Development of a methodology for estimating the heat loss of buildings based on neural networks

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***Abstract* — The study describes a methodology for estimating the heat loss of a building, including the calculation of the heat loss of a building. The features of the wooden housing stock were studied for developing a methodology for estimating the heat loss of a building based on neural networks. The stage of images collecting for training a neural network, the stage of training an optimal neural network for solving the problem of object detection are described. The technologies necessary to solve the problem are described.**

Keywords* — *neural network, thermal imager, methodology for estimating the heat loss, heat map, image processing

I. INTRODUCTION

In the areas of the Extreme North, the issue of maintaining the temperature of residential and working premises as well as monitoring heat loss is important – low ambient air temperatures accelerate heat exchange between the environment and the premises; as a result, a person begins to experience discomfort and it affects his working capacity. In the study, a thermal imager was used to measure the temperature of buildings; however, it displays information in a form that is convenient only for a human. The preliminary intellectual processing of the data output from the device is necessary for further usage of these data in the sphere of computer vision. During the study, it was found that there were no analogues of software in the open access.

For the foregoing reasons, the relevance of the research topic is determined by the lack of a tool for automated estimation of building heat loss. The aim of the study is to increase the reliability of estimating the heat loss of a building from an image from a thermal imager. The developed methodology combines a quantitative and visual assessment of the heat loss of a building, produced indirectly from the object of study.

II. METHODS

Due to the specifics of the input data, it is not possible to absolutely reliably estimate the volume of heat loss of a building; however, it is possible to determine relative indicators for comparing individual buildings with each other. For estimating heat loss, the following data are required: area of the structural element; thermal conductivity coefficient of the element; element thickness; difference between outside and inside temperatures.

Due to the inability to accurately measure the thickness of the material from the image, the area of structural elements, as well as certain difficulties in identifying the type of materials of the structural element, the developing software will mark the structural elements (roof, attic, pipes, windows, door, foundation) and according to the number of structural elements and their heat map will draw conclusions about the degree of heat loss of the building.

According to Figure 1, it is possible to note that windows occupy a significant area in the image; the wall has the lowest temperature, and the doorway has an average temperature. Hence, it is possible to conclude that the greatest heat loss in this case occurs through the windows.

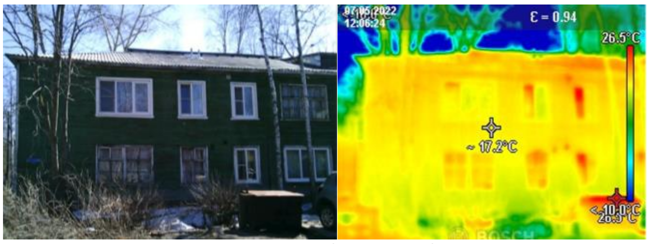

Fig.1. Image in the visible spectrum (left), in the infrared spectrum (right)

The heat loss estimation algorithm will be as follows:

1) The image in the visible spectrum corresponds in size to the image in the infrared spectrum.

2) The neural network identifies the presence of a structural element and its position in the image in the visible spectrum.

3) The average values of the parameters of structural elements (thickness, area, material) are determined.

4) The heat loss coefficient is calculated (color_coef).

5) The calculation of heat losses for each structural element is being made.

6) Information about the heat loss is applied to a new image

For calculating the heat loss of attics, windows, chimneys and entrance doors, their area is calculated as an average area value multiplied by the number of structural elements. In Table 1 showed the necessary data used to calculate the heat loss of buildings, where Name – is the name of the structural element of the building, S – is the area in m^2, T – is the thickness of the structural element of the building in m, k – is the thermal conductivity coefficient in W/(m*°C), F – formula for calculating the heat loss of a structural element. Color_coef is calculated depending on the highest presence of a certain color in the region of a feature.

Table 1 – Averaged data for estimating heat loss

Name	S	T	k	F
Attic	8 * color_coef	0,2	0,25	Q = S * $(T_в – T_н)$ / R * attics_amount
Window	1.5 * color_coef	0,1	0,35	Q = S * $(T_в – T_н)$ / R * windows_amount
Chimney	1 * color_coef	0,1	0,52	Q = S * $(T_в – T_н)$ / R * chimneys_amount
Entrance door	1.5 * color_coef	0,1	0,3	Q = S * $(T_в – T_н)$ / R * doors_amount
Foundation of the house	Home_length * 1 м * color_coef	0,4	0,14	Q = S * $(T_в – T_н)$ / R
Roof of the house	Home_length * home_width / 4 * color_coef	0,3	0,2	Q = S * $(T_в – T_н)$ / R
House wall	Home_length * Home_height – S_window * windows_amount * color_coef	0,4	0,14	Q = S * $(T_в – T_н)$ / R

The final calculation of heat losses is calculated as the sum of the heat losses of all elements, multiplied by a factor of 1,2 (heat losses due to air infiltration).

Further, a neural network was developed to determine the structural elements of buildings in the images. The averaged version of the YOLOv5m (Medium) neural network [2, 3] was used during the work. The model achieved its best results at 96 iterations. Based on the analysis of the neural network metrics, it should be noted with confidence that the network reliably recognizes objects and selects them in an accurate frame; therefore, this neural network can be imported and used in the final product.

The Bosch GTC 400 C Professional thermal imager was used to collect images. It allows to obtain two images simultaneously: in the infrared spectrum (Fig. 1.) and the visible spectrum. The shooting was carried out during the daytime, at an ambient temperature of + 5 C, with variable cloudiness, without precipitation. 293 paired images of wooden houses were collected. The shooting angle for images was any, with an acceptable slope both horizontally and vertically for increasing the variability of recognition of structural elements by the network.

The software "LabelImg" was used for images marking. During markup, 293 text files with YOLO markup were received in the format: class serial number, initial "x", initial "y", width, height. When marking, 6 classes of objects were distinguished: window; attic; roof; door; the foundation of the building; chimney. The original dataset was divided in the order of creation date into training and validation sets, 250 and 43 images, respectively. The next step was to train the network with standard parameters using the built-in tools of the YOLOv5 repository. All the images were reduced to the size of 640x640, the batch size was 16 images, the number of epochs was 100. The example of the neural network operation is shown in Figure 2.

Fig. 2. The example of the program operation.

III. RESULTS

In order to test the methodology, a user application with a graphical interface was developed that allows processing new images, detecting objects and estimating their heat loss from two photographs: in the visible spectrum and in the infrared spectrum. For this purpose, the resulting neural network model with customized parameters was integrated into the developed application. Thereafter, this application was tested on new data. The result of the created application is an image with markup and a numerical estimate of the heat loss value.

During the course of the study, the following tasks were solved:

- the approach used to estimate the heat loss of a building was determined;
- the study of wooden housing stock was carried out, a data set was collected for neural network training and software testing;
- the software for heat loss estimation was designed and developed;
- the assessment of the effectiveness of the software was carried out.

REFERENCES

[1] The principle of operation of the thermal imager [Electronic resource]. – Access mode: https://wht.ru/notes/printsip_raboty_teplovizora.html (06.11.2022)

[2] Neural network YOLOv5 [Electronic resource]. – Access mode: https://vc.ru/newtechaudit/326571-ispolzovanie-yolov5 (06.01.2022)

[3] Variations in the execution of the YOLOv5 neural network [Electronic resource]. – Access mode: https://github.com/ultralytics/yolov5/releases (06.01.2022)

[4] Seyedzadeh, S. Machine learning for estimation of building energy consumption and performance: a review. / S. Seyedzadeh, F. Rahimian, I. Glesk et al. // Vis. in Eng. – 2018. – Vol. 6. – P. 5. https://doi.org/10.1186/s40327-018-0064-7

[5] Pensado-Mariño, M. Estimation of Heat Loss Coefficient and Thermal Demands of In-Use Building by Capturing Thermal Inertia Using LSTM Neural Networks / M. Pensado-Mariño, L. Febrero-Garrido, E. Pérez-Iribarren, P. E Oller, E. Granada-Álvarez // Energies. – 2021. – Vol. 14. – P. 5188. https://doi.org/10.3390/en14165188.