Quick 3D Cave Maps using Cavewhere

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Cavewhere can create quick 3D working maps through a process called carpeting. Cavewhere implements carpeting with a 3D warping algorithm. It allows users to morph their two-dimensional cave sketches with line plot data. This paper presents the editors needed for the carpeting process: the Survey Editor and the Notes Editor. The Survey Editor allows users to enter shot data in a similar way to other survey packages like Survex, Compass, and Walls. The Notes Editor provides digitizing tools for cave sketches. After the user enters all the necessary information for carpeting, the warping algorithm morphs cave sketches in 3D. Cavewhere can display the results in interactive frame rates on standard desktop hardware. It can then export the results as a high-resolution image to aid with drafting a final map.

1. Introduction

Working cave maps are an important tool at the heart of every exploration project. Not only do they allow surveyors to orient themselves and keep track of known passage, they also show tempting leads that motivate cavers to return to systems again and again.

The complex nature of caves makes developing a working map that includes all the relevant details difficult.

Many cave systems have multiple overlapping levels. Furthermore, good cave maps have floor detail, profiles, passage offsets, cross-sections, and annotations [1]. For large cave systems, hundreds of hours of drafting can be required by multiple people to complete a map [2].

Generally on extended expeditions, cavers have little time to draft a working map. Instead, they rely on line plotting software such as: Compass, Walls, or Survex. Cavers can quickly enter data into these software packages to create three dimensional (3D) models of survey shot data.

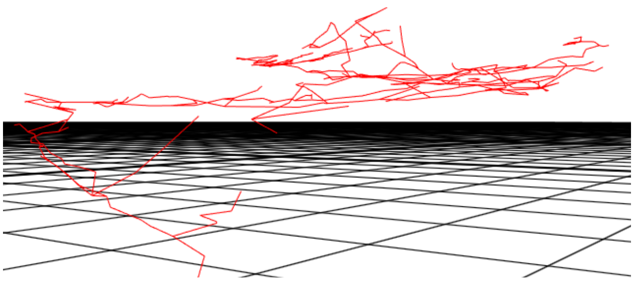

Figure 1 - A perspective view, looking north west, of the line plot of Quankou.

While 3D line plots expedite data visualization, they forgo several desirable map aspects. First, passages lack dimensions. Since all passages are visualized as lines, a large passage has the same visual impact as a small passage. Second, passages have none of the floor detail that is represented on the hand drawn map. Floor detail is extremely useful for locating survey stations, route finding, and resource inventory. Third, line plots are unable to show side leads. Finally, 3D line plot models can become indecipherable when presented in a format that doesn't allow viewers to manipulate them, as in figure 1.

Cavers have mitigated the problem of misrepresentation of passage size in pure line plots by collecting Left, Right, Up, Down (LRUD) measurements while surveying and developing software that uses this data to generate models that show passage walls like Compass and Survex. LRUD measurements are made up of four distance measurements from the station: to the left wall, to the right wall, to the ceiling (up), and to the floor (down). Unlike when collecting length, clinometer, and compass measurements, there is no standard for collecting LRUD measurements. They can become arbitrary, especially at intersections, in irregularly shaped passages, and when surveying down vertical shafts. LRUD generated models ignore floor detail, as well as wall detail between shots as shown in Figure 2. LRUD modeling tends to under or overestimate passage dimensions. This is exacerbated when shot length increases.

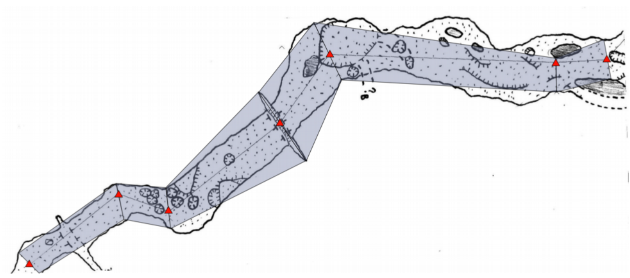

Figure 2 shows the deficiencies of 2D LRUD modeling (in blue) in comparison to a plan-view sketch.

Cavewhere combines the sketch with a 3D line plot through a method called carpeting, figure 3. Carpeting allows surveyors to understand the spatial complexity of the cave without sacrificing the passage detail from the hand-drawn map.

2. Data Entry

2.1. Overview

Cavewhere makes entering data and developing a working map an easy process. The process starts by scanning from the survey notes. Then users enter their line plot data using Cavewhere's Survey Editor. Finally, users cut out map sections for carpeting, using the Notes Editor.

2.2. Survey Editor

Once survey book pages have been scanned the Survey Editor interfaces allows users to enter normal cave survey data: station name, length, compass, clinometer, and LRUD for each station. It features an offset format similar to that of survey book pages as seen in figure 4. Just like in a survey book, Cavewhere's survey editor keeps continuous blocks of shot data together. Users need to create new blocks when entering data for divergent passage, such as a splay or a side passage.

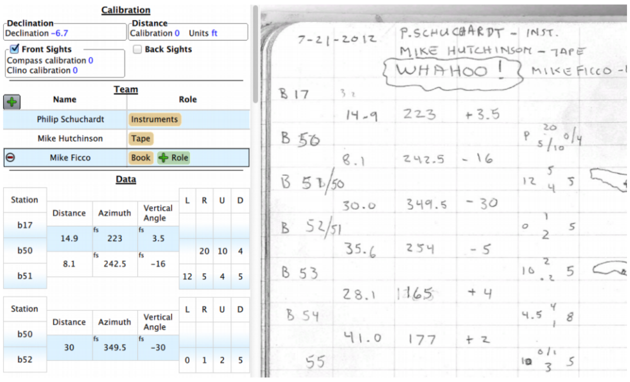

Figure 4 - Cavewhere's Survey Editor. The Survey Editor is made up of two parts: the Editor (left column) and the Notes Viewer (right column). The Editor shown 2 survey blocks with shots: B17 → B50 → B51, and B50 → B52.

Cavewhere automatically processes and updates the line plot as survey data is entered. It also updates the total distance surveyed, displayed at the bottom of the editor.

Cavewhere has smart error handling that prevents users from entering erroneous data, as well as automatic station name incrementing. For example, if the user enters a1→ a2 for the first shot, for the next shot the user only has to press 'Enter' for a2→ a3.

Cavewhere's editor doesn't lock users into its format. It can import and export survey data from and to Compass and Survex (Walls is in the works). Once data has been entered or imported users can create a model that unites the haste of line plot models with the detail of a hand drawn map in the Notes Editor.

2.3. Notes Editor

In the Notes Editor users can combine the hand-drawn map with a line plot in a process called carpeting. Carpeting is a two-step process that involves firstly, cropping the sketch with a polygon and secondly, digitizing all the station locations, shown in figure 5.

Cutting out the passage (hereafter referred to as the sketch) from the hand drawn map isn't an exact process. Users can quickly and roughly draw a polygon around the sketch using a custom shape cutting tool. The polygon should include the passage walls for best results. After creating the polygon, users digitize the stations on the sketch using the station marking tool.

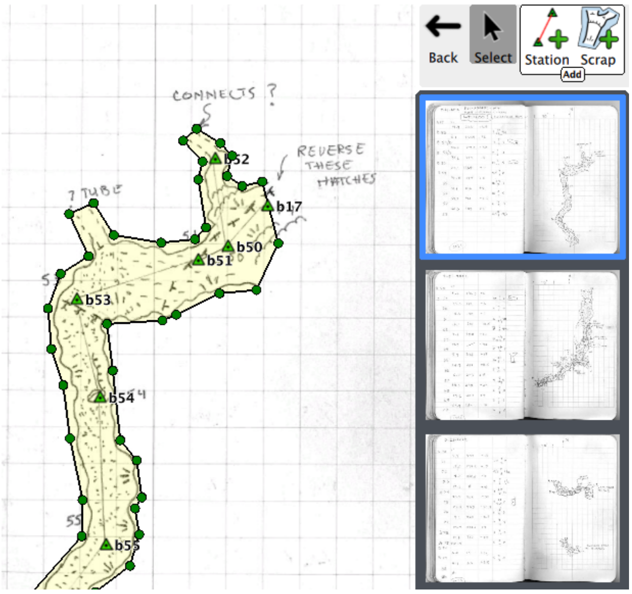

Figure 5 - Cavewhere's Notes Editor. This screenshot shows the polygon around the sketched plan, as well as the digitized stations.

Users can add station markers simply by choosing the station marking tool and clicking on the stations. After naming the first station marker, Cavewhere will automatically name all consecutive station markers by estimating the scale and rotation of the sketch, and analysing the survey data provided in the Survey Editor. Users can enter scale, rotation, and image resolution data to improve results.

These two steps are repeated for each sketch. Once the process is complete, Cavewhere will automatically carpet the sketch to the line plot data using sketch warping.

3. Sketch Warping

Sketch warping is a useful method for distributing the error in hand-drawn sketches. Sketch warping simplifies the map drafting process. When surveyors draw maps by hand there is error between the data and the sketch created. In Cavewhere, once stations have been digitized with the station marking tool, the polygon is deformed to make it fit the shot data using a warping algorithm. Unlike other 2D sketch warping software, such as Compass, Walls/Illustrator, or Therion, Cavewhere warps the sketches in 3D. Cartographers can easily draft a map using the results of the sketch warping algorithm.

4. Sketch Warping Algorithm

The warping algorithm uses station positions, as well as the cropped sketch, to create a 3D map in 4 steps:

1. The algorithm compresses the cropped sketch's image using a DXT1 compression algorithm. DXT1 is an OpenGL compression routine that provides 6:1 lossy image compression. This allows Cavewhere to store 6 times as many sketches on a graphics card and also improves rendering performance.

2. The algorithm triangulates the digitized polygon for the Notes Editor. The triangulation algorithm meshes the

polygon using a regular grid in the interior and an irregular grid to fill the space between the regular grid and the boundaries of the polygon. Users can adjust the grid resolution to produce smoother or coarser warp results.

3. Cavewhere warps the grid in 3D using station data. The warping algorithm uses a weighed averaging method to adjust the position of each point in a triangulated mesh. Cavewhere calculates the weight between each mesh point's and every station in the sketch using a distance function. The closer a mesh point is to a station the higher weight. Then the warping algorithm calculates the position of the mesh point in respect to each station. The sum of all the weighted positions produces the final mesh position, shown in figure 6.

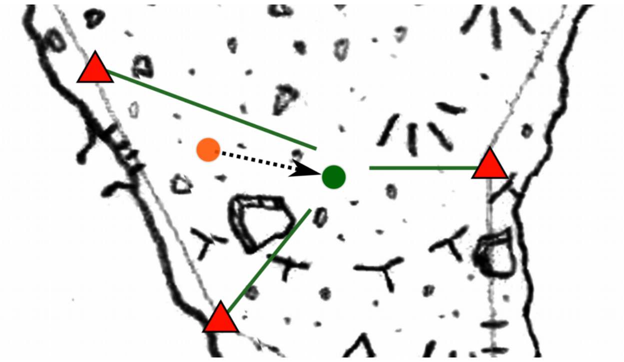

Figure 6 shows the stations (red triangles) projecting (green lines) where a mesh position (orange dot) should be located. The resulting warped mesh position is represented by the green dot.

4. The algorithm textures the warped triangulated mesh, created in step 3, with the compressed sketch image from step 1. Cavewhere can render the resulting 3D map at interactive frame rates (see results and performance).

plot. On the other hand, Beer Can Chasm, the smallest cave in the data set, uses far more disk space because the sketches are scanned at 400 dots per inch (DPI.) As the scan resolution and number of sketches increase, computation requirements also increase. Sketches from Beer Can Chasm, a muddy and wet cave, are noisy, thus preventing Cavewhere from compressing them as much as Quankou. Sketches scanned at 200 DPI have a nice balance between quality and storage requirement.

The performance results, Table 1, were generated on a 2.2 GHz AMD Athlon(tm) 64 X2 Dual Core 4400+ with 4 GB of 333 MHz DDR2 RAM and a Nvidia GeForce GTS 250, 1024 MB video ram. This system is capable of rendering each model at real-time frame rates at 60 frame-per-second.

After creating a carpeted cave map, the results can be exported as a high-resolution image and drawn in a vector graphics program. Not only can the results be exported in plan view, they can be exported in any three-dimensional orientation.

6. Improvements

6.1. Notes Editor Improvements

Although versatile, Cavewhere does not support cross-sections and running-profiles. These could be added to the Notes Editor in future versions.

6.2. Warping Algorithm Improvements.

Currently, when the warping algorithm positions a point in the mesh, it uses the weighted distance average from all the survey stations in the sketch. This can be problematic because if one shot is drawn incorrectly, then the error is distributed over the whole sketch, instead of being localized to that shot.

Table 1 – Cavewhere Results

Cave	Length	Scan Resultion (DPI)	Percent Carpeted	Sketch Scale	System RAM Used	Disk Usage	Generation Time
Beer Can Chasm	883m	400	100 %	1:480	72 mb	152 mb	21.3s
Wahoo Cave	1463m	200	100 %	1:480	163 mb	70 mb	23.4s
Quankou	12991m	200	75%	1:500, 1:1000, 1:2000	154 mb	36 mb	39.5s

5. Results and Performance

This section is a demonstration of Cavewhere using three different data sets, shown in Table 1 and Figure 3. The shot data from the Quankou and Beer Can Chasm data sets were entered in Survex and imported into Cavewhere. Wahoo Cave's shot data were entered using Cavewhere's Survey Editor. All three data sets were created using the Notes Editor.

Although Quankou is the largest cave of the three, 12,991 m, it uses the least amount of disk space. Unlike the other caves, Quankou was sketched at large scales and the sketches are free of mud and crisp, which improves the image compression, and only 75% of cave was modeled using carpeting. The other 25% was modeled as a line

6.3 Import/Export improvements

Moving data between software packages is important**.** Although Cavewhere supports import and export with Compass and Survex, there are many other software packages that Cavewhere could interact with. Future versions of Cavewhere will probably support Walls, another popular line plotting software program. Cavewhere also lacks support for exporting to GIS formats such as ERSI shapefile and Google Earth KML.

7. Conclusion

Cavewhere gives users the ability to combine the speed of line plot software with the detail of hand drawn survey maps using carpeting. This provides a better representation of a cave than either a line plot or LRUD model. After the warping algorithm has fitted the sketches to the line plot, Cavewhere can export the result as a high-resolution image at any perspective. These resulting images can assist cartographers with drafting a map. Cavewhere can also render the carpeted 3D maps in interactive frame rates on standard desktop computer hardware. It gives cavers the ability to create 3D working maps that can better help them understand cave systems. Indeed, Cavewhere is easy-to-use, quick, and versatile.

Acknowledgements

Thank you Matt Skowronski for your editing assistance.

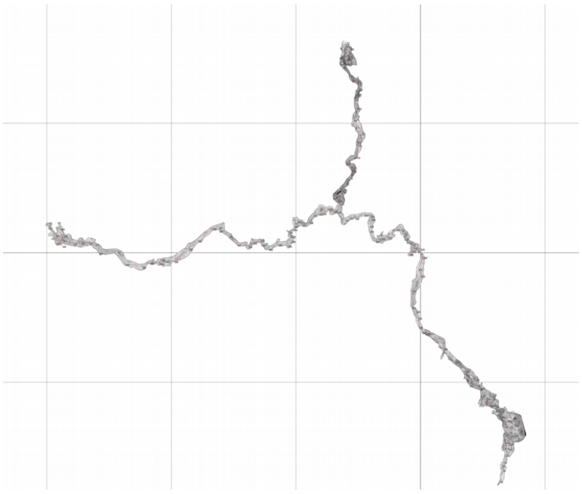

Figure 3a - Beer Can Chasm

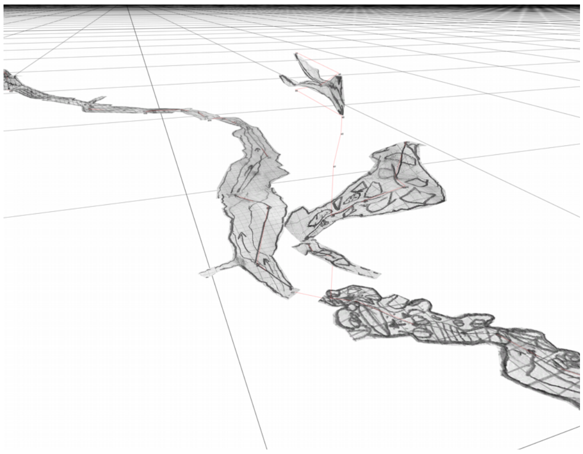

Figure 3b - Beer Can Chasm

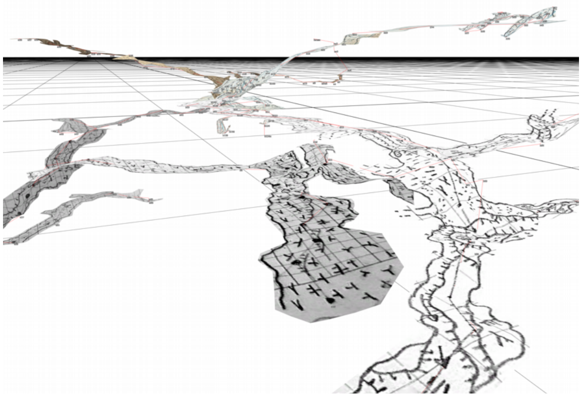

Figure 3c - Wahoo Cave

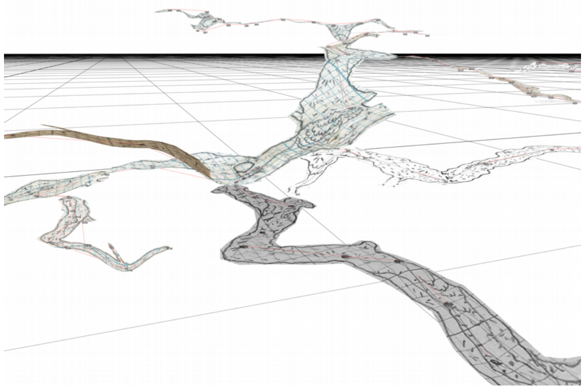

Figure 3d - Wahoo Cave

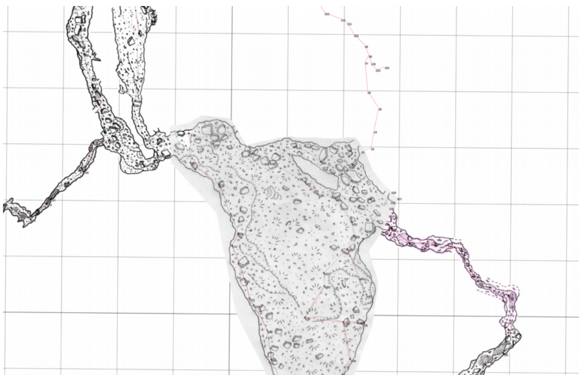

Figure 3e - Quankou, Plan view of Cloud Ladder Hall, the 6th largest room in the world, with 100m grid in the background.

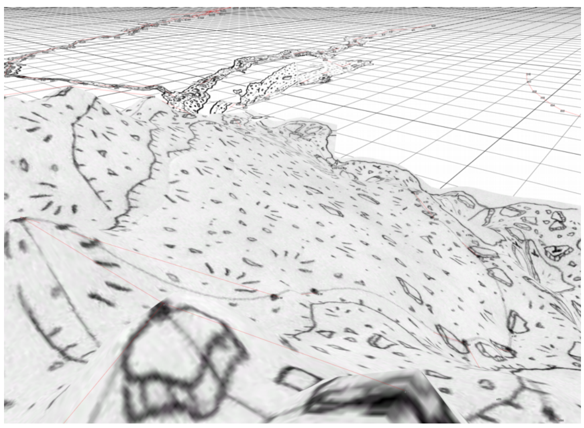

Figure 3f - A perspective view from a hill in Cloud Ladder Hall in Quankou.

References

[1] NSS, Judging Criteria for the Cartographic Salon. http://www.caves.org/committee/salons/Cartographic_Judging.htm

[2] Mulu Project, 2009, Drawing the Whiterock survey 2009. http://www.mulucaves.org/wordpress/surveying/drawing-the-whierock-survey-2009