Development of Technology for Remote Location of Unknown Underground Cavities and Deep-Seated Rockslides by Unmanned Air Systems (UAS)

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Abstract. This work aims to create new scientific knowledge by developing new innovative technology for remote detection of unknown underground cavities and deep-seated rockslides. To achieve the goal, we intend to develop new innovative technology for remote localization of unknown underground cavities and deep-seated rockslides using a thermal camera mounted on a unmanned aerial vehicle (UAV).

Technology is a defined sequence of operations and procedures under optimal conditions, varying within certain allowable limits, resulting in obtaining a particular result or product that meets certain requirements. Therefore, the development of new technology involves determining the allowable limits of deviation of the optimal conditions of operations and procedures for producing a good result that meets the established requirements. The development of new technology also involves determining the limits of its applicability under different external conditions. This paper includes determination of the allowable limits and the limits of applicability of the new technology being developed.

Until now, no technology has been developed for remote detection of unknown underground cavities or deep-seated rockslides. The goal of this work is the development of such innovative technology with numerous applications in construction, environmental studies and protection, security, defence and infrastructure.

1. Introduction (Previous research in cave remote sensing)

The principle of remote sensing research is to acquire data and information about objects located at a distance. To achieve this, tools and instruments are needed to record and measure the electromagnetic radiation emitted by objects on the surface of the Earth. Concerning remote detection of unknown underground cavities and deep-seated rockslides, the infrared range of the electromagnetic spectrum is of great importance (figure 1).

All non-contact heat measurement devices use the thermal radiation of an object to measure the temperature. Thermal imaging is based on the detection of electromagnetic waves and their conversion to electrical signals for visual display. Thermal infrared cameras detect the characteristic infrared (IR) radiation that objects emit. Every material, at temperatures above absolute zero, exhibits a temperature profile by emitting energy in the thermal electromagnetic wavelengths from 0.7 to 1000 microns [1],
The range from 0.7 to 14 µm is best suited for thermal-IR imaging and is further subdivided into near-IR (0.7–1 µm), mid-IR (3–5 µm), and far-IR (8–14 µm). Most thermal cameras operate within the mid-IR and far-IR portion of the spectrum [3].

Figure 1. Image source: Catena & Thermography "Treethermography® since 1984 (http://www.treethermography.it/infrared_radiation.htm)

When working in the infrared wavelengths, the most prevalent atmospheric window occurs between 7 µm and 14 µm. Most thermal infrared detectors, therefore, function between the 7 and 14 µm wavelengths [4].

Thompson et al. [5] use thermaCAM TM B20 HSV to localize cave entrance remotely. They use also optical camera and lenses, Delmhorst HT 3000 A Thermo Hygrometer & Dickson TH 550 Thermo Hygrometer to measure temperature, humidity and dew point at cave entrances and distances from the entrance and Fluke 52 II Thermocouple Thermometer to measure temperature readings of the substrates at cave entrances and stream water temperatures. The research proves that the radiation measured by the IR camera not only depends on the temperature of the object but is also a function of emissivity of the reflected temperature, the relative humidity and the distance between the object and the camera. As a result, the provided methods show good results for the localization of known caves entrance in Carlsbad Caverns, New Mexico and Meramec State Park, Missouri, USA.

Another research by Titus et al. [6] discusses the possibility of discovering new caves on the Earth and other planets. The site for their study is the Pisgah lava flow, near Ludlow, CA that have multiple lava tubes, trenches and al-coves, which makes this an ideal site to test the use of thermal imaging for cave and cave-like feature detection. The equipment used is QWIP (Quantum Well Photodetector) camera to collect thermal imagery. The imagery is collected from a single station (2 different viewing azimuths), approximately half-way up the cinder cone, every 5 minutes over ~24 hrs, 23-25 March 2010 (244 images captured). To verify data from the camera, additional in-situ measurements are done of surface temperature and relative humidity. To reduce the dimensionality of a data set, Principle Component Analysis (PCA) is used. PCA analysis identifies the parameters with the largest variations. For this analysis, they use the DN value of each pixel acquired throughout 24 hours as that pixel’s coordinate within a 288-parameter space. The result clearly delineates the boundaries of small cracks.

Thermal detectability of caves is best accomplished with multiple images acquired at the hottest time of day (early afternoon) and the coldest time of day (dawn).

The first groundbreaking work on terrestrial cave detection using airborne and spacecraft acquired imagery was made by Rinker [7] nearly 50 years ago. Wynne et al. [8] presented analytical techniques, improved instrument and high resolution imagery of terrestrial cave detection and confirmed cave-like features on other planets. Cave detection is typically most successful when multiple thermal images are acquired during both the warmest (mid-afternoon) and coolest (predawn) times of the day. Although data acquisition is logistically easiest on Earth, repeated thermal imagery over short temporal periods is lacking for most terrestrial locations. The main problem with extraterrestrial cave detection is a limited window of time for image acquisition, dedicated by fly-by or orbiter mission schedules. The authors show two different terrestrial cave analogs for extraterrestrial caves: deep caves and shallow caves. They provide two models of hypotheses (H1): Thermal imagery may be examined using techniques for analysing digital elevation models. All cave entrances (deep and
shallow) will appear as distinct “topographic” features on a 3-D representation of a thermal image using a topographic position index, thermal gradient (or slope) and curvature. TPI is the relative value of a specific pixel compared to the average thermal value of a neighbourhood of pixels. The thermal gradient is the rate of change of thermal values indicating where temperature values change quickly. The curvature represents the rate of change in the slope of the “thermal surface” depicted as regions of concavity (dips or valleys) and convexity (hills and peaks); (H2): Thermal signatures associated with deep cave entrances are discernible from shallow caves (e.g., alcoves and caves ≤ 50 m in length) and control points (i.e., random areas of surface) when imagery is captured at the appropriate time for a single acquisition period (either predawn or midday).

Another research of Baron et al. [9] presents a test study of the application of infrared thermography (IRT) for mapping thermal characteristics of pseudokarst crack caves related to deep-seated gravitational slope failures in the Flysch Belt of the Outer West Carpathians and for locating new systems. The IRT detection method of pseudokarst caves relies on air circulation and ventilation through open joints and cracks when, in winter, the warmer subsurface communicates with the (colder) ground surface; crack caves could be identified as relatively warm areas using IRT (FlirB360). Several warmer areas were observed and all of them were located along the main-scarp cliff. A strong blowhole was related to the entrance of the Zbojnická Cave as well as several warmer spots.

Judson et al. [10] and Wynne et al. [11] demonstrated the viability of detecting terrestrial caves at thermal-infrared wavelengths and identified times of the day when cave openings have the maximum thermal contrast with the surrounding surface regolith and gave some ideas on how to detect caves on the Earth, the Moon and Mars. They monitored the thermal behaviour of two caves in the Atacama Desert and identified times when temperature contrasts between entrance and surface were greatest, thus suggesting optimal overflight times. The largest thermal contrast for both caves occurred during mid-day. One of the caves demonstrated thermal behaviour at the entrance suggestive of cold-trapping while the second cave demonstrated temperature shifts suggestive of airflow. They suggested that cave detection using thermal remote sensing on Earth and other planetary objects would be limited by the viewing angle of the platform in relation to the slope trajectory of the cave entrance and the time of day and the season of the thermal image capture.

In Bulgaria, Rusev, A. and Slavova, T. [12] describe cave detection using ground-penetrating radar, magnetometry, gravimetry and infrared imaging and illustrate the techniques with case studies showing the discovery of new caves and entrances. Thermal Imaging Equipment: Raytheon Palm IR-250-D infrared camera, FLIR E5, FLIR ONE, DJI Inspire drones with a Zenmuse XT. Tests were conducted in very cold weather -25°C with no wind and no clouds, very early in the morning (rocks accumulate a lot of heat in daytime), before sunrise. The data is collected with very high accuracy (GNSS) and organized in GIS with the possibility to overlay. Remote methods were also used, including satellite/SAR/thermal/multispectral imaging and data collection using drones, followed by various forms of analysis such as orthophoto, thermal imaging and LiDAR.

Regarding remote sensing and GIS methods, there are several pieces of research of karst landscapes [13], [14] and cave development [15]. These researches reveal the use of different satellite data, such as Landsat, RapidEye, ASTER, Ikonos, QuickBird and aerial photos, as well as additional data such as Topo maps, Digital Elevation Models and geological data in order to develop models. Different techniques are demonstrated such as deriving vegetation and water index images to identify regions with relatively higher surface water input and possible cave entrances; GIS-integrated weighted overlay tools to aggregate morphometric, causal factors (lowest and flattest areas) influencing the susceptibility to higher surface water input; different image transformation (intensity-hue-saturation, principle component analysis, filters) to visually and digitally extract lineaments. Very high resolution images allow image interpretation of terrain elements and image elements with identification of geological features based on variations in spectral signatures with the help of satellite-based geological mapping.

Data fusion of optical and radar data is another technique that responds to possible solutions for cave entrance detection.
2. Methods and Materials
Almost all previous studies of the possibilities of remote detection of caves with thermal infrared cameras are made on previously known caves and aimed to demonstrate the potential to locate caves rather than to make thermal infrared survey for location of new caves [7], [5], [11], [6], [9]. Only Rusev and Slavova [12] attempted to detect new caves by a preliminary thermal infrared survey (table 1). Our study aims to develop a technology for remote detection of new caves by a thermal infrared camera and to make a survey for the location of new unknown caves by this technique [16], [17].

Table 1. Comparative table of the progress of using thermal cameras in the detection of known and unknown cave entrances, distance to objects, measurement of coordinates, 3D modelling and integrated products.

| Research team          | Detection of known caves | Unknown caves detection | Distance to object detection (m) | Measurement of a coordinate of cave | Building 3D models | Integration products: VIS + NIR; VIS + TIR | Integration into a global 3D earth model |
|------------------------|--------------------------|-------------------------|---------------------------------|-----------------------------------|-------------------|------------------------------------------|----------------------------------------|
| Rinker [7]             | +                        | -                       | 125 - 180                       | +                                 | -                 | -                                        | -                                      |
| Thompson et al. [5]    | +                        | -                       | 15 - 388                        | +                                 | -                 | -                                        | -                                      |
| Titus et al. [6]       | +                        | -                       | ---                             | +                                 | -                 | -                                        | -                                      |
| Baron et al. [9], [18] | +                        | -                       | 300 - 1000                      | +                                 | -                 | -                                        | -                                      |
| Wynne et al. [11]      | +                        | -                       | ---                             | +                                 | -                 | -                                        | -                                      |
| Rusev and Slavova [12] | +                        | +                       | 150 - 300                       | +                                 | +                 | +                                        | +                                      |
| This study             | +                        | +                       | 150 - 2000                      | +                                 | +                 | +                                        | +                                      |

The main method used in this research is detecting cave entrances by thermal cameras. This includes thermal ground imaging with high thermal resolution of long distances to detect caves (figure 2, 7, 8, 9). This technology is important because it is the core of the research. Our ability to discover caves depends on the sensitivity of method. The main problem of this method is the low resolution of thermal cameras, which is usually below 1 Mpx. In order to overcome this limitation, we used the Method of Fusion of Thermal and Visible Images (figure 2c).

Figure 2. Fusion of Thermal infrared and visible images: a) Thermal infrared and visible images from Bosnek karst region, Bulgaria fused in situ by FlirOne Pro radiometric thermal camera. On the left upper corner, the temperature values are given for the relevant spots on the terrain marked by crosses. b) Visible image of the same landscape captured simultaneously with the thermal image on figure 2a. c) Overlapping the images on figures 2a and figure 2b by post-processing of the pairs of images obtained by Flir Tools+ software.
By fusion of thermal and visible images, we achieve a much greater precision of locating the thermal anomalies on the surface, which is over one degree of magnitude higher than this obtainable from the same thermal image alone (figure 2).

We located a significant number of cave entrances using FlirOne Pro radiometric thermal camera. This dual camera captures simultaneously one TIR and one visible image and may overlap them instantly in the field (figure 2a). But much better results were achieved by the post-processing of the pairs of images obtained with Flir Tools+ software. Such integration of the images improves drastically the precision of locating the registered thermal anomalies on the terrain (figure 2c) because the images obtained have a much higher resolution coming from the visible image (figure 2b) and contain thermal measurements from the TIR image.

On the images obtained (figure 2a, c), several thermal anomalies are clearly visible produced by hotter air coming from the entrances of unknown caves. Temperature differences between the temperature of the anomalies registered and the surrounding terrain reached 4.4 °C. Registered objects are located at about 0.5 km from the camera.

2.1. Thermal imaging from drones
D drone thermal images are the primary source of information for automated processing. The main benefit of drone usage is the ability to move above strictly programmed trajectory and make pictures at equal intervals and programmed camera orientation. These options are the most important requirements for photogrammetry software processing. Because the thermal camera used for drone mapping has a high resolution of 640x512 pixels, the ground resolution obtained is very good and can distinguish objects only several centimeters in size from an altitude of 100 m. The temperature difference of target from the surrounding landscape is < 5 K. With this test we prove that our setup (camera/drone) is well suited for thermal mapping (figure 3). In addition, the thermal camera is equipped with GPS, so every picture stores coordinates in a file. It is very handy when starting to stitch images and the success rate is usually more than 90%.

![Figure 3. Drone thermal image testing detection of a small object (centimeter range) with minimal temperature difference < 5 K.](image)

2.2. Terrain mapping from a drone in a visual band and 3D reconstruction
Drone terrain mapping in high resolution is a very important technology because it is the primary source of detailed 3D models. Mapping in the visual band allows us to use several high resolution megapixel cameras. These images are a valuable source for point cloud generation and landscape model reconstruction (figure 4).

Small pixel size (several centimeters) gives us a very detailed reconstruction. With such a model, we can find even the smallest positive and negative landforms (cave entrances). Detailed visual orthophoto produced from this mapping is a valuable information source to check suspicious thermal images against a detailed visual image for potential cave entrances.

To create a digital terrain model, it is necessary to make UAS image acquisition with a visible-spectral camera. This can be done in two directions of the camera – image acquisition from nadir and oblique cameras (figure 5).

For maximum precision of digital models, it is necessary to make a series of images of the nadir with a high degree of overlap in the horizontal and vertical directions covering the entire area
surveyed. Acquired images serve as inputs to “computer vision” software and generate a point cloud of x, y, z coordinate to further generate Digital Surface Model (DSM), digital orthophoto and 3-D surface models.

Figure 4. A 3D terrain model generated from visual images and visual orthophoto overlay.

Figure 5. Image acquisition from nadir and oblique cameras. The coverage of nadir images is shown in red and the coverage of oblique images in purple [19]. Image source: https://www.gim-international.com/content/article/growing-use-of-oblique-imagery-by-municipalities

Nadir image acquisition mode has several advantages over oblique image acquisition mode:
- Require only one camera and one position of image acquisition of each scene;
- Allow to cover a much larger area;
- Allow to calculate DSM with altitude information;
- Allow to calculate digital orthophoto;
- Allow for initial identification of the potential location of vertical structures (high and low contrast areas at altitude), reveal terrain structural and geomorphological signs of cave entrances;
- The digital orthophoto also assists visual inspection in the initial setting of cave locations.

Despite the high degree of overlapping of adjacent objects as well as the different shooting angles in individual images, when capturing from nadir, it is highly probable that the vertical patterns of DSM and 3D models can NOT reflect the vertical relief structures where in most cases the entrances of the caves are hidden.

This requires a different approach to capturing and identifying the cave entrances for the areas with a large vertical scattering of the relief. In these areas, it is necessary to make oblique shooting mode at a certain angle (most often 45 degrees) in relation to the ground surface of at least four different directions of vision. This will provide greater visibility to vertical structures and the disclosure of potential cave openings. For even more precise modeling with already established cave entrances, vertical shooting mode with a larger number and overlapping of individual images can be used. This is applicable to areas with typical signs of vertical structures.

It can be concluded that the nadir acquisition mode is applicable in the regions of relatively flat terrain, as well as for the establishment of more significant vertical differences in areas with a high
vertical structure. The generation of DSM by nadir camera is appropriate in the initial site survey, while the oblique camera is better suited to further accurately 3D examine previously examined vertical structures.

2.3. Drone terrain mapping in NIR band and overlay onto the 3D reconstruction

Terrain mapping in SWIR band is not directly related to cave discovery based on the thermal profile of caves but its supportive role is important. The first application of NIR images is detection. Using vegetation indexes (like NDVI) we can try to locate regions with low index i.e low vegetation that possibly can be cave entrance if that spot is not reliably recognized in the visual image (Figure 6).

The second application is methodological, it helps us to test how to overlay orthophoto from the different spectral band and different resolution of the model created from the visual image. In this paper, we used only our own observation materials (TIR, NIR and VIS images) captured from the ground or UAVs.

Figure 6. A 3D terrain model generated from visual images and NIR orthophoto overlay.

3. Results and Discussion

Most of the research works performed in the field of cave discovery with thermal cameras are focused mainly on the ability of thermal cameras to discover small temperature differences in order to discover caves. Of course, this is an important aspect of the research but its practical value is limited mainly to discovery but not to mapping, i.e. coordinate and shape fixing in the earth coordinate system. This is due to the fact that a large number of the cave entrances are located on vertical walls and cannot be located precisely on orthophoto map, nor represented in 2D GIS maps. Even on a 3D map with only DEM model it is not possible to visualize the cave entrance.

Our research is focused mainly on this challenging task. The final goal is to achieve the results referenced in the earth coordinate system and overlaid on the global map platform. In order to fulfill this task, some critical technologies must be implemented.

For this reason, our research is in 2 phases. In the first part, critical technologies are evaluated and practical experience on how to use these technologies is performed. Technologies that we mark as critical are as follows:

- Ground thermal imaging with high thermal resolution at long distances to detect caves.
- Drone terrain mapping in a visual band and 3D reconstruction.
- Drone terrain mapping in NIR band and overlay onto the 3D reconstruction.
- Drone thermal imaging.

In the second part of this research, the experience gained in the first part will allow us to fulfill the following tasks:

- Orthophoto generation from thermal images.
- Overlay of thermal orthophoto on the 3D terrain model.
- 3D terrain model with thermal orthophoto referenced in the earth coordinate system and overlaid on the global map platform.

All the necessary technologies for the first part of the research are currently evaluated with excellent results.
We surveyed the location of new unknown caves using this technique. For this purpose, we studied three pilot regions with great potential for locating new caves:

- Bosnek karst region, Bulgaria, which contains the longest cave in the country, which is over 18 kilometers long and has over 11 entrances.
- Iskrets- Breze karst region, Bulgaria.
- Karlukovo karst region, with over 140 caves known so far.

### 3.1. Location of caves by thermal infrared cameras

We made an extensive survey of the first two regions for locating new unknown caves by thermal infrared cameras. As a result, we located more than 20 unknown objects, with thermal behaviour like caves. We just started their location on the ground and their underground survey, but the first results are very promising. In Bosnek karst region, Bulgaria, we detected remotely the entrance of a new unknown cave by a thermal infrared camera (figure 7).

**Figure 7.** Location of the entrance of a new unknown cave by the thermal infrared camera: a) Thermal infrared and visible images of a new unknown cave from Bosnek karst region, Bulgaria fused in situ by FlirOne Pro radiometric thermal camera. On the left upper corner, the temperature values are given for the relevant spots (Sp 1-3) on the terrain marked by crosses and the relevant regions included in circles (Bx 1-3) and squares (El 1-3); b) Overlapped visible and thermal infrared image from figure 7a of the same landscape captured simultaneously by post-processing of the pairs of images obtained by Flir Tools+ software.

We found the entrance of a new unknown cave located by a thermal infrared camera on the terrain (figure 7, 8). It corresponds to a real cave, which was not known before.

We tested the potential of this technique for remote detection of caves from far distances. So far the best achievement of remote detection of known caves from far distances by a thermal infrared camera was made by Baroň, et al. (2013) who located the entrance of Nadeje cave with a thermal imaging camera from an airplane from ~ 1 km. We located the entrances of two caves 2 kilometres far away on a straight line of view by the thermal infrared camera (figure 9). This achievement was unexpected and demonstrates experimentally the great potential of this technique for the location of new unknown caves from great distances.

### 3.2. Orthophoto generation from thermal images

The main problem with orthophoto generation is the wide dynamic range that is required for work with thermal cameras. Usually, visual images are 8-bit per colour that is enough to handle good dynamic range. In the case of thermal images, in order to detect even small differences in scene temperatures, it is necessary to measure a temperature difference within a narrow range of 0.1° K.
Because 8-bit colour handles only 256 levels, in the case of resolution of 0.1° K, the temperature span that can be measured is only 25.6° K. In real world conditions that span is too small and significant parts of the images will be underexposed or overexposed. Advanced cameras implement a dynamic range allocation algorithm so every frame is within the range, but this is achieved at the price that images from the same field are in different sensitivity scales. This can be seen at the following pictures (figure 10).

**Figure 8.** The entrance of a new unknown cave located by the thermal infrared camera: a) Thermal infrared and visible images of the entrance of a new unknown cave from Bosnek karst region, Bulgaria fused in situ by FlirOne Pro radiometric thermal camera. On the left upper corner, the temperature values are given for the relevant spots (Sp 1-3) on the terrain marked by crosses and the relevant regions included in circles (Bx 1-3) and squares (El 1-3). b) Visible image of the same cave entrance captured simultaneously with the thermal image on Fig. 8a. c) Overlapping of the images on figures 8a and 8b by post-processing of the pairs of images obtained by Flir Tools+ software.

**Figure 9.** Entrances of two caves located by the thermal infrared camera from 2 kilometers distance: composite thermal infrared and visible image of entrances of two known caves in Breze karst region, Bulgaria marked by crosses Sp1 and Sp3. On the left upper corner, the temperature values are given for the relevant spots (Sp 1-3) on the terrain marked by crosses.

**Figure 10.** Two almost simultaneously taken thermal images of the same ground from drone demonstrating automatic recalibration of the image temperature scale.
From a human point of view, this is acceptable and helps to distinguish even objects with small temperature differences but in the case of orthophoto generation, this is not usable.

The solution that we find is to work with 16-bit images that can handle the whole available thermal resolution of the camera (different models are from 10-bit up to 16-bit per pixel). In this case, the software for photo stitching and orthorectification will perform as expected.

The drawback is that the human eye can resolve only 256 gray levels and such images look very dim and this is an obstacle preventing us from the detection of objects with a small thermal difference. To demonstrate this, we prepared a sample. Below is one sample 16-bit image with a raw view and adjusted dynamic range. In a raw view, it is almost impossible to see a bird, but after enhancement the bird is clearly visible (figure 11).

![Sample 16-bit image with a raw view and adjusted dynamic range](image)

**Figure 11.** Sample 16-bit image with a raw view and adjusted dynamic range: a) Raw 16 bit thermal image, b) The same image but with an enhanced scale.

Such dynamic range adjustment is relatively easily done on a single image with limited temperature variations but significantly harder to implement it on a huge orthophoto map with large temperature variations. Because this is the main tool for cave discovery, the sensitivity of the methods will depend on the detection level. For cave detection, it is optimal to adjust the scale for the temperature range close to that of the cave entrances. These relations can be understood better if we look at a diagram for the relation between the estimated temperature and the readings from the sensor for 16-bit image (figure 12).

The requirement for image enhancement is primarily dictated by manual detection of caves in thermal orthophoto. In case that some more sophisticated software algorithm is developed, we can process directly raw images. Bellow, we show an example of thermal image enhancement for visual cave detection (figure 13).

![Relation between estimated temperature and sensor readings](image)

**Figure 12.** Relation between estimated temperature and sensor readings.

3.3. **Overlay of thermal orthophoto on a 3D terrain model**

Terrain mapping for thermal orthophoto images onto 3D terrain model is similar to that for NIR images displayed on image Fig.6, but there are some important details when we try to map cave entrances. The reason is that most of the entrances are located on vertical walls and in that case the standard procedure for DEM model generation and overlaid orthophoto images is not suitable simply
because in DEM model vertical walls do not exist. This introduces a requirement for work with 3D models that reconstruct not only height fields as DEM models but also walls of landforms as shown on the picture on figure 14 from the 3D reconstruction.

Figure 13. Thermal image enhancement: a) Visual picture of cave entrance; b) Auto exposure of 16-bit thermal image; c) Underexposure – best for hot objects; d) Optimal exposure – best for cave detection; e) Overexposure - best for cold objects.

Figure 14. A 3D model and image overlay of vertical land structure with cave entrances (encircled).

3.4. 3D terrain model with thermal orthophoto referenced in the earth coordinate system and overlaid on the global map platform
The final result of the research will be thermal orthophoto images with thermally enhanced range for best detection, overlayed on the global map platform as shown on figure 15.

Figure 15. High-resolution 3D terrain model integrated into global 3D earth model.
4. Conclusions
There is a relatively small number of works for cave detection with thermal cameras and the main target of all other research works is focused mainly on the problem of how to detect caves and the optimal conditions for imaging. In almost all works GPS coordinates of entrances are measured. Of course, this task is very important for the success of detection but it does not answer the need of how to import this information into modern 3D GIS platforms. Our team performs the first truly complex approach to the problem from the viewpoint of thermal difference detection, orthophoto generation, 3D modelling and integrating into web GIS platform.

Because this research is large it is divided into two phases. In the first phase we learn all key technologies to fulfil research requirements:

- Ground thermal imaging with high thermal resolution at long distances to detect caves.
- Drone terrain mapping in a visual band and 3D reconstruction.
- Drone terrain mapping in NIR band and overlay onto the 3D reconstruction.
- Drone thermal imaging.

In the second part of the research, the experience gained in the first part will allow us to fulfil the following tasks:

- Orthophoto generation from thermal images.
- Overlay of thermal orthophoto on the 3D terrain model.
- 3D terrain model with thermal orthophoto referenced in the earth coordinate system and overlaid on the global map platform.

The results from the first phase of the research are quite impressive and this is a guarantee that the second phase will be successful too.

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