Experimenting with 3D LiDAR modelling on newest iPhones

Jari Arkko

The newest generation of Apple's iPhones support new sensor technology. The iPhone 12 Pro models have a LiDAR (Light Detection And Ranging) sensor that can be used to build 3D models of objects and rooms. Photo 1 shows the sensor on the bottom right, next to the three camera lenses and flash opening.

LiDAR uses light to measure time of flight from reflections coming back from different objects in front of the sensor. This makes it possible to accurately measure distances and surface forms. Commonly available applications record LiDAR measurements of distances, surface texture data from the video camera, and phone movements. All this data is combined to build a 3D model that can then be rotated on screen or exported to other software.

The intended uses are about augmented reality, 3D printing, testing home remodeling ideas, and other broadly useful things. But could this technology be useful for mapping and studying caves? LiDAR measurements of caves have been performed, but for the first time, the technology is easily available in commonly available consumer products.

I should note that for now, the feature is only available in the high end models. The concept of taking phones costing more than 1000€ to the cave environment gave me some pause, but we need to find out what can be done with it. And there is of course some hope that over time, the sensors will be available more broadly and also in cheaper models.

The author set out to experiment. It turns out that the LiDAR phones can indeed be used for building detailed models of caves. But at the same time, this usage is still very much experimental. The results can be amazing and give you a completely new way to look at caves. For instance, Photo 2 shows a 3D modelling software-generated view of some details in the Lummelunda cave in Gotland, Sweden. The author particularly loves the rock forms on the outside skin of the model. For him, this reveals more about the cave than he usually is able to see. Careful work with the sensor involves pointing it to all directions, and this tends to reveal new things. Such as the contours and system of cracks in the roof.

But the use of phone LiDAR is not without problems either, and improvements and additional software will be needed in the future. This article covers the author's experiences of what is possible and what is not yet. And hopefully give the reader an opportunity to try this technology out in local caves.

3D modelling is not necessarily a replacement for other forms of surveying. 3D models are good at revealing detail, shapes and patterns. They are not as good in covering larger distances and complex systems. Traditional survey techniques are likely to remain as the most accurate way to measure large caves. And traditional cave maps are simple enough to be useful; the complexity of a 3D model may be confusing as a sole map.

On the phone

The sensor is used by an application, and there are many to choose from. I have experimented first with "LiDAR & Infrared Night Vision", by Jumping Rock Labs. This application offers a real-time view of the distance measurements, even in complete darkness. Distances are represented in different colors. The application uses either the full-blown LiDAR sensor or the similarly working face identification sensor. A session can be recorded as a video.

For actual 3D models, however, I have used the "Polycam – LiDAR 3D Scanner" application. This app is free, but a paid version (39.99$ per year) is required for exporting the actual models to other programs.

Creating a model is easy. Once you open the app, it turns on the camera and shows a view on the screen. There's a record button at the bottom, which starts the recording of an actual model. While recording, a mesh is overlaid to the camera view. This allows the user to see what shapes and distances the LiDAR sensor provides. Parts of the screen are marked in blue to indicate areas where there is not yet good enough coverage to build a model. The iPhone's LiDAR sensor range is at most five meters, so to capture far away walls and objects you must move closer.

The process is reminiscent of taking a video at first, but is actually quite different. A steady hand, slow movements, and distances to the surfaces cannot be either too far or too close. You will also need to cover all sides of an object or all walls of a space.

Once the modelled area is covered, pressing the record button again will stop the recording. The application will then offer to process the data. There's a couple of choices for the processing, relating to the type of scan and accuracy. For caves, we usually process them as "space".

The processing of a small object or room takes a few tens of seconds, but a section of a cave can take longer. I have found it useful to record maybe 50-meter sections of caves in one go, and processing that may take several minutes. Recording larger sections would be better, but the risk of human mistakes or software issues grows, possibly leading to the need to redo an entire section. I have experienced an occasional operating system error and multiple application errors while recording long sections. I've also hit limits on applications with regards to how much texture data they can process in one go. And at least in one case exceeding these limits lead to data loss.

The recording can be paused and continued. An existing recording can also be extended. In both cases it is necessary that the application recognizes the place that you continue from. In theory, it should do so based on the unique patterns in a particular place, but in practice I have found this difficult in cramped caves.

Once the processing is complete, the model can be rotated and zoomed on the phone's screen. The model includes texture, i.e., surface photography and colors (see Photo 3). The application allows also the creation of a simple video to demonstrate the model. This video can be sent to others, even in the free version.

Practicalities of using the phone in caves

There are several considerations:

- Preferably, you should avoid double scanning the same surface, as it may result in phantom walls in slightly different position.
- Given the limitations of the sensor's range, our Icelandic friends came up with the use of selfie sticks for longer reach, and the author is now using the same method.
- A consistent pattern of scanning is useful. In tunnel-like caves the author found it most useful to scan in a circular pattern, with the sensor pointing to the walls and slowly going through a circle to cover the ceiling, walls, and floor. This circling motion is quite easy to achieve, if you use the selfie stick method. Adjust the length of the stick suitable to the size of the tunnel, hold the stick from the middle, and turn it like a screw as you slowly walk further in the tunnel.
- If you plan to use the texture recording, proper light source and its use becomes important. The author's texture tends to be rather unevenly lit. It is possible that a better light arrangement – perhaps a ring light on the selfie stick – would improve the situation. Otherwise, helmet lights will have to suffice.

The selfie stick needs to be suitable for the arrangement of sensors on the iPhone. Ideally, the sensors should point out from the end of the stick, while allowing you to still see at least a part of the screen when you hold the stick from the other end.

The author used a RAM Mounts X-Grip to hold the phone, with sensors pointing out and screen pointing towards the holder such that one can still operate the app start/stop button on the screen. The X-Grip was connected via a camera-tripod screw adapter to the bottom end of a Benro MMA28C monopod (see Photo 4).

Exporting

The paid version of Polycam allows the export of a created model to a file. This greatly expands what one can do with the models.

There are several common formats, such as GLTF (Graphics Language Transmission Format) and its binary variant (GLB) or STL (Standard Triangle Language). The author uses GLB to move the models from the phone to computer. If other formats are needed, they can be created in post processing stage.

Postprocessing

Postprocessing is not necessary for small cave models that you only wish to rotate on screen. However, postprocessing can be useful when:

- Partial cave model recordings need to be put together. For instance, the Lummelunda cave model was put together from parts. You may see some of the joins in Photo 1.

- Mistakes in the model need to be corrected, or the model needs to be transformed in some fashion, e.g., simplified to make displaying it possible on all devices or processed to enable 3D printing.
- You wish to produce high-quality photographs or "fly through" videos of the model. Photo 3 shows what the insides of the Lummelunda cave model look like. Note that this is not a photo, it is a part of the model that I can rotate, fly through, etc.
- Some information needs to be retrieved from the model. For instance, the author has used measurement tools in postprocessing software to determine the length of tunnel sections, as an aid for drawing a simple map. See also Photo 5.

Again, many different software options exist. The author has used Blender, a popular 3D modelling software. The typical workflow in Blender involves importing the model parts and carefully joining them together by aligning the details in two tunnel sections. Such alignment may not be always easy but is made easier if there are easily recognizable cracks or other surface formations that help make you see when two pieces are in alignment.

Other software options include various CAD packages. All 3D software packages involve some level of a learning curve to be able to use them.

Difficulties

There are still several issues:

- Collecting high-quality material is difficult in cramped cave tunnels.
- The produced models are typically incomplete in several ways. It is usually not possible to see the entire space, e.g., because a cavity extends further than we can reach, the sensor does not always recognize water as a surface, and so on.
- 3D software is primarily built to deal with objects that have a clear inside and outside. This is required for 3D printing and binary operations such as intersection and union. Caves are spaces, with at least one hole, the entrance, and may have other issues as described above. As a result, processing cave models is not as easy as one may assume. But it is possible to modify the models manually.
- Merging partial cave models is possible, but also results easily in phantom walls separating different sections. And since some overlap is required for precise alignment, which also can result in unwanted artefacts.
- The models are big. The raw data needed for the Torhola cave (Photo 5) was 4GB on the phone and consisted of over a million separate pieces or faces as they are called in 3D models. The Lummelunda model is over 2 million faces.

Future

The application of this technology for caves is still very much experimental. Most serious issues are limits related to large models, the effort needed to compose larger models in post processing, and limitations of the post processing software with typical cave models. And there are of course also many artefacts and mistakes. Still, the models are very exciting, and in many parts there's an amazing level of detail. The author believes this is the future in caving, and we have only just begun our journey.

It also seems that additional software may be needed to improve our use of 3D models. The author has been experimenting with dedicated software that can process models into horizontal or vertical cuts, producing for instance horizontal layout maps of the cave (see Photo 6 for an example).

List of photos and illustrations

Photo 1: LiDAR-Phone-Article-Photo-Lummelunda-Detail-v0-DRAFT.jpg Caption: A detailed view of a model of the Lummelunda cave in Gotland, Sweden

Photo 2: LiDAR-Phone-Article-Photo-Tools-Sensors-v0-DRAFT.jpg Caption: iPhone sensors, with LiDAR on the bottom right

Photo 3: LiDAR-Phone-Article-Photo-Lummelunda-Inside-v0-DRAFT.jpg Caption: Computer-generated view from inside the model of the Lummelunda cave.

Photo 4: LiDAR-Phone-Article-Photo-Tools-Selfiestick-v0-DRAFT.jpg Caption: Selfie stick arrangement

Photo 5: LiDAR-Phone-Article-Photo-Torhola-Vertical-v0-DRAFT.jpg Caption: Vertical view of a model of the Torhola cave in Lohja, Finland

Photo 6: LiDAR-Phone-Article-Photo-Lummelunda-Horizontal-v0-DRAFT.jpg Caption: Computer-generated horizontal plan view of a part of the Lummelunda cave.