# Paperless Caving - An Electronic Cave Surveying System
# La topo sans papier - un système électronique de topographie

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### Abstract

The cave surveying system presented here consists of an electronic measuring device combined with a surveying program running on a PDA. The measuring device includes a laser distance meter and an electronic compass and clinometer. It is capable of measuring declination, inclination, and distance simultaneously at the push of a button, and immediately transfers the results to the PDA using a wireless Bluetooth connection. The PDA software is used to manage and store the received survey data. It displays the new survey shots together with the already known cave data and allows to make sketches directly on the PDA screen. Back home, the survey data and the sketches can be exported to the corresponding PC based cave survey and map drawing programs.

Advantages of this system compared to conventional optical instruments and paper sketches include: faster and more accurate measurements (especially in tight passages), fewer sources of errors, more freedom in steep and cross-section measurements, more precise sketching, immediate control of loop errors, and easy data transfer to PC based programs.


Keywords: cave surveying, surveying device, electronic compass, electronic clinometer, cave software.


### Résumé

Le système présenté ici est un appareil de mesure combiné à un programme tournant sur un PDA. La partie mesure comprend un laser pour mesurer les distances, un compas et un clinomètre électroniques. Il est possible de mesurer la distance, l'inclinaison et l'azimut en une unique pression sur un bouton et les résultats sont immédiatement envoyés au PDA via une connexion Bluetooth (sans fil). Le logiciel sur le PDA stocke les résultats, permet de visionner les points précédents ensemble et de faire des croquis d'habillage directement sur l'écran. Au retour de la sortie, les données topographiques ainsi que les schémas sont exportées sur un PC et ses programmes de topo et de dessin.

Les principaux avantages d'un tel système comparé à la méthode classique sont : mesures plus rapides et précises, moins de sources d'erreurs, plus de précision dans l'habillage, contrôle immédiat de certaines erreurs et transfert immédiat des données sans erreur vers les logiciels de topo.


Mots clé:
topographie spéléo, matériel de topographie, compas électronique, clinomètre électronique, logiciel de topographie spéléo.

## 1. Introduction

In the beginning of speleology, drawing cave maps was a time-consuming and tedious task which included a lot of manual work. Even the positions of the survey points were originally constructed geometrically on a sheet of paper from the data measured in the cave.

In the past decades, more and more of this process was replaced by computer-based tools. Today many cavers do their entire 'homework' using standard or specially designed computer programs. It took somewhat longer to extend the digital age into the cave. In recent years, however, several electronic devices for in-cave use were proposed. This includes measuring devices [MELZER (2003), WOOKEY (2003), EDWARDS (2004), UNDERWOOD (2007)] as well as data management applications on mobile devices [MELZER (2002), LE BLANC (2003), WHITE (2007)].

The system proposed here uses the new technological capabilities to build a framework that integrates the entire process end-to-end, from data acquisition in the cave to the final map drawing. There is no need anymore for reading data from a device and typing it in manually.

## 2. The 'Paperless' System

The system consists of special devices used in the cave to acquire the data, and PC-based analysis and visualization software to form a reliable and easy-to-use data path (Fig. 1).

The data collection part consists of two devices, a measuring device and a PDA with a data management application. The two are linked together with a wireless Bluetooth connection. Each of them is useful by itself, but the full potential of the system is exploited only if they are used in combination.

The measuring device acquires all relevant data, distance, declination, and inclination simultaneously. The compass and clinometer are both 3-axis systems that allow accurate measurements in any direction independent of the device orientation.

The PDA application is used to manage and store measured data and to add missing information like the connectivity of the survey shots. It displays the data numerically and graphically and allows to add sketches directly on the PDA screen.

At home, the PDA is synchronized to a PC and the stored data is converted and transferred to the corresponding cave survey and map drawing programs.

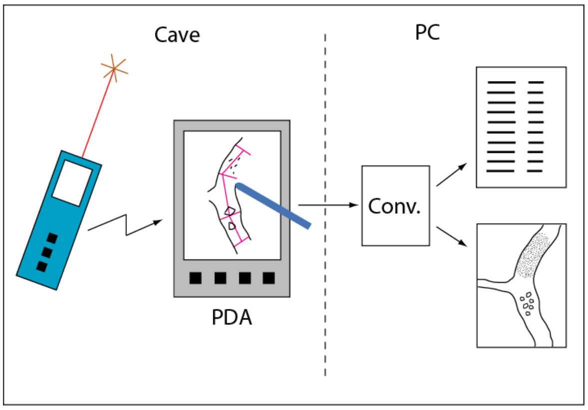


*Fig. 1: Data flow from measuring device via PDA and converters to PC based cave applications.*

## 3. The Measuring Device

To be useful for our system, the measuring device has to meet several requirements. It has to include four major parts: a laser distance meter, an electronic compass, an electronic accelerometer, and a Bluetooth communication system. In addition, its mechanical construction has to be small and lightweight but also reasonably waterproof and robust enough to be used in a cave. This is not easy to achieve because we need at least a primitive user interface and the laser distance meter includes delicate optical parts.

The solution chosen is to use a commercially available laser distance meter as base device and to add the remaining functionality to it. The device used is a Leica Disto A3. This is a small and accurate device available at a reasonable price. There are many reports of this device being successfully used underground by cavers.

The additional parts are placed on a small printed circuit board that fits inside the Disto without any changes to the existing case. Just four wires are needed to connect it to the circuit of the Disto. The board contains (SMD-) parts for the magnetic field and acceleration sensors, an integrated Bluetooth module (LMX9838), a 256 kBit EEPROM to store the measured data, and a small microprocessor (PIC16F688) to connect the parts and to do the necessary calculations. Individual sensors are used in place of an integrated compass/clinometer module because the modules are far more expensive and less flexible in terms of size and data processing.

A drawback of this solution is the fact that we cannot change the behaviour of the Disto and its user interface since we do not have access to its programming. All we can do with our lightweight connection is to read from and write to the display. In practice, however, this proves to be powerful enough. Each new distance measurement triggers a simultaneous compass/clinometer sampling, the results are shown on the display (Fig. 2), and transmitted over the Bluetooth connection together with the distance read from the Disto. The memory chip is used to queue the data when the connection is currently unavailable. In addition, it provides a backup in case the transmitted data is lost.


*Fig. 2: Leica Disto with compass and clinometer readings added to the standard display.*

## 4. The PocketTopo Application

What we need on the PDA-side to support the measuring device is essentially a database to store the received data together with the already existing survey data and other useful information. Other major features include the possibility to display graphical cave maps and to allow adding sketches directly on the PDA screen.

To ease the development and to broaden the range of compatible devices, the application is written in C# and based on the .NET Compact Framework. The Compact Framework is included or can be installed on many machines and operating systems, in particular on any Windows CE and Windows Mobile device. This includes most PDAs and many high-end mobile phones (smartphones). To be useful, the device should include a touchscreen and a Bluetooth connection.

There exist very robust Windows Mobile devices like the TDS Recon (Fig. 3, left) or the Juniper Archer. A cheaper solution is to use a mainstream PDA like a Hewlett-Packard iPaq in combination with a waterproof case like the Palmcase Armor (Fig. 3, right) or a self-made protective cover.


*Fig. 3: TDS Recon Outdoor PDA (left) and Palmcase Armor waterproof case (right).*

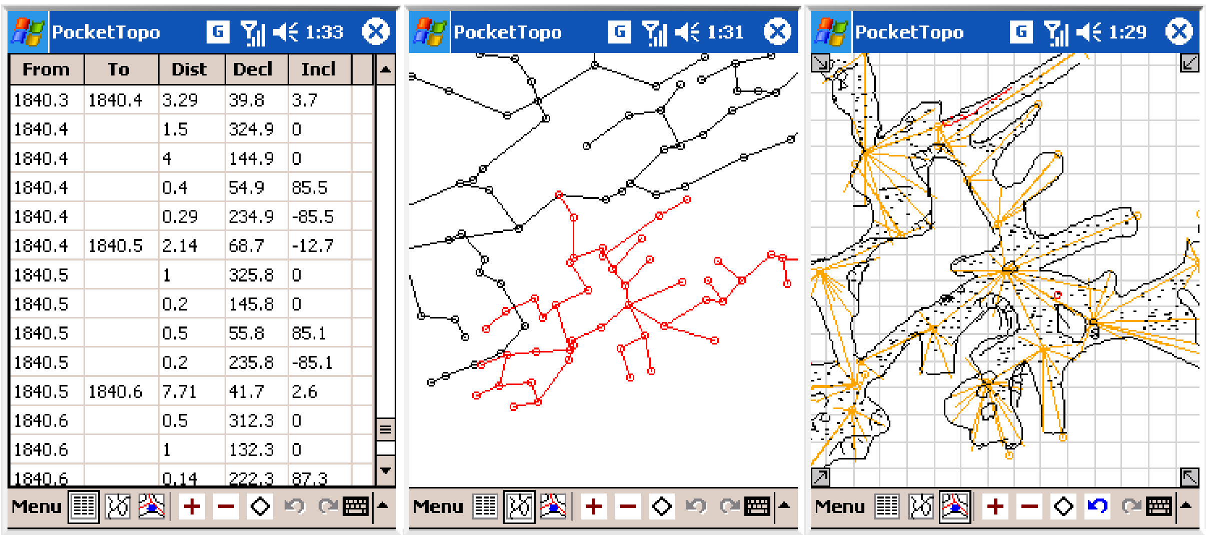


*Fig. 4: The three survey data views on the PDA.*
*Left: textual representation of branches and cross sections.*
*Middle: cave map with new and old passages.*
*Right: branches, auxiliary lines and sketches.*

The application continuously receives new data from the measuring device and displays it as soon as it arrives. The user interface consists of three main views. The first of them shows the survey data in tabular form with selectable units (degree or grad). It allows to check the details of any survey section, to group them in series and to define their connectivity (Fig. 4, left).

The other views show graphical representations of the cave data. One is used to show the outline of the whole cave. Its main use is to check the relation of newly explored passages to the rest of the cave (Fig. 4, middle). The other one is used to show the new surveys in detail, either as an outline or as a side view. The detail view shows the survey branches and all cross section and auxiliary lines. It is used primarily to add sketches by drawing them directly on the screen (Fig. 4, right). The sketches are stored in vector form for later use as a template for the final cave map drawing (Fig. 5).

The graphical views support easy zooming and panning. The sketch views allow to select virtual pens of several colours and optionally shows a meter raster in the background. For convenient editing they also support deletion and unlimited Undo/Redo.

Survey data and sketches can be saved to and reloaded from the PDA. To avoid data loss under all circumstances, the program saves all changes continuously to non-volatile memory. Optionally it also saves to an additional storage device like an inserted memory card. This allows to retrieve the data even in case of a severe hardware damage.

Back at home the device is synchronized to the PC and the survey data and sketches are transferred to the corresponding PC applications using appropriate converters. Currently there are converters available for the Toporobot cave software and for Adobe Illustrator drawings. Other converters may be added later.

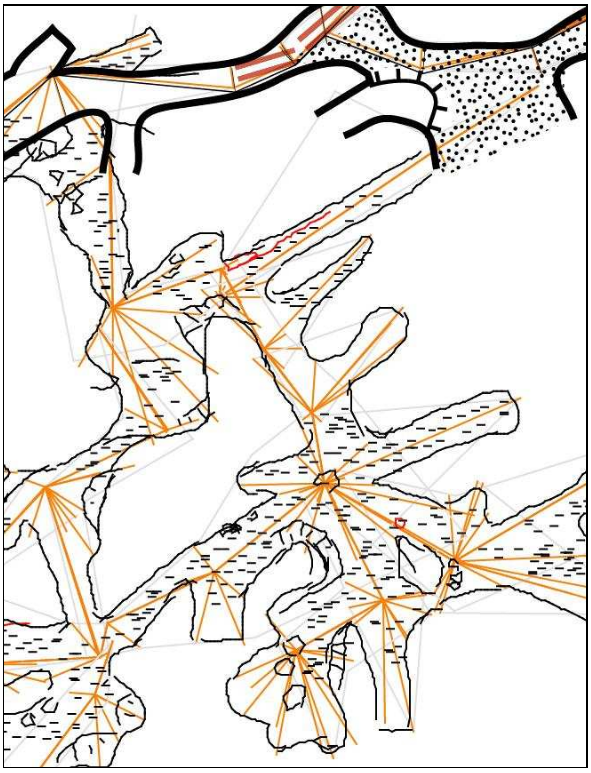

*Fig. 5: Survey data and sketches added as a template to an existing Illustrator drawing.*

## 5. Using the System in Practice

Working with an electronic surveying system is slightly different from what we are used to with optical instruments and paper sketches. Using a laser based measuring device needs a steady hand but is often more comfortable than bearing through an optical instrument, especially in tight passages. In contrast to a conventional compass that must be held horizontally and cannot be used in steep passages, there is no restriction in the orientation and direction for this device. For longer distances and for station points at the side wall it is helpful if a second person marks the point with a finger and the laser is directed to the fingertip. Care must be taken not to look into the laser beam!

In a three caver team the front member marks the new stations as usual; the second one acquires the data using the measuring device and with the help of the first, and the third member behind him draws the sketches around the measured points appearing on his screen. In a team of two, there is a minor problem. Since the sketcher has to be behind the instrument person, there is no one in front to indicate the next station. It is therefore preferable for the front member to first mark the next station and to measure backsight with assistance from the sketcher at the previous station. To support this approach, the application includes an option to take reverse measurements by default.

The measuring device is not only used for survey shots but also for cross section measurements. With a laser device this can be done quickly and precisely even if the end point is not reachable, like in a pit or in high passages. There is no need for fixed rules for the cross section directions because the actual angles recorded together with the distance can later be used to adapt the values. In addition it is perfectly feasible to measure more than the usual left, right, up, down distances. Instead, it makes sense to record distance and direction of any prominent point around the current survey station. This is of great help for precise sketches and map drawings (Fig. 4 and 5).

To allow automatic distinction between survey shots and auxiliary lines, a simple rule is followed: The survey sections are measured three times in a row. This is used in the PDA to recognize survey shots and can also be used to check the precision of the measurements. All single shots are interpreted as cross sections or auxiliary lines taken from the current station. Of course it is also possible to define the type of a measurement manually.

Drawing sketches on screen is a bit difficult initially, especially if there are additional protective layers above the screen. However, with the given guidelines, the possibility to enlarge the picture as needed, and the fact that you never reach the edge of the paper, the system by far outweighs the initial difficulties. Also bear in mind that there is no intent to draw final maps in the cave, the sketches are just templates. Drawing high quality maps is a challenging and time-consuming task not suited to be done underground.

## 6. Conclusions and Outlook

The system presented has been used successfully in several surveying projects in several caves. The gained experience shows many advantages over traditional cave surveying practice. Measurements are generally faster because there is a single instrument to handle and there is no need to read and write down the results. The automatic transfer of the results also eliminates many sources of errors.

The drawing of sketches directly on PDA screen is another major advantage of the system. Together with the ability to measure auxiliary lines it allows to produce precise sketches in a short time.

Another benefit is the availability of the survey data of the whole cave. It allows to control loop closures, to check for errors in old surveys, to discover hidden connections to other passages, and it helps to find junction stations.

Nevertheless, the project is still at its beginning. It needs improvements in many aspects, especially in the PDA application and on the PC side where many converters are still missing.

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