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Survey and Cartography Section

COMPASS & TAPE

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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.

NSS Convention Session: SACS sponsors a Survey and Cartography session at each NSS Convention. Papers are presented on a variety of topics of interest to the cave mapper and cartographer. Everyone is welcome and encouraged to present a paper at the convention. Contact the Vice Chair for additional information about presenting a paper.

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.

Back Issues: Back Issues: SACS started in 1983 and copies of all back issues of *Compass and Tape* are available. The cost is $1.00 per copy for 1-2 copies, $.75 per copy for 3-6 copies, or $.50 per copy for 7 or more copies. Add $0.50 postage for one copy or $1.00 for two or more copies ordered at once. Order back issues from the Treasurer.

Overseas Members: Overseas members: SACS welcomes members from foreign countries. The rate for all foreign members is US$4.00 per year and SACS pays the cost of mailing *Compass and Tape* via airmail. We regret that all checks must be payable in US$ and drawn on a U.S. bank. Send cash at your own risk.

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INSIDE:

Front Cover: Graphic referred to on page 10 of Greg Passmore's article "Creating High Fidelity Cave Models - Part 1 in this issue.

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SUBMISSIONS

All types of materials related to cave survey and survey data, cartography, and cave documentation in general, are welcome for publication in *Compass & Tape*. Manuscripts are accepted in ANY form but are most welcome on 3.5 inch diskettes either IBM compatible or Mac format or via email. Typed material is next best although we will accept handwritten material as long as it is legible. Artwork is any form. shape or size is also welcome. Send all submission for *Compass & Tape* to:

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NSS Survey and Cartography Section Meeting Minutes, 27 July 2001

Vice Chairman's report:

Roger Bartholemew raised the issue of scheduling talks and critiques. He said that we should recruit more papers and ask membership to bring uses of new devices and techniques to the session.

Treasurer's Report:

Bob Hoke handed out a summary of the financial report. Basically, two thirds of the balance is in CD, one- third is in checking $3300.00 available. Expenditures - 2 issues of Tape & Compass, 225 copies @ $450.00 total.

Editor's Report:

Pat has published 2 issues plus a special issue devoted to critiques from past cartography salon. Bob Thrun suggested publishing smaller volumes at greater frequency, possibly including more published maps. Pat prefers to gather enough material with a given theme to make up a volume.

Bob Thrun suggested reprinting old useful articles along with relevant updates. Pat reports that she already includes reprinted articles in some issues.

Vote on frequency of publication – 2 issues per annum

Electronic publishing possibility was raised:

Pros: Searchable, cost-effective to replace overseas mailings.

Cons: E-issues lost to future historians – need hard copy. E-pubs don't address quality issues. Editor has to transform articles to digital format. This is moot point since Pat sends layout to Bob electronically, and Bob scans issues. Have to buy server space.

Considerations: Need author's permission to post articles on web. Should be password-protected to encourage continued subscription to the section, and to discourage indiscriminate dissemination of articles.

Membership voted to continue paper publications, research electronic publishing further, and discuss issue next year.

The *Compass & Tape* Special issue for the 1999 Cartographic Salon was great success. Critiques for this year's salon have already been returned to contestants, so aren't available for publication.

Rod Horrocks noted that the judging sheets from 1999 salon were edited and changed for publication, which made some feel that the maps had been re-judged. The prevailing opinion is that critiques should be polished and summarized to emphasize the educational content and smooth over personalized comments.

Steve Reames said that personalized comments that are appropriate between critic and cartographer should be softened for general consumption.

Pat Kambesis suggested that since certain criticisms consistently recurred in the 2001 salon, these issues could be generically addressed without having to retrieve critique sheets from contestants this year. If a special issue is not published this year, Pat will include a summary of the cartography salon in a regular issue.

Selection of maps for special issue should include also-runs and medal winners to illustrate pitfalls as well as good techniques. Fabricating a flawed map to highlight all the wrong techniques (and consequent areas for improvement) would be be constructive, since good technique tends to be invisible in a well-prepared map (which is why its a good map!)

Scott and Hazel will be asked to collect critiques for this year's special issue.

Bob Thrun suggests that we don't have an annual special issue because it will become repetitious.

Pat said that cartography is evolving quickly with the use of computers, new problems will arise annually.

Bob Thrun would like to see an article explaining how to scan pen and paper maps to a crisp computer format.

Steve Reames reported on this year's Cartography Salon There were 32 maps entered. The display area was favorable, except that there was no privacy for the judges. Next year in Maine, we will take Jim Kennedy up on his offer to take digital photos of the maps, which will be projected in a private auditorium so that judges may review them without interruption.

The topic came up of whether previously entered maps be permitted for resubmission if they have been altered?

- copyright law says that a 20% change constitutes a new docment. So how much should be changed to be allowed as a re-entry?

- possibility of accounting for the submission history when judging.

* Rule * can't re-enter a map that has won a blue ribbon or a medal in an NSS salon.

A new section of the same cave may be submitted as a new entry.

Re-submission tends to discriminate against hand-drafted maps. How to encourage the submission of hand-drafted maps in the Master cartography division?

Add the following questions to the entry form:

- Has this map been entered in competition?

- Has this map won a blue or gold award in a NSS Cartography salon?

Add caveat that suitability of maps for entry in competition is left to the discretion of the judges.
Workshops:

Sketching workshops have been successful in the past. For NSS 2003 in California there may be computerized drafting, CADD facilities available, so computer drafting could be offered. Would need teachers in selected programs, e.g., Illustrator, Corel Draw, Canvas, Freehand, Compass, Walls. These could be offered as a ½ day workshop.

Since the caves are far away, it was suggested that a pre-convention sketching workshop be offered with a trip to Crystal Cave on Sunday so that participants aren't pulled away from sessions for a whole day of in-cave sketching practice.

Elections

Bob Hoke moved to re-nominate the existing slate of officers. The motion was seconded and passed.

Meeting adjourned at 3:00pm.

Minutes submitted by Suzanne DuBlois

2001 Cartography Salon Report

by Steve Reames

We had another great Cartography Salon this year in Mt. Vernon, Kentucky. The convention staff gave us a nice location in the east hallway of the high school, strategically located between the sessions. I don't think there was a single person at convention who didn't pass by the maps at least three times.

There were 32 entries by 23 cavers this year. The number of entries in each category were 15 in Apprentice, 6 in Experienced, 10 in Master/Professional, and one for display only. In my opinion, the maps are getting noticeably better each year, with some fairly impressive entries in the Apprentice category.

The critique session on Friday was well attended, to the extent that the hallway was completely blocked. This tended to annoy passers-by, but the cartographers appreciated the feedback from the judges.

Next year, Jim Kennedy has volunteered to lead an experiment. Rather than having the critique in the hallway, it will be in a classroom. Jim will take digital photos of the maps, put them into a PowerPoint presentation, and project them on a screen. The judges and participants will then discuss the maps in a somewhat quieter environment. Jim plans on taking a big picture of each map, and then detailed close-ups of particular things that the judges want to point out.

I would like to thank all the judges who did the real work while I shuffled papers. Not only did they miss out on some of the convention, but they were constantly interrupted while trying to judge—that's one of the disadvantages of having a good location.

Apprentice Category Judges: Jim Currens, Rod Horrocks, Pat Kambesis

Experienced and Master/Pro Category Judges: Hazel Barton, Jim Kennedy, Carol Vesely

We look forward to another good salon at the next convention in Camden, Maine which will be held during the week of June 24-28, 2002.

The award winners for the 2001 Cartography Salon were:

Apprentice Category:

Jason Meneely - Honorable Mention - Colliers Cave

Jim Olsen - Honorable Mention - ANFO Cave Complex

Terry Ragon - Honorable Mention - Alabama Caverns

Terry Ragon - Honorable Mention - Walter Michauds Mudhole

Dave West - Honorable Mention - Cave Mountain Cave System

Jim West & Kenneth Story - Merit Award - Cavin Cave

Dan Henry - Merit Award - Madison Blowhole #2

Experienced Category

Robin Barber - Merit Award - Cueva del Agua 1

Paul Burger - Merit Award - Breezeway Cave

Master/Professional Category

Jim Coke - Honorable Mention - Muknal Remote Siphon

Joel Despain - Honorable Mention - Hurricane Crawl

Joel Despain - Merit Award - Soldiers Cave

Pat Kambesis - Merit Award - Bull Cave System

Best of Show

Carlene Allred - Gold Medal - Wonderland, A Portion of Kazumura Cave

Pen and Ink: A New Salon Category?

by Steve Reames

Historically, the NSS Cartography Salon has been divided into a number of categories. The first grouping, which lasted for many years, was by cave length. This acknowledged the increased difficulty in mapping longer caves. As time went by, several different boundaries of separation were tried and discarded. It was only a few years ago that the salon had a "computer cartography" category because computer-generated maps couldn't compete with pen and ink. Times have changed; now I often hear the comment "I can't compete because I don't have access to that kind of computer hardware." Today, the divisions are based on cartographer skill: Apprentice, Experienced, and Master/Professional.

First, let's examine the purpose of categorizing entries. The reason we separate entries is to address a perceived difference in maps or map-makers. The idea is to create an environment where those of lesser experience can create competitive maps by virtue of skill and perseverance. No one likes a contest where the same skilled contestants win year after year, with no hope of breaking their entrenched position. Encouraging novices to compete and improve their skills is one of the explicit goals of the Cartography Salon. But there is another argument, less frequently used, for justifying a category: preservation of an art that may be lost.

This second reason is used by the NSS Vertical Section in their annual climbing contests. The division between mechanical ascenders and knots was originally designed to allow competition between those could not afford the expensive, new-fangled mechanical ascenders. Although they are not exactly cheap, there remains virtually no cavers that do not own a set. I'm willing to bet that every competitor in the knots category also has a pair of mechanical ascenders out in the car. The original reason for this division by ascender type is long gone, but the category endures. This is because the Vertical Section has made a conscious decision that they don't want the skill of ascending on knots to be lost forever.

It may be time to ask ourselves a question: do we want to preserve the skill of creating pen and ink maps? Some may question whether pen and ink is going away. There is little doubt of this. Blueprint machines are being replaced by large-format photocopiers. Although 36-inch wide machines are common, it is becoming difficult to find 42-inch wide ones. The smell of ammonia has evaporated from blueprint shops as velum is replaced by CAD programs. Finding a PMT machine is all but impossible, so the time-honored trick of reducing a pen and ink map by 10% to increase sharpness no longer is available. How much longer will we be able to purchase our treasured Rapidograph pens?

In the past we created a category to protect the infant industry of computer-based cartography. Now, as more and more awards go to computer-based maps, is it time to create a category for pen and ink?

[Please send your comments to the editor of *Compass and Tape* so we can all read and consider them. If you wish to send private comments to the author, he can be reached at reames@diskdrive.com]

Experiments in Creating High Fidelity Cave Models
Part 1 – Getting the Data

Greg Passmore[1]
3D Pipeline Corp.

Overview

For the last 10 years or so, I've been experimenting with ultrasonic scanners, LIDAR, and stereo photogrammetry as ways of improving the quality and detail of cave maps. The goal of increasing the amount of available measurement data has been to produce a more realistic representation of cave geometry. Once obtained, this geometry can be used for visualization, finite element analysis, meteorological studies, and resource management. This brief article discusses the successes and failures of this work to date.

Getting the data

Conventional survey methods record 5 distances at each survey station; up, down, left, right, and the distance to the next station. Four of these can produce a crude passage profile. In order to augment passage profile data, the surveyor will often hand sketch their impression of the passage cross-section located at the survey station. In essence, the goal of my work has been to improve the accuracy and frequency of passage profiles. In an ideal scenario, thousands of highly accurate passage profiles could be semi-automatically produced to yield tremendous detail about the cave. Such profiles would need to be axis aligned along the survey path. Although this geometry data is sufficient for many applications, the addition of wall photography can be used to produce highly realistic renderings. The only remaining data that a typical user may be interested in, are three dimensional labels that can be used to interactively call-up additional information. Such ancillary information may include formation names, temperature measurements, surveyors comments, and similar spatially related information. The result from of this mass of data results in something similar to a GIS system. By adding in an additional real time rendering engine, the user may also explore the cave, both externally and internally. A 3D engine of sufficient power would be able to utilize the available data to produce interactive photo-realistic renderings.

Current State

Before moving on to a description of the tools and techniques to gather such data, I'd like to briefly discuss the current state of the technology. None of the techniques explored thus far are suitable for adequately representing talus caves. In addition, caves with exceptionally large and complex rooms would need to be surveyed in sections and reassembled. The process of reassembly is, in itself, a large and complex task requiring page stitching, re-tesselation at boundary edges, and geometric warp to compensate for measurement errors.

The current techniques are ideally suited for phreatic passages, canyons, and maze caves. Only in the last year have I begun to test the process on entire caves, rather than on small sections of passages. That being said, the technique can also be useful for the representation of significant sections of caves or formations without specific regard for their context within a larger cave system.

It should also be stated, that the goal of this project is not to eliminate the surveyor or the artist in the process of cave mapping. The tools and processes described are intended to help the surveyor produce a more scientifically accurate representation of their work. It is also not intended to eliminate the artist from the equation. The admirable goal of producing beautiful cave maps is separate from the goal, in my opinion, of producing highly detailed scientific datasets. The production of an interactive photo realistic cave will never replace the utility or pleasure associated with using either a simple or intricately complex hand drawn a map. However, the data sets produced with techniques like those described in this paper provide a utilitarian benefit for study that may be not possible with more artistic representations of cave passageways.

Survey Paths

The process builds upon the standard cave survey. Only two additional elements are added; more numerous and detailed cross sections, and passage photography. Added to a minimum, the passage profile is measured at each survey station. A somewhat better data technique, which is already practiced in most cave surveying is to measure passage profiles at each significant change along the survey path. Ideally a nearly continuous set of passage profiles are measured of a lot of the survey line. Obtaining a relatively crude passage profile can be as simple as using a hand-held ultrasonic tape. Instead of the usual up, down, right wall measurements, the surveyor would take a set of distances at regular intervals. Using a hand-held device, its reasonable to take 11 measurements at 45 degree increments. In labor force approach, the surveyor can adopt this method along the survey aligned at each significant passage change. Such measurements are likely to be less detailed, but more accurate, then simple sketching of passage profiles. Clearly an alternate technique is necessary. Before continuing, I would like to point out the somewhat obvious fact that the passage profiles need to be orthogonal to the survey line and preferably measured from the survey aligned access. In my experience doing so requires a inexpensive handheld laser if the measurements are going to be taken between survey stations.

Passage Profiles

I have tried reducing the labor intensity of obtaining passage profiles in three ways; ultrasonics, LIDAR and photography.

In the early 1980's I experimented with placing an ultrasonic transducer on a rotating stepper motor. The device could quickly capture 72 measurements about the radial axis with an accuracy of one-tenth of an inch. This " radial ultrasonic scanner" was a nifty device. However the early device was wire wrapped and fragile. Also, problems of ultrasonics upon varying materials made the device somewhat unreliable. I've always had difficulty getting reliable results from water surfaces and goopy mud floors. The ultrasonic transducer I was using also had a limited range of 35 feet. I still believe that this type of device is suitable for experimentation and general use, but only if one were to undertake the efforts to manufacture a substantial number of well packaged units.

In the last several years, laser ranging devices have become commercially available. These devices, called LIDARs, are normally designed for rasterizing depth fields at high resolution. Although neither cheap or portable, they offer extreme accuracy, often down to microns. I have yet to find a LIDAR I can modify for radial passage profiling, but these devices are ideal for spot digitizing significant items (such as large formations) or producing digitized wall sections for later stitching into the main cave model. We are taking delivery on a new LIDAR system in October and I expect to report our results here in *Compass and Tape.*

Photographic Passage Profiling

One other option for producing passage profiles is to eliminate all of the fancy gadgets and to make use of something every survey team usually has: a camera. The primary issue of capturing passage profiles with the camera is determining how to narrow or highlight the region of interest in the photograph to that region which is specifically axis aligned to the survey line. One would think for example, that backlighting a passage would be sufficient to trace the passage profiles. In practice however, it is difficult to discriminate where on the photograph the actual cross-section line exists. An alternative approach, is to use a simple pen laser to manually outline the desired cross-section. This surprisingly simple and low-tech approach appears to be one of the most useful. Unlike radial laser and ultrasonic scanners however, the user must post process the photographic data in order to derive the profile geometry. This is simplified of course, when a digital camera is used.

Once the in-cave photographic imagery is available in the computer, a simple outlining utility is used to trace the passage profiles. One additional downside to this technique is that the laser light may be partially occluded by portions of wall between the camera and point of intersection between the laser and passage. This problem does not occur when using laser or ultrasonic scanning. In such case, the user can refer back to notes and memory to approximate the passage profiles in the missing areas.

Once the general survey is completed and all passage profiles recorded, all of the basic geometry associated with the survey can be processed to produce the final geometric model. As mentioned above, this is a bit of an oversimplification since most caves have at least a few complex areas where passage profiling insufficiently represents reality. Also passage profiling cannot reliably represent talus floors, waterfalls, complex formations, or other areas where shadowing occurs from the survey line axis. Nevertheless, passage profiling can capture the majority of geometry in " well behaved " caves. It also provides the baseline geometry that we can later build upon.

Adding Large Detail

I don't intend to go into lot of detail here about the process of adding high-resolution inserts. However, one of the earliest lessons learned from building 3D models of caves is that many interesting features must be captured separately and integrated into the baseline model. It is here that sophisticated and high resolution LIDAR scanning systems greatly help. Large and complex formations can be standard with intricate detail and merged into the baseline geometric model. The actual process of merging, stitching, and blending high-resolution inserts into a baseline model can be tedious and complex. At the moment, I have predominantly worked with off the shelf software to perform this task. In the last several months, more complex stitching and welding software has become available from universities and companies using LIDAR scanning systems.

Additional complications such as large breakdown or delicate formations such as soda straws can be built as independent models and also added into the baseline geometry. Although I have not had the time to implement this, the ideal solution for adding in breakdown, simple formations, and similar items would be to use a model library for drag-and-drop insertion. One can imagine a Visio class interface for 3D cave objects, much like 2D cave symbols are used within drafting tools today. At least in my case, the trick is finding the time to program such a productivity application. In the meantime, I have been relying on 3D Studio Max and NuGraf to perform these operations.

Adding Small Detail

At some point, the geometry to be added becomes insignificant in size. A good example of this is gravel. The level of detail required for geometric representation needs only to be as high as that necessary to yield appropriate occlusion during rendering. Macro and micro detail are best handled as photographic texture and bump maps in the model. The purpose of photographic texture maps is to create a more realistic surface representation. Photographic textures, used in this context to refer to ambient light textures, can only represent color changes of the passage walls. To represent macro and micro geometric detail, a bump map is constructed which represents varying surface orientation, rather than simple variations in color. These variations in surface orientation are stored as a surface normal map. During the rendering process, these normals are used to perturb the base geometry facet normals to yield the appearance of high-resolution geometric texture. The use of bump maps increases the visual realism while reducing the geometric complexity of the overall cave model. This is critical for real time rendering and reasonable competition times for finite element analysis.

Photographic Mosaic

In the section above, I discussed using the photographic and bump mapping techniques for increasing detail. Let's take a few moments and discuss the process of producing these types of images.

Capturing photographs of a caves walls, ceiling, and floor is relatively trivial. However, the normal photographs of cave passages are not suitable for texture mapping. The reason is that fixed lighting is built into a normal photograph. For example, a scalloped wall photographed by back light will not render correctly when the light source has been moved during interactive exploration. The shadows in the photograph which have been texture mapped onto the wall will remain fixed since the information about the light location has been lost during the process of photography.

A better way to represent a scalloped wall is through the use of a combination of ambient light textures and bump maps. To capture this information, a ring flash is placed on the camera to eliminate all shadows. The wall is photographed in this shadow-less method to capture only the color variations of the wall surface

A second photograph is taken without the ring flash. The second photograph is lit by flash as an optimal angle to capture the geometric detail of the wall. This second photograph, the bump map reference image, is used by an artist to derive the surface angles that represent the varying geometric complexity of the wall surface. When these two images are combined during rendering, the resulting model provides the data necessary to represent the shading of the surface irrespective of lighting location. Figure 1 shows an example of bump mapping a surface. Note the right edge of the cylinder; there is actually no geometry to support the lighting, so the edge looks flat. More information on bump mapping can be found in mainstream computer graphics literature.

It's one thing to capture a single image of a wall, but doing entire cave requires the production of a photo-mosiac. The photo-mosiac is produced by generating a set of overlapping photographs of cave passage. Early attempts at producing and these mosiacs were done by using a standard digital camera with the equivalent of a 55 mm lens. The problem with acquiring photos in this way is that a huge number of photographs are required to produce mosaics of even a relatively short section of passage.

Current work is focused on using a fisheye lens to capture 180 degrees at a time along the survey line. These 180 degree photographs are then mosaiced together to produce a long continual passage texture map. Regardless of the type of lens used, each image must be geometrically and photometrically normalized to prevent obvious boundaries between the photos. Although this could be done, rather painfully, in a standard program like Photoshop, I have opted to write a custom program to perform this process automatically. Regions of particular interest, like an outstanding formation, are still photographed using normal lenses and inserted into the mosaic. In this case, minimizing visual boundaries is done by using a feathered cross-dissolve at the boundary edges.

Part 2

This completes the description of how the data is actually captured. In part two of this article, I will discuss the reconstruction and rendering process. For a hint at how this reconstruction occurs, see the short article on page 15 in this issue by Tom Lesperance. The trick in reconstruction lies in the passage intersections and Tom has implemented a novel technique using implicit surfaces to solve this problem.

Getting involved

As a final note, if you're interested in getting involved in this project, drop me an email. I am looking for detailed survey data for testing. Data will not be redistributed or published without written consent and upon consent, full credit will be given. We also have a small research grant that can be used to help fund field survey efforts. I am looking for surveyors who are willing to capture data for this project. Using our grant, we can cover out-of-pocket expenses as an (admittedly minor) incentive for participation.

The International Foot versus the U.S. Survey Foot
or
The Case of the Galloping Caves

By Larry Fish

How long is a foot? It seems like a silly question, but it is a question that can have a dramatic effect on the accuracy of your cave data. Currently, there are two common standards that define the length of a foot. One is called the ***US Survey Foot*** and the other is called the ***International Foot.*** The ***Survey Foot*** is about 0.000024 inch longer than the ***International Foot.*** This may not sound like much, but if you are working with UTM coordinates in the northern United States, that small difference can make a 35-foot difference.

BACKGROUND.

I first came across this contradiction back in the early 1960's when I took a geology course. The teacher told us that most maps used the ***US Survey Foot*** when units were displayed in feet. Many years later, as I began to add geographic references to **COMPASS**, I remembered the class and decided to use the ***US Survey Foot*** whenever the program displayed coordinates in feet. After I did that, several people complained that **COMPASS** coordinates were slightly off when compared to other survey programs. Ultimately, I traced this discrepancy back to my use of the ***Survey Foot*** and the fact that other programs were using the ***International Foot***. At the time, I thought there were good arguments for using the ***US Foot,*** but I did not want to go on a crusade, so I chose to fall in line with the rest of the programmers and use the ***International Foot.***

It turned out that this was a mistake. A few months later I got an email from another caver who complained that when he tried to use the latest version of **COMPASS**, his cave had moved 10 feet and the cave coordinates no longer matched the GPS positions he had so carefully collected. I was beginning to realize that I needed to have a better understanding of these units, and so I began to do some research. Here is what I found:

HISTORY.

Over the years, several different standards have been used to define the relationship between meters and feet. In 1866, an Act of Congress declared that the meterwas exactly 39.37 inches. This made the foot exactly 1200/3937 or 0.304800609601 of a meter and the inch equal to 2.54000508001 centimeters. This standard later became known as the ***US Survey Foot*** and is often referred to as the ***US Foot.*** (To make things even more confusing, during this same time period, Britain and Canada adopted a different standard where a foot was set to be 0.3047994 of a meter.)

In 1933 the U.S. Coast and Geodetic Survey (USC&GS) developed a mapping system called the State Plan Coordinate System. Because it used the NAD27 model for the shape of the earth, it was called the SPCS27. It specified the ***US Survey Foot*** as its standard of measurement. As a result, many maps, surveys and benchmarks have been created using this system.

In 1960 the National Bureau Standards in conjunction with similar agencies in other countries, attempted resolve the conflict between the different systems by adopting a new standard. This became known as the ***International Foot*** and it set the conversion factor to be 0.3048 of meter which makes the inch equal to exactly 2.54 cm.. Unfortunately, so many surveys and maps had used the old standard, that a special exception was created that exempted surveys and mapping from the new standard. Thus maps generated after 1960 still used the ***US Survey Foot.***

Finally, in 1983 a new State Plane Coordinate system was developed using the NAD83 model for the earth called SPCS83. At the time there was still a controversy about which units should be used. Rather than take a position, the new standard specified meters as the unit of measure. Individual states were left to choose their own standard for the Foot. Today, 11 states mandate the US Survey Foot, 6 the International Foot and the rest default to the metric units specified in SPCS83.

Even into the late 1980's other arms of the government were mandating the ***US Survey Foot.*** For example, in 1989 the Federal Geodetic Control Committee officially adopted the ***US Survey Foot*** for all federally funded projects.

CONVERSION ISSUES.

Now that the history is clear, lets look at how these issues effect real world situations. First of all, these conversion issues don't become a problem until you are dealing with very large numbers. If you are measuring your house, your car or your average cave system, the difference is infinitesimal. Even over a ten-mile distance, the difference between the two units is only about an inch. However, if you are working with the larger numbers, the discrepancy can be large. For example UTM coordinates are based on the distance from the equator and a meridian. These numbers can be very large and so the conversion differences can be significant. Discrepancies as large as 35 feet are possible in the northern United States.

These problems only occur when you convert between units. The meter itself does not have multiple standards, so there is no ambiguity if meters are used throughout your work. Even with feet, there is no problem as long as you consistently use the same type of feet. In general, if you keep the data in its original units, no problems can occur.

When you do convert the data, you have to think carefully about where the data came from and how it will be used. For example, if you are converting from meters to feet, you need to think about what kind of feet your GPS, maps or other reference system you will be using. If you are converting from feet to meters, you need to know what "type" of feet was used.

Multiple conversion can make any conversion issues worse. For example, if you convert a UTM coordinate to feet using the ***US Survey Foot*** and then convert back using the ***International Foot***, you will cause an error, not just a units discrepancy. This is most likely to happen if you are using differing software packages that support different units. Each transfer can cause increasing errors.

GIS AND MAPPING SOFTWARE.

Today, most mapping is done by computer and there is a great deal of variation in how various GIS packages handle US and International units. For example, ESRI, which produces some of the finest GIS software (i.e. ArcInfo and ArcView,) has different formats formats different programs. ArcInfo uses ***US Survey Feet*** when you select "feet" but you can set your own custom units to get ***International Feet***. Some ESRI programs give you the option of either unit, others are hard coded to the ***Survey Feet***. (ERSI plans to support both units uniformly in their next release.) Generally speaking, GIS software is standardized around the ***US Survey Foot***. Drafting programs such as AutoCad (which can also be used for GIS purposes,) tends to standardize on the ***International Foot.***

I have found no cave survey programs whose documentation addresses the two units. Judging from my own experiments, most cave survey programs use the ***International Foot.*** Given my experiences, all **COMPASS** programs now give the user the choice of either unit!

WHAT UNITS SHOULD YOU USE?

Although there has been a slow migration toward the ***International Foot***, many institution still use and mandate the ***US Survey Foot.*** Further, considering that many older maps, benchmarks, control points and surveys have been done using the ***US Survey Feet***, the standard is not going to go away anytime soon. This means that you need to be careful when you are working with large numbers and feet. Here are some general guidelines:

1. Non-Georeferenced Caves.

For caves that are not tied to some kind of reference system, the choice of units doesn't mater. Even in the longest cave systems, the straight-line distance between the furthest extremes is only a few miles. These values are just too small to make a detectable difference. For example, even across the entire extent of all the caves in the Mammoth Cave system, the discrepancy would only be about 1.5 inches. The difference between the two units only becomes significant when the distances reach 100 miles.

2. Maps.

Most USGS topographic maps were originally generated before 1983 and will be based on the NAD27 data and SPCS27. Any feet units that appear on the map will be ***US Survey feet.*** Later maps based on NAD83 and SPCS83 may still use the ***US Survey Foot,*** depending on which state the map is in. Other maps will depend on the agency that produced them. If they were created with federal funds, they are required to use the ***US Survey Foot***. Maps generated before 1983 and based on U.S. Coast and Geodetic Survey (USC&GS) data almost certainly use the ***US Survey Foot.***

In spite of all this, it worth noting that the resolution of a paper topo map is such that a 35 foot error would be virtually invisible. For example, on a 7.5 minute paper map, a 35 foot discrepancy amounts to just 0.017 inch.

3. UTM.

UTM coordinates are specified in meters and almost always displayed in meters. As long as you maintain meters no discrepancies can occur. If you do choose to display UTM coordinates in feet, you need to think carefully about how they will be used. If they will be referenced to benchmarks or maps that use the ***US Survey Foot***, you need to be sure that the appropriate units are used.

4. Digital Data.

With the advent of computers, more and more mapping data is now available in digital forms such as DEM's, DLG's and DRQ's. This data is georeferenced in a variety of ways. For example, 7.5 minute DEM's are referenced to UTM and one degree DEM's are referenced to Longitude and Latitude. The DEM specification also allows for State Plane Coordinates, but I have never seen it used.

Unfortunately, the resolution and quality of DEM's makes the units issue almost irrelevant. The highest resolution DEM's have a point spacing of about 99 feet. In other words, the worst case discrepancy between units (35 feet) is only about one third of the point resolution of the DEM. Further more, the USGS documentation states that SDTS DEMs created before January 1, 2001 may contain up to 30 meters of horizontal error. My experience with DEM's is that the data is even worse, with anomalies, artifacts and errors, particularly in how they are georeferenced. For example, the downloadable version of the Mount Saint Helens DEM has internal inconsistencies of greater than one mile.

5. GPS.

GPS receivers will generally display locations in several different reference systems. I have been unable to find any information about which feet units are available on the most popular units. If you are planning to use GPS coordinates to set the location of your cave entrances, you need to be careful if you are working with feet.

6. Government Projects.

Although I did not do an exhaustive search of all government regulations and agencies, it appears that the Federal Geodetic Control Committee recommendations apply to most government work. If you are generating data for a government project, you may be required to use the ***US Survey Foot.*** By the same token, if you are referencing your caves to maps or surveys generated by a government project, you should be aware that any feet units are probably in ***US Survey Feet.***

CONCLUSION. Even though the ***International Foot*** is the world wide standard, in the United States, most maps and surveys use the ***US Survey Foot*** when they display feet. While it would be nice to have one standard, given the amount of old data and the inevitable inertia, it is not likely to change anytime soon. Besides, with properly designed computer programs, it is easy to convert and display virtually any kind of units.

Tunnel Reconstruction from Sparse Range Data Using Interpolated Implicit Surfaces

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Introduction

Implicit surfaces have been used for modeling complex shapes for use in computer graphics and CAD applications [4]. The construction of implicit surfaces has been studied recently in order to solve several problems creating and modeling implicit surfaces interactively [1]. Recent work with interpolated implicit surfaces use point data specified by the user to form an implicit surface representation of complex surfaces [2, 3].

The surface reconstruction of a complex tunnel network can be approached by using interpolated implicit functions to create a polygonal mesh representing the tunnel surface from sparse range based survey data. This technique offers an efficient solution to the problem of recreating a complex tunnel surface, which may have many intersecting passageways that cannot be realistically specified by geographical survey data.

Background

The initial structure of a tunnel system, or interior architecture, can be specified by a set of range-based measurements. These measurements can consist of a station identification number, position, orientation, and a series of distance measurements at various angles around the station's principle axis. These measurements can be used to construct a three dimensional polygonal structure of the entire system, including any intersections.

In order to find the interpolated implicit function representation of a surface, known points that reside on the surface must be specified. These points form the *boundary constraints* of the surface. Also, at least one known interior point must be specified, which forms the *interior constraint* point for the surface [2]. Using tunnel survey data, the range data measurements taken at each station form a set of points that reside on the surface of the tunnel. These points can be used to form the full set of boundary constraints used to interpolate the implicit surface function. Since the position of a measuring station can always be assumed to exist within the surface, the station position data forms the set of interior constraint points for the surface.

Once the constraint points are found from the survey data, an implicit function representation of the surface can be created by solving a system of equations representing a sum of weighted radial basis functions at each constraint point [2]. This implicit function representation of the surface can be polygonized using an isosurface extraction method that examines the intersections of the surface with a cubic lattice. The surface polygonization is then formed by a moving the cube along the surface defined by the implicit function and forming a polygon within the cube, which gives a geometric approximation of the interpolated implicit function.

Results

The results of using interpolated implicit functions to reconstruct a circular tunnel structure with a cross sectional pathway is shown in Figure 1. This illustrates how the entire system of corridors is constructed using the polygonized implicit function. Figure 2 shows that this technique is capable of dealing with T-shaped junctions. The raw data set for the T-junction shown in Figure 2(a) contains no explicit information about the intersect
ing tunnel paths, yet the geometry is reconstructed accurately. An inside view of the T-junction is shown in Figure 3.

Conclusions

Interpolating implicit functions provide an efficient surface reconstruction of tunnel and corridor geometry using sparse range data. The algorithm is capable of dealing with complex intersection such as T-junctions and cross intersections accurately.

The reconstruction of tunnel surface geometry could be combined with photographic information from the survey sight in order to reconstruct a complete three-dimensional model of the tunnel system. A catadioptric camera system could provide wide range views from the station measurement positions, which could then be mapped to the reconstructed geometry.

Further improvements in the surface reconstruction algorithms involve optimizations for speed and memory considerations using efficient radial basis function representation, which pro vide a faster and more efficient sparse matrix representation for evaluation and solution of the interpolated implicit function representation [3].

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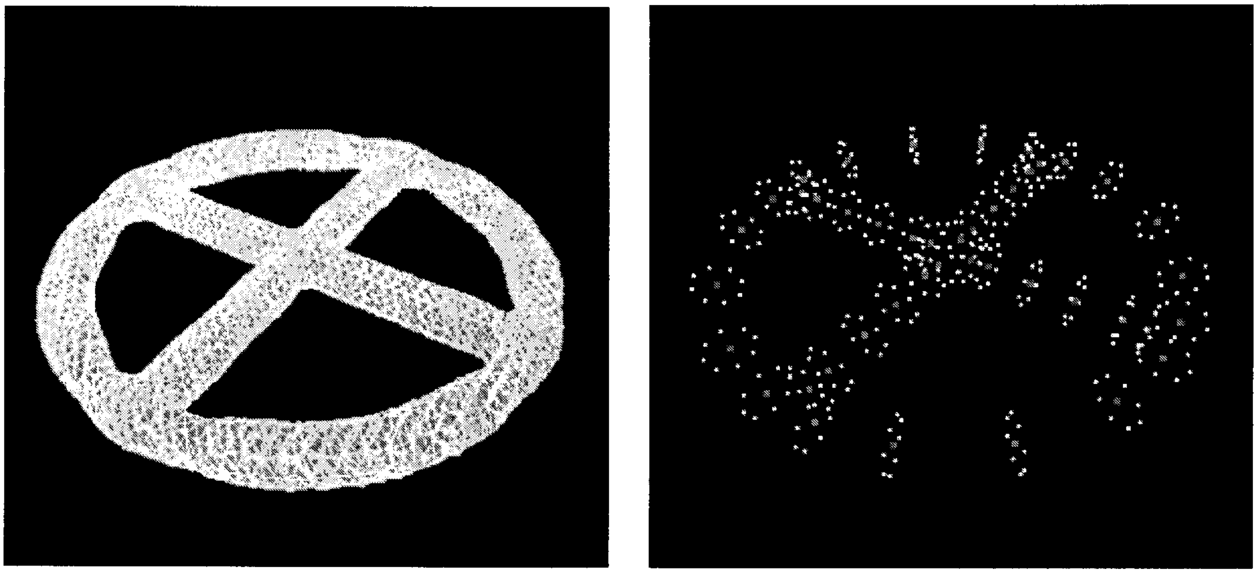
[2] G. Turk, H. Q. Dinh, J. O'Brien and G.Yngve. "Implicit Surfaces that Interpolate", *Shape Modelling International 2001* Genova, Italy, May 7-11, 2001.

[3] B. Morse, T. S. Yoo, P. Rheingans, D. T. Chen, and K. Subramanian. "Interpolating Implicit Surfaces from Scattered Surface Data Using Compactly Supported Radial Basis Runctions", *Shape Modelling International 2001* Genova, Italy, May 7-11, 2001.

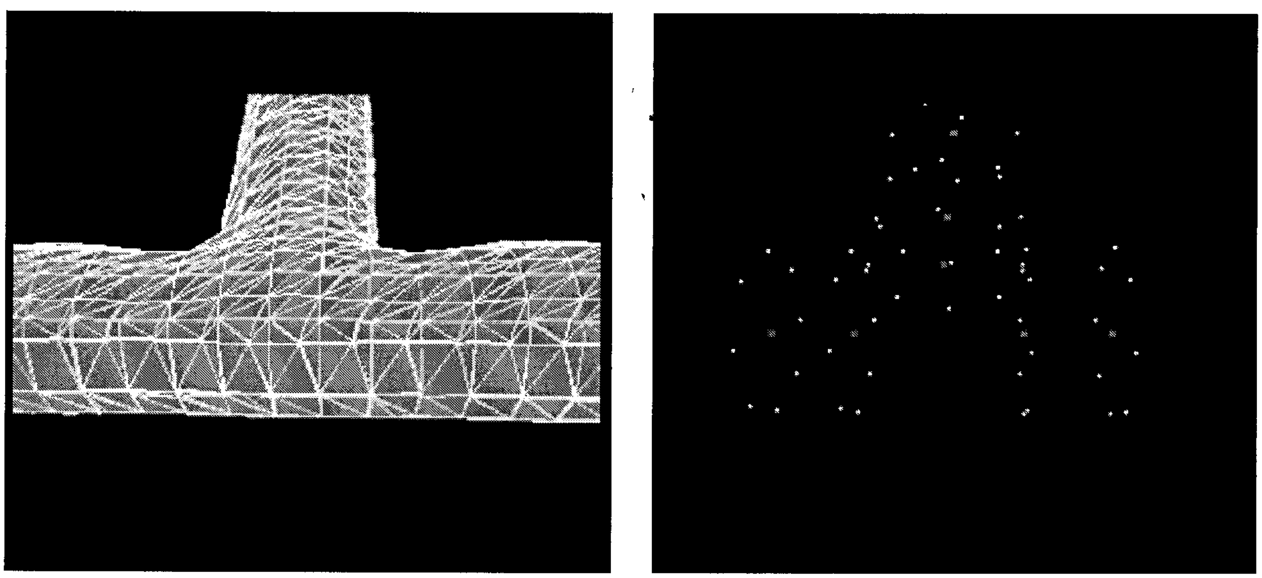
[4] J. Bloomenthal, editor. *Introduction to Implicit Surfaces*. Morgan-Kaufman, 1997.

[5] J. Bloomenthal. "An Implicit Surface Polygonizer", in P.S. Heckbert, ed., *Graphics Gems IV*, pages 324-349, Academic Press, 1994.



(a) (b)

Figure 1. (a) Polygonal reconstruction of the survey data shown on the right. (b) Raw survey data. Magenta points represent the station measurement positions. White points represent the distance measurements taken at a station point.



(a) (b)

Figure 2. (a) Polygonal reconstruction of a T-junction. (b) Raw survey data used in the reconstruction on the left. Magenta points represent the station measurement positions. White points represent the distance measurements taken at a station point. Note that no explicit information about the intersection is present in the survey data, only surface points and interior position points.

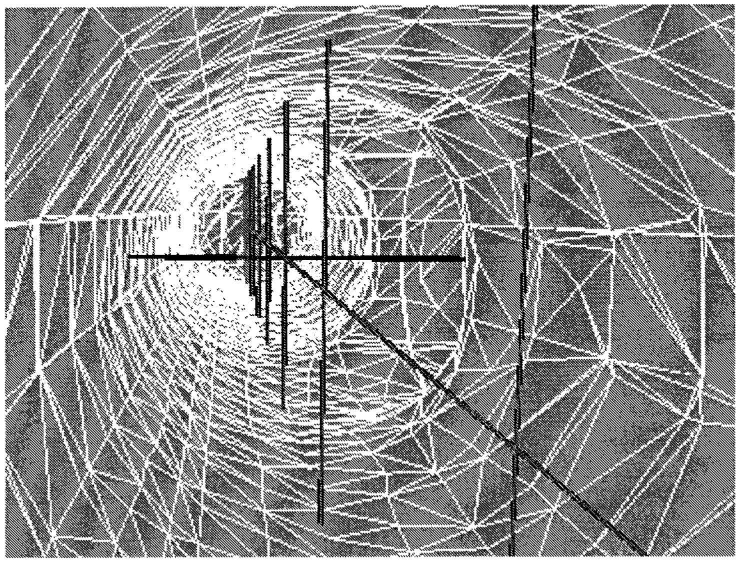


Figure 3. Inside view of the T-junction reconstruction shown in Figure 2.