

DistoX2, SAP5 and BRIC4

marco.corvi@gmail.com

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Cave surveying workflow

The cave surveying process has several stages

- 1) data acquisition (measuring devices)
- 2) preliminary data organization and sketching (cave notebook)
- 3) final data processing,
- 4) map drafting,
- 5) cave data storage and management.

The first two steps are carried out in the cave, the last three at home. Data acquisition is done with Suuntos, DistoX, SAP, BRIC4, CaveSniper, or other devices. The second step is done with paper and pencil notebook, or "paperless", with a program such as Auriga, PocketTopo, TopoDroid, etc. For the other steps cavers use cave PC programs (Compass, VisualTopo, Survex, Therion, etc.) as well as programs not specifically written for cave surveying (Illustrator, Inkscape, AutoCAD and similar, QGIS, ...).

The measuring device records the measurements: distance, azimuth, inclination. It would be good if it also sets the stations, but this operation is still not automatic underground. It would require to know the position from which the reading is taken and that of the point that is shooted to. In principle this could be done with a "perfect" odometry. In practice the station assignment must be done by the user (SAP, BRIC, CaveSniper) or is ignored and left to the second-stage (DistoX, Suuntos).

Readings, notes and sketches used to be recorded in the cave notebook. Nowadays the use of programs for handheld devices is becoming common. Auriga, an electronic notebook, has been around

for almost 20 years, and has evolved from organizing the survey data, with the addition of sketching functions and the integration with the electronic instruments.

The *DistoX* has been released with PocketTopo, a windows program that manages the data, and allows to draw sketches. Several Android programs are now available to work with the DistoX.

CaveSniper comes with its own PC program.

SAP has its program, *PonyTrainer*, which can download the surveys from the device. The data are in the format of *Survex*.

BRIC saves the data on the internal SD card, in CSV text files. These can be transferred to a PC attaching the *BRIC* as an external memory device, like a USB key.

For the third stage dozens of PC programs have been created. The development of most of them stopped after a short time. Some turned out to be quite successful and are currently used and maintained: *Compass*, *Survex*, *VisualTopo*, *CaveRender*, ... Other programs used in the U.S. are *Walls*, and, to lesser extent, *WinKarst* and *OnStation*. In Europe *TopoRobot* is still very popular. The original program does not seem maintained, but it has influenced several other programs.

Therion is the worldwide reference for drawing cave maps. However most people find *Illustrator/Inkscape* more intuitive. Others use *AutoCAD*, usually because of the personal technical background. There are other map drafting programs (*cSurvey*, *Tunnel*, *TopoCalc'r*, *GHDRAW*, ..., *CaveRender*). Either the programs of the second stage exports directly for these, or specific "converter" programs or plugin have been created.

For the last stage, people used *Cave Kadasters*. Nowadays these are being replaced by web repository, online *Karst Information Database*, etc. These are becoming more and more integrated with geographical information system servers.

DistoX

The DistoX2 has been around for over ten years and it has become the reference standard for an electronic integrated cave survey instrument. It is well known, it has been described by B. Heeb [refs], and there exists a fair number of papers that describe its features and test the accuracy (of which only a few are listed below).



The DistoX (based on Leica Disto A3) weight about 150 g, and has size 135x45x31 mm. The DistoX2 (based on Leica Disto X310) weights about 150 g. Its size is 55x31x122 mm.

The DistoX interfaces via bluetooth with an application in order to download the survey data. The applications that supports DistoX are PocketTopo, TopoDroid, Auriga, CaveSurvey, and SexyTopo.

The DistoX calibration requires to take 14 groups of four shots each, distributed in all directions. The calibration data are downloaded and the calibration coefficients are computed and uploaded to the device. The application that supports the calibration of the DistoX are PocketTopo, TopoDroid, Auriga, and SexyTopo.

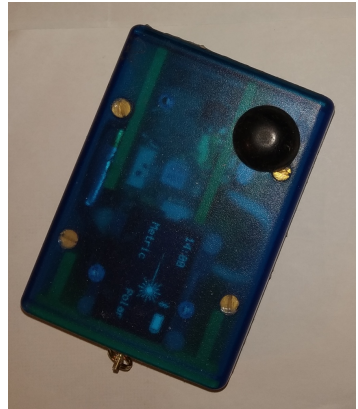
From version 2, the DistoX firmware can be upgraded via bluetooth. The applications that support firmware upgrade are PocketTopo and TopoDroid.

Website: <https://paperless.bheeb.ch/>

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Shetland Attack Pony

The Shetland Attack Pony (SAP) is an early project for an integrated electronic device for cave surveying, like the DistoX and CaveSniper (and the no-longer developed DUSI). Initially (2007) it measured only azimuth and inclination, however the latest version, SAP5, appeared in 2020, measures also the distance and there is a model that has bluetooth and can immediately transfer the data to a connected handheld device (usually Android).



The case seems a bit flimsy compared to that of the DistoX. It is sealed with silicon, so it is not clear how much it can resist water and dust (lime).

It weighs less than 100 g, and has size 90x65x27 mm (not considering the button which is 10 mm high). On the rear there is a holder for a wrist strap. Under it is the micro-B USB socket. The socket is not protected against water and dust, and this can be a problem in the cave.

The SAP is recharged through the USB connection. If it is connected when it is off, it will start recharging. If it is connected when it is on it does not recharge, however if it is turned on while recharging it will continue to recharge.



The SAP has a single-button user interface and a small display. A double press of the button turns the device on or off. It has a timeout to turn off by itself if not used for a while. When the SAP is turned on the laser goes on. The display shows the battery charge, the time and the units.

A long press of the button, until the displays blinks, starts a reading. One can hold the button down until the reading is complete. If there a device connected via bluetooth, the shot is transferred to that. Readings that are not immediately transferred, will not be transferred later.

The user can choose to store or discard the reading on the SAP itself. By default a reading is not stored. Therefore if the user takes immediately a second reading, the previous one gets lost (unless it has been transmitted to a connected device). The shots stored in the memory can be inspected with the PC program PonyTrainer, which connects to the SAP over USB. PonyTrainer is available for Windows and for Linux. It accesses the stored data and convert them into Survex format.

The display shows azimuth, inclination, distance and extension, either one at a time (large setting) or all together (compact setting). Tilting the device it cycles thru the readings and three options:

- Store
- Discard
- Main menu

Pressing the button while a reading value is displayed, starts a new measure. The other three cases are for actions or the menus.

The Store submenus lets you set the stations and save the reading in the SAP memory

- A -> B, eg, 3->4
- A ->
- B -> A
- B ->
- CUSTOM lets choose stations AA->BB
- Back (goes back to Store)

Discard discards the reading and goes into "measure" mode. The Main Menu has several submenus

- Settings
- Measure, which goes back to measuring
- Calibrate
- Visualize
- Info
- Off, which turns off the device

With "Settings" the user can set units (Metric, Imperial), style (Cartesian, Polar, Grad). display mode (Compact, Large). timeout (30 s, 60 s, 2 min, 5 min, 10 min), and date and time.

Calibrate is used to for sensors calibration, as well to set the distance zero.

Visualize displays a plot of the midline, and it is still under development.

Info shows lots of data and infos:

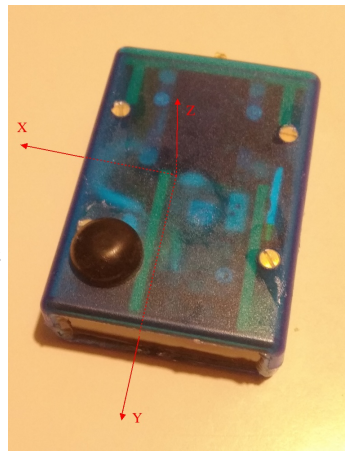
- Raw M and G: XYZ
- M and G
- Name compass clino
- Field and dip (at this point the laser turns on)

on)

- Stddev of magnetic and gravity values:

XYZ

- time, date, battery, temperature
- hw fw data-format



The axes of the SAP are as in the picture. Y aligned to the laser, and Z upward.

Calibration

The old model of SAP required a calibration course consisting of 12 or more stations around a central master station, and the truth values of the directions of the calibration stations with respect to the master

station. Therefore, the SAP precision was limited by the accuracy of these directions. Four readings were necessary for each direction at four orientations of the SAP display: up, right, down, and left. After having taken the readings of the calibration shots, these were downloaded to a PC program, supplied also with the true values. The program computed the calibration and uploaded it to the SAP.

The 2020 models do not need a calibration course, and the calibration is computed directly by the SAP. However the process is somewhat awkward. To start the calibration the user goes to "Main menu" on the device, then "Calibration", "Sensors", and confirms. At this point the SAP display says to put the device on an inclined surface and rotate 90 degrees at each beep. Then the display goes black while the user places the SAP on the surface and rotates it at each beep. Then the SAP display says to place the device on a horizontal surface face up and turn it upward, face down, downward at each beep. Again it goes black while the user follows its instructions. Lastly the SAT says to take 8 readings at a distance point, rotating about 45 degrees each time. As usual it beeps after each reading. It can do this for more than one point. Finally it says "processing" and spits out the result: a percentage, whether or not the calibration is good, and whether it has been stored.

The user has to be alert to follow the SAP instruction timely. He has better have spotted the two surfaces and the two target points in advance, because the SAP does not give much time to choose them.

In conclusion it seems that overall the SAP suffers from a device-centric design (similar to the CaveSniper): a shot consists of readings and stations. Taking readings is as simple as pressing a button, but the station assignment requires going thru menus and making a choice. The DistoX avoids this by leaving it to the program in the second stage.

The data transfer protocol is rather simplistic. The fact that the readings are lost when the SAP is out of reach from the Android is

likely to be a problem in certain surveys.

The single-button interface is limited, and the "tilt" to cycle thru the options is awkward to say the least: one may accidentally get to the next option without willing to do that.

The choice of having the calibration procedure driven by the SAP is very bad. The user must follow the timings given by the device.

Furthermore, the screen does not provide any feedback during most of the steps. Finally, the SAP does not offer a choice whether to store a calibration, or discard, or acquire further data.

Hopefully its usability will be improved in the future.

Website: <https://www.shetlandattackpony.co.uk/>

Github: <https://github.com/furbrain/SAP5>

[] Ph. Underwood, Calibrating a combined electronic compass/clinometer, Compass Point 37, 2007, 5-7

[] Ph. Underwood, A combined electronic compass/clinometer, CREG Journal 66, 2007, 12-14

BRIC4

BRIC4 (Bluetooth Ruggedized Integrated Cartographer, version 4) is enclosed in a shock- and water-proof Pelican case. The BRIC4 weights about 350 g, and has size 150x88x45 mm, not considering the case hinge, lock, and strip holders, and the BRIC4 tail.

There is a single button (on the bottom side) for normal operations and four internal



buttons to adjust the device settings, and to calibrate it. Inside the cave there is a mini-B USB socket that is used to recharge the device battery as well as to connect it to a PC to download files. A mini-B USB connector is not very common nowadays - it is an old connector that you might find at home if you have an old digital camera. The BRIC4 can be charged from the PC. While charging the main screen shows the battery charge with a flickering percent symbol.

When connected to the PC, the BRIC4 acts as external SD-card. The filesystem root folder contains:

- calibration folder
- data, a folder with the survey data in CSV format.
- Sn.txt, a text file containing the BRIC serial number.
- "System Volume Information"

There is one survey file for each survey day. The "calibration" folder contains the calibration files, CSV, report (text file), and raw (binary file). Maintenance files are uploaded to the root folder.

To turn the BRIC on press the button three times in quick sequence. To turn it off press and hold the button for 2 seconds. It turns off by

itself after a minute of inactivity.

The laser is not immediately switched on when the device is turned on. To start it press the button once. To take a reading: press the button again (with the laser on).



The four inner buttons are the menu (and navigation).

When the display is in normal mode the buttons are

Menu, Light-Up, Light-Down, Menu

When the display is in menu-mode they are

Enter, Up, Down, Back

Pressing any internal button, when the BRIC is off, turns it on.

Main menu

Options

Distance units	m / ft
Temperature units	C / F
Shot delay	0 s
Charge current	500 mA
Error sensitivity	1 deg
Backlight color	white, red, blue, green, purple, cyan
Backlight level	0

Error info

Measurement	48 (index)
Comp2 High	14.6866
Mag delta ax2	51.809 %

Calibration

Display the report of the current calibration.

Loop test. A loop closure test carried out by the device.

- Quick Azimuth calibration
- Full Azimuth+Clino calibration
- Range finder: distance calibration
- Set Clock (format: yyyy mm dd HH MM SS)
- Bluetooth info (name, MAC, status, etc.)
- Debug menu
 - Sensor raw data
 - Backlight manual
 - Charger info
 - Reprocess full calibration
 - Reprocess azimuth calibration
 - Firmware update

The normal mode displays five rows of data:

- index (last four digits), distance, azimuth, clino

and a bottom row with

- time, battery_level, temperature, bluetooth (if connected)

The index starts with an 'E' if the BRIC4 detected an error. The BRIC\$ as redundant sensors both for acceleration and for magnetic field. It signals an error if there is a discrepancy in the sensor readings.

The data protocol transfers primary shot data (date, time, distance, azimuth and inclination), additional data (index, roll, dip), and error data. If the client does not subscribe to additional and error data, only the primary data are transferred. When the client is not in reach (or not connected) the data are stored and transferred upon regaining the connection.

The transferred data are automatically acknowledged by the bluetooth stack. No acknowledgment is expected from the client. This leaves the possibility that a data does not reach the client and is lost.

Calibration

The calibration of the BRIC4 is quite similar to that of the DistoX. However the computation is done by the device, and there is no need for an external program. The user must take at least 14 groups of four shots in directions as for the DistoX. Within each group the device must be rotated about 90 degrees at every shot. The BRIC4 displays the number of groups and the number of shots in the last group (with four circles that gets filled as the four shots are taken). It is possible to take more than 14 groups.

After taking the shots the calibration coefficients can be computed and a report is displayed.

Calibrating the BRIC4 feels very like calibrating the DistoX. I have not yet tested what happens if a shot is taken badly.

Firmware update

The BRIC4 has two firmwares. The system firmware is updated from a PC with Windows (and maybe also Linux). The Bluetooth firmware is transferred to the BRIC4 sdcard and updated from the menu of the device.

Website: <https://www.caveexploration.org/gear/bric4>

Accuracy test

A DistoX2, a SAP5, and a BRIC4, have been calibrated at the same place and time.

The DistoX has been calibrated with 22 groups of four data each (for a total of 88 shots). The calibration has been computed with TopoDroid, using the "TopoDroid" policy which compares the shots within each group, for all the groups and not only for the first four. The data distribution shows a complete (100%) cover of the directions. The average error is 0.13 degrees and the original delta is 0.356. The error standard deviation is 0.10 degrees and the maximum error 0.54 degrees.

The SAP5 calibration has been done following the SAP instructions: two groups of four shots each, on an inclined surface and a horizontal surface, followed by two groups of eight shots each aiming at two targets with an inclination of roughly 45 degrees. The calibration file can be retrieved from the device using the PonyTrainer. The file (in json format) contains the shots and the calibration coefficients,

```
"accel":      1.0089497, 0.0124098, 0.0008267,  
              -0.0136654, 0.9943023, -0.0028016,  
              0.0007578, 0.0050781, 1.0007210,  
              -0.0140548, -0.0232518, 0.0323913  
"mag":        0.0191062, 0.0000952, 0.0000050,  
              -0.0003655, 0.0191116, -0.0000852,  
              0.0000080, -0.0000473, 0.0194873,  
              -10.7116508, 48.5108490, 30.87334061  
"laser_offset": 0.0900000
```

The BRIC4 has been calibrated with 18 groups of four shots, The azimuth standard deviation was 0.106 degrees, the inclination standard deviation 0,079 degrees. The accelerometers delta percent $x=0.006$, $y=0.007$, $z=0.007$. The magnitude percent error $A1=0.013$ and

$A_2=0.015$. The magnetometers $\delta x=0.043$, $y=0.074$, $z=0.047$, with magnitude percent errors $M_1=0.167$, and $M_2=0.162$. The rangefinder has a calibration of 0.18 m.

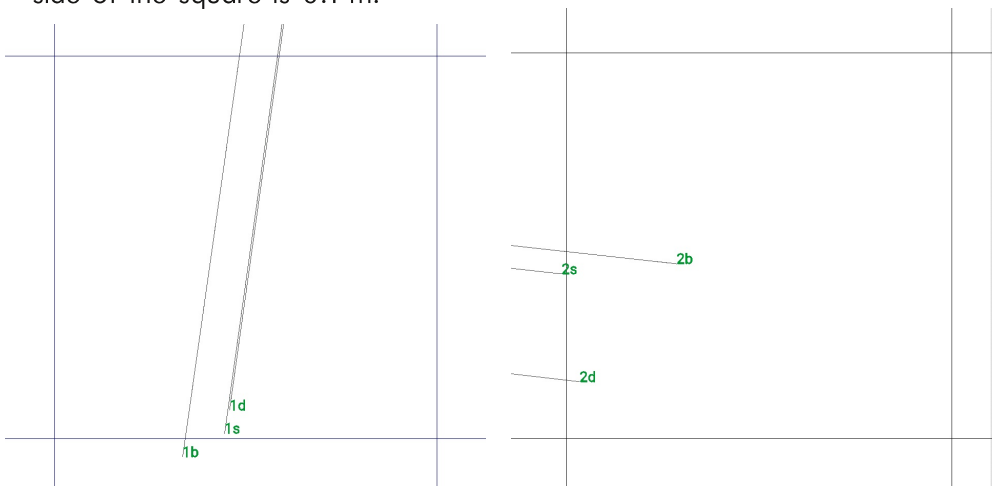
After calibrating the three devices a simple test has been performed, measuring the same two legs with the three devices. The legs are

Distance	Azimuth	Inclination
6.16 m	188.0	2.9
9.07 m	96.6	-40.9

For every device each leg has been measured with four shots with orientations at 90 degrees. The maximum difference between leg shots for each device are

device	leg-1	leg2	
DistoX	0.4	0.3	azimuth
	0.2	0.2	inclination
SAP5	0.5	0.5	azimuth
	0.2	0.2	inclination
BRIC4	0.2	0.3	azimuth
	0.2	0.2	inclination

The following images show the plan view differences among the three devices. The suffixes are 'd' DistoX2, 's' SAP5, and 'b' BRIC4. The side of the square is 0.1 m.



The three points for the horizontal leg are within a couple of centimeters, which is well below the accuracy of setting the instruments on the station and aiming at the target.

The points of the inclined leg are distant about 4 cm from one another. However the target was farther away (9 m, instead of 6 m) and not as clearly marked, as it was the top of a barrel.

A second test was carried out a week later. Although the test time was after sunset, I have experienced difficulties with the SAP. It often failed to get the distance with the laser. I do not know whether this was because of the excessive daylight or because of the rugosity of the aimed surface.

Six legs were measured with the DistoX and the BRIC5. Only the first four could be measured with the SAP5, and in some case not all four orientations.

Distance	Azimuth	Inclination
3.62 m	208.9	9.4
6.87 m	301.4	26.1
6.20 m	220.8	10.1
7.51 m	234.5	12.8
10.64 m	84.1	-53.3
7.15 m	23.0	-29.1

The variation among the angles read by the DistoX stayed inside 0.4 degrees for the azimuth and 0.2 degrees for the inclinations. For the BRIC4 both the azimuth and the inclination variations stayed within 0.2 degrees. The SAP5 inclination variations were within 0.2 degrees, but the azimuth variations were almost 1 degree.

A graphical comparison shows that the leg endpoints for the DistoX and the BRIC4 remain within a distance of 2 cm from each other. This is quite satisfactory considering that the target could be aimed with an accuracy not better than a couple of centimeters. On the other hand

the SAP5 endpoints were as far as 15 cm from the DistoX/BRIC4 points. This is an relative error of 0.025 on a 6 m shot. The accuracy of the SAP5 is therefore 1 degree.



Conclusions

There are many factors that must be taken into account for an electronic integrated device for cave surveying. Cave surveying presents many different challenges depending on the variety of cave conditions.

In order to compare the three devices I consider eight points:

- 1 - handyness
- 2 - robustness (resistance to shocks and water)
- 3 - transportability (weight and size)
- 4 - usability
- 5 - calibration
- 6 - accuracy
- 7 - integration with cave surveying software
- 8 - cost

For the first point, the DistoX2 is definitely the winner. To this extent the main advantage of the DistoX2 lies in its case which is produced by a top quality company. The BRIC4 is enclosed in a Pelican box which is a bit bulky. The SAP is small and easily handled.

For the second point, the best choice is the BRIC4. The DistoX2 is water resistant only to splashes. The SAP5 is definitely bad because the USB socket is exposed on the outside.

As for weight and dimensions DistoX2 and SAP5 are optimal. However a protection case must be expected in most caves. Considering this they are not much better than the BRIC4.

Considering usability, the DistoX2 is optimal (again because of its industrial case). However the presence of many buttons is confusing at times, and one may happen to press the wrong button. The SAP5 button is bit clumsy, especially because one must hold it pressed a second or two. The BRIC4 button is not as smooth as those of the DistoX2, but it offers the advantage of a single button interface. Both the SAP5 and the BRIC4 can be operated with gloves, contrary to the DistoX,

The BRIC4 comes with an extension tail with a rubber tip which is very handy to precisely place it on the station. Similar extension tails have been designed for the DistoX2. Both the SAP5 and the BRIC4 do not have a thread to attach the device on the tripod.

For the calibration the BRIC4 is the best because everything is done on the device and there is no need of an external software. Also the SAP5 calibration is done on the device, however the procedure, driven by the device instead of the user is distressing.

The DistoX has a precision suitable for UIS grade 6 (Ph. Hauselmann, UIS mapping grades, Int. J. Speleol. ?), when properly calibrated. The test shows that both the SAP5 and the BRIC4 are suitable for accurate cave surveying. However the SAP5 can achieve a UIS grade 5 survey (1 degree errors). The BRIC4 attains a survey quality comparable to that of the DistoX, if not slightly better.

All the three devices are well integrated with cave surveying applications. The DistoX2 has its own program, PocketTopo for

Windows, and is supported by all Android apps and by Auriga. The SAP5 is supported by TopoDroid and SexyTopo. The BRIC4 is supported by TopoDroid and CaveSurvey. Both the SAP5 and the BRIC4 store the survey data on the device in formats that can be easily transferred to a PC. For the SAP5 one need its program PonyTrainer, which retrieves the survey data in Survex format. For the BRIC4 the device memory is visible as external sdcard, and the surveys are CSV files.

The SAP5, with a price below 200 euros, is an interesting option for surveys of small caves, especially for people who survey with the paper notebook. The cost of the DistoX2 varies, as one need to buy the DistoX board, the non-magnetic battery, and the Leica Disto, and assemble the device. It can be estinated around 400 euros. Finally the BRIC4 costs 850 US \$.

The chart below summarizes these considerations using a scale 0-5 for each factors. DistoX: red, SAP5: cyan, BRIC4: blue. It reflects only my personal opinion, and it might change over time as the devices get improved.

