

Lessons learned from a large-scale 3-D mapping project with Faro laser scanners of the Gomantong Caves, Borneo

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Abstract

During a large T-Lidar scanning project of the Gomantong Caves in Sabah, Malaysia we learned that using reference spheres is not really necessary. Not using the references accelerates the pace of scanning, and eliminate the risks associated with placements in hazardous situations. This increase in scanning efficiency does come at a price because scan registration becomes more complex. However, the extended time required for a more complex cloud-to-cloud registration in an office environment is more than compensated for by the increased efficiency and reduced risk of the fieldwork. In this paper we will also review some other “lessons learned” during this project.

1. Introduction

The Gomantong Caves, Sabah, Malaysia consist of more than 4 km of large passages that are of notable geomorphological, biological and cultural significance. Beginning in July 2012, an ambitious project was undertaken to map the caves using Faro terrestrial LIDAR scanning with the goal of providing 3D point cloud data to address specific biological and geomorphological questions (Lundberg et al. 2012, McFarlane et al. 2013). The project continued in July 2014, requiring approximately 24 field days to complete the job in this very demanding environment. A total of 271 scans was collected, resulting in a dataset of 12.6 billion scan points. The size of the dataset creates significant difficulties in data processing and analysis. Addison (2011), faced with 18 million data points from a scanning in Mammoth Cave, summarizes very well the difficulties: *“The ability to collect massive point data sets appears to be well beyond the ability to do anything meaningful with the data back at the office”*. The Gomantong Caves project engendered 700 times more data than this, considerably exacerbating the difficulties that Addison encountered. Valuable lessons were learned in the course of both field work and data processing, which provide the basis for planning future projects of this nature.

2. Planning the project

Scanning a cave is a costly affair. So, before doing the field work, time should be spent defining the goal of the final product: for example, are the data to be used to create a virtual cave, or for volume calculations, or for map making, for bat counting, for printing a 3D model, etc.? The goal of the project will determine the resolution needed for the scans. For example, a 3D print of the cave requires only low resolution scans and it makes no sense to spend additional resources scanning in full resolution, whereas the highest possible resolution should be used if, for example, a bat roost is to be scanned for determination of species (Azmy et al., 2012).

Modern scanners have the capacity for very high resolution, but a basic knowledge of the limitations is necessary. As an example, the Faro Focus ^{3D} X 330 has a resolution of 40960 points over 360°, which can be translated in a resolution angle of 0.009°. A full scan like this takes almost an hour and produces a massive point cloud of 711 million points. So, in most cases, scanning at ¼ resolution with 10240 points on 360° or 0.036°, which results in clouds with 44 million points, will suffice.

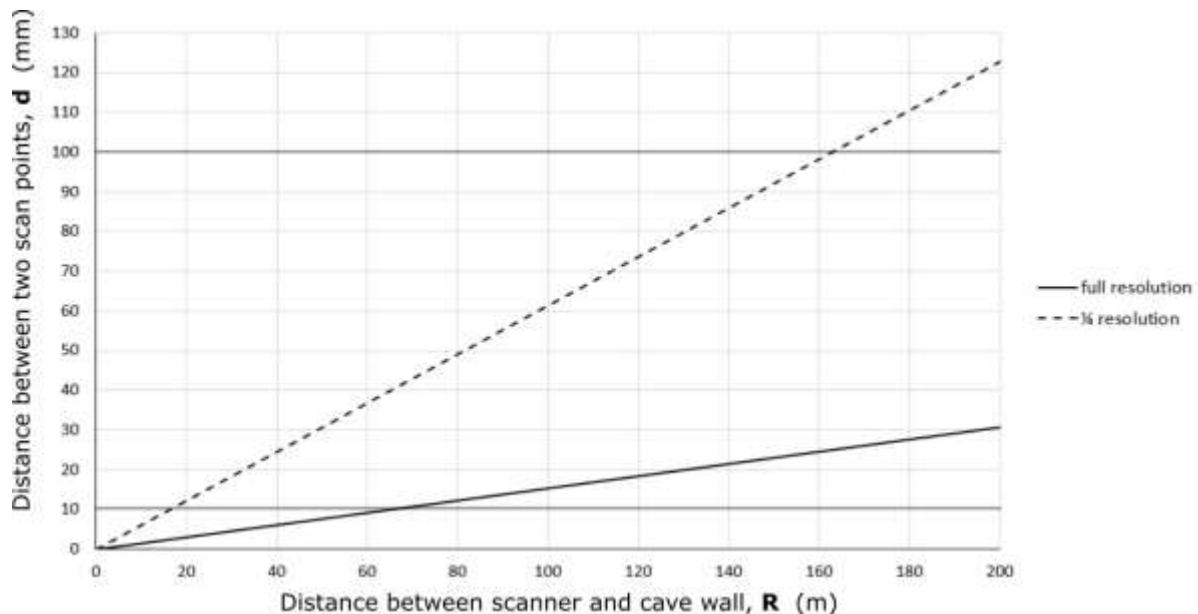


Figure 1: Influence of the resolution angle and distance from the scanner, R, on the distance between two adjacent scan points, d.

The main factor to consider in order to achieve the requisite resolution is the distance between the instrument and the scanned surfaces (Figure 1). For example, the distance between the Lidar and the cave walls should be closer than 20 metres when centimetre resolution is needed and the scanning is at $\frac{1}{4}$ resolution. If the project involves detailed scans of high cave ceilings it might be impossible to get the wanted resolution even when working with full resolution. As figure 1 illustrates, it is not possible to get centimetre-scale detail if the ceilings are higher than 70 m.

3. Fieldwork

3.1. Reference spheres

Scanning caves is an expensive and risky business. So the shorter the time spent in the cave the better. A time-management analysis of the scanning process underground reveals that most of the time is used for transportation of the equipment and setting up the reference spheres. Placing these spheres can be tedious and optimal placement often involves significant risk to personnel. Another difficulty with the spheres is trying to keep them clean in muddy environments. Furthermore, complex caves may require many spheres, adding a layer of complexity to transportation arrangements and required workforce.

The lesson we learned from field experience is that reference spheres are really not needed. They are used for semi-automatic registration of the point clouds, with specialized software. However, alternative registering processes are available that does not require reference spheres (see section 4.1 below). We conclude that not using the reference spheres will significantly speed up the scanning process, thus minimizing the dwell time underground and also reducing the risk of accidents.

3.2. File names for scans

The second lesson we learned is to use logical file names for the scans (rather than something without much geographic meaning such as numbers) One should define a logical pattern for naming the individual scans and stay with this definition during the entire project. This is certainly important for big projects where different people will work with the scanner or where the project is stretched over different scanning periods. It would be helpful to integrate the date, name of the cave and a section number into the name. Well-chosen filenames during field work will greatly facilitate the subsequent registration, management and archiving of scanner files.

3.3. Additional graphical documentation

The third lesson we learned is that it is important to take many photographs in the field. Scans may not be enough for registering the cave after the field work. Point clouds taken in the dark have only reflection data and no colour information. A photograph can be used for

reference to solve difficulties while registering or analysing the cave. The photographs do not have to be of good quality; they simply need to be taken often and consistently, in logical relation to the scanning. Pictures are also useful reminders while analysing the data when the fieldwork has long been finished.

3.4. Backup

Unfortunately, data files can become lost or corrupted over time. Therefore, the fourth lesson we learned is that scan files should be backed up during field work, labelled clearly, and archived in several different and trustworthy locations (preferably after each day of data collection).

4. Post-field data processing

4.1. Registering the scans

The process of joining all the point clouds scanned with reference spheres into one big point cloud is called **target-base registering**. Specialized software uses these spheres to semi-automatically find matches between the different scans, speeding up the process of registering. This is not so demanding on CPU resources (match the spheres and the rest will follow) and can be done with a powerful laptop, and possibly even during the fieldwork.

When no reference spheres are used, the scans are processed instead with **cloud-to-cloud registering**. This works by manually positioning the scans as close as possible. This has to be checked in the horizontal and vertical planes. The computer will try to do the final match. This is very demanding on CPU resources and needs long processing times, but the results are very good with low mean target tensions. To use cloud-to-cloud registering a powerful computer is needed with many and fast cores, a lot of RAM (64 GB is a good start) and fast SSD disks. A laptop would not normally meet these requirements. So registering will not be possible during the fieldwork and can only be done afterwards. This also means that registering is best done by a person who knows the cave well. This insight into the cave will make solving the 3D jigsaw-puzzle during registration a lot easier.

4.2. Final product

Further data manipulation can only proceed after registering the point clouds. The complexity and time needed to create the final product depends on the predetermined goals of the project.

4.2.1. Illustrations or animation

3D point clouds of caves result in wonderful X-ray-like pictures. This output is easy to produce using an image editor to process the pictures. Animations of point clouds are normally used for fly-throughs. Most registering software has a built-in function for making these amazing videos.

4.2.2. Making a mesh

Making a mesh (Figure 2) from a point cloud is not an easy task and can take a lot of time. A mesh is used for, e.g., 3D rendering, printing a 3D model (STL file) or analysis for a science project with, e.g., GIS applications. There is a learning curve involved in getting the mesh ready. Here are some useful tips:

- Delete the foliage around entrances. Meshing software cannot easily process foliage and will give bad results.
- Filter the point cloud to remove stray points.
- Reduce the number of points by Poisson disk sampling (in accordance with the requirements of the goal of the mesh, such as 3D printing or rendering).
- To print a 3D model a closed mesh is needed. This can involve closing entrances by hand with specialized mesh-editing software.
- Specialized software can be expensive. A lot of work can be done with open source software, e.g. :

MeshLab (<http://www.meshlab.net/>) the swiss knife application for meshing, filtering and a lot more.

CloudCompare (<http://www.danielgm.net/cc/>) can be used for registering.

Blender (<https://www.blender.org/>) for rendering the point cloud.

Polymender (<http://www1.cse.wustl.edu/~taoju/code/polymender.htm>) tool for repairing the mesh.



Figure 2: A mesh generated from the Gomantong dataset rendered with *Blender*.

4.2.3. Making a map

Classic cave maps incorporating plans, profiles and sections are universally used by cavers for navigation and exploration. These maps are made with great determination and effort by cave surveyors and are, to some extent, personal interpretations of the underground landscape. Cave maps can be considered as pieces of art and the introduction of T-Lidar will not make them obsolete. A printed point cloud or mesh is not very effective to find your way in a cave, and the fragility of a tablet with a 3D model of the cave precludes its use underground. Therefore, cave maps are still required.

However, creating a classic cave map (e.g., Figure 3) from a point cloud is a very tedious business. One of the reasons is simply because there is just too much detail available. It needs experience to filter through the overwhelming amount of data. But using a point cloud for making sections of the cave is incomparably superior to the classic way of guesstimating the dimensions and features of the passages. Working with point clouds opens the door to new insights into the cave genesis because of all the details available in the scans of the ceilings, the birth ground of many caves. In classic caving the ceilings are, most of the time, hidden in the dark. Darkness is no obstacle for the laser of the scanner and will register the ceilings in full detail.

5. Conclusion

T- Lidar is opening fantastic new ways to analyse caves and has much more to offer than classic cave surveys. But the cave surveyor will not be a dying breed. Point clouds won't replace a classic cave map any time soon because of costs and the amount of work involved.

Before starting a scanning project it is good to know the limitations of your scanner. It is quite possible that the unit cannot achieve the desired goals. Cave scanning needs a different approach than architectural or industrial scanning. The usual scanning routines used at the surface may be cumbersome and even dangerous in a cave environment. Time can be saved by not using reference spheres and by using cloud to cloud registration.

6. References

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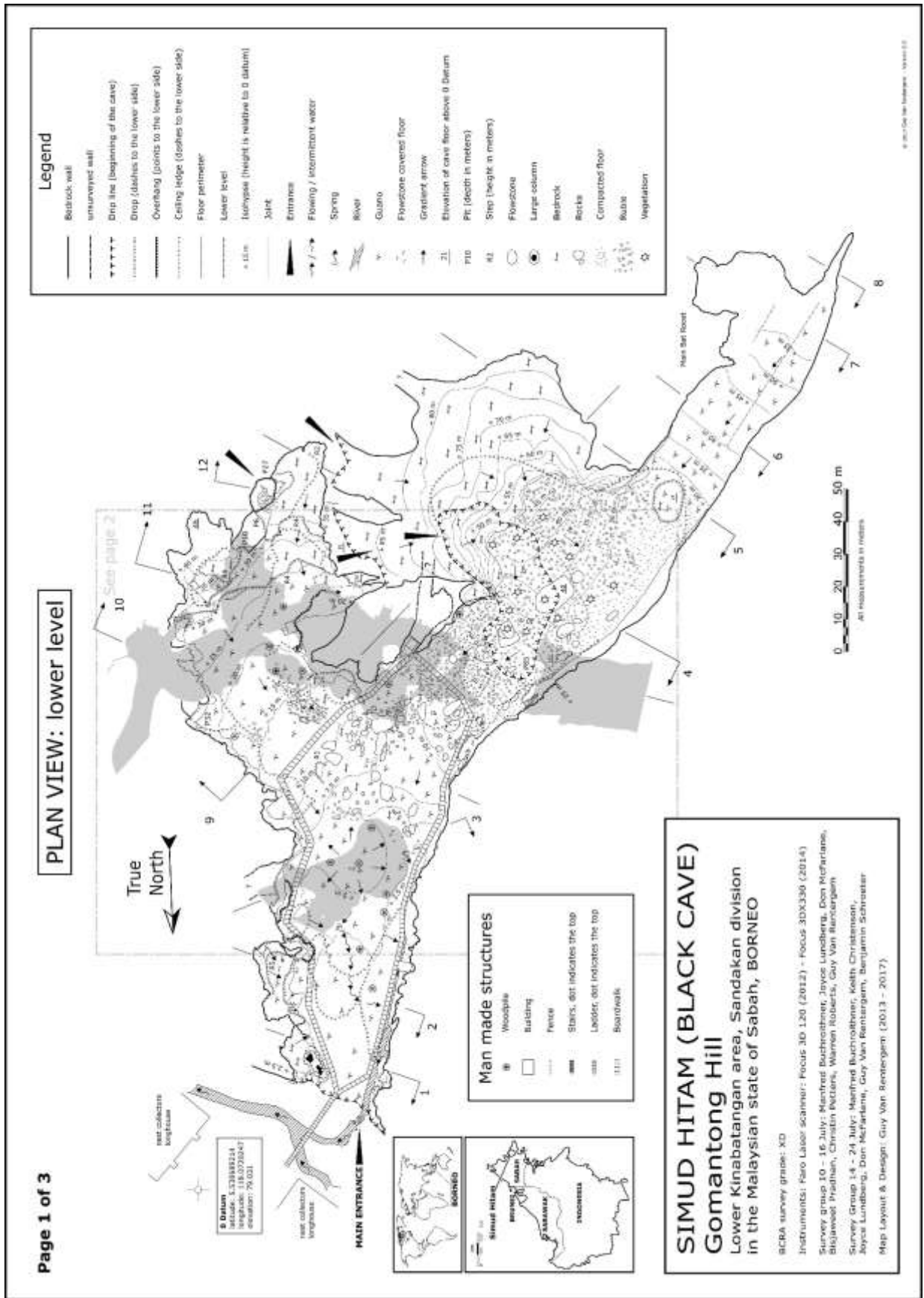


Figure 3Appendix 1: cave map of Simud Hitam, one of the Gomantong caves, made solely based on T-Lidar obtained data (still a work in progress).