

# **Development the Heat Leak Detection Method for Hidden Thermal Objects by Means the Information-Measuring Computer System**

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**Abstract.** The purpose of this paper is to develop a thermographic method for detecting the places of heat energy leak on the underground thermal pipes using the computer system. Innovativeness of this work would be to develop an analytical model for constructing a heat map with an account of seasonal changes on separate temperature scales. It's proposed to upload the data that was received from the information-measuring computer system into the cloud storage. Due to the heat map laid on Google Maps, the repair equipment could be precisely allocated in place of the heat leakage displayed on the heat map. The implemented process using a Testo 805i infrared thermometer, which data is transmitting to the mobile devices (smartphone, tablet, etc.) with iOS version 10 (or later) and Android 4.3 (or later). The experiments confirm the correctness of the theoretical assumptions and sufficient accuracy for practical usage while eliminating the heat pipes leaks.

**Keywords:** thermal pipeline, leak detection, pyrometer, GPS coordinates, information-measuring computer system, Firebase Authentication.

## **1 Introduction**

The urgency of the searching problem and the reduction of heat loss via the engineering construction elements is due to the need for a rigorous energy saving. This problem is exacerbated by the work of heat power engineering in many countries by reason of limited natural energy resources. Therefore, big attention is paid to reducing operating costs, and timely detection and elimination of emergency situations on the

heat mains. The most problematic this is the detection of heat energy losses on hidden thermal pipes.

New methods the detection and repairing the founded defects in transmission pipelines have been described by many researchers and scientists. All of the world common attention is paid for non-destructive techniques and technologies like acoustic leak detection, tracer gas, radiotracers, the combination of visual and thermographic inspection, etc. [1–5].

It should be noted that manual acoustic and pulse measuring devices are harmful to the health of the operator of such equipment [4, 5].

It's available to detect places of the local heat leak on the underground thermal pipelines using the computer system. Such a system should use infrared thermography devices which is able to transmit data through wireless ports.

The proposed solution would allow pinpoint precision thermal energy loss location to eliminate unnecessary digging, destruction and expense.

## 2 Formal problem statement

The detection and recovery time of the carrying capacity of pipeline sections with local damage can be significantly reduced through the measuring and numerical analytical procedures with using of the information-measuring computer systems (IMCS).

Infrared is a proven noninvasive technology, which locates leaks in the systems of heat pipes without any destruction owing to the digging of highways, under which heating mains in cities are usually laid.

The purpose of the work is to develop a thermographic method for detection the places of heat energy leak on the underground thermal pipe by means computer system.

The object of the work is the data handling process for detection heat loss using a combination of terrain maps and results of heat measurements.

The subject of the work is an IMCS for creating heat maps of energy leak on the thermal pipelines according to the data of pyrometric non-contact measurements.

The tasks of the study include:

- analysis of existing algorithms and methods implementing heat map construction on the basis of collected data;
- analysis of the existing base of devices for research and analysis the current temperature of objects;
- development of an analytical model for forming a heat map with an account of seasonal changes on separate temperature scales;
- development of a software application for detection of heat energy leaks on thermal pipelines and visualizing the results of measurements on heat maps of the area.

The practical value of the work is:

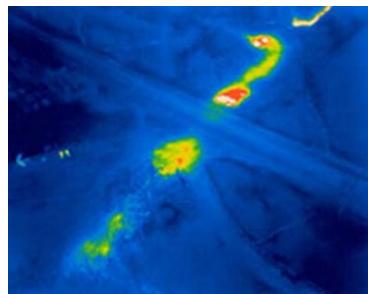
- detection and localization of the breakthroughs of the heating main for the planning of repairing works, etc.;

- the possibility of identifying objects that emit heat.

### 3 Literature review

A hot-water pipeline heats the surface of the ground and, therefore, can be detected by a thermographic method. In Fig. 1 shows how using a thermal camera located on the drone, areas can be detected where the heat main is broken [6]. The positive is that the movement of such IMCS can be set strictly within the spatial corridor [7], that is, the street. Also, it can be a study at once of the entire specified area, such as city block, sub-district. etc. [8].

The leak imaging system based on rotor-wing and fixed-wing UAVs [8, 9]. One of the best modern hardware solutions for studying energy losses on the thermal line is the Thermal imaging cameras Zenmuse XT developed by FLIR technology (that costs about \$7,000 USD) on board at Drone DJI Matrice 210 (that costs about \$12,000 USD), are shown in Fig 2.



**Fig. 1.** Infrared detection using a drone the placements of heat energy loss [6].



**Fig. 2.** Drone DJI Matrice 210 with Thermal Imaging Cameras Zenmuse XT and video camera on board [10].

Usually, such systems don't determine accurate GPS coordinates of the accident and are therefore useless for the repair team. At present, the leak detection team should wait for repairmen at the identified accident site or create written, scheme and photos documentation [2].

Due to the lack of methods for identifying technological objects, is done a manual inspection with accordance to the route was visualized on the map, after which a heat map is created [11].

In the Czech Republic has developed the system Workswell WIRIS, which can be fitted with a GPS sensor for storing location information on the position of the drone when producing a record about detection of hot water leaks [6]. This system is designed to be mounted on a drone (UAV) too.

But there are two problems for the implementation of this method of study of energy losses. First, the above version of the thermal measurements is too expensive. Second, on June 11, 2018, the State Aviation Service of Ukraine banned flights of

remotely manned aircraft (drones or UAVs) over roads of state importance, streets of cities and villages, etc. [12]. Similar prohibitions on the use of drones on the territory of settlements exist in other countries – Italy, Austria, Czech Republic, Great Britain, etc. [13, 14]. Thus, the problem under consideration is relevant not only for Ukraine.

In this article, we proposed to collect thermal data using an on-duty car with a manual pyrometer. One of the best solutions is the Testo 805i Bluetooth pyrometer (Fig. 3).



**Fig. 3.** Infrared thermometer Testo 805i using wireless transmitting data to a smartphone.

Unlike the above examples, this device (that costs about \$100 USD) has several advantages such as:

- measuring the temperature of the object with the help of non-contact infrared beam;
- the ability to transmit data through Bluetooth port 4.0 to computer equipment;
- laser sight in the form of a circle with a point in the middle;
- it is compact and comfortable when carried [15].

#### **4 The modified thermographic method to detect heat loss place improved by the addition of leak geo coordinates**

##### **4.1 A Development of the IMCS Structure and Technological Process**

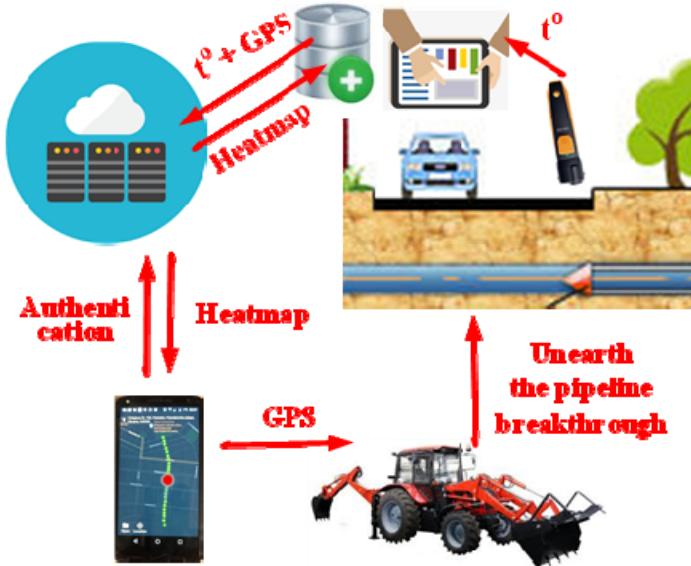
Thus, due to the inability to use drones for the inspection of heating mains in urban areas, it is proposed to inspect the thermal pipe using a non-contact pyrometer. For example, the model Testo 805i could be used, which is equipped with a diagnostic team moving the on-duty car.

Bluetooth infrared thermometer Testo 805i has the means to transmit the measurement data to the mobile device (smartphone, tablet, etc.) via Bluetooth port 4.0 at a distance of 15–20 m. It requires iOS 8.3 (or later) / Android 4.3 (or later).

Unfortunately, the Testo 805i doesn't measure automatically, so it is necessary to press the button on the device to receive data. If it is to do every 10 seconds, then at a speed of 40 km/h (10 m/s) the temperature will be measured every 100 m.

The measured temperature is recorded into the database of the mobile device and can be uploaded to the cloud storage. Then measured data can be plotted on the terrain map as values or as a heat map.

The structural scheme of the technological process is shown in Fig. 4.



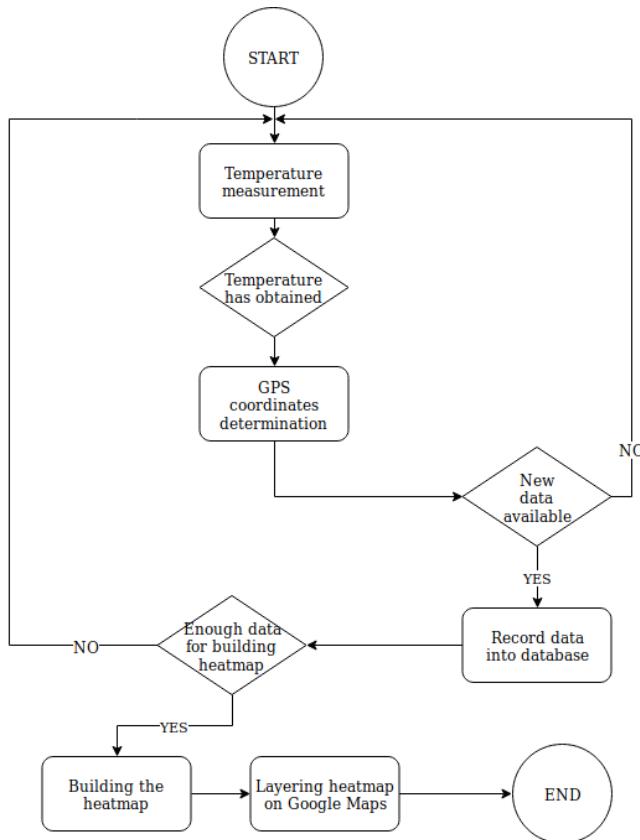
**Fig. 4.** Scheme of the technological process.

In Fig. 5 shows a block diagram of the formation of a heat map.

Initially, temperature data are measured with a pyrometer, and if these data have measured – they are recorded in the database, if not – the heat map will not be built, further measurements are needed.

Further, when the temperature data to the phone (or tablet) received there is a process of tracking the coordinates, namely latitude and longitude, using a GPS module of mobile phone or tablet. If the data have received – they are also entered in the database and in the case of their absence – the heat map will not be built. In this case, the on-duty car with measuring equipment moves further, to a point with new geolocation, where subsequent measurements would be made.

The final stage is the very construction of a heat map. Then it adds to Google Maps [16]. To do this, it needs to use the library `com.google.maps.android:android-maps-utils.Subsequent`.



**Fig. 5.** Block scheme of the heatmap building algorithm.

The further development of the proposed method is the application of cloud technologies when the obtained data (temperature and GPS coordinates) are uploaded to Google Firebase [17, 18]. In this case, the complete technological process is shown in Fig. 4.

#### 4.2 Results of measurements and input data for research

Since Mykolaiv is one of the large industrial cities of Ukraine with a significant number of heating mains under urban highways, it is possible on its example to study the measurements of the temperature above the heating main were carried out in Mykolaiv (Ukraine).

As a result of the temperature measurements, a breakthrough of the heat pipe at the intersection of the streets was detected as shown in Table 1. The temperature data from the pyrometer to the tablet are transmitted in tabular form or as a graph (Fig. 2) and are supplemented in the database combined with geocoordinates from the GPS module of the tablet and from Google Maps at the time of temperature measurement (Table 1).

**Table 1.** The fragment of a training sample for temperature measurements on the thermal pipe in preparation for the heating season (in October)

Data (DD.MM)	Time (HH:MM:SS)	Tempera-ture (°C)	North latitude (degree)	East longitude (degree)	Street name	Conclusion on the state of the thermal pipe
18.10	16:24:10	+20.1	46.970312	32.011009	Velyka Morska Str.	holistic
18.10	...	...	...	...	...	...
18.10	16:25:50	+20.1	46.967368	32.012510	Kolodyazna Str.	holistic
18.10	...	...	...	...	...	...
18.10	16:27:02	+21.1	46.965597	32.013154	Central Avenue	holistic
18.10	...					
<b>18.10</b>	<b>16:27:16</b>	<b>+28.1</b>	<b>46.962030</b>	<b>32.013060</b>	<b>Chkalova Str.</b>	<b>break-through</b>
<b>18.10</b>	<b>16:27:24</b>	<b>+28.2</b>	<b>46.961526</b>	<b>32.012981</b>	<b>Chkalova Str.</b>	<b>break-through</b>
18.10	...	...	...	...	...	...
18.10	16:29:05	+16.4	46.958510	32.012688	Pogranychna Str.	holistic
18.10	...	...	...	...	...	...
18.10	16:30:30	+16.4	46.953942	32.011994	Kuznetska Str.	holistic
18.10	...	...	...	...	...	...
18.10	16:33:15	+15.1	46.949474	32.012019	Zavodska Str.	holistic

As can be seen from Table 1, the temperature above the heat main on the map segment with Chkalova Str. differs significantly from others.

After carrying out repairs, the second temperature measurements on the heating main were made at the same points during the heating season (in January).

The environment temperature was lower, and therefore the average temperature of the thermal pipelines fell compared with the previous measurements made in October.

But the temperature doesn't differ in a large measure from each other along the heat pipe. This is why we conclude that the breakthrough in the pipeline has been eliminated.

#### 4.3 An analytical model for the formation of a heat map

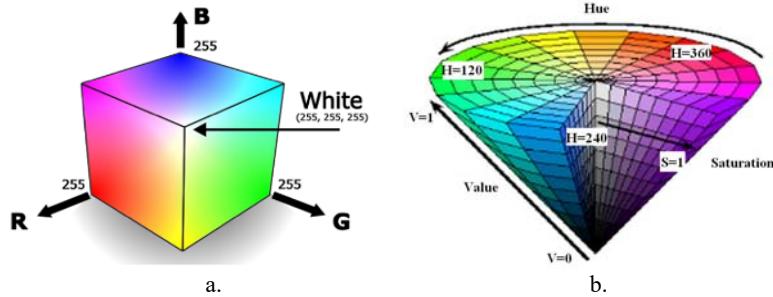
It should be noted that tabular data is very inconvenient for perception and rapid analysis. Therefore, it was decided to build on the basis of the measurements of the

heat map of the process of finding emergency sections on the heating main. For this purpose, an analytical model for the formation of a heat map was developed.

From the data analysis in Table 1 it can be seen that the measured temperature of the road surface over the heating main was above the ambient temperature at the date of research [19] on 2°C, and at the place of the leakage was recorded at an additional exceeding of 1...4°C. Even the direction of the flow of water through the heating main channel is revealed – the temperature of the road along the pipeline in this direction gradually drops to the ambient temperature.

From this, it follows that in the analytical model it is advisable to take into account the different levels of surface temperature above the heating main with the help of a color gradient.

So, two color models – RGB and HSV – are discussed [20]. The RGB model describes the color space based on Red, Green and Blue colors (Fig. 6, a). The HSV model operates with parameters Hue, Saturation and Value (Fig. 6, b).



**Fig. 6.** RGB (a) and HSV (b) color models with fixed value of parameters.

However, if the colors are supposed to be interpreted using the human visual system, it is advisable to integrate the RGB space and the HSV space [21]. In addition, diagnostic and repair work on heating mains can be carried out at different times of the day, and the HSV color space is more resistant to changes in lighting [22]. Therefore, it is advisable to formulate the mathematical equivalent of the projection of the HSV model vectors in the RGB color space.

In this article, only parameters Hue and Value of the HSV color model are used to construct the color gradient in the RGB color model.

The pyrometer readings, corresponding to the seasonal temperature value of the section of the pipeline, are successively added to the array of temperatures  $\{t_{i,j}\}$ , where  $i = \|N_{Jan} N_{Feb} \dots N_{Dec}\|$  – the numbers of all  $N_{day}$  rows of maximal temperature values in the frame of month,  $j = \overline{0, X}$  – the numbers of columns with each of the  $X$  measured temperature value in the matrix of the input file data for heat map.

The maximal temperature values  $N_{day}$  of each scale are calculated from the maximal temperature  $T_{day}^{\max}$  in researching area from the weather web resource such as [19] in the date (for example, on October 18). The parameter  $N_{day}$  takes into account the possible rise of the surface temperature of the road due to existing of pipeline  $T_{heat}$  and due to a leak in heat main  $T_{leak}$  on values described above on October 18:

$$N_{day} = 19^\circ C + 2^\circ C + 4^\circ C = 25^\circ C.$$

It should be noted that the numbers of rows  $i$  correspond to the number of temperature scales and can be less than the number of months. It would be possible, since the months in different seasons may have equal temperature scales. This approach saves the computational resources needed to build a heat map.

To recount the parameters of the HSV color model in the value of each spectrum of the RGB color model, the temperature coefficient  $k$  of the HSV model should be calculated. This will allow scaling the temperature values to the color of a certain tone. To switch to the parameters of the color model, it is also necessary to calculate the basic statistical parameters, namely the maximum and minimum values of temperature (2) – (3) from the set of temperatures (4) – (5):

$$k = \frac{(sp_{\max} - sp_{\min})}{(t_{\max} - t_{\min})}, \quad (1)$$

$$t_{\max} = \max \{t_{i,j}\}, \quad (2)$$

$$t_{\min} = \min \{t_{i,j}\}, \quad (3)$$

$$i = \left\| \overline{N_{Jan}}, \overline{N_{Feb}}, \dots, \overline{N_{Dec}} \right\|, \quad j = \overline{0, X}, \quad (4)$$

$$N_{day} = T_{day}^{\max} + T_{heat} + T_{leak}. \quad (5)$$

Therefore, the next step in forming a thermal image in the proposed analytical model is the conversion of temperature data into a color RGB model based on the normed values of parameters of the HSV model.

The values of the red, green, and blue components of the RGB spectrum are labeled  $R_{i,j}$ ,  $G_{i,j}$  and  $B_{i,j}$ , respectively and calculated based on the set of normalized  $H_{i,j}$  values as follows:

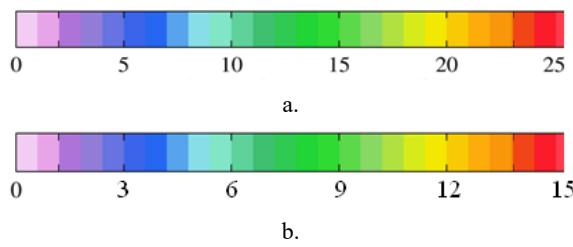
$$R_{i,j} = \begin{cases} V_{\min}, H_{i,j} = 0 \text{ or } H_{i,j} = 1; \\ |V_{\min} - ad_{i,j}|, H_{i,j} = 2; \\ V, H_{i,j} = 3; \\ |V_{\min} + ad_{i,j}|, H_{i,j} = 4 \end{cases}, \quad (6)$$

$$G_{i,j} = \begin{cases} V_{\min}, H_{i,j} = 0 \text{ or } H_{i,j} = 1; \\ |V_{\min} - ad_{i,j}|, H_{i,j} = 2; \\ V, H_{i,j} = 3; \\ |V_{\min} + ad_{i,j}|, H_{i,j} = 4 \end{cases}, \quad (7)$$

$$B_{i,j} = \begin{cases} V_{\min}, H_{i,j} = 0 \text{ or } H_{i,j} = 1; \\ |V_{\min} - ad_{i,j}|, H_{i,j} = 2; \\ V, H_{i,j} = 3; \\ |V_{\min} + ad_{i,j}|, H_{i,j} = 4 \end{cases}, \quad (8)$$

$$ad_{i,j} = (V - V_{\min}) \cdot H_{i,j}. \quad (9)$$

In this case, the higher the temperature the more the color is close to the red, and vice versa – the colder the temperature the more the color is closer to the blue. As shown in Fig. 7, a, in the described model, the temperature scale is implemented in the temperature range from 0 to  $+25^{\circ}\text{C}$ , which corresponds to the season when the heating pipes are cooked for the heating season.



**Fig. 7.** Temperature Scale-25 for the pre-heating (a) and Scale-15 for the heating (b) season

It should be noted that thermal measurements can be carried out in different seasons when the temperature of the environment varies considerably over the seasons. For

example, in the region under consideration, seasonal temperature fluctuations are from 0 to +25°C in the autumn and to +15° C in the winter. In this case, the visual temperature scale should have been replaced by the scale shown in Fig. 7, b.

When constructing temperature scales, it should be noted that the operating temperature range for the pyrometer is from minus 10°C to +50°C [15]. But with negative values of the ambient temperature, the measurement error is significantly increased. Therefore, further temperature scales were built only for ranges in which the pyrometer measurement error did not exceed 1.5 %.

#### 4.4 Software development

The software was developed in Android Studio 3.3.1, an application is created for the Android platform with JDK ver. 11.0 [23, 24].

Consider the life cycle of the application. On the initial phase of the application, the task should be sent to diagnostic teams for inspection of the area.

Using the Firebase Cloud Messaging (FCM), the system server sends messages to clients about current tasks. There is an ability to send notifications (up to 2K bytes) and data messages (up to 4K bytes).

Upon receiving the assignment, the diagnostic teams on a duty car are headed to places of information gathering. After their arrival, the system reads the GPS coordinates and sends a message to the server about the diagnostic team location.

The diagnostic team specialists, using pyrometers, measures the temperature values. Data via Bluetooth 4.0 technology are transmitted to a tablet/notebook storing a local database in SQLite. When the tablet is connected to the Internet, information is sent to the cloud database.

After completing the inspections by the diagnostic team, other services (mobile clients) will receive a message through the FCM for further works on the territory.

Using the web version of the application helps to create reports based on the data collected. The *JasperReports* library is used to generate reports on the server.

### 5 Experiments and results

The proposed methods and indicators characterizing their quality were implemented as software and experimentally investigated in solving the problem to detect the heat leak in underground thermal mains on Chkalova Street of Mykolaiv city (Ukraine) during preparation to the heating season in October.

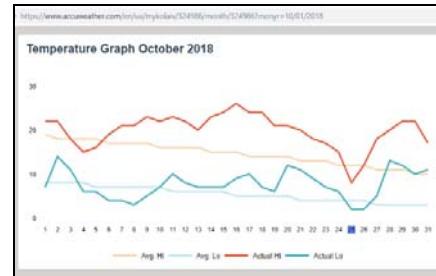
Temperature values along this street were obtained as the table and as the graphic (Fig. 8) from pyrometer Testo 805i to the tablet of developed IMSC mounted to the on-duty car. Based on the graph of the ambient temperature from the weather site (Fig. 9), using the algorithm discussed above, a heat map was built for the thermal main under the road on Chkalova str. and was layered on Google Map of the specified area of the Mykolaiv city.

Based on Fig. 8 it is also possible to conclude that on pipe segment after the detected leakage point, the temperature over the surface of the heating main has been reduced to the ambient temperature for the specified date of Oct. 18, 2018 (Fig. 9).

In Fig. 10 shows screenshots of the interface of the developed Android application. You can see the map and two buttons on the smartphone of IMCS. The button "Location" is responsible for the current location of your mobile device (or tablet). The button "Open" is responsible for opening a file from the database needed to build a heat map.



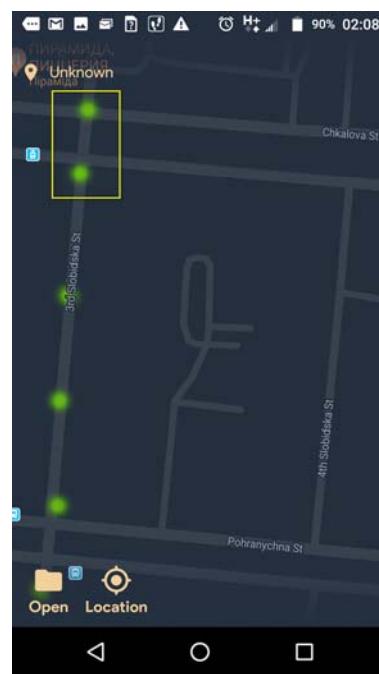
**Fig. 8.** Temperature graphic from pyrometer to a smartphone on October



**Fig. 9.** The temperature of the environment on the date of measurement [19]



a.



b.

**Fig. 10.** The heatmap with reflected the accident (a) and its eliminated (b)

From the analysis of the heat map in Fig. 10, a can be seen that on the corner of the 3rd Slobidska Str. and Chkalova Str. the heat energy leak from the underground pipeline.

The advantages of the proposed method are that the repair team can operate independently of the work schedule and the location of the diagnostic team specialists. When the repair team arrives at the place of heat energy leakage, the brigadier from any mobile device (smartphone, tablet, etc.) is authorized on Firebase. In this case, his profiles in any social networks can be used – Google, Facebook, Twitter, etc. (Fig. 11).

After the computer diagnostics were carried out, the received data was transferred to the corresponding repair company. The unearthing of the heating pipeline by the found coordinates of the breakthrough has confirmed the fact of the accident exactly on the corner of the 3rd Slobidska Str. and Chkalova Str. in the detected place (Fig. 12).



**Fig. 11.** Integrate Firebase Authentication with popular services [25].



**Fig. 12.** The detected places of the local heat leak on the underground thermal pipe.

When the access to the heat map of the thermal pipeline has given, brigadier of the repair team can compare the own GPS coordinates with the coordinates received from the cloud service. Then he is able to accurately to combine the repair equipment (excavator, pump, etc.) place with detected places of the heat energy leak from heat map together.

In Fig. 12 shows the same breakthrough of the heating main that was detected as a result of temperature measurements and reflected in Fig. 10, a. The red color in the center of the spot corresponds to the raised temperature. And in Fig. 10, b shows the same place, but already with the eliminated breakthrough (see the yellow rectangle).

## 6 Conclusion

Analysis of leak detection methods in thermal pipelines suggested that the thermographic method in combination with the determination of the geographic coordinates of the measurement point should increase the accuracy of determining the location of the breakthrough of the heating main.

Innovativeness of this work would be to develop an analytical model for constructing a heat map with an account of seasonal changes on separate temperature scales. The proposed reduction of the HSV color model basis due to the fixing value of the "Saturation" parameter as constant significantly reduces the number of computations when converting the temperature values measured by the digital pyrometer to the image of the color RGB model using the parameters of the color model HSV.

A software application for building heat maps based on measured temperature data for the Android platform with JDK 11.0 version was developed. Introduced Firebase Authentication, integrated with popular social services.

The software implementing the proposed methods has been developed and studied for the detection places of the heat energy leak on the underground thermal pipelines. Due to the heat map laid on Google Maps, the repair team gained access to detected places of the heat energy leak regardless of the work schedule and the location of the diagnostic team is provided. The conducted experiments have confirmed the performance of the developed software and allow recommending it for use in practice.

The prospects for further research are to a wider of applied developed IMCS while solution to the problems associated with various heat leak, not only thermal pipelines. Also, It would be useful to study the accuracy (error) of developed methods for the different temperature scales.

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