On Creating Complex Modelling Systems Of Caves

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Abstract - **Caves are such underground objects, which are important not only for speleologists, but for medical treatments, security protection, or even for casual tourists as well. Basically, the knowledge on the geometry of a cave may be essential: based on that several cave-arms can be discovered, which may be interesting for several aspects. The mapping of caves is done by surveying tools and method. In practice, these are outdated techniques, which does not provide the appropriate accuracy demand of the mapping. Therefore, in the present study the viability of more recent surveying instrumentation is investigated. Subsequently, GIS database has been developed based on surveying measurements of several Hungarian caves and additional data collection related to the certain caves. The developed GIS has become a complex modelling systems of caves, which can be a valuable tool for several applications ranging from healthcare to family excursion.**
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I. INTRODUCTION

Caves are such underground objects, which are isolated from the outer world since the beginning of the prehistoric ages. The dust-free and partly weather-independent environment allows the formation of a very special flora and fauna. The geologist can look into the secrets of the Earth by reconstructing the history of the crust. From a different aspect, caves are important for tourists; many people are amazed by the world of the eternal night. The changes on the Earth surface and the water pollution affect the sensitive balance of underground world. That is, why it is so important to create complex modelling systems of caves, which integrates spatial processes in a cave, and their links to each other.

The geographic information system (GIS) sciences have gone through dynamic changes in the last few years in Hungary. People has recognized that the protection of natural environmental sights can be achieved only by close cooperation of the different civil services. This can be supported by GIS by building a complex information system, which provides a uniform base for all technological and economical planning. Not only the national parks and nature conservation areas are claiming up-to-date digital maps, but these may also be relevant for local governmental bodies, technological and economical firms. In fact, most Hungarian caves are not secure against humans, the bluntness and fear of some common men are often destroying them – this moment is maybe the last, when we can do something to rescue them. The primer task is to build a cadastral information system based on measured three-dimensional geometric data of the caves and the mountains for identification and registration. Subsequently, basic processes and properties of the caves can be attached to these data, which gives a description of its spatial distribution and the actual environmental effects. The emphasis is on the spatial data, since a good decision can be based only on knowing the coherence between the underground world and the surface of the Earth.

In this study I was build two cadastral information system: one about the caves of the Keszthely-mountain, and the other about the caves of the Tihanyi-peninsula. The most caves in the Keszthely-mountain are limestone/dolomite caves and basalt-caves [1, 2], and all the caves of the Tihanyi-peninsula are non-karstic caves, they are about gejsirit [2]. To create a map of a karst-area, or a non-karst area, or to measure a karst-or a non-karst cave are essentially different tasks, making use of different methods, which can be supported by an information system equipped with variable kind of attribute data. The whole workflow I can partition to four steps [4]:

1. Determination of cave entrances
2. Surveying the underground world
3. Making a map about the measured data
4. Building the complex information system

II. DETERMINATION OF CAVE ENTRANCES

Coordinates of the entrances of most caves can be determined with the Global Navigation Satellite System (GNSS). The entrances can be identify only with sub-meter accuracy, so use of GNSS receivers must be sufficiently adequate. In the summer of 2001, I was investigating the optimal measuring method in the area of the National Park of the Balatonfelvidék [3]. I was looking for the optimal measuring time and processing method in many modes of observation. Approximately, I have measured 300 cave entrances with four GPS-receivers: the Leica-500 (a receiver with geodetic precision), the Trimble ProXr (suitable for GIS measurements), and the Magellan Tracker and Garmin Etrex (navigation devices). Auxiliary instruments were a tape, a compass and a Leica laser distance-meter. Often we cannot set up the instrument right at the entrance of the cave, but in a few meter distance apart from it (Fig.1).

For measuring the direction between the instrument and the entrance we have used a compass, and for measuring the distance, a tape or a distance-meter has been used. Using the latter was difficult in strong Sunshine, since we could not identify exactly the place of the laser-point. Even though we have measured slope distances, it was not necessary to reduce them to horizontal distances due to the short distances and the nearly horizontal measurements. Due to the masking of the trees or the hang over rocks, in most cases only the signs of four satellites could been observed, so we had to extend the measuring time from the originally estimated 10 minutes to 20-25 minutes. In the processing manner of the measurements several options have been investigated. Coordinates have been processed using different permanent stations (BME, Penc, Eszék, Graz, Bratislava), with code- or phase-method, with precise- or broadcast ephemerides, using measurements with 1-5-10-30 minute duration, observed on 4-5-6-8 satellites. We have measured the caves both in the summer, when the vegetation were high, and in the winter, when only the stocks and arms of the plants and the hang over rocks were covering the sky. We have investigated the loss of lock, loss of satellites near the horizon or the zenith.

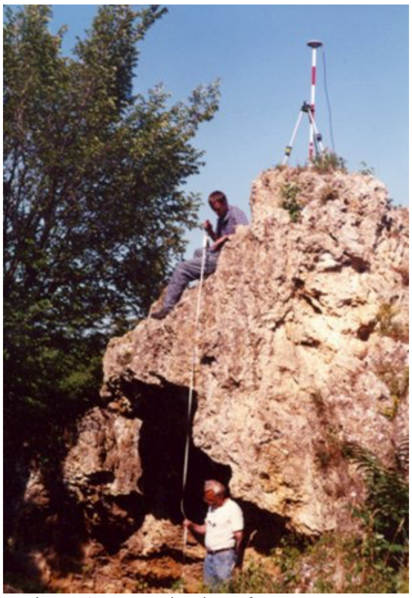
Figure 1. Determination of a cave entrance

The short summary of the results:

1. Although GNSS satellites at the entrance of the caves are often highly masked, measurements with the Leica and Trimble GPS could also be performed. The accuracy of the navigation receivers were not sufficient, since those instruments can only provide reliable data if they have been initialized beforehand.
2. The optimal measuring time was 10 minutes. It was found that the best solution can be achieved by processing the coordinates from the nearest permanent station. Processing with the phase-method or with precise ephemerides is unnecessary; it is sufficiently adequate to calculate the coordinates with the code-method and with broadcast ephemerides.
3. It is useful to set out the receiver as high as possible, because of the masking effect of trees and hang over rocks. The investigations were demonstrating that masking the satellites near the horizon results in less errors, than masking of some satellites near the zenith. The most important effect of masking is due to the stocks and arms of the plants, while the season-dependent leaves have negligible effect on the accuracy.
4. It is sufficient to use a general transformation parameter file for transforming between WGS-84 and the Hungarian EOV for the whole area of Hungary. Also, use of some troposphere- or ionosphere-model was found to be not necessary.

III. SURVEYING THE UNDERGROUND WORLD

Traditional surveying instruments (compass, tape) are the widely used instruments in cave surveying. The surveying-method is in most cases the traverse surveying and the polar method. After the measurement the data should be adjusted and the corresponding error estimated derived. Nowadays, total stations and laser scanners are the most up-to-date instruments to carry out precise measurements in large numbers. The laser scanners provide more thousand measurements per seconds, representing the wall of the cave with point cloud in an extremely fine resolution. The measured point cloud then can be imported in almost every desktop mapping software. Conversion of the three dimensional point cloud to a digital terrain model is only a question of the adequate knowledge of the software. In a subsequent step, database can be juxtaposed to the map, containing attribute data, for example the colour or health condition parameters of the dripstone, estimated lifetime. The accuracy of the laser scanners exceed the demanded accuracy of cave surveying; only their cost and size limits their spreading. A lot of scanners are enabled to be set up at a point, to measure the instrument height, to orient – these functions are basic conditions of the measuring in a local coordinate-system. When we have a correct transformation equations between the local and a national projection system –the later in Hungary is the EOV– all editing and post-processing steps can be performed in the national projection system (Fig.2).


Figure 2. A laser scanner in the Csesszneki-cave

In the last few years the surveying instruments are going through a heavy development. The total stations are always improving, their automatization is gradually getting into higher level, enabling their applicability for more colourful tasks on the spectrum of the surveying works. The development of the GNSS-receivers allows real-time measuring methods, so in the field we can get phase-processed coordinates in real time with centimetre accuracy. In the first times it was feasible by using an own base station in a reference point, but due to the development of the GNSS-infrastructure, this can be solved by using stations of the permanent station network (also called active GNSS-network). Recently, in the last 5-10 years Smart-Stations have been developed, with are combined total station and GNSS-receiver instruments, allowing convenient solution of complex surveying tasks. Cave surveying is basically a similar task to a survey of the interior of a building, but in the former case survey of the entrance of the cave and the nearby area of it is also included. Several relevant information on the evolution of the cave can be drawn geologist and geographers based on karst-shapes of the surface of the mountain. Determination of the direction of water flows, or the relative position of underground objects and surface karst-objects may give us information on the location of undiscovered cave-arms. Nowadays, the speleologists are using traditional surveying instruments. The directions are being measured with a compass, the distances with tapes. With this instrumentation and the applied methods the errors are usually above expectations, especially in case of big horizontal and vertical caves. The measurement of the nearby area of cave entrances has been failed due to financial reasons and time limitations. Compass and tape are not sufficiently precise for a reliable surveying. Several underground objects are undiscovered due to the lack of known connection between the extant cave-arms and the surface [1]. This is important, not only from the aspect of the natural conversation, but also from the aspect of tourism or healthcare, for example the Abaligeti-cave in the Mecsek-mountain, or a Kórház-cave in a Bakony-mountain are very important for cure pulmonary diseases. The appropriate surveying instrument to deliver sufficiently accurate geometry of the cave and the mountain (for detecting cave-arms) is the Smart-Station (Fig.3).

Figure 3. The Smart-Station

With a Smart-Station we do not need control points at the cave-entrance, since by using the RTK-method we can manage the control-point densification. Determination of the coordinates of a single point takes only a few minutes, so we can determine a large number of points, depending on the shape of the surface and the cutting-off angle. Based on these points, we can measure a regular network of detail points (in essence a set of three-dimensional points), which can be the input data of the post-processing and visualisation. After the control-point densification the GNSS receiver and the total station can be used separately, the former by mounting it to an antenna-pole. Thus, the measurement work can be done parallel at two different part of the area, which makes the measurement more efficient both from financial and temporal aspects. The aim of the surveying either can be a line-levelling, which yields a vertical model of the surface, or a Digital Terrain Model (DTM), which combines horizontal and vertical information in one model. When the cave is not too narrow, we can use the total station under the ground. The polygon-points and the cross-sections can be determined simultaneously in one workflow, since with the laser-distance meter we do not need a reflector tape or a reflector prism. Smart-Stations can also be programmed, which can control the measurements, and they can be performed in an automatized way like a robot-theodolite. We can get in shorter time much more information than before, making the measurements much more efficient in every aspects. Caves are classically displayed in cross and longitudinal sections, in horizontal map in a stretched sections. However, this new surveying method allows the illustration of the geometric information on an isometric or plastic map. Both maps are represented in a three-dimensional coordinate system, resulting in an impressive visualisation of the caves.

IV. MAP PRESENTATION

The most relevant documentation of a cave surveying campaign is the resulted map. It visualizes the spatial range of the cave in context to the surface. The map is an important tool for effective and purposeful explorations. A cave-map, like a geodetic map is showing the geometry in scale, ground plane after a generalization. As caves are three-dimensional objects, the visualization in two-dimensions is not that efficient; we favour the three-dimensional mapping methods, or plan-maps with many attribute data. The most cave-maps are sections, where the duct width on the map refers to the real width of the duct. When the cave is a vertical one, more sensible to display it in two or more layers projected onto a vertical plan. We can illustrate the cave with an isometric, axonometric method, where we replace the cave-arms with prisms, or by the hydrotermical caves with ball-chambers. When we want make a useful map, we should be informed on the maps, which are regularly used by speleologists (Fig.4).

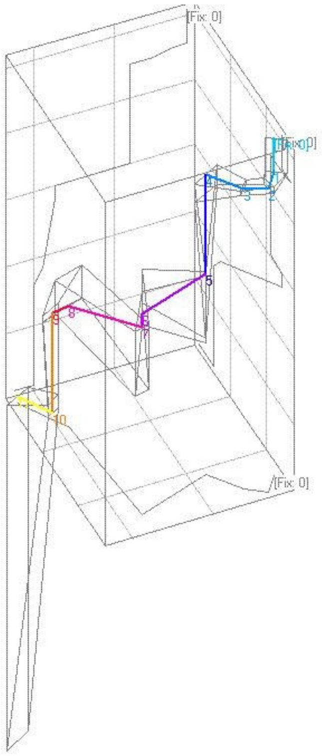

Figure 4. The 3D-model of the Wind-cave

V. BUILDING AN INFORMATION SYSTEM

The most effective, multi-faceted form of presenting the collected, spatial data of caves is the information system. It contains a lot of geometrical and attribute data, which is although a diversified database, can be practical by properly defined (simple or complex) queries (Fig. 5). Such information systems can be made available via the internet, so they can appease wide user claims ranging from the scientific to the touristic demands.

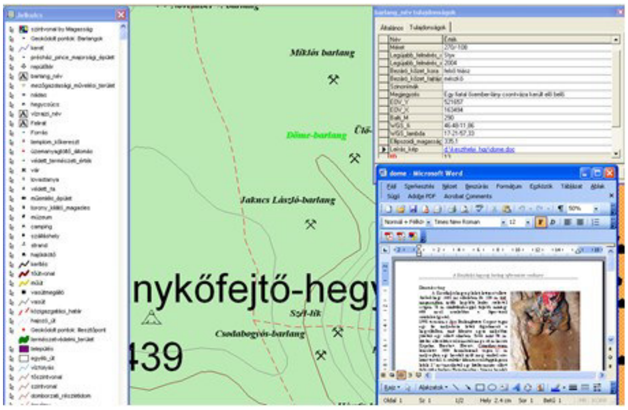

Figure 5. The information table of the Döme-cave

Building an Information System of caves, I can define two steps [4]. The first step is shaping the map, and the second step is compiling the descriptive attribute data. For shaping a map, it is very important to choose a good base map, with adequate content. Visualization of all important detail is demanded, when the representation of the actual geometry of the cave and of the surface is based on homogeneous point distribution. The most suitable example is the Hungarian topographical maps in a scale of 1:25 000, which can conveniently be handled, and the details are presented in reasonable resolution. After choosing the adequate map-section, we must scan it with a professional scanner. For that either a flat-bed plotter or a drum-plotter can be used, though the latter is preferred by the author. In the drum-plotter not the sensor moves over the paper, but the paper is moved by numerous rolls. There is no positional error, and the plotter requires only a few places. Finishing the map-design, the next important step is collecting the attribute data. The attribute data is the actual purpose of the Information System, as this is the useful content which is juxtaposed to geographical locations. An important point of view in my project was that the data collection was widened to numerous kinds of data in cities, towns, villages and natural sights; in a given region there are not only caves, but cultural and ethnographical values as well. The operative part of the documentation was filling the attribute tables of the caves. All table contains the following information: cadastre number of the cave, the name of the cave, length, depth, name of the researcher spelunker club, the year of the last research, type of the rock, age of the rock, other ethnographical name of the cave, comments, coordinates in the Hungarian system (EOV_Y, EOV_X), height above mean see (Baltic-see), WGS coordinates (WGS_fi, WGS_lambda, ellipsoidal height), description, pictures, maps. These information are in a hyper allusion, under the name of the caves. Out of the cave's data, in this Information System further useful attribute content is provided, such the descriptions of the cities, towns, villages and natural signs. With this data, the information system can be used even for planning of a family excursion.

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