# An All-In-One Electronic Cave Surveying Device

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*This device consists of a Laser Disto equipped with an add-on board carrying a 3-axis electronic compass/clinometer and a wireless Bluetooth connection. The board is powered by the Disto and fits entirely inside the original case. It allows measurement of distance, azimuth, and inclination with a single button press. The result is a compact, robust, and easy to use surveying device.*

## Introduction

The huge progress in micro-electronics in the resent years has brought us new parts and devices like MEMS sensors, compact Laser range finders, and small wireless communication modules. This made it possible to think about the 'perfect' electronic cave surveying tool. A device which measures all relevant values, azimuth, inclination, and distance at once, presents them on a display, and allows a wireless transfer of the results to a connected device for immediate on-site analysis of the acquired data.

To approach this goal, the DistoX device presented here includes the following components:
- A time-of-flight based Laser distance meter.
- A 3-axis, fully tilt compensated compass/clinometer which allows measurement in any direction with any orientation of the device without performance degradation.
- A Display to show all components of the result.
- A Bluetooth transceiver module to enable wireless readout of the results.
- A non-volatile memory to queue the measurements for later transmission.

Two similar devices exist, namely the SAP ('Shetland Attack Pony') [1] and the DUSI (Digital Underground Surveying Instrument) [2]. They both provide an equivalent 3-axis compass/clinometer system but no Laser distance meter.

## Overall Design

The most challenging part of such a device is the Laser distance meter. Delicate analog and high frequency circuits are needed as well as a sophisticated optical system. The mechanical construction of the case has to be small and lightweight but also reasonably waterproof and robust enough to be used underground.
An easy solution to this problem is to use a commercially available Laser distance meter and to add the missing functionality. The device chosen 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 used successfully by cavers.
To extend the functionality of an existing device, an interface to it is needed. However, no standard interface is present in such a device and no support can be expected from the manufacturer. A simple way out is to connect to the link between the LCD display and the CPU inside the Disto. In case of the A3 this is a simple standard SPI connection which can be tapped easily using just a few wires. A drawback of this solution is the fact that we cannot

change the behavior of the Disto and its user interface since we do not have access to its programming. All we can do with such a lightweight interface 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. 1), and transmitted over the Bluetooth connection together with the distance read from the display.


Fig. 1: The DistoX with azimuth, inclination, and distance readout.

## Circuit Description

The heart of the extension board is a PIC16F688 microprocessor. It handles the data transfer between the sensors, the Disto Display, and the Bluetooth module and does all the necessary calculations. A 24C256 IIC EEPROM is connected to the CPU to queue the measured data for later transmission over the wireless connection. In addition, it provides a backup in case the transmitted data is lost. 4096 complete measurements fit into the 256 kbit device.
Inclination is measured by an SCA3000-D02 accelerometer. This single chip sensor measures acceleration in all three axes. The results are available numerically over an IIC connection.

The compass consists of three magneto-inductive sensors connected to a related integrated circuit. The sensors are in fact small coils wound on a special core material which changes permeability and thus coil inductance in proportion to the applied magnetic field. The 11069 IC contains the necessary analog and digital parts to run an oscillator using each of the sensors in turn and to measure the period of the actual oscillation. The results are read out over an SPI like serial connection. In contrast to the more usual magneto-resistive sensors, there is no need here to handle small analog voltages, nor for the relatively high ‘reset’ voltage used to recondition the sensors.
The Bluetooth solution used is an LMX9838 Bluetooth module. This is a fully integrated, certified Bluetooth 2.0 system including radio, oscillator, antenna, and protocol implementation in a small SMD case. The module is connected to the UART of the PIC over an asynchronous serial connection and two handshaking signals. An external 32kHz crystal is added to support the optional low frequency oscillator. This saves a lot of power during idle times. The handshaking signals are mainly used to wakeup the module when it is put into the power saving state.
The connection to the Disto consists of just four wires: two for power and ground and two to tap the data and clock lines of the SPI connection between the Disto’s CPU and display. Two outputs of the PIC are tight together to get the necessary driving power to properly ‘overrule’ the signals of the Disto to change the display contents. Thanks to protective resistors present on the Disto board, no current limits are violated.
Power is taken from the main 3.6 Volt source of the Disto and stabilized to 3.3 Volt by an LP3985 voltage regulator. In the Disto, the 3.6 Volt are generated by a voltage converter fed directly from the batteries.
An In Circuit Serial Programming (ICSP) connection is available to program or reprogram the PIC CPU. This can be done any time without detaching the board from the Disto.

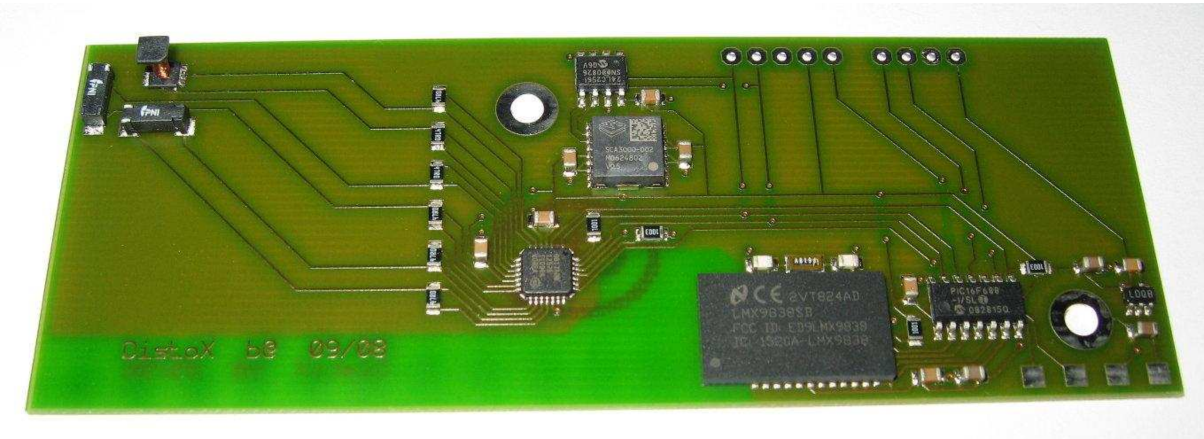

Fig. 2: The DistoX upgrade board. Main parts from left to right: magnetic field sensors and support chip, serial EEPROM, acceleration sensor, Bluetooth module, PIC processor.

## Mechanical Construction

Very little space is available inside the Disto A3 case. The only possibility to integrate the additional parts is to use a thin one-sided SMD board mounted upside down on the backside of the internals of the Disto. The board occupies all the available area but only those parts of it with free room under them can be populated with components. To minimize disturbance of the compass, the magnetic field sensors must be placed as far away as possible from the batteries (Fig. 2).

An existing threaded hole in the chassis of the Disto is used to fix the board with an M2.5 x 14 screw (Fig. 3). In addition a double adhesive tape between the board and the battery case of the Disto may be used to assure it stays in place. Four wires run from the extension board to four test pads of the Disto's main board.

Fig. 3: Upgrade board mounted to the chassis of the Disto

**Software**

The data flow is managed by an assembly program stored in the PIC CPU. To get compass and clinometer data, the program reads all six sensors (3 acceleration and 3 magnetic field components) every 200ms. The acquired samples are stored in a 10-entry circular buffer and summed up to get a moving average over the last two seconds. The resulting sensor values are corrected by a linear calibration function and then converted to the final azimuth, inclination, and roll angles. Instead of vector arithmetic and trigonometric operations, the program uses a variant of the CORDIC algorithm to implement the necessary conversions. CORDIC (coordinate rotation by digital computer) [3] is a long known algorithm to perform 2D vector turns on primitive computing hardware. It is based on simple shift and add operations only and does not require floating point arithmetic.

To communicate to the Disto, the CPU continuously analyses the serial data stream sent from the Disto CPU to the display bit by bit. To monitor the serial clock efficiently, it is connected to the asynchronous clock input of one of the PIC timers. Nevertheless, up to 60% of the available CPU time is used up by this task. If the display data line is driven by the PIC, it is possible to overwrite the data and to change the contents of display without changes or influences on the Disto behavior. The following manipulations to the display are actually made:

- The topmost line is overwritten to show the actual azimuth angle (0 - 360° or 0 - 400g).
- The second line is overwritten to show the inclination angle (-90° - 90° or -100g - 100g).
- If Bluetooth is switched on, a normally unused Bluetooth symbol present in the bottom left corner of the display is turned on. The symbol blinks if the device is actually connected.
- The memory number at the upper edge of the screen shows the number of results stored but not yet forwarded.

To manage the Bluetooth connections and to transfer the results of the measurements, the CPU communicates to the Bluetooth module using special command packets sent over the serial connection. The actual Bluetooth protocol is handled entirely inside the module. To safe power, the connections are forced into ‘Sniff’ mode and the module’s serial interface is disabled whenever possible. If the connection drops because the remote device is switched off or gets out of range, the measured data is buffered in the EEPROM and sent as soon as the connection is re-established.

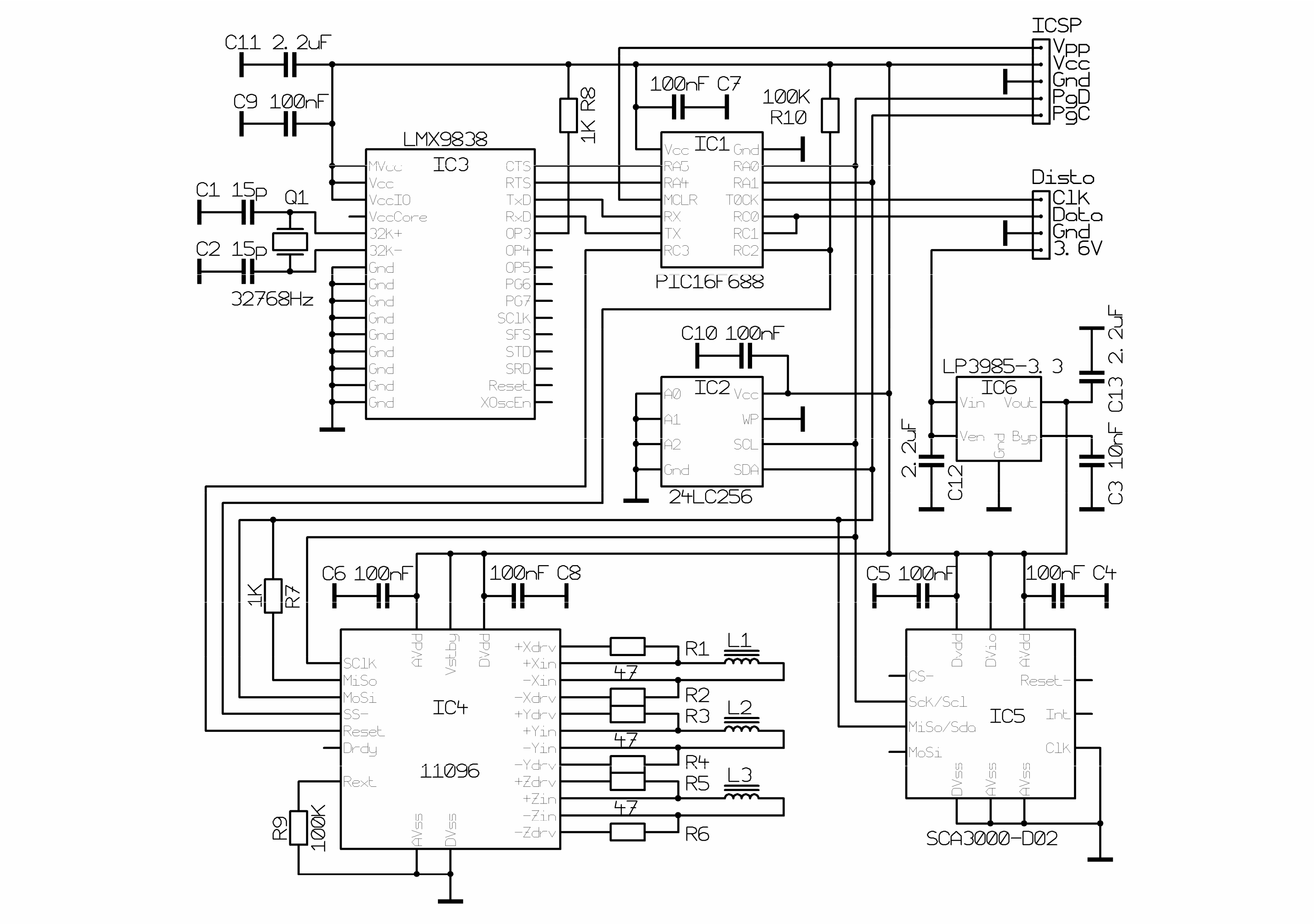


Fig. 4: Schematic of the upgrade board

## PDA/PC Connection

The Bluetooth connection allows to use the device in conjunction with a PDA or PC based application to manage and visualize the measured data. With an appropriate PDA this can be done on site in parallel to the measurements. An application called PocketTopo was developed to support the special needs of cave surveyors. It runs under Windows and Windows Mobile and allows you to do the following main tasks:

- Maintain a wireless connection to the DistoX.

- Manage the received data with the ability to edit, delete, and insert measurements, to assign station numbers and to categorize them into cross sections or survey shots.
- Display a plan of the whole cave to look for potential connections and loop closures.
- Show plan and side views of the actual passage with all survey shots and cross sections.
- Draw sketches directly on the screen of the PDA.
- Import and export data and sketches from or to traditional cave surveying programs and graphics editors.
- Add complementary information like entry locations, trip date, and declination correction
- Acquire and manage calibration measurements and calibrate a connected DistoX.

A system consisting of a DistoX and PDA running PocketTopo to manage the data and to draw the sketches electronically is referred to as a ‘Paperless Caving’ system [4].
For users of Palm OS based devices, the DistoX can also be used with the popular cave surveying software Auriga [5].

## Calibration

A small drawback of 3-axis compass systems is their need for proper calibration. Calibration is necessary to adjust for offset, range, and mounting errors of the sensors and to compensate deviations of the magnetic field caused by metal parts in the device, especially the batteries. Calibration of a 3-axis system is much more tricky than in the case of a traditional measuring devices. A sophisticated software algorithm is needed to get the calibration coefficients from a set of calibration measurements [6]. The big advantage of 3-axis systems is the fact that no precisely known reference environment is needed for these measurements. Instead they can be done any time at any place featuring an undisturbed magnetic field. An implementation of the algorithm is included in the PocketTopo software.

Because of the poor magnetic behavior of the batteries, a recalibration is needed whenever the batteries are changed. This may be viewed as a huge drawback. However, good batteries last for weeks of surveying and a recalibration from time to time is a good idea anyway to ensure accurate measurements.

## Conclusions

Over a hundred devices were built successfully so far. The experience shows a considerable improvement over traditional mechanical measuring devices. Surveying is generally more convenient because of the all-at-once operation and of the full freedom in direction and orientation of the device. It is also faster and less error prone, especially when used in conjunction with a PDA.
The main drawback of the device is its dependence on a commercial Disto. It is becoming difficult to buy a Leica A3 because it is no longer in production and it is not easy to find a good replacement.

For further information about the DistoX, PocketTopo, and the availability of extension boards refer to the projects web page: http://paperless.bheeb.ch.
The user manuals and the PocketTopo application are available from: http://paperless.bheeb.ch/download.html.

**DistoX Technical Data**

**Range**
Distance: 0.05 – 100m
Azimuth: 0 - 360°
Inclination: -90° - +90° (no steepness limit)
Roll angle: -180° - +180° (fully tilt compensated)

**Precision**
Distance: 3mm
Angles: 0.5° RMS (after proper calibration)

**Features**
Selectable Units: m / ft / inch, ° / grad
Memory capacity: 4096 measurements
Laser Type: 635nm, 1mW, class II

**Mechanical**
Size: 46 x 32 x 135mm
Weight: 160g
Protection: IP54

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**References**


[1] Phil Underwood: A combined electronic compass/clinometer; CREG Journal 66: p. 12-14; BCRA Cave Radio and Electronics Group; http://shetlandattackpony.co.uk.

[2] Sean D'Epagnier: The DUSI Datasheet; http://www.digitalsurveyinstruments.com/doc/DUSIDatasheet.pdf

[3] Jack E. Volder: The CORDIC Trigonometric Computing Technique; In: IRE Transactions on Electronic Computers; Sept. 1959.

[4] Beat Heeb: Paperless Caving – An Electronic Cave Surveying System; Proceedings of the IV European Speleological Congress 2008, p. 130 – 133; http://paperless.bheeb.ch.

[5] Luc Le Blanc: Auriga, or Trading your Survey Notebook for a PDA; Compass Points 32: p. 8-11; BCRA Cave Surveying Group; http://www.speleo.qc.ca/auriga.

[6] Beat Heeb: A General Calibration Algorithm for 3-Axis Compass/Clinometer Devices; to be published.