanning period by line – programmable (≈12 s);
– accuracy of installation of the rotary system: in the azimuthal plane – 6°, in the elevation plane – 6°;
– maximum range of scanning angles of the OPU: in the azimuth plane – ±30°; in the elevation plane – ±30°.

Structural scheme of MTRRME is given in [16].

The ambient layer was the air in the room in which the experiment was carried out (during the experiment, the temperature was maintained at 20 °C). A layer of skin and a damaged human body with an elevated temperature is simulated during the experiment using a reference noise generator. In this case, the opening plane of the horn antenna of the noise generator was located in the plane of temperature measurements of the MTRRME (in the region of the near focus of its elliptical antenna). The dressing material layer was imitated by plaster bandages of the same type and thickness based on standard plaster bandages.

The choice of a reference noise generator for modeling a section of a damaged human body is due to the fact that radiothermal signals are noise-like in nature. Therefore, receivers of radiothermal signals are usually made in the form of accurate noise power meters.

First, the opening of the noise generator antenna was covered with a plaster cast (having an area that significantly overlaps this opening). Then, at intervals of 1 hour, measurements were made of the values of the relative humidity of the plaster bandage and the magnitude of the attenuation of radio wave energy in the presence of this bandage. For this purpose, the plaster cast was removed from the noise generator antenna and the initial output power level of the noise generator P_{1i} was reduced to the value P_{2i}, restoring the signal power level equal to P_0 at the output of the radiothermograph.

In this case, the relative value of the attenuation of radio wave energy in the presence/absence of a plaster cast was determined by the formula [16]

$$\delta = 10 \times \lg \frac{P_{2i}}{P_{1i}}, \quad (2)$$

where P_{1i} is the output power of the noise generator under conditions when, having opened its antennas, it is covered with a plaster cast, and the signal power at the output of the radiothermograph is P_0, W; P_{2i} is the output power of the noise generator under conditions when the plaster cast did not cover its antenna opening, and the output power of the radiothermograph signal is P_0, W.

The relative humidity of plaster casts was determined by the formula [16]:

$$B_i = \frac{m_i - m_п}{m_п} \cdot 100\,\%, \quad (3)$$

where m_i is the mass of the plaster cast at the *i*-th weighing (at the beginning of the *i*-th hour) after its manufacture, g; m_i is the mass of a plaster cast with established moisture during its long-term use (approximately 10 hours after its manufacture).

During the experiment, three copies of the same plaster cast were used. The results of measuring their mass mi are given in Table 1 [16].

The results of measuring the relative humidity B_i and the damping value δ are presented in Table 2 [16].

Table 1

The results of measuring the mass m_i of plaster casts used in the experiment

Measurement, *i*	Cast type			Measurement, *i*	Cast type		
	Cast 1	Cast 2	Cast 3		Cast 1	Cast 2	Cast 3
1	20.2	20.8	19.8	7	18.2	18.6	17.7
2	19.92	20.5	19.4	8	17.04	17.3	17
3	19.63	20.2	19.3	9	16.8	17.2	16.4
4	19.4	19.9	19.1	10	16.1	16.1	14.95
5	19	19.4	18.6	11	15.62	16	14.65
6	18.6	18.9	18	12	17.04	17.3	17

Table 2

The results of measurements of the relative humidity B_i and the attenuation value δ of electromagnetic waves in the 8-mm range during the experiment

Measurement, *i*	Cast type								
	Cast 1			Cast 2			Cast 3		
	m, g	B, %	δ, dB	*m*, g	B, %	δ, dB	*m*, g	B, %	δ, dB
1	20.20	42.054	20.35	20.8	40.068	17.5	19.8	45.588	18.1
2	19.92	40.647	17.20	20.5	38.604	14.2	19.4	43.527	15.6
3	19.63	39.15	15.60	20.2	37.097	13.2	19.3	42.999	14.5
4	19.40	37.93	14.60	19.9	35.545	12.6	19.1	41.924	12.8
5	19.00	37.74	13.38	19.4	32.851	10.2	18.6	39.137	11.95
6	18.60	33.45	12.80	18.9	30.015	9.5	18.0	35.588	10.8
7	18.20	31.064	11.80	18.6	28.239	8.0	17.7	33.724	9.3
8	17.49	26.558	9.70	18.3	26.42	7.1	17.45	32.121	9.2
9	17.04	23.508	8.00	17.3	19.836	5.9	17.0	29.118	7.6
10	16.8	21.815	7.50	17.2	19.137	3.9	16.4	24.856	6.2
11	16.1	16.588	5.50	16.1	10.875	0.9	14.95	13.147	1.0
12	15.62	12.732	3.00	16.0	10.067	0.5	14.65	10.434	0.4

There is a clear dependence of the attenuation of electromagnetic radiation (EMR) depending on the moisture content of the dressings, which can be explained by the attenuation of the waves of the corresponding range in an aqueous medium. Subsequently (after approximately 8–10 hours), the moisture content of the bandage does not exceed 7 %, the energy attenuation is 0.6–0.7 dB (1.2 times) and has little effect on the results of observations. Therefore, there is an urgent need to determine the type of the found dependence for the subsequent refinement of the coefficient A of the model (1).

5. 2. The dependence of the attenuation of radio wave energy on a plaster cast on its relative humidity

The data given in Table 2, allow to establish a specific type of dependence δ=g(B) of the attenuation of radio wave energy on a plaster cast (δ) on its relative humidity (B). For this purpose, a regression analysis of the data from Table 1 was carried out. 2 using Statgraphics v. 15.1 (USA).

As a result of the analysis, it was found that the dependence of the attenuation of radio wave energy on a plaster cast on its relative humidity has the following form:

$$\delta=\left(-1.92425+0.91434\sqrt{B}\right)^2. \qquad (4)$$

To assess the admissibility of using the regression dependence (4) using the software product Statgraphics v. 15.1 (USA) quality metrics for this dependency were defined. These indicators include [25, 26]:

a) assessment of the overall quality of the regression equation (4);

b) assessment of the statistical significance of each coefficient of the regression equation (4);

c) assessment of the statistical significance of the entire regression equation (4) as a whole.

The calculation of these indicators is an integral part of the regression analysis [25, 26].

The results of calculations of the statistical significance of individual coefficients of equation (4) are given in Table 3. The results of calculations of the statistical significance of equation (4) are generally given in Table 4. The results of calculations of the overall quality of equation (4) are given in Table 5.

Table 3

Quality indicators of the coefficients of the regression equation (4)

Parameter	Least Squares Estimate	Standard Error	T-statistic	P-Value
Intercept	–1.92425	0.128364	–14.9906	$<1\cdot10^{-4}$
Slope	0.91434	0.024118	37.9104	$<1\cdot10^{-4}$

Table 4

Analysis of variance of the regression equation (5)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	11.7835	1	11.7835	1437.20	$<1\cdot10^{-4}$
Residual	0.0819894	10	0.00819894	–	–
Total (Corr.)	11.8655	11	–	–	–

Table 5

Quality indicators of the regression equation (5)

Quality indicator of the regression equation	Numerical values of the quality indicator of the regression equation
R-squared,percent	0.996539
R-squared (adjusted for d.f.), percent	99.2399 percent

Based on the quality assessment results (Tables 3–5), it is possible to conclude that the obtained equation (4) is reliable.

The graph of the empirical dependence δ=g(B) is shown in Fig. 2. Due to the features of the software system used, the symbol D on the y-axis corresponds to the symbol δ in (4).

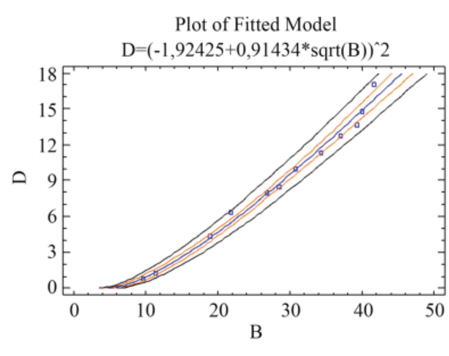

Fig. 2. Graph of the empirical dependence δ=g(B)

The relative sensitivity (elasticity) of the value δ to the change in the value B has the form:

$$EL = 1 + \frac{a}{g\sqrt{B} - a}. \qquad (5)$$

Graphical representation of expression (5) is shown in Fig. 3.

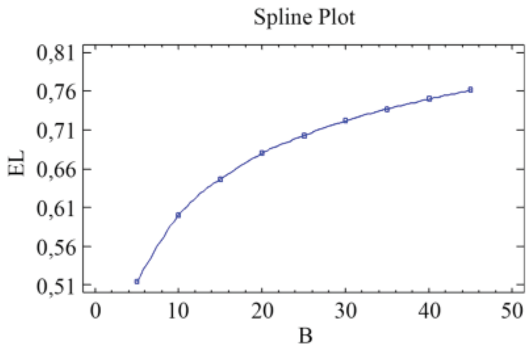

Fig. 3. Relative sensitivity (elasticity) of a quantity to a change in the value B

When constructing model (4), the data were averaged over the values of δ and B. This is permissible only if the influence of the mass of the plaster cast can be neglected. To test this assumption, let's use a variant of one-way non-parametric analysis of variance (the Kruskell-Wallace criterion) in the form described in [26]. This method of solving the problem was chosen in order to avoid testing the hypothesis about the normal distribution of the initial data, which is not sufficiently reliable for a small amount of initial data.

As a result of the calculations, it was found that the numerical value of the Kruskell-Wallace criterion for the data used is 1.5009 with a P-Value of 0.4721. Therefore, it can be argued that the hypothesis of the absence of a statistically significant difference between species, and, consequently, between the masses of dressings, does not contradict the experimental data.

The results obtained make it possible to correct the model (1) for the case of diagnostics in the course of providing primary medical care to people injured as a result of a natural or man-made disaster. The result of the correction will look like this:

$$T_b = T_0 R(1-b) + T_N R b + \\ + T_D\left(-1.92425 + 0.1434\sqrt{B}\right)^2 + T_S \eta. \qquad (6)$$

The use of a refined three-layer model of a damaged human body (6) for passive radiometry is possible using data on changes in the degree of humidity of the plaster cast (Table 2).

6. Discussion of the results of refinement of the three-layer model of the damaged human body

In the course of the study, an experiment was conducted that simulated the measurement of MTRRME radiation from the human body with a plaster cast of varying degrees of humidity. The results of the experiment (Table 2) confirmed the dependence of EMR attenuation on the moisture content of the dressings. This dependence can be explained by the attenuation of the waves of the corresponding range in an aqueous medium. It should be noted that after approximately 8–10 hours, when the moisture content of the dressing no longer exceeds 7 %, the energy attenuation is 0.6–0.7 dB and has little effect on the results of observations. Therefore, the dependence of EMR attenuation on the moisture content of plaster casts should be taken into account in the course of diagnostics, which is carried out as soon as possible after injury.

Further, using regression analysis, the form, values of the coefficients (4) and quality indicators (Tables 3–5) of the equation were determined, which describes the dependence $\delta = g(B)$ of the EMR attenuation value on the plaster cast (δ) on its relative humidity (B). The view and graphical representation (4) (Fig. 2) confirm that the desired model is a parabolic function, a significant part of which can be approximated by a linear function. This can be explained by the invariability of environmental conditions, which affect the drying rate of the plaster cast during the experiment.

The experiments described in [21, 24] simulated the use of a radiometer to measure the temperature of a human body under constant conditions. At the same time, it was assumed that only clothes or dressings are present on the human body, the characteristics of which do not change over time. In contrast to these experiments, this study established the fact that EMR attenuation changes over time when a wet plaster cast is on the human body. The development of a mathematical model describing this attenuation makes it possible to further tune the radiometer for diagnostics in the first hours after injury.

The results obtained allow, due to the possibility of prompt correction of the measurement results, taking into account the presence of plaster casts, to increase the reliability of diagnosing pathologies of the human body. In this case, it is proposed to carry out an operational correction of the results of applying the MTRRME by supplementing the existing software of this system with a new function for calculating the corresponding correction. To this end, it is proposed to correct the MTRRME software, in particular, the software module for processing measurement results. The data in this module comes from the analog-to-digital converters of the control unit and signal processing MTRRME. The calculation results of this module are displayed on the display of the computer used to process the primary results of the MTRRME. The essence of the correction is to create an additional function for calculating the corrections to be made if there is a plaster cast on the damaged area of the human body. This function asks the operator for the number of hours that have passed since the cast was applied, as well as the type of cast. After the operator enters the relevant data, the function determines from the Table 2 the value of B and calculates the corresponding element of the model (6). Further, the function transfers the calculation results to the software module for generating and displaying the final diagnostic results.

The results of taking into account this correction made it possible during the study to determine areas of the damaged body with a resolution over the surface of 1.2×1.2 cm with an accuracy of temperature measurement of ±0.1 °C, taking into account the presence of a plaster cast on the body area. It should be noted that the vast majority of similar microwave radiometry tools (for example, those considered in [20, 21]) require the complete absence of any fragments of clothing and dressings on the body area under study.

The results obtained made it possible to refine this model for the case of diagnosing people whose injuries resulting from a natural or man-made disaster were fixed with plaster casts. This opens up the possibility of remote non-invasive express diagnostics of the state of the human body prior to its delivery to a stationary point of medical care. At the same time, not only plaster-gauze bandages can be on the body of the victim, but also clothes, medicines, traces of secretions, soot, etc. Providing such an opportunity allows one to ensure one of the basic rules of disaster medicine – the golden hour rule.

The main limitations of this study should be recognized:

– establishment of a constant ambient temperature during the experiment, which is not always observed in real conditions;

– lack of data on the effect on the drying rate of plaster casts of their contamination with drugs, soot, secretions of the human body, etc.

The study is not without known shortcomings. The main of them should be recognized as the organization and conduct of experimental studies in the absence of disturbances in the external electromagnetic environment. At the same time, in the course of remote non-invasive express diagnostics of the state of the human body in disaster medicine, there is always a rather high probability of the influence of external electromagnetic interference. These interferences, as a rule, are a consequence of the manifestation of the characteristics of the territory on which such diagnostics are carried out (the presence of working power lines, radar stations, sources of direct or alternating current, etc.). This disadvantage can be overcome by tightening the requirements for the location of the corresponding MTRRME. However, such a solution is palliative. It is necessary to carry out additional studies to assess the influence of external electromagnetic disturbances on the results of the work of the MTRRME.

A certain disadvantage should also be recognized as an orientation in the course of the study to a specific type of microwave radiometric equipment. Additional studies are needed, on the basis of which it will be possible to draw a conclusion about the degree of influence of plaster casts of different humidity for the main spectrum of such means of remote non-invasive express diagnostics available for use in Ukraine. In addition, it is necessary to carry out work on the creation of applied methodological recommendations that allow making appropriate amendments to the diagnostic results directly in the area of the incident.

Further development of this study is most appropriate to focus on improving the following aspects:

– medical and technical requirements for the MTRRME antenna;

– medical and technical requirements for the MTRRME radiometric system;

– a technique for diagnosing patients in disaster medicine using MTRRME.

In addition, it is necessary to continue research aimed at studying the influence of various environmental factors, possible dressings, clothing and their contamination on the MTRRME operation.

7. Conclusions

1. The results of the experiment show that at the beginning of the twelfth hour after application, the weight of the plaster bandage decreases by an average of 4–5 g with an average initial weight of the bandage of 20 g. This change is significant and refutes the initial assumption that the properties of the dressing material are unchanged over time. According to the results of the experiment, it was found that the refinement of the basic three-layer model of the damaged human body is necessary in the part that describes the effect of the dressing on the results of measuring body temperature.

2. Using the methods of regression analysis, the type of equation was determined that describes the change in the characteristics of the dressing material in a three-layer model of a damaged human body. This equation is non-linear. The input variable of this equation is the value of the relative humidity of the plaster cast. The output variable is the attenuation of the radio wave energy on the cast. According to the results of the experiment, it was found that the value of the input parameter decreases over time. With a decrease in the value of the input parameter, the value of the output parameter of the resulting equation decreases. The quality assessment carried out confirmed the reliability of the resulting equation. The resulting equation made it possible to refine the basic three-layer model of a damaged human body for the case of using plaster casts in the treatment of the consequences of traumatism.

Conflict of interest

The authors declare that they have no conflict of interest regarding this study, including financial, personal nature, authorship or other nature that could affect the study and its results presented in this article.

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Data availability

The manuscript has no associated data.

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