

MODERN METHODS AND DEVICES FOR MAPPING UNDERGROUND GALLERIES AND NATURAL CAVES

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Abstract

It is made a review of the classical techniques and devices used for mapping underground galleries and natural caves. A new method is proposed and realized by the means of modern technologies in the Pepelyankata cave nearby the village of Bosnek, Pernik Province.

A GPS receiver is used to determine the coordinates of the starting point. Another device - a combination between a laser rangefinder, a compass and an inclinometer, is used to measure the traverse and certain points inside the cave. All of the measurements are transferred wirelessly to a PDA device and represented by a suitable mobile GIS-enabled software. Some other data, including photos made by the PDA's integrated camera, is collected as an additional attribute information.

Back in the office, the results are superposed on an old map of the cave, an orthophoto image and topographic map of the region for further analysis.

1. INTRODUCTION

Nowadays, caves are considered to be among the last geographic frontiers on Earth. As they provide a first-hand view of the subsurface, rock structure and underground water as well as biology, oil and mineral distribution, their value is getting more and more appreciated. However, no matter what studies are to be done or problems to be solved, all of them are referenced to certain locations and exact points in a cave. The ultimate goal is a three-dimensional map that shows the cave layout to help in understanding the cave and lead to further studies and to target promising areas for advanced exploration (Palmer, 2007).

The basic stages of mapping a cave are collecting the data, managing it and drafting the map (Dasher, 1994).

2. CLASSICAL METHODS AND DEVICES IN CAVE MAPPING

A typical cave survey is divided into several jobs – locating and marking the survey stations, lighting the target points, holding and reading the instruments, notekeeping, sketching, often in a combination with exploration, checking mazy and side passages, and overall coordination and leadership. Usually these responsibilities are handled by two to five people.

Choosing surveying instruments depend on different criteria – ruggedness, accuracy, cost, transportation size, ease of learning, ease of using and includes compass and/or clinometer. The compass-tape-inclinometer method is a classical technique, widely used even nowadays for its ruggedness, sufficient accuracy, low cost, compactness and so on. In comparison, theodolite survey is extremely accurate, however it is quite fragile, large and expensive. It is much the same with 3D laser scanners which offer a complete and accurate gallery modeling at the expense of their large transportation size, fragility and high cost. In terms of the final target – a cave map, different means are classified in an official grading system (Table 1).

Table 1. UIS Mapping Grades

Grade	Description	Precision length, [m]	Compass, [°]	Clino, [°]	Expected accuracy, [%]
-1	No map available	-	-	-	-

0	Ungraded	-	-	-	-
1	Sketch from memory, not to scale	-	-	-	-
2	Map compiled from annotations, sketches and estimates made in the cave. No instruments used.	-	-	-	-
3	Directions measured by compass, distances measured by cord, pace or body dimensions. Significant slopes estimated.	0.5	5	-	10
4	Compass and tape survey, using deliberately chosen and fixed situations. Slopes measured by clinometer or horizontal and vertical components of line.	0.1	2	2	5
5	Compass and tape survey. Directions and slope by calibrated instruments, distances, by fiberglass or metallic tape, or tacheometry.	0.05	1	1	2
6	Survey or triangulation using calibrated, tripod-mounted instruments for directions and slope. Distances by calibrated tape, precise tacheometry, or calibrated DistoX type	0.02	0.25	0.25	1
X	Survey by theodolite or comparable means	variable			variable

3. EXPLORING AND SURVEYING PEPELYANKATA CAVE.

3.1. Choosing instruments.

Pepelyankata is a natural dry cave nearby the village of Bosnek, Pernik Province. As limestone is the host rock in the region, there are many other cave formations nearby, including the longest cave system in Bulgaria – Duhlata.

For the aim of this study there are prepared two GNSS handhelds and a laser rangefinder:

- Trimble® GeoExplorer® 3000 GeoXH™ – a GPS-enabled mobile device that supports postprocessed positioning accuracy up to 1 cm. It is used at the cave entrance to coordinate the starting point of the whole survey.
- Trimble Juno™ SC – one more GPS enabled PDA (Personal Digital Assistant) device which, however, because of its compactness is used to store and manage measurements inside the cave. Its features – 3.5” touch screen, 533 MHz processor, 128 MB RAM, 128 MB flash data storage, internal all-day battery (2600 mAh) and lightweight (240 g) and small size (12.9 cm x 7.4 cm x 3.0 cm), as well, is suitable for the task.
- Trimble LaserAce™ 1000 – the device with the most important role in this survey as a combination of laser rangefinder, compass and inclinometer. Its technical specifications – up to 150 m passive range of laser and accuracy of 10 cm, compass accuracy of 2° and inclinometer accuracy of 0.2°, are comparable to current widely used surveying instruments, however its lightweight (464 g) and 3-in-one compactness appears to be much more attractive. Dust proof and water resistant casing (IP63) are suitable enough for the harsh conditions inside Pepelyankata. Although it provides powerful standalone measurements previewed on its backlit LCD display, in this case it is combined with the Juno handheld connected via Bluetooth.

As these devices allow collecting data in the harsh environment of a cave, the right software enables the task to be completed in a fast and efficient way. That is why the solution is completed with a suitable GIS-enabled software for the Juno handheld:

- DigiTerra Explorer™ (DTE) 6 Professional – compared to the other two, lower versions – Basic and Advanced, version Professional supports the full mobile and desktop GIS and GPS functionality of DTE software. As it allows using map backgrounds, displaying and editing data in a wide range of vector and raster formats, integration with external sensors (like laser range finders), built-in cameras, topological, preview and editing tools., it is the right choice for the task. In addition, the software supports different coordinate systems and projections, including the Bulgarian UTM Zone 35 N, WGS 84. Offering a native support for mobile computers (Windows® Mobile/CE OS's) and for desktop computers (Windows® 2000, XP, Vista, 7), DTE is a plug-and-play software and so doesn't require any installation. It is distributed on a SD/miniSD card which is put in the slot of Juno. It supports a variety of languages including Bulgarian, English, French, German, Italian, etc.

3.2. Collecting the data.

The work inside the cave was divided between three people – an experienced caver to lead the team throughout the cave and to point out its special characteristics that must be surveyed in order to get a complete cave layout, and two surveyors to operate with the Juno handheld and LaserAce. At the very beginning, at the cave entrance outside the cave, it is coordinated the starting point of the whole survey. The achieved accuracy by GeoXH after 20 minutes at the point was 7 cm. Inside the cave measurements are organized as a standart mine traverse using LaserAce.

Survey stations are chosen due to line-of-sight and any special features and then marked with small rocks or natural formations. Once foresight stations are marked, measurements are done by one person himself, lighting target points and reading and verifying records. Measured distances, azimuth and inclination angles are transmitted directly to the Juno handheld via Bluetooth where the new measured points are previewed and recorded (Figure 1). Paperless sketching and notekeeping are also done on the handheld.



Figure 1. a) Collecting the data with b) LaserAce 1000 rangefinder and c) Juno handheld.

In advance, it has been created an attribute table in DTE so that point coordinates are not the only recorded information. The table is filled with the exact measured values – angles and distances, photo captures and additional notes (Figure 3). The software allows adding new attributes and editing old whenever needed (Figure 2).

Field	Value
ID	6
Label	
Date	2012.01.05
Length	0.00
Area	0.00
Up	
Down	
Left	
Right	
Distance	7.24
Az	299.4
V	-5.98
pic	Img000005.jpg
Notes	

Figure 3. Cave surveying attribute table of DTE

New data field

Name: Notes

Alias: Notes

Default: [Dropdown]

Type: Text (N)

Width: 200 decimal 0

Rule: None

OK Cancel

123 1 2 3 4 5 6 7 8 9 0 - = [Left Arrow]

Tab q w e r t y u i o p []

CAP a s d f g h j k l ; ' [Left Arrow]

Shift z x c v b n m , . / [Left Arrow]

Ctl á ü ` \ [Left Arrow] [Down Arrow] [Up Arrow] [Right Arrow]

Figure 2. Creating new data field

The whole process of exploring the cave and collecting the data is completed within two days – the first one mapping upstairs, and the second day downstairs.

3.3. Managing the data.

DTE workspace contains a variety of tools for data import/export (the File menu bar, Figure 4), sketching (the Edit menu bar), data preview (the View menu bar), feature information (the Query menu bar), GPS functionality (the GPS menu bar) and different tools for raster orientation, survey settings, polygon modification (the Tools menu bar), etc. The workspace frame consists of shortcut buttons for the layers list, attribute table, GPS, faster preview and easy map navigation on the map screen.

All stations and measured points are previewed real-time in the DTE workspace, organized in different layers according to their type - point, line, polygon. Measured points are recorded in a point layer, and cave sides and the traverse line – in a line layer (Figure 5 **Error! Reference source not found.**). Data is labeled due to its layer and corresponding attribute information (**Error! Reference source not found.**). By selecting a feature its attribute table is easily previewed.

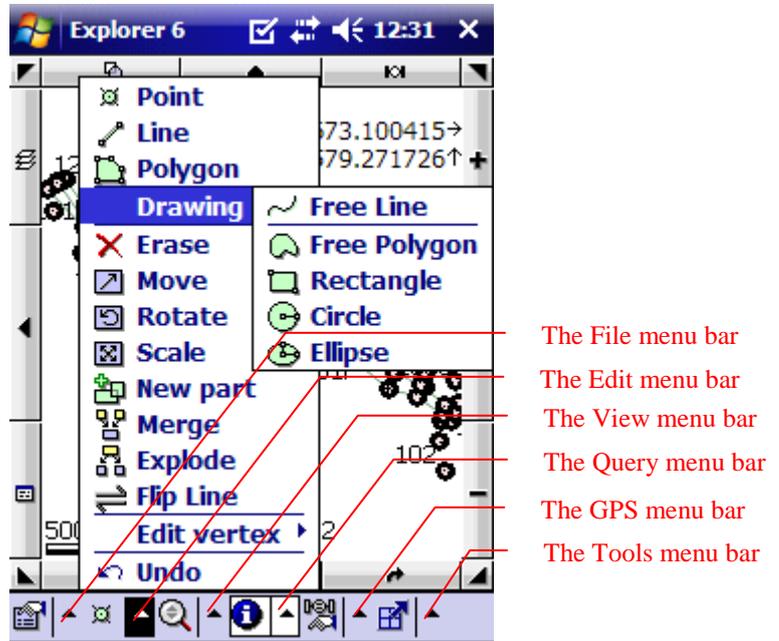
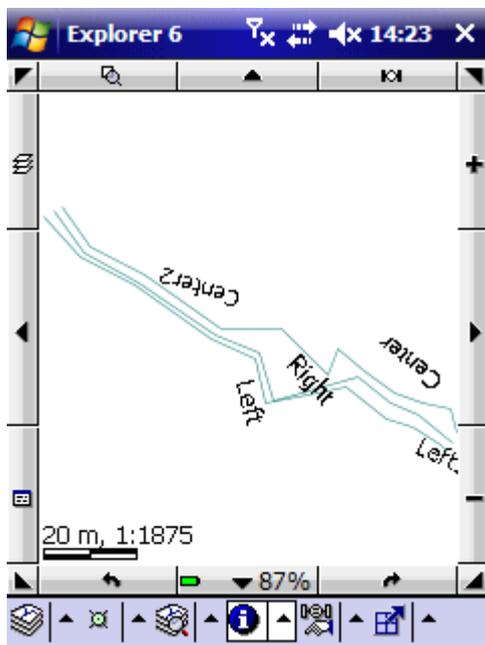
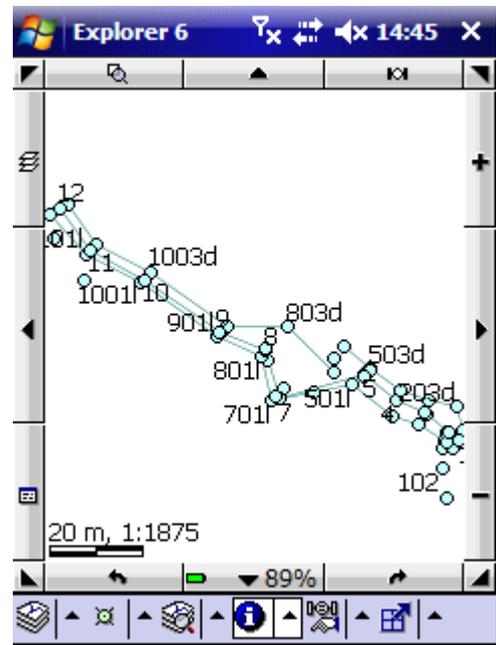


Figure 4. DTE mobile workspace, shortcut buttons frame and menu bars



a)



b)

Figure 5. Map Window of DTE: a) The line layer, including both measured upstairs cave sides (labeled as Left and Right) and traverse line (Centre); b) Both line and point layers, measured side points and stations are labeled with their IDs.

The Layer dialog box is where a list of all the loaded layers is shown (Figure 7). It is used to manage the layers in the map and set various layer properties. In this dialog box layers can be added, edited, reordered, turned on or off, saved,

removed. The Scale, Source, Classes and Labels are additional dialog boxes that can be opened to view and change properties of the selected layer.

Feature labels and symbols can be turned off or displaying feature's information of up to 3 chosen fields from the corresponding attribute table (Figure 6). Their visibility also can be limited by defined scale value. As labels are usually an important part of map contents, DTE supports different fonts, text sizes, bold, italic, underline and other designing tools.

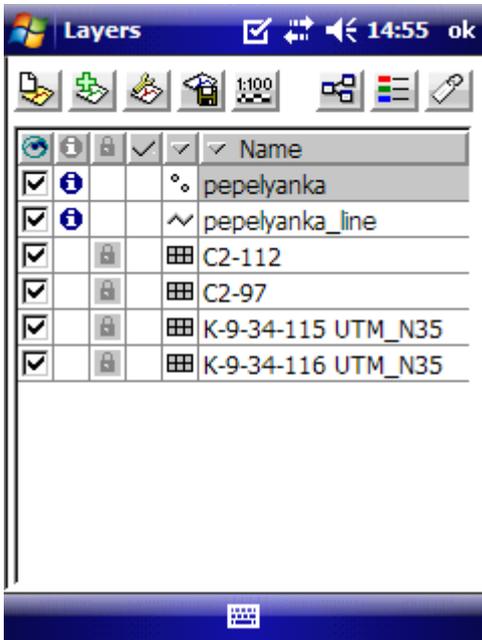


Figure 7. Layer dialog box

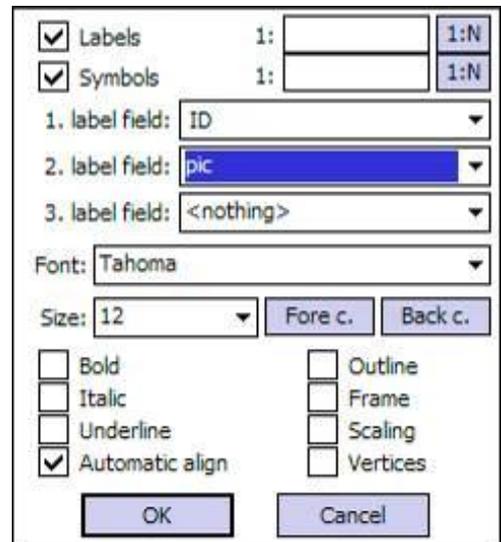


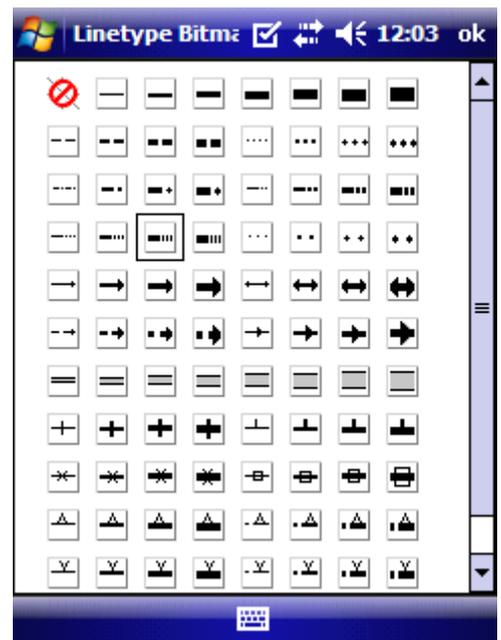
Figure 6. Feature labels can be formatted in many different ways

3.4. Drafting the map.

Quick and structured data is achieved still inside the cave due to the mobile GIS-enabled solution. As the task is basic surveying no special symbols are used, although DTE supports a variety of markers and possibilities to load new sets (Figure 8).



a)



b)

Figure 8. DTE supports a variety of a) Point symbols and b) Linetypes.

The measurements are saved as a DTE map file in a user defined directory. Back in the office the results are previewed with the desktop version of DTE. DTE desktop screen and tools are much similar to those in the mobile version, except the difference in their positions, also the full path of the open project and coordinates of the current cursor position shown in DTE desktop.

Both mobile and desktop DTE Professional support a variety of vector, raster and table file formats to import as layers:

- Vector: BNA, CRD, DAT, DGN, DXF, LOG, MAP, MIF/MID, SHP;
- Raster: BIL, BMP, ECW, ERS, JPG, JP2, LAN, PCX, RAS, SID, TIF;
- Table: DBF, MDT, TAB, TXT.

For further analysis the cave map could be superposed on an aerial orthophoto image, topographic map, old cave map, etc., in order to show its relation to the surrounding landscape, local geology, regional drainage and so on (Palmer, 2007). A raster layer could be modified by its brightness and contrast features, and setting a certain colour or the entire layer transparent as well (Figure 9).

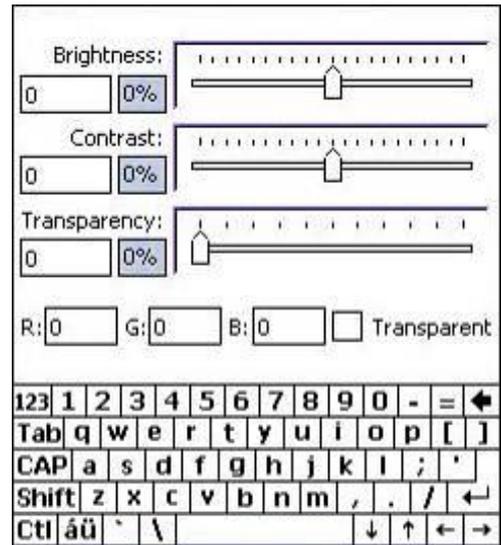


Figure 9. Raster options

On Figure 10 it is shown the map drafted inside the cave and a topographic map (.jpg) and an orthophoto image (.tif) loaded as background layers. Eventhough they have been georeferenced in advance, it is also possible to be done by DTE. A full list of loaded layers can be seen on the left part of the screen, where they can be inserted, selected, labeled, edited, reordered, turned off, deleted.

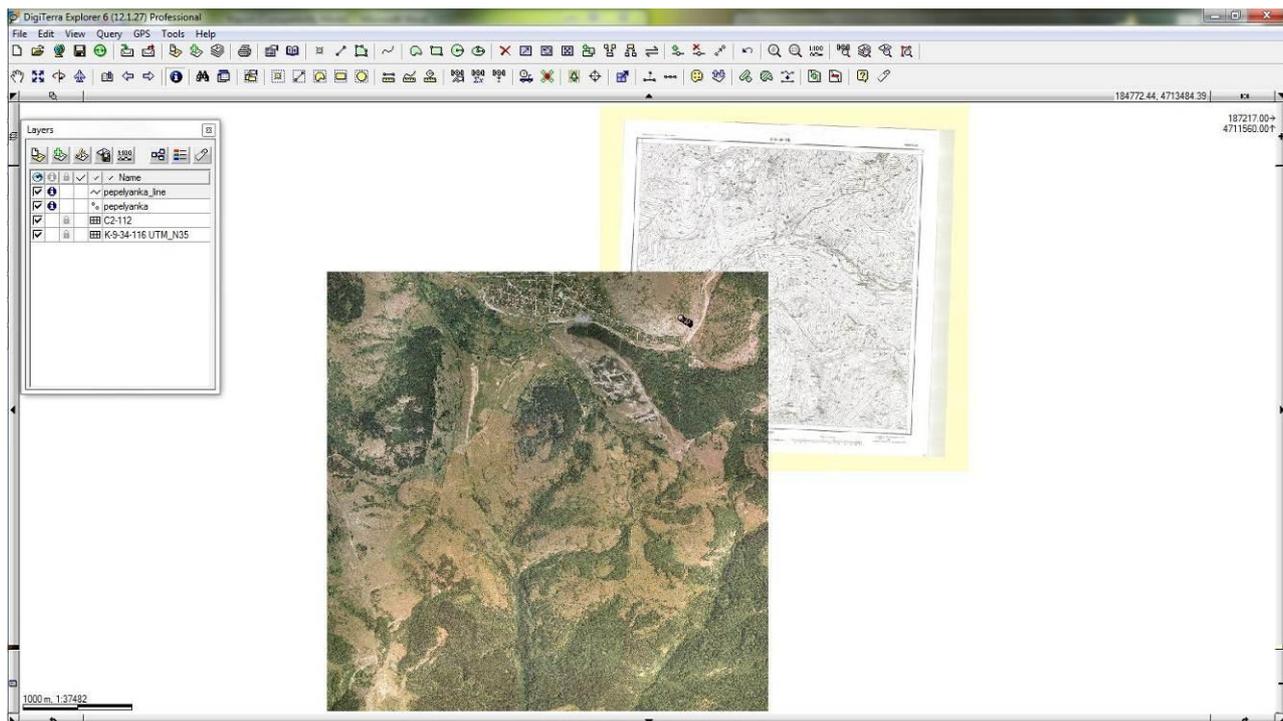


Figure 10. DTE desktop screen

4. KEY FEATURES AND BENEFITS.

After all data is collected, managed and the cave map is drafted, objectively, there could be drawn the present benefits of the proposed method of cave mapping and supposed future opportunities:

- The LaserAce 1000 rangefinder: could be used as a standalone 3-in-1 solution compared to tape/rangefinders, compass and inclinometer. No need of preventing tape kinks or cleaning of mud to read. Just one person is needed to operate with LaserAce in comparison to the classical techniques. Its point-and-shoot simplicity allows capturing a point with one single shot and immediate visualization of the measured data;

- The Juno handheld: excludes the need of paper and pencils for sketching and notekeeping, and more people for these activities. This also means not only less tools to bring, but no problems with their damages or lost inside the cave, and their further storage. The amount of recorded data depends on the Juno's flash memory and SD card expansion which compared to the classical tools are practically inexhaustible;
- DTE: its support of external sensors allows using rangefinders, cameras and many more devices to collect a wide variety of information. The range of supported file formats allows loading additional vector, raster and table data for further analysis, field navigation, new explorations, etc., file exporting for easy integration with other software applications and GIS databases.
- LaserAce 1000, Juno and DTE: the seamless combination between LaserAce and Juno via Bluetooth allows measurements and their consistency to be easily checked. The solution gives the confidence of a fully automated calculation process which protects from any personal mistakes when coordinating measured points. Collecting spatial 3D data makes possible both plan and profile view to be drawn wherever needed. All data can be easily updated later, including new features and additional attribute information. It is a compact, lightweight and rugged GIS-enabled solution for easy and quick work done still inside the cave. Mapping could be done even by one single person.

5. CONCLUSION.

The proposed method, including handheld devices, a rangefinder and software with GIS functionality, provides a powerful modern tool for spatial data collection in harsh environments. Compared to the UIS Grading System, classical and modern surveying methods, the proposed one is the optimal solution that allows cave mapping in a reliable, quick and easy way.

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