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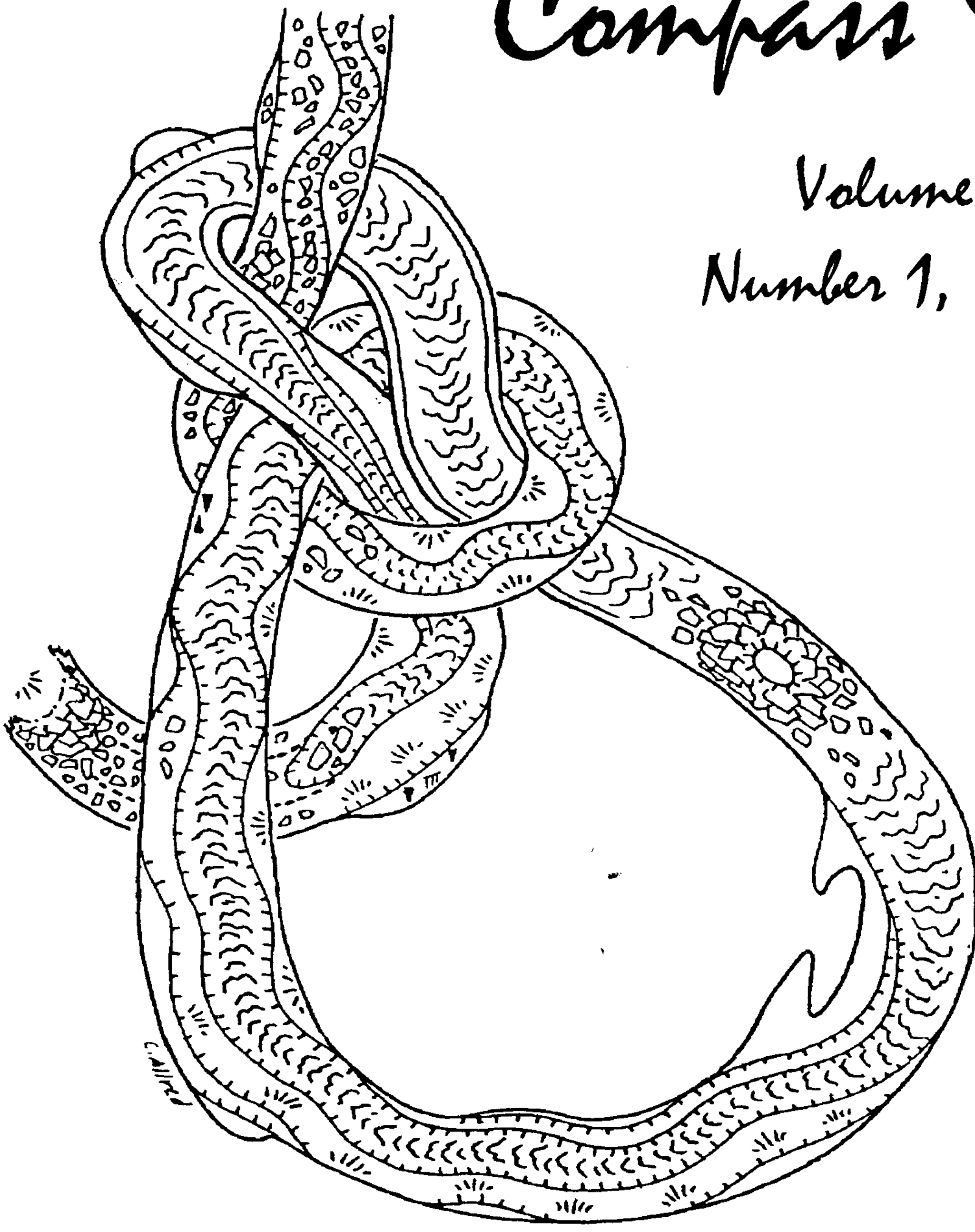

Lava Tube - Kazumura-Style

Publication of the Survey and Cartography Section of the NSS

Survey and Cartography Section

The Survey and Cartography Section (SACS) is an internal organization of the NSS that is devoted to improving the state of cave documentation and survey, cave data archiving and management, and of all forms of cave cartography.

Membership: Membership in the Section is open to anyone who is interested in surveying and documenting caves, management and archiving of cave data and in all forms of cave cartography. Membership in the National Speleological Society is not required.

Dues: Does are $4.00 per year and includes four issue of *Compass & Tape.* Four issues of the section publication are scheduled to be published annually. However, if there are fewer, then all memberships will be extended to ensure that four issues are received. Dues can be paid in advance for up to 3 years ($12.00). Checks should be made payable to *"SACS"* and send to the Treasuer.

Compass & Tape: This is the Section's quarterly publication and is mailed to all members. It is scheduled to be published on a quarterly basis, but if insufficient material is available for an issue, the quarterly schedule may not be met. *Compass & Tape* includes articles covering a wide range of topics, including equipment reviews, techniques, computer processing, mapping standards, artistic techniques, all forms of cave cartography and publications of interest and appropriate material reprinted from national and international publications. It is the primaly medium for conveying information and ideas within the U.S. cave mapping community. All members are strongly encouraged to contribute material and to comment on published material.. Items for publication should be submitted to the Editor.

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Annual Section Meeting: The Section holds its only formal meeting each year at the NSS Convention. Section business, including election of officers, is done at the meeting.

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Chair: Carol Vesely
817 Wildrose Avenue
Monrovia, CA 91016-3022
(818) 357-6927

Secretary: George Dasher
5096 W. Washington Street - #101
Cross Lanes, WV 25313
(304) 776-8048

Vice Chair: Roger Bartholomew
310 Laurel Street
Rome, New York 13440
(315)-336-6551

Treasurer: Bob Hoke
6304 Kaybro Street
Laurel, MD 20707
(301) 725-5877

Editor: Pat Kambesis
P.O. Box 343
Wenona, IL 61377
815-863-5184

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by Carlene Allred

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by Pat Kambesis

From the Editor:

The debate rages on as Bob Thrun and Larry Fish step into Round 2 of the discussion on Sequential vs. Similtaneous loop closure algorithms. Enter John Halleck, guest lecturer on surveying at the University of Utah, to add some perspective and a reality check on those discussions.

Keep in mind that whatever method you choose to use, no amount of loop closing is going to fix inherently bad data. Even more basic, if loops are not surveyed during the mapping process, then there is no way to perform quality control on your survey data. There are all sorts of errors that can creep into your survey, from the actual process itself, to typographic errors and bad tie-ins. If, after taking all of this into account, closure errors are still unacceptable, use a program that features a blunder detection application. This will help you isolate where the error may be - then go back into the cave and fix it!

Obviously there will be situations where an in-cave fix of the survey data is impossible. That is where minimizing the distortion from closure algorithms is most important.

I've been holding on to Carlene Allred's looped lava tube graphic for just the right issue - this is it hands down.

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Send all submission for *Compass & Tape* to:

Patricia Kambesis
P.O. Box 343
Wenona, IL 61377
815-863-5184
Email: pkambesis@bigfoot.com

Suunto Compass Holding Methods

By Eric Hendrickson

Cave maps and cave surveying are a major part of cave exploring. This activity is a natural for Maine where there are few cavers and even fewer caves to map. As a high school science teacher I have used Speleology as a theme for chemistry and as with any science course measurements, accuracy and precision are important concepts to understand. These are used while verifying most principles in the lab through experimentation. In this investigation the accuracy of hand held vs. tripod mounted KB14's and the increase in precision with both with time and training are being examined.

In this experiment the students used a Suunto KB14/360r compass to read a four-point course with each leg was 25 -35 meters in length. All stations were mounted plastic picnic tables with no metal parts that would interfere with the compass. The course was laid out and verified by a professional surveyor with a Topcan 210 All Weather Total Station Unit.

The Suunto KB14 was selected for several reasons. First it appears in the literature as the current compass of choice for cave surveying because it is a heavy-duty precision compass with both actual and reverse readings. I also find that the students have a difficult time reading the Brunton compass that the school owns. Finally it is the compass that some of them will use when they go underground for a field experience.

Most people don't realize that they are making an error until the data is transposed into a map or drawing. Generally a compass of any quality or type has the potential for some error. Many errors are out of the control of the user, such as deadband, systematic error and north alignment error. Here errors have been discussed in detail by Brod (1). The error being evaluated here is the misreading of the compass by movement, which can be minimized by increased accuracy and precision on the part of the reader. Cadrin describes a method of tripod use, which is being compared to the hand-held method.

This experiment was carried out under ideal conditions where the data was collected in daylight under dry and clean conditions. This is never the case while using a compass during a cave survey. Yet, the data still offers some insight into successful use of the Suunto KB14 as a major instrument for cave surveying. The data that is being evaluated represents readings done over a period of two years by thirty students with no prior experience with any type of compass. The course was done forward and reverse starting at different points. This was done so the data would not be a constant repeat, which could lead to error. The data was recorded at the time of the readings and turned into a central location where it was tabulated based on a standard deviation in loop closure that was measured in degrees.

The data in the graph shows that in the beginning the use of a tripod mounted KB14 gave good results quickly with little training. Most readers suggested that this was because the dial quickly comes to rest and is easily maintained over the station. But as time passed and the user became more proficient reading the compass the readers found that the tripod became more of an inconvenience and that having a sturdy object worked just as well. Finally it was discovered that some readers never improved even with training and special instruction. Most of these readers were eliminated by their choice from the trial. This eliminated group represented about 10% of the readers.

After reviewing the data there are several recommendations that can be made based on the analysis of the data:

1. When reading the KB14 be sure to notice the distinction between the top and bottom numbers and always double read the numbers.

2. Be sure to have the target line directly over the station when reading.

3. The compass must be held on a flat plane away from metal objects, including batteries.

4. Little is gained by using a tripod, accurate results can come if the compass is held against a sturdy or hard object.

5. Resurveying a small well-mapped cave is the best way to begin and gain confidence in your abilities as a cave surveyor.

6. Some people are not suited to reading the compass and no amount of individual practice or training will ever give them a good

Acknowledgements:

The suggestions and recommendations for this article came in part from the following students at Presque Isle High School:

Yuran Lu, Carrie Boyce, Melissa Hendrickson, Bethany Blackstone, Kristin Beaulieu

Bibliography:

(1)Brod, Lang 1998. "Errors in the Suunto Compass Used for Cave Surveying" *Compass & Tape* Vol. 13 #3 Issue 43

(2) Cadrin,Guy 1998. "Topographie A Boischatel" *Sous Terre* Vol. 12 #1

More Thoughts Regarding Simultaneous and Sequential Loop Closures

by Bert Ashbrook

I read with interest Bob Thrun's and Larry Fish's articles in Compass & Tape 13:4 (44) from March 1999 where they debate simultaneous and sequential loop closures. Both Bob and Larry make many good points, but I believe that combining their ideas will give a better result than using either one alone.

First, a couple of quick definitions: Random errors are small and happen when, for example, a frontsight is read as 129.5 degrees and the backsight is read as 131 degrees. Blunders are often huge errors, and they happen when mistakes are made, like a compass which is read as 219.5 degrees instead of 129.5 degrees. Systematic errors, like a compass that always reads 2 degrees too high, were ignored by both Bob and Larry. That's okay for now, because systematic errors can make all this very complicated.

Bob advocates the use of the "Least Squares Simultaneous Equations" (LSSE) method which Vic Schmidt and John Schelleng wrote about in the NSS Bulletin in 1970. This method adjusts all the errors in all the loops all at the same time. Both theory and experience tell us that this method is excellent for closing loops with random errors. But as Larry has pointed out, the LSSE method allows bad loops which have huge blunders to "contaminate" the good loops which have only small random errors. Since blunders happen regularly, using LSSE alone can cause problems.

Larry prefers a sequential method which adjusts the best loop first and"locks it in" so that it will not be altered as less accurate loops are adjusted. Then the next best loop is adjusted and "locked in," and so on. While this method works well for loops with blunders, there can be a problem using this method for loops with random errors which is explained in the sidebar.

Illustrating a Problem with the Sequential Method.

by Bert Ashbrook

In his article in *Compass & Tape* 13:4 (44) from March 1999, Larry Fish used an example where three surveys (A, B, and C) independently reached the bottom of a cave. Because Surveys A and B nearly agreed on the depth of the cave, but because Survey C told us a different depth, Larry ignored Survey C and determined the depth of the cave using only Surveys A and B.

Larry assumed that Survey C had a blunder, and that Surveys A and B did not. Given this assumption, I agree with Larry's reasoning. However, if we had three surveys in which we did not suspect any blunders, then the sequential method may not give a satisfactory answer.

For example, lets pretend that Survey A says the cave is 104.0 feet deep, Survey B says the cave is 100.0 feet deep, and Survey C says the cave is 95.9 feet deep. We do not know what the true depth of the cave is, and we believe that all three surveys are equally accurate and free of blunders. It is reasonable, therefore, to average the three together and call the cave 99.97 feet deep. The sequential method, however, looks at the difference between A and B (4.0 feet), between A and C (8.1 feet), and between B and C (4.1 feet). Since A and B agree the best, the sequential method essentially ignores the C survey and reports the cave depth using only surveys A and B, approximately 102.0 feet deep. For this reason, I believe the sequential method works better for loops with blunders, and does not work as well for loops with only random errors.

So, the LSSE method works best for loops without blunders (only random errors), and sequential methods work best for loops with blunders. I believe that applying each method to the kinds of loops where it works best will give better results than using either method alone.

To pick which method to use to adjust each individual loop requires that we decide which loops have blunders in them, and which do not. Larry Fish's COMPASS program has an interesting method for doing this, in which you guess at how big the random errors are for compass readings, clinometer readings, and tape measurements. Then, how well each loop closes is compared to your guesses. For the moment, lets not debate how bad a loop must be before we consider it to have a blunder.

The only change I would make to Larry's method for finding blundered loops is to allow you to make different guesses for different shots, since some shots can be expected to have larger random errors than others. For example, a tight belly crawl half-filled with 35 degree water which was quickly surveyed without backsights will probably have larger random errors than a comfortable walking passage which was carefully surveyed with backsights.)

After we've decided which loops are have blunders in them and which loops do not, all the loops without blunders can be adjusted simultaneously using the LSSE method. Then, all these loops can be "locked in" while the remaining blundered loops are adjusted sequentially. Using this hybrid simultaneous-sequential method, the random-error loops are not contaminated by blunders, while the problem of sequentially adjusting loops with random errors is also avoided.

Without making it too complicated, I will propose just one more small addition to this hybrid method.

Problem, cont.

For example, lets pretend that Survey A says the cave is 104.0 feet deep, Survey B says the cave is 100.0 feet deep, and Survey C says the cave is 95.9 feet deep. We do not know what the true depth of the cave is, and we believe that all three surveys are equally accurate and free of blunders. It is reasonable, therefore, to average the three together and call the cave 99.97 feet deep. The sequential method, however, looks at the difference between A and B (4.0 feet), between A and C (8.1 feet), and between B and C (4.1 feet). Since A and B agree the best, the sequential method essentially ignores the C survey and reports the cave depth using only surveys A and B, approximately 102.0 feet deep. For this reason, I believe the sequential method works better for loops with blunders, and does not work as well for loops with only random errors.

An under appreciated aspect of Schmidt and Schelleng's LSSE method is the use of weighting factors. Weighting factors let us assign to each shot individually how much influence that shot should have on loop adjustments. Because it's easier and more efficient for computers (and programmers!) to calculate all the weighting factors at the same time, many programs do just what Schmidt and Schelleng did; that is, they make each shot's weighting factor equal to the inverse of that shot's length. However, if we have already made different guesses as to the accuracy of different shots (while finding blundered loops), then we should make use of this same information in assigning different weighting factors to different shots.

Alternatively, for those who want to avoid the sequential method altogether, shots with suspected blunders can simply be given very low weighting factors and then all the data adjusted using LSSE in one step. Like the sequential method, this will also avoid the "contamination" of good loops by the blundered data.

Simultaneous/Sequential Closure: Round 2

by Robert Thrun

I hoped that the exchange of articles in *Compass & Tape,* Issue 44 would fully cover the topic of simultaneous and sequential closure adjustments, but Larry Fish raised some new issues that should be addressed. I have also learned things as I examined sequential closures in detail.

Mixing of Arguments

I mixed arguments in my first article. I had the finished article submitted to the editor when I learned of an error in my terminology and then came across a major bug in COMPASS. I did not feel that I could ignore the bug, so I worked a discussion of it into the existing text and submitted a revised version of the article to *Compass & Tape.*

Random Numbers

The comparison of the closure adjustment methods doesn't require a very good random number generator. We should not be discussing random numbers except that Larry blames much of the poor performance of sequential adjustment on the random number generator. I used a good random number generator from a high-quality math library. The routine generated a uniform distribution and then transformed these variables to a normal distribution (the familiar bell-shaped curve) by the polar method. The underlying random number generator is that recommended by Park and Miller,"Random Number Generators: Good Ones are Hard to Find", *Comm. of the ACM,* Vol. 31, No. 10, Oct. 1988, pp. 1192-1201.

The pattern of columns in Figures 1 and 3 of my first article is due to the order of the survey shots in the data files. The data were generated in a north to south order. This produces initial linkages in a north-south direction in both CMAP and COMPASS and affects the adjustment sequence in COMPASS. The variations in row widths in the unadjusted plot were due to the length errors. The variations in column widths were due to the angle errors, which have ten times the effect of the length errors. I rearranged the data so that the survey shots are presented in a west to east order. I now get row-oriented patterns. This is with exactly the same survey shots.

Autocorrelation is a valid test of randomness, but not the way Larry's RTEST program did it. My shot length data were from a normal distribution centered on 30 feet. Instead of simply subtracting the mean from the lengths, RTEST split the normal distribution down the middle and transformed it to a strange distribution that is highest at the ends and empty in the middle. Larry compared this strange distribution with a uniform distribution. Although an autocorrelation can be done on any number of points, RTEST was written to use 2048 points. To get 2048 points from 760 lengths, the length data were repeated. As Larry recognized, the repetition caused a peak at 760. Larry claims that the peak at 528 is an indication of a poor random number generator, but it is actually due to the data repetition too (760 + 760 + 528 = 2048).

Blunder Handling

I am not too concerned about how really large blunders are handled. A decent survey program would identify large blunders and most cave mappers would correct the raw data. My surveys have less blunders than the ones Larry cites. If I have to use a survey with a large blunder, I prefer to make the decision on how to handle it myself, rather than accept some computer program's arbitrary choice.

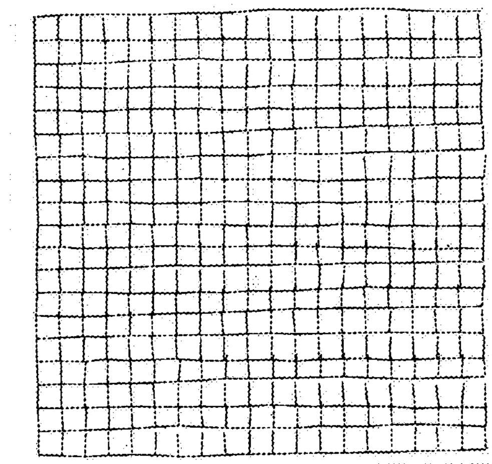
Error Propogation

The horrible examples of blunder propagation that both Larry and I show are useful in that they show how errors of any kind will be propagated. Larry claims in his CCLOSER.HLP file that least squares "distributes survey errors evenly across all the loops in the cave." My tests show that an error consistently damps out one or two loops away from where it occurs.

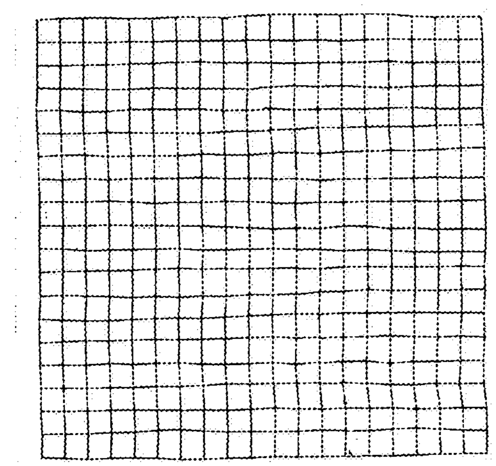
For a square grid like I used for my test cases, a blunder on about half to shots would be ignored by COMPASS. For the other half of the shots, the blunder would be propagated onward. If large blunders can be propagated, so can smaller blunders and random errors. These will eventually build up build up in a large enough network. This is shown by my statistics and plots. Good loops will be contaminated by errors from good loops. I suspect that this will happen in any sequential process where errors in an earlier loop can affect a later loop, but not the reverse.

One of the examples in my first article, Figure 4, had a single reversed shot in the middle of a grid. The six loops next to the reversed shot were badly distorted. The next layer of loops, the ones Larry labeled 7 to 16, are visibly distorted, but they are less distorted than some of the loops in a sequential adjustment when there is no blunder. I would expect a blunder this large to be corrected. Then the distortions in a least-squares adjustment would disappear, but the distortions in a sequential adjustment would remain.

The current version of COMPASS (as of May 1999) still has the bug where it uses the first survey to a station for every loop involving that station. this is a flaw of the loop detection method, not of the best-loops-first philosophy. I am curious how a different best-loops-first implementation or a fixed version of COMPASS would do.



Grid in west to east order, unadjusted



Grid in west to east order, adjusted by COMPASS

Throwing Away Information

Look at the bottom of the grids in this article. The two southernmost west-east rows of survey shots drift away (from each other, but come together at the east side, forming a "good loop" that extends across the entire width of the grid. The loop has a couple of bulges in it. The lengths of the north-south shots that extend (or fail to extend) across the bulges indicate that the bulges should be pulled in. Since the end stations of the north-south shots are already part of a good loop, all the measurements of the north-south shots inside this loop are ignored. There are many other places where survey shots are squeezed between good loops and their measurements are ignored.

Larry's Tests with Random Errors

Larry's sample file showing a comparison between SMAPS and COMPASS is based on a 4 by 4 grid. On grids of this size I got results similar to Larry's. Sometimes the errors were slightly decreased and sometimes they were slightly increased. Most of my tests were done with 20 by 20 grids, where sequential adjustment consistently increased the errors. I conclude that sequential adjustment methods perform worse for large survey networks.

Larry bases his statistics on the differences between station coordinates and a perfect grid. I base my statistics on the survey shot measurements, like those put out in a COMPASS .CLP file. I can't use Larry's method because my unadjusted loop closure stations have at least two sets of coordinates.

The Basic Difference Between Methods

Imagine a large sheet of cardboard with some bullet holes in it, all made by aiming at the same point. We wish to estimate what the aimpoint was. A least-squares method would use the average of all the shots as the best estimate of the aimpoint. The best-loops-first philosophy considers the two shots that are closest together to be the most accurate just because they are the closest together and would average only those two. The algorithm in COMPASS would use the average of the first shot and the one closest to it.

Summary

Best-loops-first sequential adjustment is an idea that sounds good. It was definitely worth a try. Unfortunately, it is no better than least squares for small networks and worse for large networks. COMPASS contaminates loops with errors from earlier loops and ignores shots that connect already-closed loops. Maybe an algorithm that finds a minimal length set of loops will do better, though I doubt it. There is only one way to find out.

More Discusion On Least Squares Loop Closure

by Larry Fish

Many months ago I wrote an article describing some problems I had found in cave survey programs using Least Squares to close loops. Since then, there have been two rebuttal articles focusing on my program, COMPASS, as a way of proving the efficacy of Least Squares. I think it is now time to return to the original topic of discussion, Least Squares.

MOST PROGRAMS DO LEAST SQUARES WRONG

In the course of this discussion, I received a series of letters from John Halleck. John is extremely knowledgable about surveying mathematics and he has given me some very interesting insights into the Least Squares issues.

I had always assumed that the cave survey programs that used Least Squares were written correctly, so I assumed that the problems I was seeing were due to flaws in Least Squares itself. John pointed out that these problems were actually due to the fact that most cave survey programs do Least Squares incorrectly.

Most Least Squares cave survey programs are based on an old article that appeared in the *NSS Bulletin* in 1970 written by V. A. Schmidt and J.H. Schelleng. John says that this article was intended to be a simplified introduction to the topic of Least Squares loop closure. These simplifications make the technique unsuitable for dealing with blunders. Thus, any program that uses the Schmidt and Schelleng technique will have trouble handling blunders.

Thus, any program that uses the Schmidt and Schelleng technique will have trouble handling blunders.

WEIGHTS AND LEAST SQUARES

The problem with the Schmidt and Schelleng technique is the way it deals with weights. Weights are used by Least Squares to compensate for parts of a survey where the data is bad. When you have a cave survey with multiple loops, some loops will close better than others. When you close a survey, you want to make sure that the program favors the data in the best loops over the data in the poorer loops. The weights control how the program processes different parts of the survey. If the weights are high, the program assumes this part of the data is good and will favor these loops when it closes the cave. Likewise, if the weights are low, the program assumes the data is poor and will not rely as heavily on this part of the survey. In this way, the program can compensate for any blunders in the data.

Obviously, the way in which a program assigns weights is very important. The correct way of assigning weights is to have the program derive the weights by analyzing the quality of the loops in the cave. Unfortunately, the Schmidt and Shelleng technique does not do this correctly. Instead of looking at the actual errors in the loops, it simply assumes that longer shots will have larger errors and so it assigns weights based on the length of the shots. Since Bob Thrun has presented his program as an example of the superiority of Least Squares, we should look at how his program assigns weights. Looking at his distributed software, you find that he has several options for assigning weights. These include the number of shots, the shot length, the standard deviation and the variance. All these methods attempt to project amount of error there ***should*** be in a survey but do not take into account the ***actual*** errors in the survey. For this reason, the program cannot deal with blunders in a mathematically correct way.

THE CORRECT WAY TO ASSIGN WEIGHTS IN LEAST SQUARES.

The key to assigning weights correctly is to compare the predicted errors with actual errors. If you know what kind of errors your survey instruments have, you can then predict what kind of errors a loop should have if there are no blunders. For example, you might say that your Suunto compass has a typical error of about two degrees. Once you have this value, you can apply it to each shot in the loop and predict how much total error there should be in the loop. Any error that exceeds the predicted value must be a blunder. The ***prediction*** and the ***actual error*** can be used to calculate precise values for the weights based on the quality of the data. Thus, in places where the errors exceed the predictions, the weights will be low and these loops will be given low priority in the closing process. Conversely, data that matches the error prediction will be given high weights and will be given high priority in the closure process. In mathematical terms, the comparison of the "projected error" with the "actual error" is called "covariance."

Thus, if Least Squares is done correctly, it will deal with blunders as effectively as any other technique. In fact, the whole argument about sequential versus simultaneous closures is a red herring. According to John, correctly implemented, sequential and simultaneous closure techniques produce provably indentical results. The problem is that few cave survey programs do Least Squares correctly.

HOW TO KNOW IF A PROGRAM IS IMPLEMENTED CORRECTLY.

How can you tell if a program implements Least Squares correctly? Without examining the computer code it is difficult to tell if the program does Least Squares correctly, but there are some clues. Here is a list:

1. Schmidt And Schelleng:

Any program that is based on Schmidt and Schelleng is suspect unless it uses a different method of deriving the weights. Since Schmidt and Schelleng uses the inverse of the shot length to derive weighting factors, any program that uses this technique is also wrong. Even if the program uses a different method, it must be based on analyzing both the ***projected*** errors and the ***actual*** errors. Thus, programs that derive weights based on things like the number of stations or the projected variance are incorrect for the same reason. All these techniques are wrong because they make a projection about what the errors ***could be*** without taking into account what they actually are. The correct method uses both the ***predicted*** error and the ***actual*** error. Again, in mathematical terms, the correct method uses the ***covariance*** to derive the weights.

2. Instrument Uncertainties:

In order to predict the expected error for a loop, you must estimate the size of the typical error you would find with each survey instrument. For example, if you know that your compass has a 0.5 degree error, you can easily project how big the error should be at end of particular survey loop. Since the quality of instruments can vary, you would expect that a correctly implemented program would allow you enter error values for the instruments. This is not completely reliable. For example, a program might set these values internally and still implement Least Squares correctly. Likewise, a program might allow you to enter error values and not use them to calculate ***covariance*** based weights.

3. Test Blunders:

I first discovered the problems with poorly implemented Least Squares when I wrote a program based on Schmidt and Schelleng and found that it smeared a large blunder in Groaning Cave all over the map. One way to tell if a program has a properly implement Least Squares is to test it with a blundered survey in it and see if the plot is distorted.

FURTHER INFORMATION

I have deliberately steered away from the mathematical aspects of the problem in this article, but these concepts are based upon well-established principles in land surveying. John is working on an article that includes a detailed mathematical and theoretical discussion of the topic and sample code. He also describes other important problems with the current crop of Least Squares programs. I hope his article appears in this issue, but in case it does not, you can find the information on his web page. The web address is:

Overview of Least Squares Cave Survey Issues

By John Halleck

John Halleck has been a guest lecturer on surveying at the University of Utah. He has a strong background in mathematics and has been surveying caves and lava tubes for years. -ed

There is, unfortunately, a lot of confusion in the cave survey community about analysis and adjustment of survey data. The problem is bad enough that some cave survey programs have massive misunderstandings built into them.

The reasons for this are many. Most cavers have neither the time nor the motivation or even the chance to take a detailed theory of surveying course. Such a course may not even be taught in their area. So they hunt around in the literature for the pieces of information they can understand. What they find understandable are those things that have been simplified so as to be easy to understand. What they don't get from that are which simplifications were made, and how to tell when those simplifications were begin violated.

The offshoot of this is that cave survey software is often just flat out wrong. It is not uncommon for two programs that claim to do a "least squares" solution of the survey problem to produce dramaticly different answers given the same data.

Maybe "wrong" is a bit strong as a term... They correctly solve some simplified problem, but they don't state the simplifications, and they don't test for the data violating those simplifications.

Why don't more people notice problems?

A least squares solution to a problems produces a solution that is a "linear combination" of the various loops. What this means in non mathematical terms is that if several traverses put a point in a different location, the final point will be somewhere between these locations.

Exactly where in that area the points go is determined by the weights. Large changes in the weights don't normally produce results that look very different to the naked eye. Since even bizarre weights don't cause passages to move to strange locations there is a feeling that weights are less important than they are.

IF all you are doing is drawing a map, then almost ANY location for a final point (between the various places the data claims) works. Only in the case of major blunders will you see a difference... and in those cases the initial adjustment is wrong anyway (without post processing) (see below).

Why care? Correct processing gives you a LOT of useful statistical information about the survey (although most cave survey programs ignore it). This can help you look out for systematic problems. From a practical standpoint, correct processing keeps blunders from screwing up every loop they are attached to.

If all you care about is a pretty map, almost anything will work and arguments between various methods are little more than aesthetics issues.

Common Issues

Adjusting a cave survey is what mathematicians call a "non-linear" problem. (Some people say that "non-linear" is a slang term for "really ugly").In order to deal with the data at all, the problem is generally "linearized".In this case this is done by reducing the Distance, Azimuth, and Inclinationvalues to a vector which is the change in X, Y, Z for the shot. This changes the problem into what is called a linear approximation to the original problem. The equations that linearlize the problem also force a weighting on the problem. Because this is done, the problem being solved is NOT the original problem, but only one (hopefully) near the real problem.

A linear approximation to the original problem works perfectly well *IF* the solution lies close to the original data. For professional surveys this is almost always the case. For surveys with hand held instruments this is usually the case. For surveys with major blunders the linearized solution is probably junk.

Least squares analysis will give statistical figures (if one checks) on how well the data matches the model. Many cave survey programs don't bother to check, and don't generally do much statistical analysis at all. Most cave survey programs don't know what to do when the data doesn't fit the model anyway.

Issue 1: Programs that don't know when the linearized model is being violated.

Since a professional grade survey is almost never programs sometimes don't have checks for whether the linearized solution is good enough. This can be handled correctly, but it involves making new approximations after the first adjustment, and rerunning the adjustment. This is not hard to do, but cave survey programs never do. In caving, the fit between the model and the data is often very bad because blunders are left in. For example, there is no way a 1000' long eight inch high passage with four inches of running 33 degree water is going to be resurveyed. And there is a high probability that the freezing cavers made mistakes.

Issue 2: Ad hoc and bad weights.

Converting from Distance, Azimuth, and Inclination to X, Y, Z imposes certain *structured and computable* relationships between the uncertainties of the X, Y, and Z. Using anything else can make ones weights wrong by an order of magnitude. The weights are determined by the uncertainties of the original DAI information, and the transformations used to get X, Y, Z. They are not just pulled out of a hat.

A large number of cave surveyors use the standard transformations to convert the problem to X, Y, and Z, and then don't want to accept the statistical weights this imposes on their answers. Often they don't even realize that doing the transformations has any bearing on the covariances and weights at all.

Throwing away the covariance information (that information that relates the uncertainties of the variables to each other) and continuing to process violates the underlying assumptions of the least squares fit. Making up weights from other assumptions (chain rule, length fit, etc.) may have intuitive appeal, but violate the underlying assumptions that made a least squares fit a good idea to begin with. In some cases ad-hoc weights can mean you are running statistics on correlated variables claiming them to be uncorrelated.

Some people even solve the unweighted problem, with any number of arguments as to why the weights don't matter.

Issue 3: "Least squares is least squares".

The net abounds with least square programs you can just hand a matrix to. The underlying assumption that went into deriving them is that you are solving a LINEAR least squares problem. They have no idea you are handing them a LINEARized problem. Therefore they don't report when the linearization assumptions are being violated (such as when there are the right kind of blunders).

The cave survey program authors are prone to almost religiously defend this usage of their canned routines since they were "being used to solve least squares problems for many years by many high powered organizations like NASA". The fact that the programs work correctly on the problems they were designed for means nothing if you give them a linearized problem they weren't designed for, and don't take correct care around it.

Note however that if the correct care is taken around them, any program that solves linear least squares problems at all can be used to solve the full linearized weighted least squares problem.

Issue 4: Simplifications.

Many cave survey programs make "obvious simplifying" assumptions. However the authors often don't know what the true effects of the simplifications are, since they didn't go back to the general principals to measure the affects. A good example of this is adjusting X, Y, and Z data separately. This can cause your weights to be off by a factor of two or more. It may make the program simpler, but it also makes it wrong.

Issue 5: Schmidt and Snelling said...
(A reference to a quick introduction to least squares published in the *NSS Bulletin.*)

Just because a quick introduction to a subject doesn't cover all the details doesn't mean an implementation based on that (which doesn't cover the details either) is right.

Issue 6: "The program is god".

For some reason people tend to take an output of a least squares adjustment as if it were magicly "right". Some authors encourage this. Just because a program applied good mathematics to bad data doesn't magicly make the data clean and right. If there were errors in a loop there still are, they've just been spread around in a fashion that has good statistical properties.

Issue 7: "Fancy mathematical XXX for simultaneous loop closure"

There are sequential least squares techniques. There are simultaneous least squares techniques. They produce (modulo round off errors) the exact same answers. Since the sequential least squares methods produce the same answers, the argument that simultaneous' loop closure is better than 'sequential' loop closure is clearly bogus. (But I continue to see them in print.) The 'real' issue is more often "I don't like the manner in which you do sequential closures" with an appeal to a (possibly misimplemented) least squares program's output as being the magicly correct one.

Note that this doesn't mean sequential least squares can find the adjustment of one loop magicly without the ones to follow... it just means that as a new loop is added the appropriate adjustments can be made to whatwe have so that the adjustment is at all times correct for all the the datait has seen.

Issue 8: "This program tested with 1000 different cave surveys".

The adjustment of a cave survey has a lot of answers that can "look good". The weights could be dramaticly wrong and still produce a result that "looked good". Was the program tested with data where the mathematically correct answers were known? (Some never have been.) Were the parts of it checked with data sets that tested it's ability to handle problems nearly unstable? Did it notice? Does it even notice if it is handed bad data that produces a singular matrix that gets 'solved'? What sorts of libraries does it use and how were they tested? (If the inverse of the inverse of the problem matrix is not close to the problem matrix, it surely doesn't matter how well the least squares evaluation is done.

Issue 9: "Nobody cares about the statistical part anyway".

My favorite. If the statistics are bad, why believe the adjustment is good? EVERYBODY should care if the survey contains blunders and mistakes. A network adjustment that doesn't downweight blunders is just flat out wrong. A correct least squares adjustment, taking into account the non-linearity of the problem, does this automaticly. But you see people showing off adjustments that give blunders the same weight as good shots... and they often try to claim that is is "THE RIGHT WAY" because it came out of a least squares program.

A least squares adjustment IS a statistical technique. If you violate the assumptions of a statistical technique, then the result has no statistal significance.

Issue 10: Terminology.

As long as cavers read cave survey literature, instead of survey literature, cavers are going to end up with terminology that is different than real surveyors.

An immediate side effect of this is that when they search for literature they are only going to turn up cave survey papers, because they are the only papers that use those terms in that way.

This also makes real papers hard to read for them, since the terminology used in real survey papers is totally new to them.

Cave survey documentation that doesn't also give the real survey terms continues and worsens the problem. Remember: Surveyors have been at this game a lot longer than cave surveyors have. They've already dealt with many of the problems we are just now dealing with.

Cave Survey Software

Part I: What Features do you need and/or want?

by Pat Kambesis

There are many options in cave survey software these days. The "brand" of software that you ultimately choose is a function of your computer hardware/operating system capabilities and the desired use of data/derivative output, both digital and hard copy.

The first point is easiest to deal with. Do you have a Mac or PC. Is the operating system DOS, Windows, UNIX? What do you have in the way of Random Access Memory, hard drive space, monitor capabilities, printers/plotters. Compare your system information with that listed in the Cave Software Tables to determine which programs will run on the computer that you have.

The second point, data use and derivative output, can be easy or complex depending on the nature of the cave, the duration of the survey project and what type of information and/or output is desired from the data. Whatever the scenario, the data is entered into a cave software program, which will convert it to xyz coordinates, check closure errors, display an on-screen representation of the reduced data and generate a digital or hard copy line plot. This output is provided to the cartographer who then draws up the map (either by hand or with a CAD or drawing application). All of the existing data/reduction/plotting cave survey programs can do this.

However...

If your survey activities involve short term projects and relatively uncomplicated caves then any data entry/reduction/plotting program will give you just about everything that you need. If you are working with long term survey projects, and complex cave systems and/or series of caves, then your software requirements are going to be a bit

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Templates for Reading Topo Map Coordinates

by Robert Thrun

Cavers often have to locate points on topographic maps. Latitude and longitude in degrees, minutes, and seconds is tha traditional method of specifying coordinates. The problem is that there is no easy way of measuring lat-lon. The are no readily available lat-lon scales, probably because the longitude scale varies with the latitude of the map. The miltary adopted the Universal Transverse Mercator grid, which is a square grid with distances in meters. To use the UTM system with civilian USGS maps it is necessary to draw straight lines across the maps.

I wrote some programs to make templates for reading or plotting coordinates on topographic maps. To make the templates you need a laser printer compatible with a Hewlett-Packard Laserjet at 300 or 600 dots per inch and some plastic material of the kind meant for making Viewgraphs. I have two programs. UTMGRID makes a 10x10 grid for maps of any scale. LLGRID makes a latitude-longitude grid for USGS topographic maps at 1:24000 at a user-specified latitude. The scale of the templates may be adjusted to compensate for printer and map scale errors.

The latitude-longitude grid is particularly easy to use. It beats measuring map sizes and taking ratios. It is also beter than drawing extra lines and putting a scale across them at an angle. The tick marks for the corners of the grid are already printed on all the USGS maps. I find that a particular grid is good for about a half degree range of latitude.

Since these grids are of use to users of GPS receivers, I uploaded the programs to Peter Bennett's web site, http://vancouver-webpages.com/peter . The programs are in the file mapgrid3.zip. I have included full source code.

more involved. In order to work efficiently and effectively, you need software that provides the following:

1 an easy, "friendly" data entry interface and editing function;

2 organizational and archiving capabilities;

3 loop closures for quality control;

4 a mode to facilitate blunder detection;

5 versatile viewer that will allow on-screen manipulation of the line plot;

6 option-rich portability, so that you can export or import your data to and from other programs and applications

7 variety of printer/plotter attributes that can provide a range of output from simple line plots to multi-level quadrangles (all with north arrow and scaleor course).

In addition...

For extensive cave systems and/or project areas, topographic overlays are key to relating the cave passage and features to the surface topography and for assessing the potential for more cave development and connections. A number of cave survey programs can import topography, either as a scanned bitmap or as a DEM (digital elevation model). And a few programs will even accept GPS data that can be used as your "surface grid" or be incorporated into an existing one.

As you work a cave or cave area, additional information about the cave/system/area, begins to accrue. Data on passage features and morphology, air movement, scientific attributes (mineralogy, biology, geology,hydrology etc) and of course leads, are important pieces that when integrated, will help you explore, study and understand the 3-dimensional puzzle that you are working to solve.

Some cave programs allow comments to be added to the survey station information. Others take it a step further and produce a database that can be queried, listed and displayed on the digital or hard copy map.

What Features are Important and What Do I Really Need?

That is for you to determine. Hopefully the following guide will help you make that determination. This list was compiled from the input of individuals with a lot of experience in cave data entry, project data management and manipulation, long-term survey/cartography projects and from those who have used computer-generated information for finding more cave. A comprehensive data entry/reduction/plotting program should have the following features:

A User Friendly Interface for Entering and Editing Cave Data:

This is an extremely important function, especially if you are going to be entering lots of survey data. The data entry screens should be easy to use - those that resemble spreadsheets and/or the data fields of a survey book are best. You should be able to customize the entry window to accomodate the type of data you are entering and the order in which that data is entered. Some programs have a verification function that checks to make sure that you enter data in the appropriate fields i.e. program won't let you enter + or - values in the "azimuth" field, won't accept values greater thatn 360 degrees in the zimuth field or greater than 90 degrees in the inclination field.)

Measurement selection options refers to the units of measure that the program will support. A program that supports a good selection of units allows flexibility in the use of various instruments and tape measures for survey fieldwork. Using a variety of survey gear won't affect the quality of your surveys as long as you calibrate your instrumentation and incorporate that data in the corrections fields often associated with the data entry section of a program. If you are a cave diver, some programs support depth guage measurement. Topofil is even supported by a few programs.

Support of non-sequential data entry means that you don't have to enter the survey stations in the exact order in which they were mapped. The program will allow "floating" stations which will be held in memory until the compiler finds the survey string to which the "floater" ties i.e. If a cave passage was surveyed "on-the-way-out", you won't need to manually re-sequence so that the tie-in station must be defined (entered in the program) before the rest of the stations can be processed. In general this function makes the program figure out how things should tie together - providing, of course that all of the tie-in station information is accurate and correctly entered!

Autoprefixing is a function that automatically enters the next station prefix and number based on the previous prefix and number. For example, if you enter A1 to A2, then the program will assume the next station is A3 and will automatically put that in the next station field. If the next station is a tie-station rather than the next station in the logical sequence, you can manually overide the editor and just enter the tie-in (i.e. if A3 connects to B5, rather than A4, you enter the correct station over A4.) Autoprefixing makes data entry easier especially if the station names are rather long. This feature can be turned off or on.

Project Management Function

This is essential for large and long-term survey projects where the amount of data collected is voluminous. It is even useful if you are just mapping a bunch of small caves since they can then be grouped by area. A "project manager" organizes data by displaying a "tree" diagram - similar to the way that Windows handles files. And just like Windows, files can be created, organzied, selected and processed via mouse.

Project manager functions allow you to perform a function on a group files or a group of functions on one file. Also, you can use the same survey file in several different projects.

Does the program allow you to record Header Information? i.e. sometimes called metadata. This header information contains data about the data i.e. survey date, survey party, survey designation, area of cave etc. This information is extremely useful for organizing and archiving your data - an absolute necessity especially when you have many surveys to deal with.

Loop closure, Blunder Detection and Statistics

All data entry/reduction/plotting programs must process (reduce) the data in order to produce a line plot. You should have the option of performing data reduction (and loop closures) on an individual survey/area file or for the entire cave.

Loop closures are a tool for determining the accuracy of your surveys (provided of course that loops were surveyed during the mapping process.) The algorithm used for loop closure is either the Sequential or Simultaneous (least squares) method. The Simultaneous method closes all loops in a cave at the same time - thus distributing the error throughout the entire cave. The Sequential closure method closes the good loops then locks them in, so that the errors from the not-so-good loops don't affect them. Both methods will distort the cave plot to some degree - but this distortion will be insignificant for data sets that contain minimal errors. Remember, loop closure DOES NOT increase the accuracy of your data. All it does is provide a percent measure of how inaccurate your data is and then distributes the error in the data so that the line plot loops will "close". Though you wouldn't want to produce final maps from data that has large closure errors (remember, the plot will be distorted to close the loops), you can still utilize the data to produce interim line plots (for display or field checking),

Blunder Detection: Before you start making final maps, all of your loops should close to within an acceptable measure (standard is 2%). If they don't close within an acceptable standard, then you need to find the errors and fix them. This is a real pain when you have to deal with lots of data. Some programs offer a blunder detection function that provides you with a list and/or a graphical representation of which survey stations are the ones in question. You then use this information to help determine the level of "fix" necessary i.e. is it a "clerical" error that can be fixed on the spot or is some resurvey required?

After processing is complete, many programs produce a list of Statistics about the data from specific surveys or the entire system. The stats can include: length,exclusions, depth,closure errors,average shot length, loop stations, number of stations, suspended stations, number of shots, parent stations, number of loops, rose diagrams, station coordinates, surveys per year, cave size (x,y,z) standard deviation, etc. At the very least, you want length and depth of the cave for reporting purposes (to motivate the "troops", or impress the land owner/land manager), and/or for inclusion on maps or in reports (interim or final).

On-screen Viewing Capabilities/Options

A good visual understanding of the cave is important for the explorer, the scientist and the cartographer. Versatile on-screen viewing capabilities help you visualize the layout of the cave and the relationship between cave passages (and between other caves). If you happen to have a computer in the field (during expeditions or cave trips), screen visuals are an excellent motivator, and good for PR. Everyone is more inclined to help with data entry when they can see almost instant results from their field work. Survey errors can be detected and fixed in the field (important on remote expeditions) And exploration efforts are given an added boost when the line plot heads off into unknown areas or toward potential connections.

All cave survey programs allow you to see the line plot after the data is processed. Most of them now allow you to manipulate the line plot with rotate, zoom, pan and move functions. Look for the ability to let you color by attribute: (by depth, date,survey etc.). This is another good visualization aid.

A Clipping function is very useful for removing per and/or lower levels or adjacent passages to make it easier to view or print out sections of the cave.

Import/Export Function

This is a highly underrated but very important feature. Look for a program that can convert its data to other data formats. (Providing the user with many import/exportoptions is the a sign of a confident, forward-thinking programmer who understands and anticipates the speed at which technology changes and the necessity for it to do so.) Keep in mind that no program can "do it all". A variety of import/export options give you the ability to use innovative or useful features that may not be inherent to your program of choice. Look for export cabability that will allow you to bring lineplots into drawing, imaging or rendering programs. Versatile file formats are insurance that your data will not get stuck in a program that ceases to be supported or upgraded.

Versatile Hardcopy Output

You definitely want the option to generate hard copy printouts of the cave plot. This is imperative for the cartographer who still makes maps by hand (most of us at this point in time though things are changing) Hardcopy maps are useful for publication and presentation. They are a morale booster for your survey teams, useful underground and good PR for land owners or land managers. Windows eliminates the problems associated with defining print drivers since you define the default printer there. Most programs can produce line plots (plan and profile) at any scale and orientation and should include north arrow and scale. For big systems, the option to make quadrangle plots is a plus. A color printer will make your plots even more fun and informative.

Software Support: Manual/On-screen help/ Website Support

This is another underated feature. A comprehensive and concise software manual is a valuable resource and reference in helping you to understand exactly what features the software offers and how to use those feature. Most programs that offer manuals include it with the program files. Some programs offer their manuals as PDF files than can be downloaded at the website.

On-screen help offers quick reference while you are working with the program andadds to the overall "friendliness" of the software. Look for a program that offers a comprehensive table of contents and listing of keywords for searching on its feature descriptions. Many of the software websites provide feature summaries and illustrations to help you use and uderstand the program.

Any program that can provide most or all of the above features will more than accomodate the needs of any size or duration survey project.

Why Stop here?

Ever-changing computer technology and the availability and affordability of that technology to the home computer owner helps drive the evolution of cave survey software. As a result, the potential of what can be done with cave survey data, along with the cornecopia of "extra" feature selections are taking cave survey programs to a new level. The bells and whistles of today often become the standard features of tomorrow.

Surface Terrain Modeling:

In simple terms, this feature displays the relationship between surface topography and cave passage. The combination of a scanned topographic image, plus a cave passage plot results in a digital topo overlay (a fairly easy representation to produce.) Digital Elevation Models (DEM's), which are digital 3D topographic maps available from the USGS, coupled with the 3d line plots of the cave system illustrate the three dimensional relationship between topography and cave passage and allow for full surface terrain/cave passage modeling. Terrain models can be viewed and manipulated on screen (which is great for expedition use) and can also be output in hard copy. A number of software programs support these functions and it is well worth the effort to learn how to use then.

In keeping with the trend of changing computer technology, the USGS has been converting all its DEM data to SDTS format. Some of the cave survey software have begun to support this format also.

Cave Passage Modeling

Passage modeling involves the use of passage dimension data (left, right, ceiling, floor) along with the standard survey data, to produce three-dimensional models of cave passages. Color, perspective, texture and realistic shadowing make for outstanding 3 dimensional visualizations of cave passage that can be zoomed, panned and rotated. These visualizations can provide insights into passage morphologies and relationships that would not be visible on a standard lineplot.

GPS Support

If you want to incorporate data from your GPS unit with survey data, there are cave survey programs that support this feature. A few programs generate Track and Waypoint export files from cave surveys which can be uploaded to the GPS unit. The unit can then be used to navigate to possible entrance locations where the cave approaches the surface. (Think of the possibilities!)

Comments/Databases/Queries/GIS

Most cave survey programs allow for the addition of comments in association with survey stations. Some programs have incorporated database functions which allow the creation of your own database of cave information and the input of attributes such as pictures, and drawings. Powerful queries allow the search and display of information on the cave map - in effect provding you with a useful GIS application.

Geographic Calculators

A few of the software programs contain applications that will translate values such as longitude/latitutde to x/y coordinates, calculate UTM coordinatoes and even determine magnetic declination.

This article in no way lists all features available in the various cave survey programs. Hopefully it will help guide you in your choice of software.

Next Issue of Compass & Tape:

Cave Survey Software- Part 2: A Table of Comparisons of Features Between Various Cave Software Programs.

Survey and Cartography Session Abstracts
NSS Convention 1998
Sewanee, Tennesee

The following abstract is to accompany the series of maps produced by Joel Despain. Maps were displayed for several days during convention. (**Note:** This map series won the Medal for the 1998 Cartography Salon -ed)

The Crystal Cave and Sequoia and Kings Canyon National Parks Cave

Cartography Project

Joel Despain, NSS 23136RE, HCR 89 Box 211
Three Rivers, CA 93271

In recent years, the cartography salon at the annual NSS convention has seen steady increases in the content, layout, and presentation quality of cave maps. During this same period, a rise in the use of geographic information systems (GIS) by land management agencies, local, state and federal governments, and universities has revealed that maps are much more versatile tools for the storage, display and analysis of spatial information them may have been previously realized.

The Sequoia and Kings Canyon Cave Cartography Project seeks to integrate aspects of standard cave cartography and data bases into a cave GIS program for the inventory, monitoring and analysis of mineralogical, geological, cultural, infrastructure and biological information. The project also asked the questions, "what can be displayed on a cave map, and "how can these maps further the understanding and management of park caves". A key component of the project was the drafting of maps on a computer using a powerful graphics package (CorelDraw!). This allows such aspects of the maps as the cave walls to copied repeatedly to create new maps and displays.

A final aspect of the project has been the integration of caves within the landscape of Sequoia and Kings Canyon National Parks. These maps were produced using Compass, Cave Tools Extension and Arcview (the most popular GIS program) software packages.

Session Abstracts

SpeleoMeshing: A Technique for High Definition Cave Surveys

Greg Passmore, NSS 14008RL
3D Pipeline Corp., 599 Mathilda Ave., Suite 39
Sunnyvale, CA 94086

This paper describes a set of novel computer techniques for cave and mine mapping which are collectively referred to as SpeleoMeshing. The process yields detailed volumetrics, dense meshes for structural finite element analysis and photorealisitc rendering. The techniques are low cost, high in accuracy and suitable for use on personal computers.

The process is composed of three steps; collection of passageway profiles, conversion of the profiles into 3-dimensional models and, optionally, collection and application of texturemaps on passageway walls for photorealistic rendering.

The first step of the process uses a simple pocket laser to outline each passage profile along survey lines for photographic capture. The photograph is subsequently digitized and used to calculate passage profile axiometric distances. In the second step, the resulting axiometric passage profile data is extruded between profiles into a 3-dimensional wireframe mesh. This wireframe mesh data is suitable for high accuracy volumetric analysis and for structural finite element analysis. For high quality rendering, a third step, the photographing of passageway walls are taken for color and texture definition. The resulting photographs are then texturemapped onto the 3-dimensional model and computer rendering techniques are used to produce near photo-realistic renditions of the cave.

This paper will present the details of the process, a description of the tools needed, and examples of computer imagery resulting from SpeleoMeshing.

Subsurface Geologic Mapping and Color Digital Cave Cartography

Paul Burger, NSS 26452RE
Geology Department, Colorado School of Mines
Golden, CO 80401

To date, most of the uses of color in digital cave cartography have been limited to the addition of photographs and other graphics on maps, or to portray streams and other gross features. This talk focuses on the use of color to present information such as bedrock geology, unconsolidated cave fill, and floor detail. This type of detail can be easily understood by non-geologist cavers, and can be easily added to cave maps by non-geologist-cartographers. The use of color to portray information beyond what we as cavers and cartographers normally put on our maps has far-reaching potential for archaeology, paleontology, hydrology, and geology.

Compass, Autocad, CorelDraw! and Arcview: Lessons From Sequoia and Kings Canyon National Parks

Digital Cave Cartography Project

Joel Despain, NSS 23136RE, Ash Mountain, PO Box 211
Three Rivers, CA 93271

This session will present a discussion on the successes and failures of the many aspects of the Sequoia and Kings Canyon digital cave cartography project. These maps, many of which include data bases tying specific features to survey stations, may represent a slightly different approach to cave maps. This approach can be a powerful tool for cave specialists and mangers in both defining and illustrating management plans, in storing and displaying biological inventory and monitoring results, and in the documentation of cultural and mineralogical features. However, this approach is not without its problems, which may include too many trips to delicate cave areas, time consuming initial drafting, and acquired file conversions.

A Versatile Rangefinder

Dale J. Green, NSS 3669RE,
4230 Sovereign Way
Salt Lake City, UT 84124

Optical rangefinders based on the parallax method are almost totally worthless in the cave environment because of low light levels. Even with powerful (heavy and bulky) lights, converging the illuminated images does not produce satisfactory results. However, if an object at the distance being measured is illuminated with a spot from a laser beam, the result is astonishingly accurate. Using an instrument with a lens separation of 4 inches, repeatable accuracy of 1 inch is possible up to about 20 feet. Accuracy degrades to 2 inches at 30 feet, 1/2 foot to 50 feet, 1 foot to 90 feet, and about 5 feet up to 150 feet (if you can see the spot.) Using this instrument it is possible to make accurate, non-invasive measurements to inaccessible or environmentally sensitive areas.

Freezing in Colorado: Techniques for Surveying Extremely Cold Caves

Hazel A. Barton, NSS 38664RE and T. Evan Anderson, NSS 37478RE

Department of Surgery, C320 University of Colorado Health Sciences Center 4200 E. 9th Ave. Denver, CO 80262

Palmer Lake Ice Caves are a talus system in the foothills of the Rocky Mountains, forming part of an aquifer which supplies the nearby town of Palmer Lake. The heavy volume of water through the system makes survey trips easier during the winter, when the streams are frozen. Unfortunately, Winter causes its own problems. The cave lies at the bottom of a thermocline valley, with multiple entrances receiving little direct sunlight. As a result, the winter temperatures in the system drop below 20°F; cold enough to freeze your pack to the floor.

These severe conditions have prevented successful surveys of the system in the past. We have found some techniques which are allowing a more successful survey. Our observations include the useless nature of heated socks, how a woolly hat increases team moral more than promises of only one more shot, and a thermos of hot tea is great. More serious problems include sensitive frostbite injuries and the contraction of the metal in suuntos, causing them to 'freeze-up' in this environment . Despite the severe cold, we have encountered gorgeous ice formations and discovered that a linear distance of 30 ft on the surface corresponds to 1200 feet underground. With the lowest and highest entrances of the system being more than half-a-mile from each other, along with the complexity and multi-level nature of the intervening cave indicate that if the survey can be completed, Palmer Lake will rank among the longest granite caves in the world.

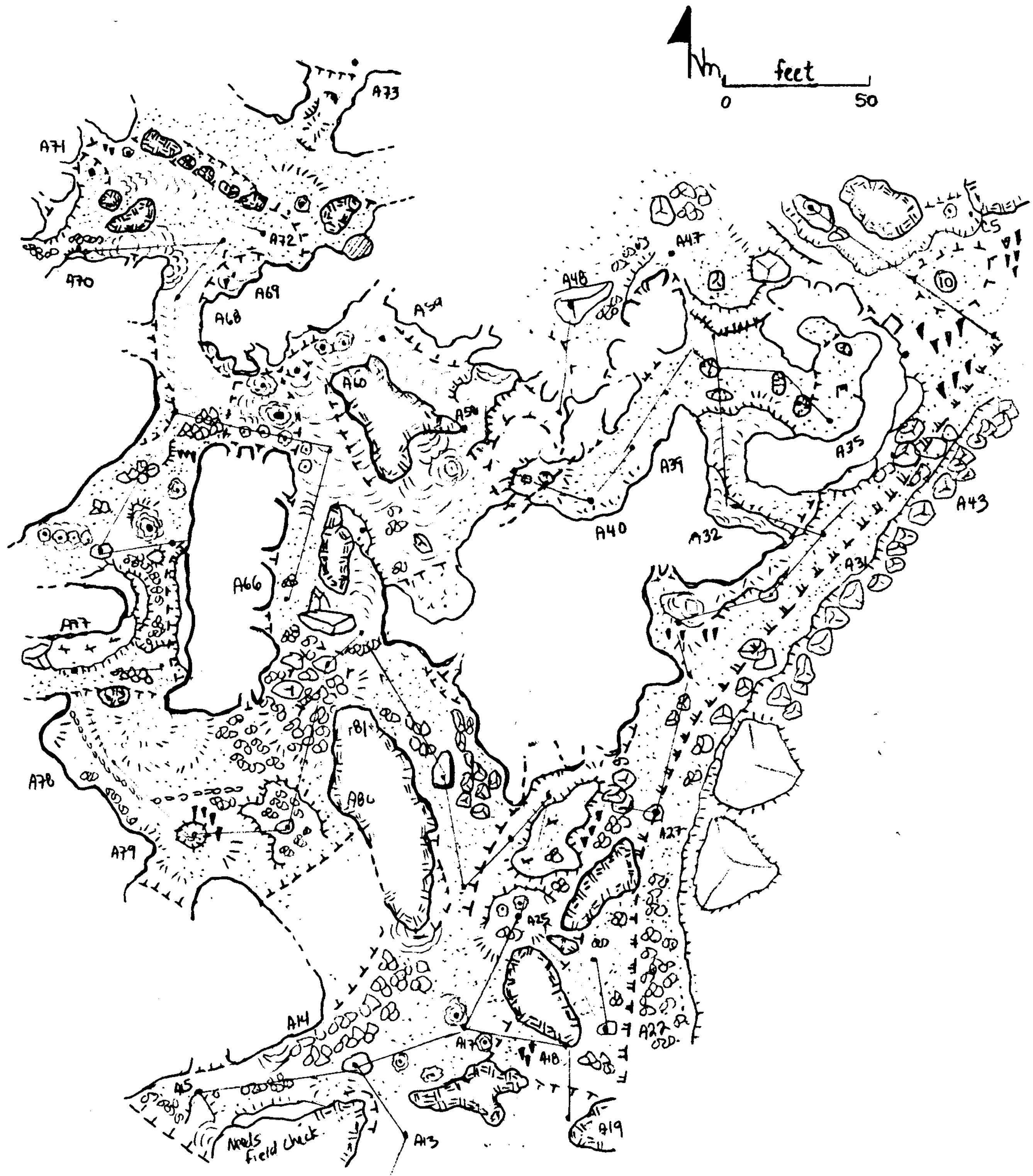
Automatic Underwater Surveying and Mapping

Fred Wefer, NSS 10845RL, P.O. Box 47, McDowell, VA 24458
Barbara am Ende, NSS 15789RE, 18912 Glendower Rd.,Gaithersburg, MD 20879
William C. Stone, NSS 12783RE, 18912 Glendower Rd., Gaithersburg, MD 20879

In October 1998 the U. S. Deep Caving Team will field an expedition to Wakulla Springs, a show cave in The Edward Ball Wakulla Springs State Park south of Tallahassee, Florida. The objectives are to continue the exploration, survey, mapping, and scientific study begun in 1987 by The Wakulla Springs Project and continued by the Woodville Karst Plain Project. Wakulla Springs is an underwater cave exceeding 5 km in length and 100 m in depth.

Surveying will be done automatically by a Digital Wall Mapper (DWM) mounted on a Diver Propulsion Vehicle (DPV). The DWM uses an inertial navigation system for determining the position and orientation of the DPV and a sonar device that simultaneously measures thirty-two wall distances for determining cross sections. Data are gathered several times per second; the resulting spacing of wall points being a fraction of a meter.

Within the DWM, data from the inertial navigation system, the sonar device, three pressure sensors, and a thermometer are stored in an on-board computer. When the DPV returns to the surface the data are downloaded to a Personal Computer (PC). The PC reformats and writes the data to a zip disk which is then transferred to a Silicon Graphics workstation. Nine separate programs, written in ANSI C and using OpenGL for graphics support, comprise the software suite. A three-dimensional interactive cave map is produced with minimal human intervention. This paper describes the hardware and presents some details of the software being employed.



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