Caveatron
User Guide

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Contents

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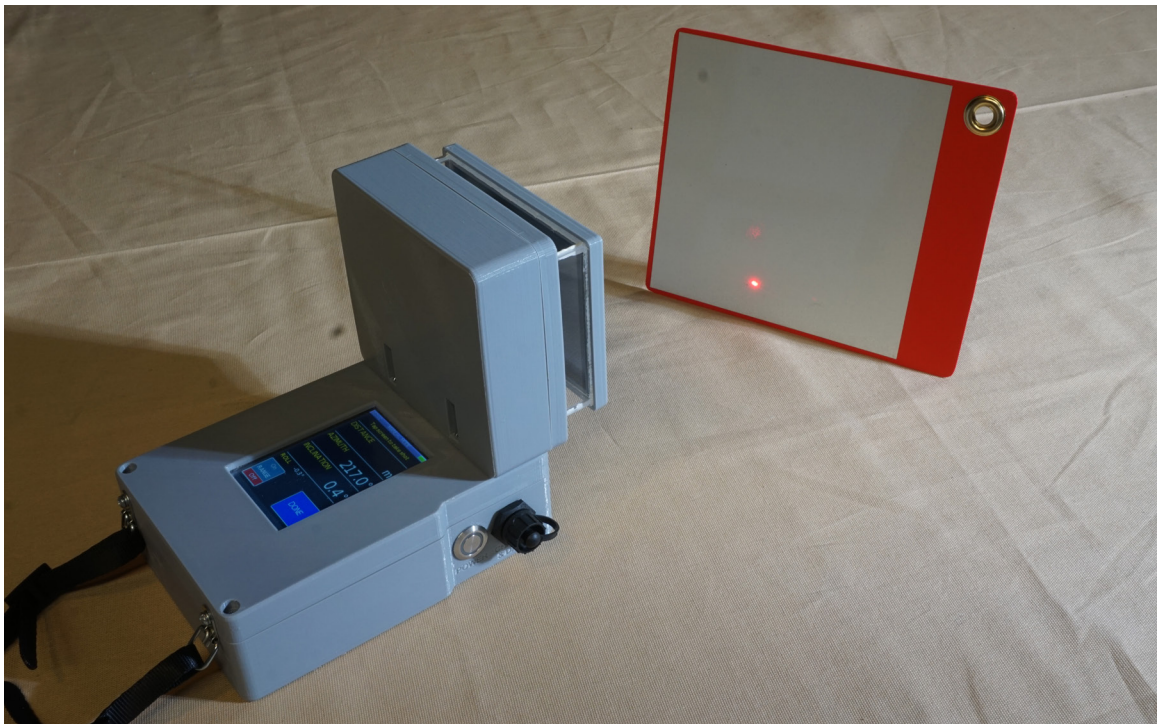
Software and Technical Info Github Site: https://github.com/Caveatron

Cover Photo by Bennett Lee

Introduction

The Caveatron is a handheld all-in-one electronic device for surveying and 3D mapping of caves or other underground environments. It provides a caver-friendly, self-contained system for recording all station-to-station measurements, mapping of the cave with walk-through 3D point cloud scanning with its integrated LIDAR, entering information such as station names, and reviewing vector and scan data. The Caveatron is designed to be reasonably lightweight and compact with an environmentally sealed enclosure that contains a rechargeable battery, data storage, and a standard USB port for charging and data download. After returning from the survey, data are downloaded to a computer for review and post-processing with the Caveatron Process software which generates 3D point clouds that can be rendered into meshed solid models for visualization or 3D printing.



DEFINITIONS

Shot – A vector measurement between two station consisting of a distance, azimuth, and inclination

Traverse – A LIDAR scan taken while moving the Caveatron down a passage or through an area toward a station.

Splay – A LIDAR scan taken from a fixed position while rotating the Caveatron.

***FROM* Station** - The station from which you are starting a shot, where you hold the Caveatron.

***TO* Station** - The Station which you are targeting in Shot, Passage, or Room Modes. This is where the reflective card is held.

Getting to Know the Caveatron

EXTERIOR COMPONENTS

Touchscreen Display – All interaction with the Caveatron is done via the touchscreen. It is recessed and covered with a screen protector to reduce the chance of damage. The screen is not resistant to significant impacts, so treat it with care. The screen is less sensitive to touch than most smartphone type screens so needs a heavier touch to activate. Using the tips of your fingers and/or fingernails works best.

Power Button – The button is a momentary press type, so press it once to turn the Caveatron on and again to turn it off. The button must be pressed fairly deeply to activate it which prevents accidentally turning it on or off by bumping the switch. When the system is turned on the display screen turns on. If the display screen is not on, than the system is off.

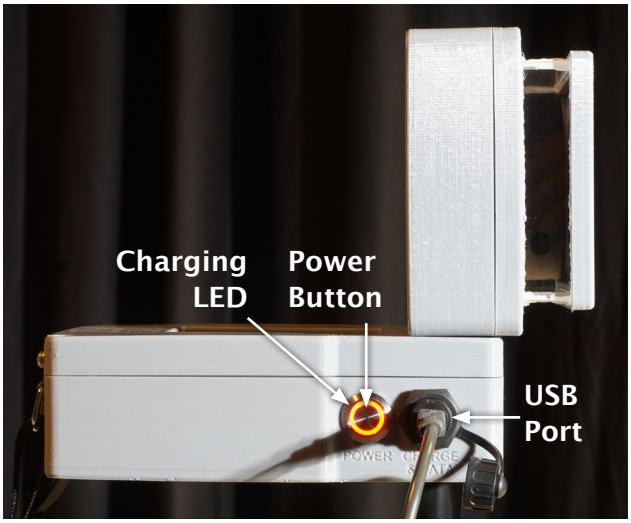
Charging LED Ring – Around the Power Button is a two-color LED ring. When the system is charging, the LED is illuminated red. This is true whether the system is powered on or not. If the system is fully charged and still plugged in to external power, the LED is green. A yellow LED indicates a charging fault. If the Caveatron is unplugged the LED is off.

USB port – This port has a USB-micro style connector and is used for both charging and data transfer. It can be plugged into any standard USB power adapter or the USB port on a desktop PC to charge. A rating of at least 1.5 Amps is needed to achieve maximum charging rate. It will charge for a lower current adapter but at a slower rate. For data transfer, the port is connected to a Mac or Windows desktop PC. A twist-on dust cap protects the port from dirt and water and should always be closed when not charging or transferring data.

Strap rings – These rings support connecting a neck strap. Use of a neck strap is highly recommended to avoid dropping the Caveatron.

LRF window – The Laser Range Finder (LRF) operates through this small window and its visible beam also serves to point the Caveatron to the station. Do not stare into this window when the laser is operating. Keep the window reasonably clean to avoid blocking the rangefinder. The window is recessed to provide some damage protection.

LIDAR windows (if equipped) – The LIDAR scans through these windows 360˚ around



the Caveatron, perpendicular to the direction of the red laser. It is important to keep these windows as clean as possible to prevent loss of scan data. Various configurations use either 4 flat windows, a single round dome window, or no windows.

Reflective card – This card is held on stations during measurements or scanning to provide a positive target for the laser rangefinder.

MAIN INTERIOR COMPONENTS

LIDAR – Takes rapid distance measurements at known angles while it continually rotates in order to build a detailed set of points with x, y, z coordinates known as a point cloud. The LIDAR data produces the 3D map of the cave.

Laser Range Finder (LRF) – Takes precision distance readings for the station-to-station distance measurements. It uses a red laser that is also used for pointing the Caveatron.

Inertial Measurement Unit (IMU) – Contains an accelerometer, magnetometer, and gyroscope. Together, these sensors provide the orientation of the Caveatron and measure its rotational motion.

Real Time Clock (RTC) – Maintains the date and time and is used to create the survey filenames and log the time of each shot and scan. The RTC is powered by a very small continuous current from the main battery, so would not discharge it for many years.

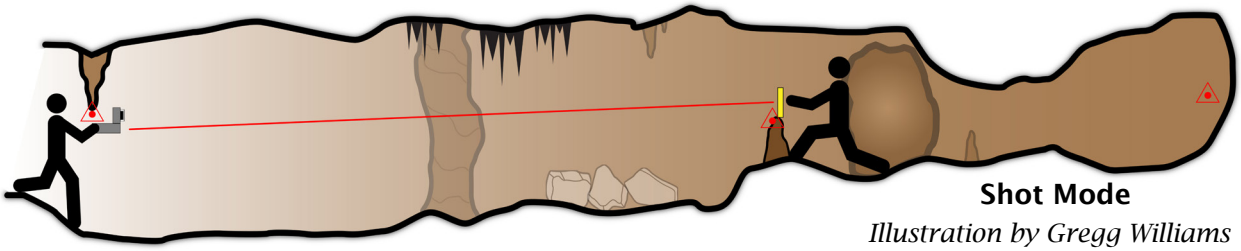
MicroSD Card – All survey and scan data is stored to files on the microSD card inserted into the main Teensy processor module. The card also holds files used to load and save calibration data. The files on this card are accessed from a computer through the USB Port. The card is formatted in standard FAT32. It could potentially be removed or replaced but afterwards a magnetometer recalibration would be recommended.

Battery – The main battery is a rechargeable lithium-ion battery so care should be taken to avoid damaging it or a fire could result. The battery is charged through the USB port and should take about 3-4 hrs to fully charge.

Operating Mode and GUI Overview

Main Menu – This screen appears when the Caveatron turns on and provides access to the operating modes, the Survey menu and Utilities Menu

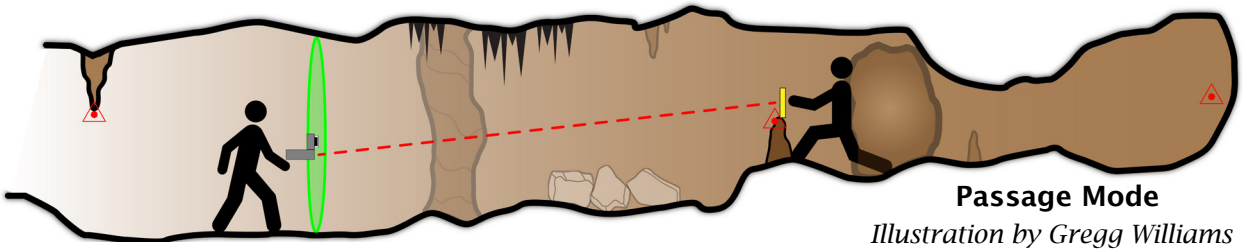
Shot Mode – This mode is used to collect the traditional station-to-station survey measurements of distance, azimuth and inclination. All these measurements are taken in a single step by placing the Caveatron on a station, having a survey partner hold the reflective card on the other station, pointing the Caveatron's laser at the card and pressing a button.



Shot Mode

Illustration by Gregg Williams

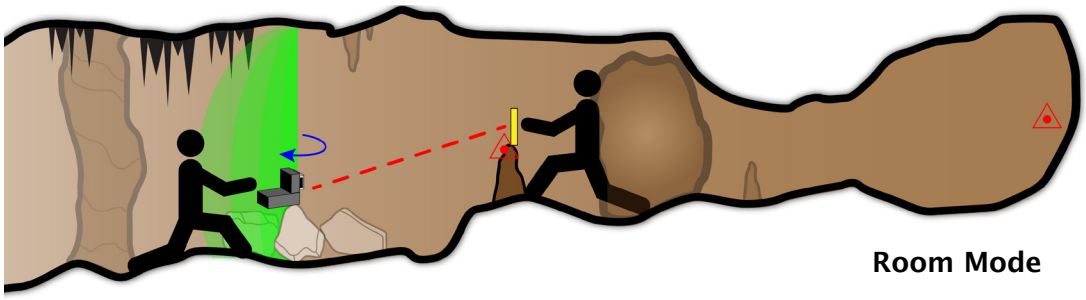
Passage Mode – This mode is used to take 3D LIDAR scans while moving the Caveatron along a path toward a station. In this mode, the Caveatron is effectively taking detailed cross sections of the passage several times a second as you move forward. The measurements are taken with a survey partner holding a reflective card on a survey station while you attempt to keep the laser beam on the card as much as possible and move to the station. No specific starting point is required for this mode, so long as you have a clear path to the station you plan to use.



Passage Mode

Illustration by Gregg Williams

Room Mode – This mode is used to take 3D LIDAR scans around a single position while rotating the Caveatron through an arc. The point where the scan is conducted can be a station or some other spot that is visible from a station. In the latter case, an initial reference shot is performed to the station, otherwise the reflective card is not used in this mode.



Room Mode

Manual Mode – This mode is used to quickly view real-time azimuth and inclination data or acquire distance measurements. No data is stored in this mode.

Survey Menu – Within the survey menu are functions to setup and start a new survey, review and delete shot data, view plots of the scan data, view a line plot of the cave, and obtain information about the survey.

Utilities Menu – This menu contains a variety of controls to adjust settings, connect to a computer over USB to transfer data, calibrate the Caveatron, obtain a live display of the LIDAR output, and view other information about the unit. A list of surveys stored on the SD card can be viewed and previous ones reopened.

Using the Caveatron

PREPARING THE CAVEATRON

Charge the Caveatron by plugging the USB port into any USB adapter. The battery is full when the red light on the power switch button turns green (or turns off if so configured). A full charge can take up to 4 hrs.

Turn on the Caveatron by pressing the power button fully in and releasing. The screen will show the Main Menu.

STARTING A NEW SURVEY

Go to **Survey ➜ Start new Survey**

Type in the name of the cave and press **ENTER**

Press **ENTER** again to accept the filename and a success message will briefly appear.

A screen appears allowing survey info to be entered, such as the names of the survey team members. This is optional and can be edited later. Press **ENTER** when done.

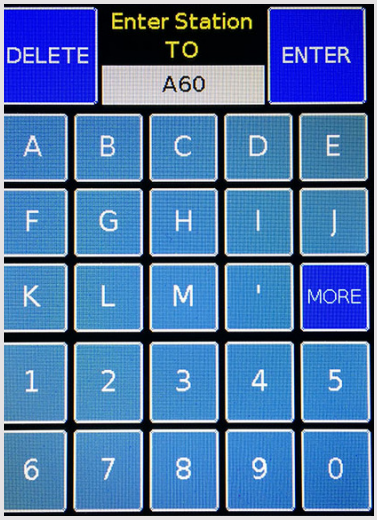
TAKING A SHOT BETWEEN TWO STATIONS

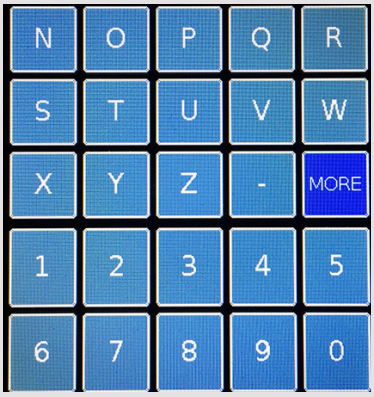
Choose your station locations in the cave. These are picked like regular survey stations except that the shot length should be limited to around 10-15 meters to avoid long scans and considerations should be made for where you need to obtain scan coverage.

Have your survey partner hold the card on one station with the corner held over the next station point with the retroreflective side pointed back toward the Caveatron.

KEYPAD USAGE

The keypad is configured to provide the most number of buttons practical for the limited screen size available. The keypad varies depending on the type of data that can be entered, however, in general letters A-M appear on the first page and N-Z appear on a second page. Numerical characters appear on both. The second page is accessed by the **MORE** button (from the second page, pressing the **MORE** button returns to the first page.) At the top right is the **ENTER** button, which is pressed to confirm an entry and move to the next screen. The upper left button appears as a **CANCEL** button when no characters have been entered and exits the current mode. When characters are entered, then the **CANCEL** button changes to **DELETE**, which removes one character at a time when pressed (by deleting all characters, the **CANCEL** button reappears.)





Some variations of the keypad have additional specific buttons for entering special characters, spaces, or common words.


Photo by Albert Parvin

Enter Shot Mode by pressing the **SHOT** button. For the first shot, enter the *FROM* Station name and press **ENTER** then enter the *TO* Station name. On subsequent shots, pick one of the options for automatic station names or enter your own station name.

Place the rear bottom left corner of the Caveatron on the station point. If the rear bottom right corner works better, press the button on the screen to select that corner instead. Point the red laser so that it is just on the corner of the card covering the station.

Holding the Caveatron as steady as possible, press the **TAKE SHOT** button and continue to hold it steady on the card corner for approximately the next 3 seconds. You will hear the *Start Tone* followed by three short beeps about 1 second apart. If the shot was successful, this will be followed by the *Success Tone*. If the shot failed, you will hear the *Failed Tone*. The results will be displayed on the screen. Press **DONE** to accept the shot and go back to the Main Menu or **REDO** if you want to take the shot over again.

Optional: Take a backsight from the *TO* Station back to the *FROM* Station to improve the accuracy of the survey and find errors. Repeat the process above but pick one the brown buttons from the automatic station naming screen when first entering *Shot Mode*. Only take a backsight for a station pair

AUDIO INDICATIONS

The Caveatron uses audio tones to indicate the status of shots and scans.

LRF Beep (Very short high-pitch) – Indicates that the LRF has obtained a measurement.

Start Tone (0.5 sec high-pitch) – Indicates when a shot or scan starts.

Success Tone (1 sec high-pitch) – Indicates when a shot or scan completes successfully.

Caution Tone (Continuous medium-pitch) – Can occur during a Passage Mode scan when too much time has elapsed since the last valid LRF reading. Indicates that the operator should get the red laser back onto the reflective card target.

Failure Tone (1.5 sec low-pitch) – Indicates that a shot or scan has failed.

for which you have (or will get) a frontsight as they are processed differently. Backsights improve accuracy, but are not required.

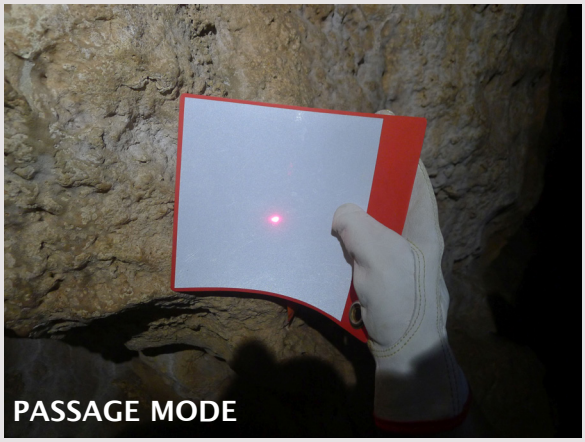
CHOOSE A SCAN MODE

Passage Mode scanning involves moving with the Caveatron along a path toward a station and scanning as you go. Room Mode scanning involves holding the Caveatron at a fixed location and rotating it to scan an arc of area around that location. Most scans are done in

USING THE REFLECTIVE CARD

The reflective card needs to be held at a station during shots and scan. It should be angled so the reflective surface is pointed roughly in the direction of the Caveatron. If the angle is too steep, it might not get a good return signal. It may also need to be wiped clear of mud and dirt occasionally.

These photos illustrate the way to hold the card during the different modes using the station as shown in the photo at right.



PASSAGE MODE

For Passage Mode, hold the reflective card as centered over the station as possible. This allows for averaging the position around the station since the spot will wander across the card as you move during the scan. The card can be bent, if needed, to fit into some areas (as shown). There will be cases where the station may have to be near one edge of the card, in which case try to aim more toward that edge while moving. If you have to hold the card so that it is not touching the station, don't allow it to be more than a couple of centimeters away. Its better to have to offset the card to the side so it is not centered rather than have it be much in front of or behind the station. You can also bend the card if necessary. Just be sure some part of the card is covering the station.

SHOT & ROOM MODE

For Shot Mode, hold the reflective card so it is touching the station with one corner just overlapping it. This allows for maximum accuracy since there is a definite point to aim the red laser toward. This configuration is also used for the splay shot at the start of Room Mode when referencing the scan position to another station.

Passage Mode to cover the areas between stations. Room Mode is used to cover corners when the path of the survey changes direction, scan small rooms or the ends of passages, or to obtain coverage of obscured areas or side alcoves.

SCAN IN PASSAGE MODE

Choose a location to start the scan. This is usually somewhere near where the *FROM* station is located for the previous shot, and usually roughly in the center of the passage. However, you can start a scan from anywhere so long as you can see the station toward which you are scanning. Back up a meter or more, if possible, to get some overlap with the previous scan. Also observe your path before starting the scan to avoid obstacles and get the best scan coverage, then position your start location accordingly.

Enter Passage Mode by pressing the **PASSAGE** button.

Accept the station name automatically provided or type your own and press **ENTER**.

Accept the traverse number automatically provided or type your own and press **ENTER**.

Have your survey partner hold the retroreflective card so it is centered over the station as best as possible (bending the card or centering it over one side work if necessary but be sure it is not more than a centimeter or two in front of or behind the station.) Be sure the retroreflective side is pointed toward the Caveatron.

Point the red laser at the card at a point as close to the station as possible.

Press **START SCAN** while staying stationary and holding the laser spot as still as possible. You will hear an initial *LRF Beep* followed by the *Start Tone* about one second later.

Start moving forward toward the card. Keep the red laser on the card as much as possible, though it is not necessary to keep it on the card continuously. Move gradually and avoid suddenly jerking the Caveatron in any direction as the scan will fail if it detects too large of

a motion. A speed of about 0.25 meters per second is optimal but slower speeds provide a more detailed scan. Whenever the Caveatron detects the card and gets a distance reading, the *LRF Beep* will be heard. If too much time has passed since the laser was pointed at the card, the *Caution Tone* will be heard. If this happens, stop and get the Caveatron back on the card. When the *Caution Tone* stops, continue forward. If a total of 12 sec passes since the last detection of the card, the scan will fail.

As you approach the station while scanning, you can end the scan in one of two ways. Approach within 0.15 m and after two seconds (two distance readings) the scan will automatically end. Alternatively, you can press the **END SCAN** button. It is important to continue to keep it steady and pointed at the card and station while ending the scan and not be tempted to pull it up to press the button. Otherwise, the last few seconds of data will be faulty or the scan may fail. Hearing the *Success Tone* will indicate that the scan is complete.

The screen shows the results of the scan. Press **DONE** to accept the scan or **REDO** to do the scan over again. If you want to do an additional traverse to the same station but along a different path, choose **ANOTHER TRAVERSE** to shortcut back to the Traverse number screen.

If a scan fails during a traverse such as due to a bump or a sudden motion due to a stumble, you do not have to redo the entire scan (though you can if you want). Just choose **ANOTHER TRAVERSE**, back up a few steps to get overlap and continue the scan as the next Traverse.

SCAN IN ROOM MODE

Choose a location to perform the scan. Sometimes the easiest location to use is directly on the station, but any location can be chosen so long as a station is visible. If possible, use the top of a rock to get a stable spot on which to rotate the Caveatron, however you can also scan freehand if you are steady enough.


Photo by Albert Parvin

Enter Room Mode by pressing the **ROOM** button.

Accept the station name automatically provided or type your own and press **ENTER**.

Accept the splay number automatically provided or type your own and press **ENTER**.

If you are scanning directly on the station, press the blue **USE STATION** button in the bottom left corner.

If you scanning away from a station, have your survey partner hold the card on the station so that a corner is right on the station location and the retroreflective side is pointed toward the Caveatron. Place the front center of the bottom of the Caveatron over the spot where the scan will be performed. Hold the Caveatron steady and press the **TAKE SHOT** button. As you continue to hold the Caveatron steady, two *LRF Beeps* will be heard over the next two seconds as the position is obtained.

Observe the area you will be scanning and pick the starting and ending directions for the scan and where you will position yourself. The Caveatron only scans the left 180 degree (as seen from the rear) when in Room mode, so you can safety be on the right side. It is always best to overlap some part of the scan with another scanned area. Reorient the Caveatron to the start of the scan arc, with the center front bottom on the point where you took the reference measurement (or on the station).

Press **START SCAN**. After the beep, start slowly rotating the Caveatron around a vertical line through the LIDAR module. Try to keep the rotation as steady and smooth as possible with no jerking motions. The slower you rotate, the more detailed the data will be.

When you reach the end of the arc you want to scan, press the **END SCAN** button. It is important to continue to keep the Caveatron steady and not be tempted to pull it up to press the button or the last few seconds of data will be faulty. Hearing the *Success Tone* will indicate that the scan is complete.

DOWNLOAD AND PROCESS THE DATA

Connect the Caveatron to a computer by the USB port.

Turn on the Caveatron and go to **UTILITIES ➜ SD CARD ➜ USB CONNECT**

The Caveatron will appear as a drive called “Caveatron” (Windows or Linux) or open the Android File Transfer app (Mac). Each survey is stored in its own folder with the cave name and date the survey was started. Copy the entire folder to your computer to download the data.

Turn off the Caveatron to disconnect from the computer.

Process the survey data using a program such as Walls Cave Mapping software or Compass Cave Survey software. To use Compass, the data must be converted using the Caveatron Process software. Instructions are provided in the manuals accompanying those programs.

UPDATING THE CAVEATRON CALIBRATION

CAUTION: After performing a calibration, you must start a new survey before conducting any new scans, otherwise the scans will not be correctly processed.

Periodically the Caveatron needs recalibration of its compass. Its probably best to do this

before each survey trip.

Go to a location far from any buildings, power lines, motors, or metal objects.

Turn on the Caveatron and go to **Utilities ➜ Calibration ➜ Compass Calibration**

Press **Start Calibration**

Rapidly rotate the Caveatron through all possible directions in a sphere around the device as much as possible. This is best done by a combination of turning it more up and down while turning yourself around. A progress bar on the screen will drop toward zero but may jump up again as you cover new angles. When it reaches zero, the Caveatron will beep and is ready for the next step. You do not need to keep rotating more than about 30 sec and can just let it go to zero if it has not already done so.

Press **Continue Calibration** and, at a more medium speed but in the same manner as before, continue to rotate the Caveatron through all possible directions in a sphere as much as possible. A progress bar on the screen will slowly increase toward 100%. Continue rotating the Caveatron as long as it takes for the progress bar to reach 100% at which point the calibration is complete. The last few percent may take longer – try to be sure you hit angles you may have missed previously to get it to reach 100%.

The new calibration values are displayed on the screen. Press **SAVE** to store the new calibration values or **CANCEL** to keep the previous values. After saving, its best to turn the Caveatron off and on before taking any new data.

Main Menu

This screen appears when the Caveatron is turned on. It provides buttons to access the primary operating modes of the Caveatron: Shot, Passage Scan, Room Scan, and Manual. In the bottom portion of the screen are button to access the Survey and Utilities menus. The Utilities Menu provides a page with additional functions including Settings, SD Card/USB connection functions, Calibration, Live LIDAR view, and an About screen. At the top of the menu screens is the Status Bar which shows the current time in the upper left (24 hour format), the currently active menu or mode in the center (in most screens), and the battery level indicator in the upper right. The battery indicator fill level decreases as the battery discharges and changes from green to red when it drops below 15% charge remaining. If the battery reaches 2% charge remaining, the battery outline changes from white to red. At the bottom of the display is the Info Bar which displays information or gives prompts related to the current screen. Both the Status Bar and Info Bar are present on most screens.

Shot Mode

Shot Mode is used to acquire and record the cave survey measurements traditionally taken with a tape measure, compass and inclinometer. The Caveatron uses the LRF to acquire and average 3 distance readings and the IMU to acquire and average 75 azimuth and inclination readings. The measurement process takes about 3 seconds. The data is stored to the internal memory card along with the station names and the date and time of the shot.

Either one of the rear bottom corners of the Caveatron enclosure are placed at the starting station or position of the shot. The red laser beam is then used to align the Caveatron to the station or position toward which the shot is be taken and the reflective card is placed at the target point.

Shot Mode collects both frontsights and backsights for any given vector between two stations. Frontsights are required and form the basis of the survey whereas backsights are optional. Backsights are used to improve the accuracy of the survey and find potential errors. You can also retake (Re-shoot) previous front-sights that are unsatisfactory with the originals replaced by the new ones.

FRONTSIGHTS AND BACKSIGHTS

Do not get confused about the frontsight/backsight terms – they do not refer to a specific survey direction in the cave. In the terminology of the Caveatron, a frontsight is any shot that is the primary (and usually first) measurement between taken between two stations, regardless of the actual direction of the shot relative to the rest of the survey. The backsight is a secondary shot taken in the reverse direction between two stations for which a frontsight exists (or will exist) and is averaged with it. If a backsight exists without a frontsight, that vector will not be counted during data processing and a gap will exist in the survey (though there are ways to work around this in post-processing). Below is an example of how this is intended to work:

- A1-A2 frontsight
- A2-A1 backsight
- A3-A2 frontsight
- A2-A3 backsight
- A3-A4 frontsight

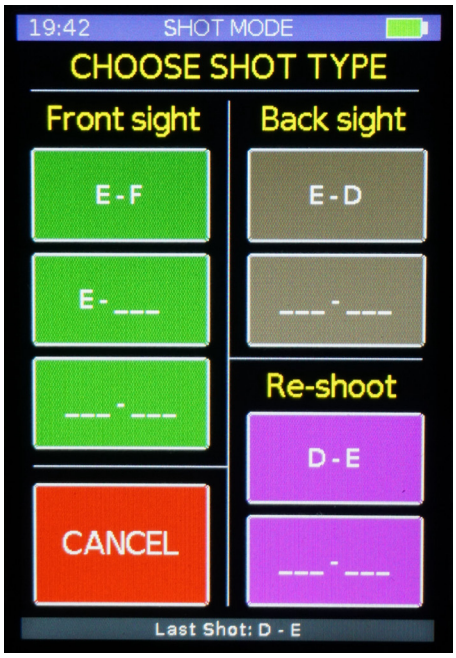
Note that A2-A3 was taken “backwards” in relation to the other two shots but it is a frontsight because it was the first shot taken between these two stations. The actual direction relative to other stations has nothing to do with the frontsight/backsight terms – only that the backsight is in the opposite direction of the frontsight for a given vector.

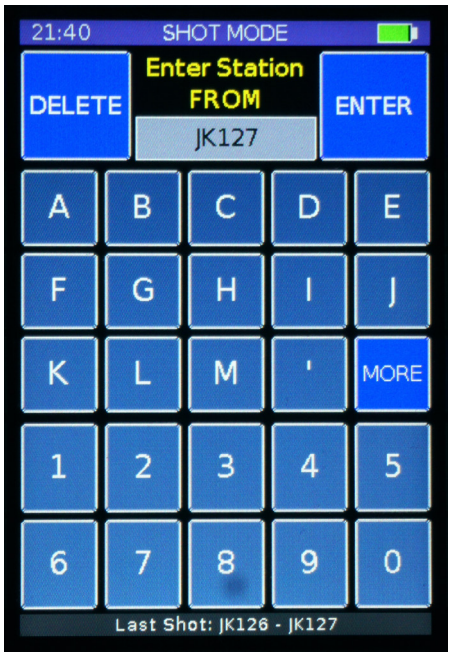
Here is an example of what NOT to do:

- A1-A2 frontsight
- A3-A2 backsight
- A3-A4 frontsight

A3-A2 should have been taken as a frontsight and since no frontsight exists for this shot, a gap exists in the survey in the Caveatron’s displays in the Survey menu and will exist in the Caveatron Processing software for post-processing. (It can however be used as a frontsight when processing the scan data if the survey file is processed in Walls software first.)

OBTAINING A SHOT

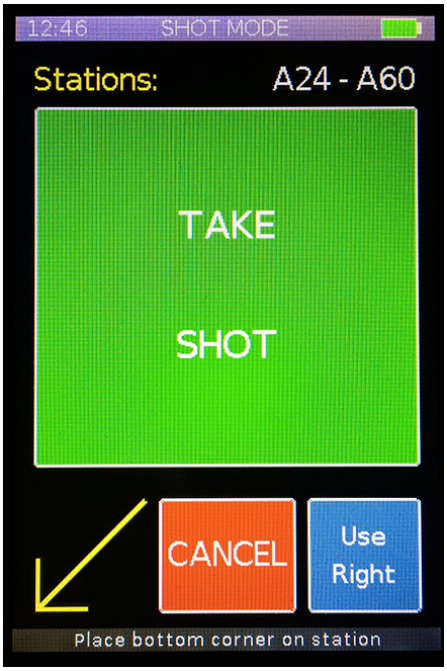


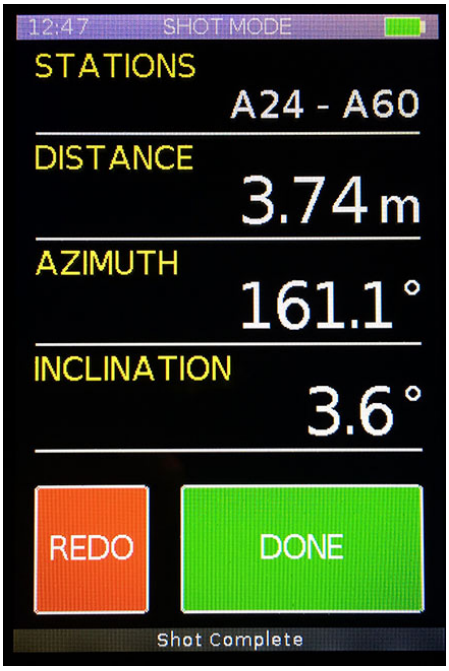


When starting Shot Mode, the user is presented with a series of screens to enter the names of the *FROM* station and *TO* station. The station entry screens provide a alpha-numerical keypad to enter in the station names and a box into which the station name appears as typed (usage of the keypad is described in the sidebar on p. 7). A station name can be up to 7 characters in length.

During the first shot of a survey, the *FROM* and *TO* station entry screens are presented successively for entering the station names. The second and subsequent shots in a survey bring up a different initial screen when entering Shot Mode – a station name shortcut screen. The Caveatron attempts to predict the station names for the next shot and several options are presented. If the shot is going to be a frontsight, one of the three green buttons at the top is selected. If the shot is going to be a backsight, then one of the two brown buttons at the bottom is selected. Each of these buttons provides different naming options. The first is a fully predicted option and selecting it skips both cave name entry screens and takes you directly to the screen for taking the shot. The options with '__' allow you to enter a different station name and for either one or both the *FROM* and *TO* stations. The purple Re-shoot buttons are for quickly retaking previous frontsight shots to fix errors. The Caveatron will search for any set of Re-shoot station names you enter and select them if they are found or alert you if they are not. Note that Re-shoot is for front-sights only. If you need to retake a backsights, you will need to delete it from **View/Edit Shots** in the Survey Menu and then take a new one the normal way.

After completing station name entry, the Shot screen appears. The red laser automatically turns on and the Caveatron and reflective card are placed on their station points. The Caveatron is placed on the *FROM* station so that either the left rear bottom corner or right rear bottom corner touch the station. The default is the left rear bottom corner and is indicated by an arrow in the lower left corner of the screen pointed in that direction. If you use the right rear bottom corner, tap the **Use Right** button to switch to that corner and the arrow changes location (You can then tap **Use Left** to switch back to the original corner). The Caveatron can shoot any inclination up to +/- 90 degrees without any issue. However, be sure the roll angle of the Caveatron (its tilt angle left to right) is relatively level. If this angle exceeds 30 degrees in either direction, the shot will fail. The Caveatron can be held upside down to take a shot without any issues as sometimes using the ceiling is more convenient. Again, just be sure that the roll angle is relatively level near 180 degrees (between 150 - 210 degrees) as with the upright orientation.





For the reflective card, it is best to place one of the corners so it is touching and just covering the station (see Using the Reflective Card sidebar on p. 9). That presents a precise point for the Caveatron operator to aim at to get the most accurate reading. Note that if the card is at too steep of an angle or the spot on the card that the laser is hitting is too dirty, the shot may also fail.

When you are ready, press the large green **Take Shot** button to take the readings. This takes about 3 seconds and the Caveatron needs to be held steadily on the card to get an accurate result. Be especially careful when hitting the button, that you don't tap so hard that it knocks it off alignment. It is best to brace the Caveatron against the station with one hand and hit the button with the other to keep it steady. Keep your eyes on the position of the laser during the shot to prevent it from wandering off of the card.

During the shot, you will first hear various audio indications as described in the sidebar on p. 8. After pressing, **Take Shot**, the *Start Tone* will be heard, which will be followed by three *LRF Beeps* – each one indicating a successful distance reading. If the shot is successful, the *Success Tone* will follow at the end. If the shot fails, then the *Failed Tone* will be heard and an error message will display on the screen. The most common error is that laser moved off of the reflective card and one of the distance measurements did not get a return. This might also happen if the card is too dirty or at too much of an angle. Other errors might occur if the Caveatron was suddenly moved during the reading causing a large angle shift or if the magnetic field around it changed such as from a headlamp being too close to it.

When the shot is successful, the distance azimuth and inclination readings are displayed on the screen along with the station names. The **DONE** button at the bottom saves the data to the Survey (*.SRV*) file on the memory card. If you do not like the reading and want to take the shot over again, tap **REDO**. This takes you directly back to the **Take Shot** button and retains the station names as well as remembering which corner was used.

POST–SHOT MESSAGES

If there is an error in the shot, the type of error (no LRF return, azimuth shift, etc.) will be displayed. You can hit **DONE** to exit and no data is saved or hit **REDO** to go directly back to the Take Shot button to try the measurement again.

Another alert that may appear after taking a shot is a magnetic anomaly detection. This

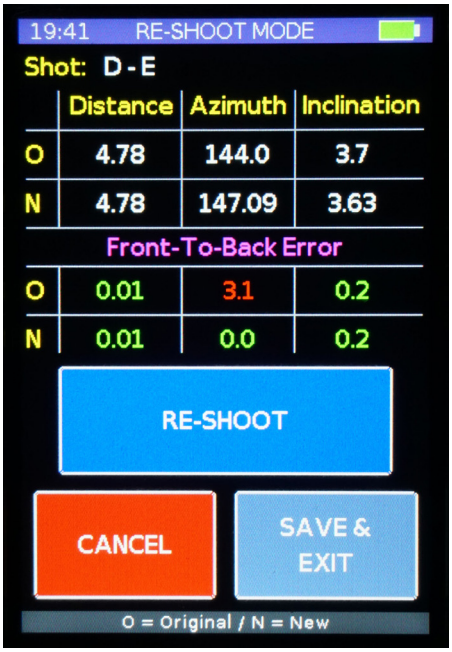
can occur if the Caveatron is too close to an object that generates a strong magnetic field such as iron objects (like a cave gate), rocks with a high ferromagnetic content, or even your headlamp (especially the battery). This often results in an erroneous azimuth reading. The Caveatron still saves these shots as normal but you should consider re-taking the shot or at a minimum doing a back-sight to double check it. If the alert continues to occur, even after you have ensured any magnetic sources such as your headlamp are not near the Caveatron, then try moving the station to a different location. Note that the threshold values that generate the alert can be set in the Settings Menu and they might vary at your location from the defaults. Check the Settings section for more information.

If you are obtaining a backsight, a different screen is displayed after taking the shot that shows the error between the the backsight and the matching frontsight. The distance, azimuth and inclination of each are shown along with the error in degrees or meters. The error is colored green or red (the cutoff values are in the table below) so that you can quickly check if there is a problem with one of your shots. The colors are for display only and do not affect anything about the operation of the Caveatron or what is saved.

Red/Green Cutoff Values for Frontsight/ Backsight Error

Distance	Azimuth	Inclination
0.05 m	2.5˚	2.0˚

RE-TAKING SHOTS



If after taking a backsight, you determine that the frontsight is probably faulty, you can quickly retake it from the initial shot selection screen when starting Shot Mode. The most recent shot is displayed but you can also enter another station pair. The Caveatron tries to find the station pair. If they are not found, an error message is shown. If a match is found, a screen appears that shows a table with the shot data and the front/back errors for each measurement (colored according to the table above). The row labeled **"O"** is the error between the original front/back pair whereas the row labeled **"N"** is the error with the newly retaken front shot (initially blank until the new shot is taken).

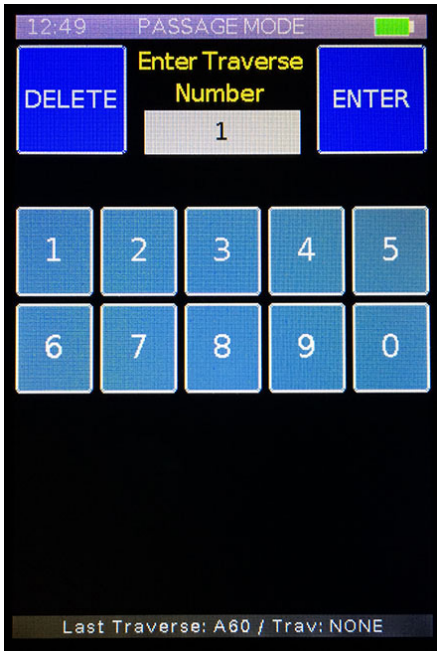
Press **RE-SHOOT** to go to the standard shot screen and retake the shot as usual. Afterwards, the Caveatron returns to this screen with the values and the error for the new shot displayed. If you want to try again, you can press **RE-SHOOT** and take it yet again. Once you are satisfied, press the **SAVE & EXIT** button to delete the original shot in the survey file and store the re-taken shot. If you press **CANCEL,** the original shot is not changed.

Passage Mode

Passage Mode is the main mode for scanning with the LIDAR. With Passage mode, scanning is done while moving forward with the Caveatron toward a station. Since the operator is in motion during the scan, the scans in this mode are referred to as “Traverses”. The LIDAR scans are perpendicular to the direction the Caveatron is pointing and moving, over a 360 degree circle in a counterclockwise direction, as shown in the figure at right. Essentially, it continuously scanning closely spaced cross-sections of the cave as it goes. It returns single point measurements of the range reading and angle of each point. The rotation speed and data rate of the LIDAR can be adjusted in the Caveatron’s settings.

Passage Mode Scan

Performing the scan involves selecting a station to which you will traverse toward during the scan. This is usually to the next station in the survey which was just measured in Shot Mode. However, it can be any convenient station, which allows you to scan the area however you want. The reflective card is held on the station during the scan as the pointing target for the red laser spot. As you traverse, the Caveatron continually attempts to take LRF readings from the card and, when it gets a return, it establishes that as a positive fix on its distance and orientation. These fixed points provide a framework which allows reliable computation of the positions of the Caveatron throughout its scan. As such, it is best to try to obtain as many fixed points during a scan as possible. However, practical considerations of moving through a cave make this difficult so the Caveatron allows limited intervals of time to pass without obtaining a fixed point. The longer the time between fixed points, the greater the potential position error, so the maximum interval without a fixed point has been set to 12 seconds, after which a scan fails. The Caveatron provides a warning tone after 6 seconds to give the operator time to stop and re-acquire the card.



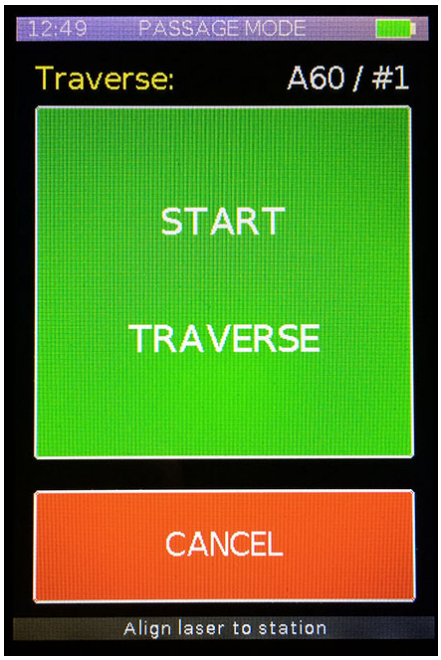
During a scan, you do not need to follow an exactly straight line, but can make gradual moves to go around obstacles as necessary. It is important to keep movements smooth, since sudden jerking motions will result in sizable errors and can cause a scan to fail.

Simultaneously with collecting the LIDAR and LRF data, the Caveatron collects frequent readings from the IMU to determine its orientation and to estimate its position between fixed points. All of this data is written to the *.CVL* file on the memory card.

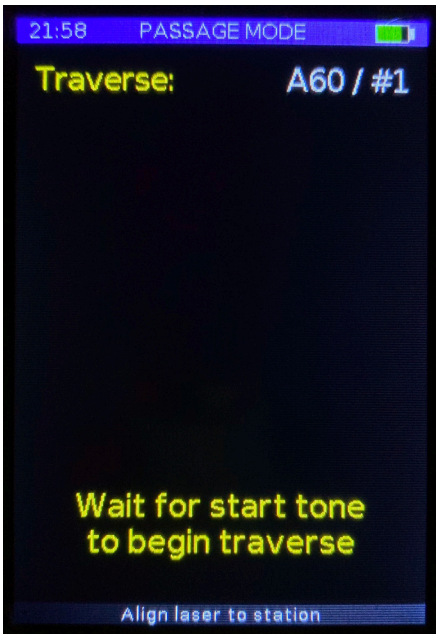
Entering scan mode on the Caveatron first presents a screen into which the *TO* station name is entered. This is the station toward which the traverse will be conducted and onto which the reflective card will be placed. The Caveatron assumes that this is the station toward which the

last shot was taken and pre-fills the station entry box with this recommendation. An alphanumeric keypad is presented which can be used to enter a different station (see Keypad Usage sidebar on p. 7). Pressing **ENTER** accepts the station name and moves to the next screen or press **CANCEL** (which appears after deleting the characters) to quit Passage Mode and return to the Main Menu.

The next screen is for entering the traverse number. Since multiple traverses can be made to a single station, the traverse number is used to distinguish between them. Up to 9 traverses can be made to a single station. The suggested number is entered automatically based on how many previous traverses the Caveatron thinks were made to the station. The traverse number can be changed using the **DELETE** button and the number buttons provided. Pressing **ENTER** accepts the traverse number and moves to the Start Scan screen.



The reflective card is centered over the station with the reflective surface pointing back toward Caveatron (see Using the Reflective Card sidebar on p. 9). Before starting the scan, it is important to evaluate the path that you will take to perform the scan. You need to pick a path that does not have too many hazards that will make it difficult to traverse. Think about where you will need to place your feet or what you will have to climb over. If there is a transition like a climb or large step, its best to place the next station just past that point and conclude the scan by reaching past the transition. Then start the next scan after making the transition. It is also better to scan upslope than downslope. Downslope is usually more hazardous and can also result in scanning your own legs. Another factor is to consider what will be covered by the scan and what might be obscured. For example, if you can scan along the top of a ridge, that would be better than going along one side since the other side would be obscured. Also, when getting in the starting position for a scan, try to get a meter or more of overlap with the previous scan since it will make alignment easier.



After the traverse number is entered on the Caveatron, the red laser turns on, so it can be aligned to the reflective card. Once you have the Caveatron in position with the laser pointed at the card, and as close to the station as possible, you are ready to start the scan. Hold the Caveatron steady without moving, and press the large green **START TRAVERSE** button to begin the scan. When a scan is initiated, the Caveatron takes an initial shot with two distance measurements to the station to obtain its starting position and you will hear two *LRF Beeps* for each distance readings. During this, you will see a screen warning you to “Wait for Start Tone to begin traverse”. The **END TRAVERSE** button allows you to cancel. Continue to hold the Caveatron steady on the station and wait a few seconds

while the LIDAR starts up and initializes. As soon as it is ready, you will hear the *Start Tone* and you can start moving forward.

While traversing, try to maintain a slow, gradual and uniform pace while trying to keep the laser pointed at the reflective card. Try to avoid moving the Caveatron quickly from side to side and keep moving it toward the station. Its ok to gradually move and shift the Caveatron to one side to avoid an obstacle, just try to keep moving forward if you can while doing it. Often you will have to slow down or pause during the scan to pass an obstacle. Try to keep the laser as much on the station as possible while making the transition. If the Caveatron detects too sudden of a change in direction either in azimuth or inclination, the scan will fail to prevent a bad quality scan. A scan will also fail if it detects a large bump or jerking motion, such as from a stumble.

During a scan, you will hear the *LRF Beep* about once per second – one beep for each time the LRF gets a valid measurement to establish a fixed point. By listening for the beeps you can be sure you are still on the card. Its nearly impossible to keep the laser on the card throughout the scan, which is ok – the Caveatron is designed to handle that by computing intermediate positions with the IMU data. However, the longer without a fixed point, the more the error will increase. After 6 seconds without an LRF return, the Caveatron will start sounding the *Caution Tone* which will continue until the card is re-acquired and a new LRF reading obtained. When you hear the tone, it is best to slow down or stop and just focus on getting the red laser solidly back on the card. Once the tone is off, you can continue forward with the scan. If however, you cannot obtain a new LRF reading after 6 more seconds (12 total seconds since the last reading), then the scan will fail and the *Failure Tone* will be heard.

While the scan is in progress, the screen shows the station and traverse number, the LIDAR scan settings, and the **END TRAVERSE** button which can be pressed at any time to end the scan.

As you approach the end of the scan, its important to continue to stay pointed at the station as accurately as possible. When you end the scan, resist the temptation to pull the Caveatron up to look at it or point it away in another direction before you hear the *Success Tone* indicating the scan is complete. Otherwise you might end up with a sudden and erroneous diversion in the scan direction at the end of the scan. There are two ways to end a scan. First, you can allow the Caveatron to end the scan automatically. If you get the Caveatron inside 0.2 m of the station and it obtains two successive LRF readings inside this range, then it will end the scan on its own. This may require holding the Caveatron stationary right in front of the reflective card for a couple of seconds to get the two LRF readings to register. The other option is to end the scan manually which can be done at any distance from the station and at any point during the scan. Just tap the **END TRAVERSE** button on the screen, being sure to not cause the Caveatron to shift angle when you press it. When the scan ends successfully, you will hear the *Success Tone* indicating the scan is complete.

If the scan finished successfully, the screen displays some information about the scan so you can assess its quality. LRF Data % indicates the percentage of LIDAR points obtained as compared to maximum number possible for the given the data rate of the LIDAR and length of the scan. Valid LRF % indicates how many fixed points you got in your scan as compared to how many you could have gotten based on the length of your scan and how often the LRF takes a reading. If this value is too low, the scan will be less accurate since more position interpolation will be required. Both numbers display as green, yellow, or red to provide a quick assessment whether the parameters were very good (green), ok (yellow), or possibly of lower quality (red). If the either of the numbers are red, it doesn't always mean a bad scan, since the scan quality parameters depend on the area being scanned or how difficult it was to obtain the scan. For example, a scan in a large room where the walls or ceiling areas are beyond the range of the Caveatron would result in fewer LIDAR points being obtained. Likewise, a challenging traverse with lots of crawling or climbing over rocks could prevent you from getting LRF readings as frequently. However, if none of these conditions were the cause of the lower quality scan values, you may want to consider redoing the scan. Finally, the Total Scans value indicates how many complete LIDAR rotations occurred during the traverse.

If the scan failed, the screen provides a message indicating the cause of the failure. Note that all scan data is always saved to the *.CVL* file, even a failed scan, so the data is still available for post-processing if you choose to use it (but is flagged as a failed scan in the post-processing software.)

At the bottom of the screen, the **REDO** button provides an option to do the scan over again and will take you directly back to the Start Scan screen with the same traverse number. If you choose this option, the scan just obtained is flagged as a Redo scan to indicate it may not be the scan you want to use when post-processing the data. The **ANOTHER TRAVERSE** button is for taking a new scan to the same station and takes you directly to the Traverse number screen with the next number pre-entered. Finally, the **DONE** button exits Passage Mode and takes you back to the Main Menu.

If you have a failed scan, you may choose to redo the scan from its original starting point, but that is not required. You could also choose to continue the scan from the place where the failure occurred. In this case you would select **ANOTHER TRAVERSE** with a new traverse number. Then step back far enough to be sure you are starting before the failure point and have at least a meter of overlap with the good part of the previous scan. If you have a difficult spot in the survey or some other reason you have to "pause" the scan, you can manually end the scan, then use the same process to start a new traverse when you are ready to continue.

Room Mode

Room Mode Scan

Room Mode provides a second way to scan that is more like a traditional LIDAR scan. Unlike, Passage Mode, Room Mode scans from a fixed point while rotating the Caveatron. Oftentimes the scan points are not station, but are off to the side of the main survey, so are referred to as “Splays”. In Room Mode, the LIDAR only scans the left 180 degrees of its arc in a counterclockwise direction (as illustrated in the figure at right). This allows the operator to move around the right side Caveatron while rotating it without getting into the scan. The geometry of the Caveatron means that the rotation should be around an axis through the front of the base directly under the LIDAR. Basically in most cases, you will be holding it roughly level and rotating it in azimuth to get a series of closely spaced half cross sections at varying azimuth angles. The purpose of this mode is to scan areas that would not be easily covered with Passage Mode such as dead end rooms at the end of a passage, the outside corner of a large angle turn in a passage, a side alcove or other occluded area, or to obtain coverage in an area that may be too difficult to traverse through. An example of the latter is pits requiring rope, which would be unsafe to scan while climbing or descending in Passage Mode. A better approach is to conduct a room scan at one end of the pit, climb or descend some distance (say 5-10 meters) perform another Room scan while on rope, and then repeat this for the depth of the pit.

A room scan requires referencing the splay location to a particular station. This could be the station itself or some location within view of a station. If the latter, a reference shot must be taken to establish the location of this splay position. It is best if the position for the splay is chosen to be on a point that allows free rotation of the Caveatron with a clear view, such as the top of a large rock. However, such locations may not always exist, so free handed splays are possible if you are able to maintain a steady position during and after the reference shot and then rotate it about that point without offsetting it in any direction. For the reference shot, the reflective card is held on the station during the scan, as in Shot Mode, to get an accurate position. Once the reference position is obtained the card can be removed and is not needed during the actual scanning.

A splay scan covers any arc length. During a splay scan, you should try to maintain a slow smooth rotational motion and not jerk it in angle too rapidly. You should only rotate in a single direction and not reverse direction during the scan. The Caveatron should be roughly level during the scan and not tilted more than about 20 degrees in any direction. You can perform a Room Scan with the Caveatron upside down if the ceiling makes a more convenient point. Again, just be sure it is roughly level. Simultaneously with collecting the LIDAR and LRF data, the Caveatron collects frequent readings from the IMU to determine its orientation. All of this data is written to the *.CVL* file on the memory card.

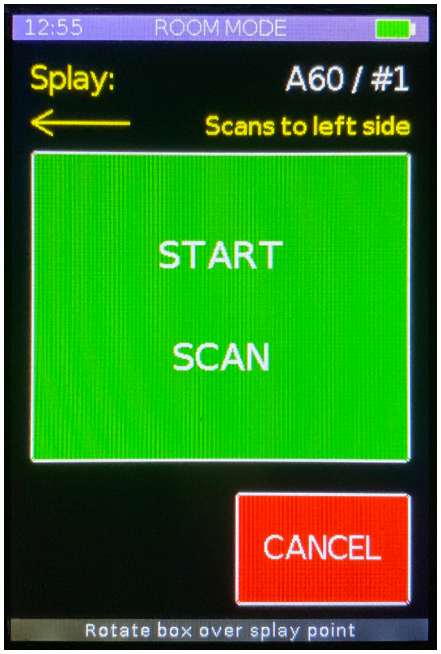
Entering scan mode on the Caveatron first presents a screen into which the station name is entered. This is the station that will be used as the reference station. The Caveatron assumes that this is the station toward which the last shot was taken and pre-fills the station entry box with this recommendation. An alphanumeric keypad is presented which can be used to

enter a different station (see Keypad Usage sidebar on p. 7). Pressing **ENTER** accepts the station name and moves to the next screen. or press **CANCEL** (which appears after deleting the characters) to quit Room Mode and return to the Main Menu.

The next screen is for entering the splay number. Since multiple splays can be made to a single station, the splay number is used to distinguish between them. Up to 9 splays can be referenced to a single station. The suggested number is entered automatically based on how many previous splays the Caveatron thinks were referenced to the station. The splay number can be changed using the **DELETE** button and the number buttons provided. Pressing **ENTER** accepts the traverse number and moves to the next screen.

At this point there are two choices. If the reference station is to be used as the point where the Room scan is conducted, then tap the blue **USE STATION** button which jumps to the Start Scan screen. If the point where the scan is to be taken is not the reference station, then you need to take a Splay Shot. Have the corner of reflective card placed at the reference station just like in Shot Mode (see Using the Reflective Card sidebar on p. 9). Place the center front of the Caveatron on the point you plan to use to rotate the Caveatron about. Point the red laser at the corner of the card covering the station. While holding the Caveatron steady, tap the **TAKE SPLAY SHOT** button. The Caveatron takes 2 distance readings and 50 azimuth and inclination readings to establish its position and you will hear *LRF Beeps* if these readings are successful. If they are not, such as if the red spot moved off the card during the measurement, the splay will fail and the *Failed Tone* will be heard. A screen will show the failure reason and provide a **REDO** button to retake the splay shot.

If the splay shot is successful, the **START SCAN** screen will appear. It is very important not to move the Caveatron away from the scan point once the Splay Shot is complete or you will lose the established position and will need to retake it. Observe the arc you wish to scan and plan where to position yourself to be out of the scan. Remember that in this mode, the scan is only to the left (as seen from the rear) so you can position yourself on the right side to be out of the scan. Be sure to hold the Caveatron so you do have not have to reach across the LIDAR and do not lean over the Caveatron while scanning or parts of your body will be scanned. Determine where you want to start and end the scan and which way you want to rotate. It is always good practice to have part of the scan overlap some other area that has been scanned. This makes it easier to join up the scans in post processing. Move yourself into position and rotate the Caveatron to the starting point of the scan, keeping it on the point just established for the scan.



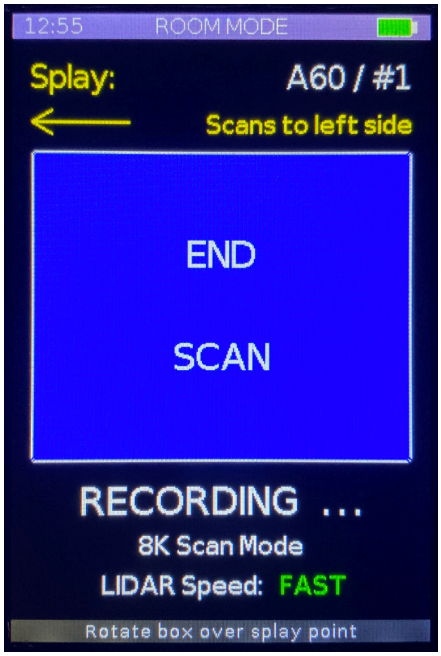
The LIDAR starts up and initializes as soon as the **START**

SCAN screen is displayed. Grip the Caveatron securely and press the large green button on the screen to start the scan. After hearing the *Start Tone*, you can start rotating the Caveaton. Be sure to rotate slowly and smoothly, not inducing any sudden jerking motions. You can vary the rotation speed as you go, depending on what the LIDAR is scanning. If you are scanning a very close wall, you can rotate faster since the points being collected are very close together, but if you are scanning something far away or down a passage, you should rotate much more slowly to be sure you capture enough points since they will be spaced much further apart. Sudden jerking motions or a rotation that is too fast will result in a failed scan. Remember to avoid putting any part of your body into the 180 degree scanning zone.

As you come to the end of the scan arc, be sure you do not pull the Caveatron up to look at it or point it away in another direction before you hear the tone indicating the scan is complete. Otherwise you will end up with erroneous data in the scan. To end the scan, tap the **END SCAN** button on the screen, being sure to not cause the Caveatron to shift angle when you press it. When the scan ends successfully, you will hear the *Success Tone*.

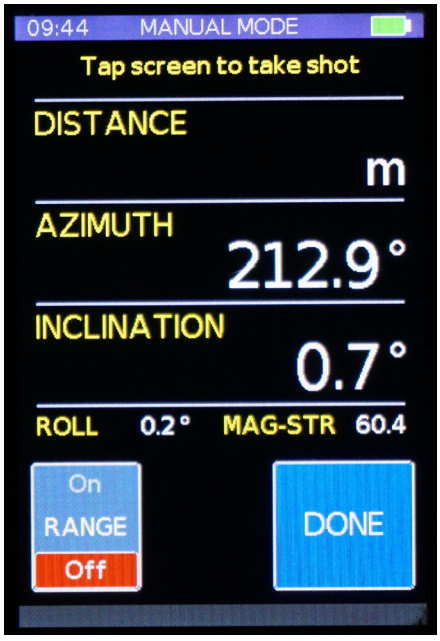
If the scan finished successfully, the screen displays the LIDAR Data % which is the number acquired of LIDAR points as compared to maximum possible number given the data rate of the LIDAR and the length of the scan. The number can display as green, yellow, or red to provide a quick assessment whether the parameters were very good (green), ok (yellow), or possibly of lower quality (red). If the number is red, it doesn't always mean a bad scan, since the scan quality parameters depend on the area being scanned or how difficult it was to obtain the scan. For example, a scan in a large room where the walls or ceiling areas are beyond the range of the Caveatron would result in fewer LIDAR points being obtained. However, if this is not the case, you may want to consider redoing the scan. The Total Scans value indicates how many complete LIDAR rotations occurred during the traverse.

If the scan failed, the screen provides a message indicating the cause of the failure. Note that all scan data is always saved to the *.CVL* file, even a failed scan, so the data is still available for post-processing if you choose to use it (but is flagged as a failed scan.)



At the bottom of the screen, the **REDO** button allows you to retake the scan. If the last scan was taken at a station, then the screen will go directly to the Start Scan screen. If the last scan used a splay shot for its position, then the screen shown at right will appear from which you can choose to **USE LAST SPLAY SHOT** if you want to perform the scan from the same location, or **RETAKE SPLAY SHOT** if you want to change locations or were unhappy with the previous splay shot. You can also choose to move onto the station with the **Use Station** button. Depending on the button selected, you will be taken back to the Splay Shot or Start Scan screen with the same splay number selected. In this case, the scan is flagged as a Redo scan to identify it in post-processing. The **ANOTHER SPLAY** button is for taking a new scan using the same station as reference and takes you directly to the Splay number screen with the next number pre-entered. Then you are taken to the screen shown at right to select to reuse the last splay shot (if the new Room scan is at the same location) or retake it (if you are at a new location). Finally, the **DONE** button exits Room Mode and takes you back to the Main Menu.

Manual Mode



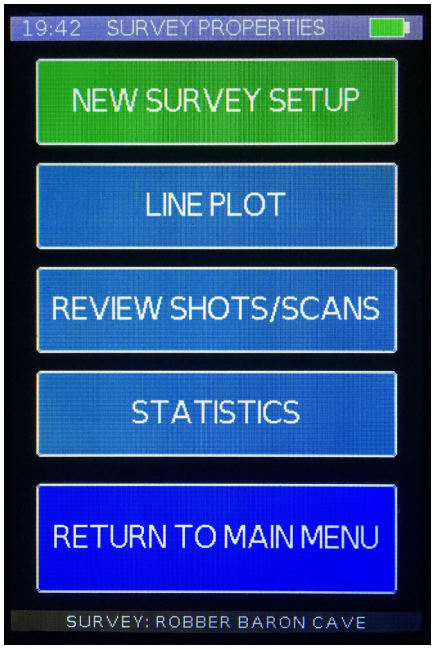
Manual Mode allows a quick check of angles and distances without having to enter station names. This mode is for viewing measurements only and does not record any data.

After starting Manual Mode, a screen appears that shows live azimuth, inclination, and roll angle values and the red laser turns on. The magnetic strength (MAG-STR) is also shown to help identify the presence of strong magnetic fields that may interfere with azimuth measurements. You can immediately view the actual pointing angle of the laser from the on-screen numbers (relative to a marked point on the rear of the Caveatron). At the bottom of the screen is the **RANGE** switch for turning **ON** or **OFF** the distance measurement (the default is Off).

By tapping anywhere in the middle portion of the screen, a shot is taken in the same way as a shot is taken in Shot Mode (an average of 75 angle readings and 3 distance readings). If the distance reading switch is **OFF**, then only the angles are acquired. If the distance reading switch is **ON**, then the Caveatron also attempts to acquire the distance measurements. As with Shot Mode, the laser must be pointing at the reflective card in order for the distance readings to be taken, or the shot will fail. After the shot is complete, the result is displayed. To return to the live angle view, tap the center portion of the screen. To exit Manual Mode and return to the Main Menu, press the **DONE** button.

Survey Menu

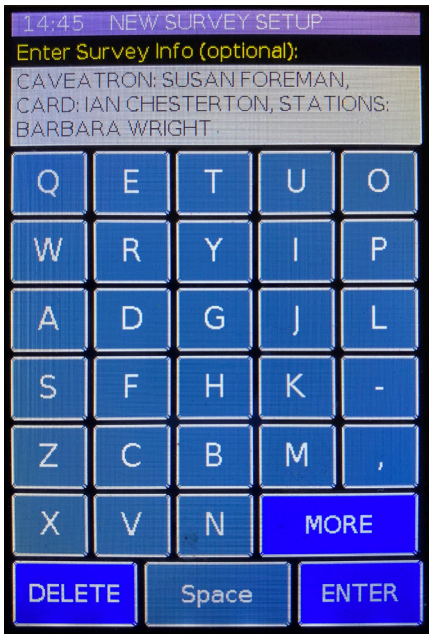
The Survey Menu provides functions for viewing survey and scan data, performing some limited editing, and for creating new surveys.



SETTING UP A NEW SURVEY

Before starting a survey, the survey files need to be created and initialized. This is done by selecting the **NEW SURVEY SETUP** button, which brings up a keypad to type in the name of the cave. Shortcuts are provided for the words “Cave” and “Pit”. The name entered here is also used for the folder name in which the survey’s files are stored. If you want to cancel creating a new survey, press delete repeatedly to remove all the text, after which it will turn back into the **CANCEL** button.

After entering the cave name, press **ENTER** and the next screen appears showing the automatically generated base filename for all the files. It must be 8 characters and uses the first 4 characters of the cave name, the 2 digit month, and 2 digit date. Press **ENTER** to accept the default name or change it to any to any combination of numbers and characters you want. Once the base filename is entered, the files are created for the survey on the internal micro SD card and initialized with headers and starting values. A message box will briefly appear to inform you that the files were successfully created.



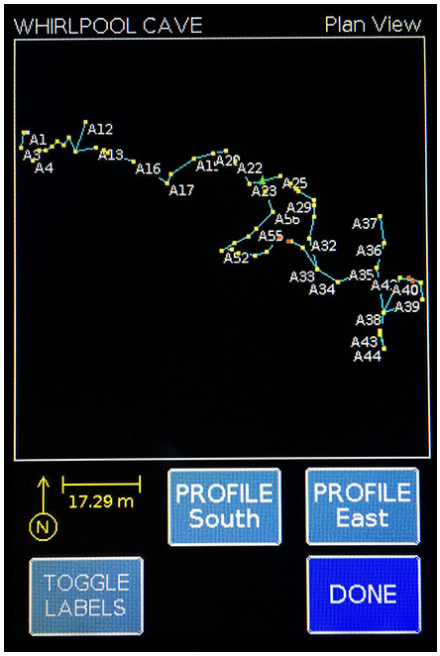
The next screen that appears is for entering survey information such as the names of the team members, conditions or other info about the cave. This information is optional. The screen shows a QWERTY-like keypad and a text entry box. This box is limited to 84 characters. Numbers and special characters can be found by tapping the **MORE** button. A second tap of the **MORE** button brings back the letters. Press **ENTER** to save the info which will appear near the top of the *.SRV* survey file when viewed in Walls Cave Mapping software. The info can be viewed and edited later from within the survey statistics page or added from there if you don’t want to do it at this time.

VIEWING A LINE PLOT

The line plot shows the shot vectors taken in the current survey. This is useful for getting a sense of the direction and interconnection of the passages and where additional survey may need to be performed. The plot shows stations as yellow squares and the shot vectors between stations as cyan lines. The stations are labeled with their names, though some labels are not shown if stations are too close together. The line plot also shows the most recent station as a larger green triangle and any duplicate stations (such as loop closures) are shown

as red squares. Note that loops are not actively closed in this plot which allows you to see how good the closure is by how close the closure points are to each other. The plot may be viewed from three possible directions which are selected by tapping the indicated button: **PLAN** View from above, **PROFILE** view from the south, and **PROFILE** View from the east. The plot automatically scales to encompass the entire survey and a scale bar shows the current scale. There is also an option to **TOGGLE LABELS** on or off. If there is more than one group of unconnected shots, a **TOGGLE GROUP** button will be available to switch between them. Up to 120 shot vectors can be displayed. If a survey has more than that, the newest ones are not shown.

The line plot viewer also has a zoom and pan mode to get a more detailed view of part of the survey. Tap on the line plot display box to enter pan/zoom mode. The buttons at the bottom now change to include a **ZOOM IN** and **ZOOM OUT** button. When zoomed in, you can pan the view by tapping near the edge of the plot box in the direction you want to pan. The **RESET VIEW** button restores the fully zoomed out view and **EXIT ZOOM/PAN** mode returns to the initial line plot screen.



VIEWING AND EDITING SURVEY DATA

This function provides a list of the shots taken during the current survey and the ability edit them and add notes. This list shows the *FROM* and *TO* station names, the distance, azimuth, and inclination readings, and whether it was a backsight. This list is sorted backwards in time so that the most recent shot is first. Eight shots are shown per page and pages are stepped through by pressing the **NEXT** button at the bottom to go to the next page or the **PREV** button to go to the previous page. The current page number and total number of pages is also shown. A maximum of 12 pages of shots can be viewed. If a survey has more shots than that, the earliest shots in the survey cannot be viewed or edited on board the Caveatron.

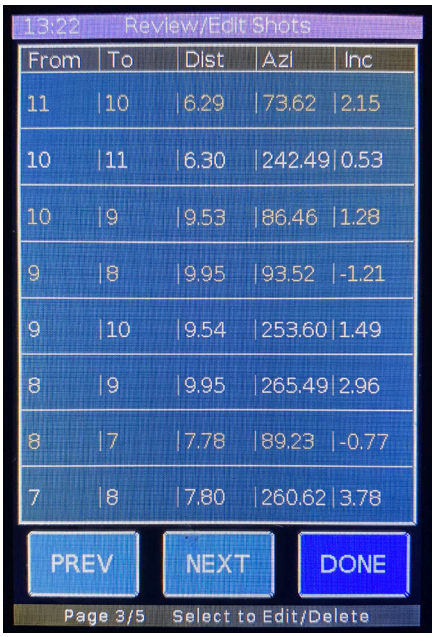
Tapping on one of the shots brings up a contextual menu with several options for editing the shot. **ADD NOTE** displays a screen with a QWERTY-like keypad and a text box into which a note can be entered for that shot with information of interest such as a description of the

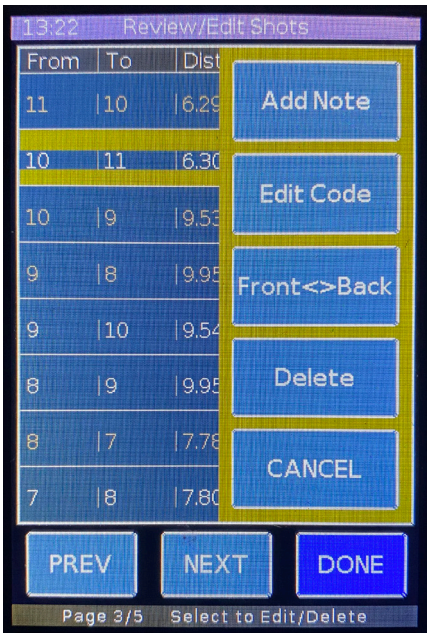
area, whether formations are present, if the station corresponds to a previous survey station, etc. Up to 84 characters can be entered and the information is stored in the survey file and is displayed in the Walls Cave Mapping software. Press **ENTER** to save it and exit. If you select **ADD NOTE** to a shot for which a note is already entered, the note is displayed in the text box and can be edited. To leave the note unchanged, press **ENTER** or press **DELETE** until the **CANCEL** button appears.

The **EDIT NAME** menu option allows you to change the **FROM** or **TO** station names in the event they were entered incorrectly or need to be changed. A box appears to select the FROM or TO station and then the station code entry screen appears with the current station name entered in the text box. After changing it, press ENTER to accept the new name. To leave it unchanged press ENTER or DELETE repeatedly until it turns in tot he CANCEL button.

The **BACK<->FRONT** menu option changes a front-sight into a back-sight or vice versa.

The **DELETE** menu option will completely remove the shot from the *.SRV* file survey file along with any note entered for it. A dialog box appears to confirm that you really want to delete it before doing so.

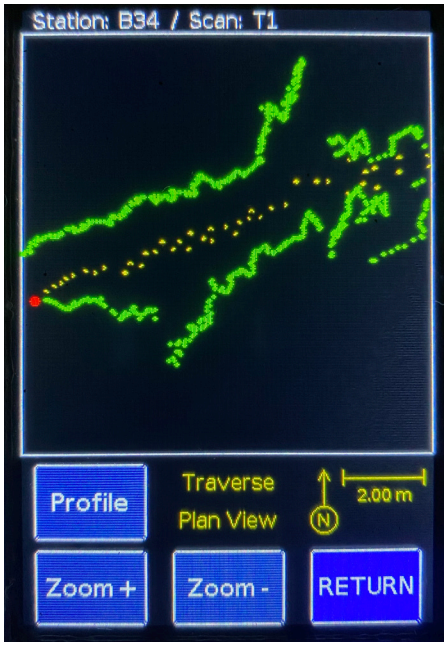




VIEWING SCAN DATA

The individual LIDAR scans for the current survey can be viewed in a basic way to confirm that the Caveatron is recording the data you want and to get a simple visualization of the plan and profile of the passages. This may also be useful if you are creating a traditional hand-drawn sketch along with the scans. The scan list shows name of the reference station used for the scan, the type of scan (Traverse (T) or Splay (S)) and scan number, and the number of points scanned. The rightmost column labeled “Ok” indicates the status of the scan with a blank entry meaning the scan was completed successfully, “FR” meaning a failed and redone scan, or “FC” meaning a failed and canceled scan. Eight scans are shown per page and pages are stepped through by pressing the arrow keys at the bottom of the page with the right arrow key going to the next page and the left arrow key going to the previous page. The current page number and total number of pages are also shown.

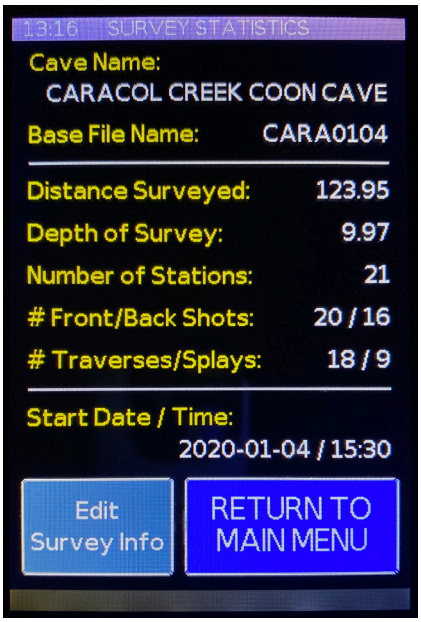
Tapping on a scan loads that scan and displays it graphically in a window. The plot shows stations as large red dots and the wall points as green dots. If the scan is a Traverse scan, the estimated path of the Caveatron during the scan is also shown as small yellow points. If the scan is a Splay scan, the point where the scan was taken relative to the station is shown (if the scan was not taken directly on the station). Note that the data shown in this window is not processed in any way, so will show errors from body movement, shaking or tilting the unit, and noisy outlier points that are all handled or removed in post-processing. If you have loaded a Traverse scan, two view options are provided: **Plan** view which shows the wall points directly to the left and right of the Caveatron and **Profile** view which shows the wall points directly above and below the Caveatron. For Splay scans, only the **Profile** view is available. The plot automatically scales to encompass the entire scan and a scale bar shows the current scale. There is also a **Zoom +** and **Zoom -** for zooming in and out.



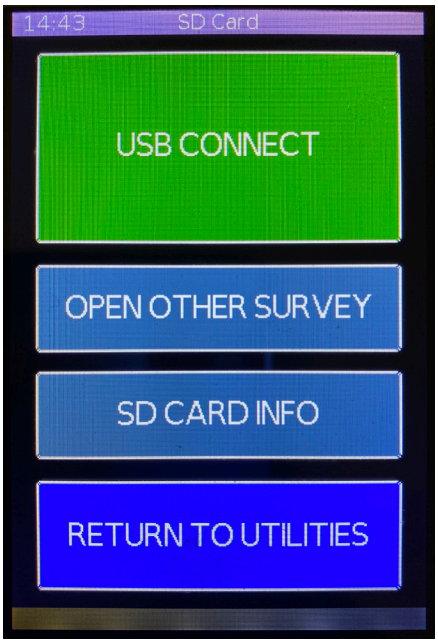
VIEWING SURVEY STATISTICS

This function provides a list of the statistics for the current survey including the cave name, file base name, the distance surveyed, the depth of the survey, the number of stations, the number of frontsight/backsight shots, the number of traverse scans and splay scans, and the date and time that the survey was started.

At the bottom of the page, the **EDIT SURVEY INFO** allows you to view or edit the survey info that was entered when setting up the survey or adding info if it was not entered at that time. After editing or entering new info, press **ENTER** to accept. To leave the info unchanged, press **ENTER** or press **DELETE** until the **CANCEL** button appears.



Transferring Files with a Computer



The Caveatron uses the Media Transfer Protocol (MTP) to allow computers to connect, view, transfer, and delete files. The MTP protocol is primarily used by Android devices so its level of support varying by computer operating system (see sidebar below). The connection is not normally active and is initiated by selecting a menu item in the Caveatron GUI after which the connection is automatically established.

To connect to the Caveatron to a computer, perform the following steps:

- Plug a USB to USB-micro cable into the Caveatron and computer.
- Be sure the computer is awake.
- Turn on the Caveatron.
- Go to **UTILITIES ➜ SD CARD** and press the **USB CONNECT** button.

Depending on the operating system, different actions will occur:

Windows: The Caveatron will appear as a mounted drive called “Caveatron”. Opening it reveals an SD card folder containing the files on the Caveatron. You can browse, copy and delete files and folders like a normal USB drive.

Mac: Open the Android File Transfer app and it will connect to the Caveatron as “Caveatron” (the app may also open automatically depending on how it is configured). It provides a window to browse, copy, and delete files and folders.

Linux: The Caveatron will appear as a mounted drive called “Caveatron MTP Disk” or similar. Opening it reveals an SD card directory containing the files on the Caveatron. You can browse, copy and delete files and folders like a normal USB drive.

After completing the file transfer, you will have to turn off the Caveatron before using it for any other function.

OPERATING SYSTEM MTP SUPPORT

Windows: MTP is natively supported by the operating system. Nothing further is required.

Mac OS: MTP is not natively supported and no free system-wide drivers are known to exist. The only free software currently known to work is an app called Android File Transfer, which contains its own MTP drivers. Android File Transfer can be downloaded from here: https://www.android.com/filetransfer/

Linux: Some recent distributions include built-in MTP support. For others, libmtp can be installed to provide support. Information can be found at: http://libmtp.sourceforge.net/

FILE STORAGE AND TYPES

Files used by the Caveatron are in plain text format and can be viewed in any text editor program. Several different files are generated for each survey. All the files for a particular survey are stored within a single folder titled with the name of the cave followed by the date in YY-MM-DD format. Spaces are converted to underscore characters. The files inside the folder have names that are 8 characters in length and all have the same base name with the 4 letters that are entered when setting up the survey and 4 numbers forming the date in MMDD format. Each file has a different extension depending on the type described below. An example would look like this:

Folder: LIMESTONE_ROCK_CAVE_20-12-06

Files:
LIME1206.SRV
LIME1206.CVL
LIME1206.IMU
LIME1206.LOG
LIME1206.DAT

It is possible to have more than one set of survey files within a single folder, so long as they have different base file names. This can be done if the same cave name is used to create a new survey on the same date. Or if no cave name is entered when creating a new survey then the current cave name and folder are used. In those cases a different first four letters would need to be entered for the base file name. The Caveatron will not allow you to overwrite any existing files. A list of other surveys on the SD card can be viewed within the **SD CARD** utility and re-opened as the current survey, so long as a valid .DAT file is present for that survey.

The different file types are:

Survey file (.SRV) – contains the station-to-station shot vector data from Shot mode. This file is in Walls survey format and can be opened in Walls or by the Caveatron Process software. The format of this file can be found in the manual for Walls software.

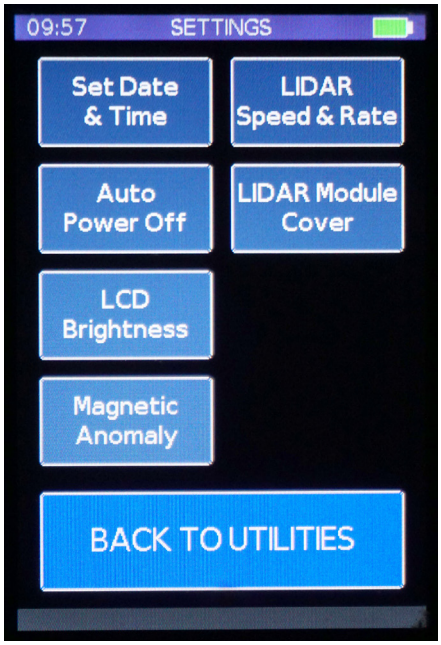
LIDAR file (.CVL) – contains the LIDAR scan data from Passage and Room modes. This file is in a custom format this is opened by the Caveatron Process software.

IMU calibration file (.IMU) – contains calibration data. Used by the Caveatron Process software to enhance the accuracy of the LIDAR scan data. The format of this file is described in detail in the “Caveatron Setup & Calibration Instructions” document. Special versions of the *.IMU* calibration files are used to load new calibration parameters and are uploaded from a computer to the Caveatron.

Log file (.LOG) – contains internal logged information about the Caveatron state useful for debugging and raw sensor data from shots which may be useful if you had a calibration error. This file does not normally need to be used.

Settings file (.DAT) – contains information about the survey used by the Caveatron to maintain an internal list of shots, scans and other info about the survey. This file is not used outside the Caveatron and should not be edited.

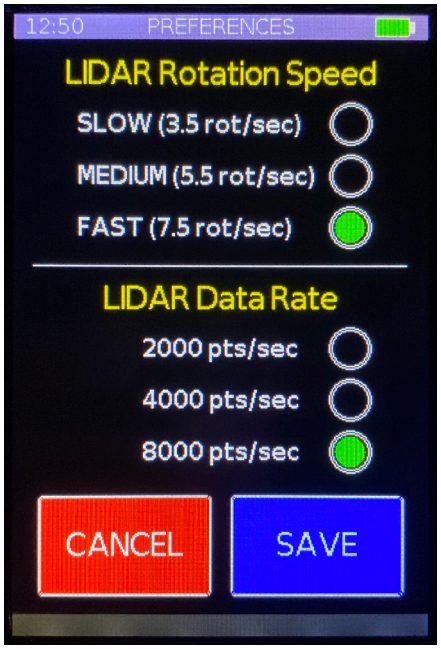
Settings



The Caveatron has several settings that can be adjusted to select your preferred operating parameters. The specific settings shown will differ depending on the hardware in your Caveatron. These settings are retained after powering off and on the unit. After changing settings, its best to re-boot the Caveatron to ensure they are applied.

When opening a setting, a list of settings are shown with radio buttons or a check box to the right. The radio button next to the currently active setting is filled with a green dot. Tap any other radio button to select a new setting. For check boxes, the setting is active if filled with a green square. Tap the square to enable or disable. The new settings are not applied until the **SAVE** button is selected. To return to the previous menu without making any changes, press **CANCEL.**

LIDAR SPEED & RATE



LIDAR Rotation Speed

This can be changed between SLOW, MEDIUM, and FAST. This only changes how fast the LIDAR spins, not how much data is collected. A slower rotation speed means that there will be a smaller spacing between points in a rotation, but unless you also move much slower, you will have a larger spacing between each rotation. The higher speeds on the other hand provide more rotations so as you move you get more frequent scans. As such the spacings between rotations are closer, allowing movement at a faster rate. The specific rotation rates available for SLOW, MEDIUM, and FAST vary depending on the LIDAR module installed.

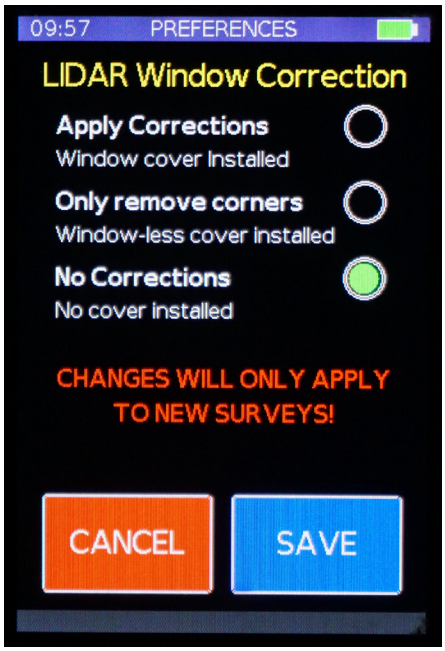
LIDAR Data Rate.

This can be changed between settings for the possible data rates of the RP LIDAR. The available options vary depending on the LIDAR module. For the A1M8, 2000, 4000, and 8000 pts/sec are available. For the S2, 16000 and 32000 pts/sec are available. Generally you want to pick the highest rate available, but a lower rate may produce slightly less noisy data or have a slightly better range in some cases. However the advantage of having more points at the higher rates typically outweighs the slight reduction in precision.

For the RP LIDAR A1M8, the FAST setting in combination with the 8000 pts/sec data rate provides a good balance of point spacing and distance between each scan rotation for typical sized passages, moving at about 0.25 - 0.5 m/sec. The SLOW setting combined with 8000 pts/sec would be appropriate for a location where the walls are close by and you want to get maximum detail. If you have concern about getting the maximum precision, then a setting of SLOW and 2000 pts/sec would give the best results, but this only makes sense if the

Caveatron were mounted on a tripod and moved very slowly (0.1 m/sec or less) since body motion would outweigh any advantage this combination would provide. For the RP LIDAR S2, the rotation speeds are 8, 11.5 and 15 rot/sec. The highest speed of the RP LIDAR S2 has a noticeable reduction in scan quality, so 11.5 is recommended.

LIDAR MODULE COVER



If you are using a triangulation based RP LIDAR (A-series) then the LIDAR Module Cover setting is available. It allows you to choose what window corrections are applied depending on what cover is installed. In this way you can remove the cover or only use the window-less cover to obtain maximum data in caves that are dry and then install the cover with Windows for wet caves or when you want maximum protection for the LIDAR. “Apply Corrections” uses the corrections for Window distortion and removes the corners where the support posts exist. “Only remove corners” just removes the support post corners but does not apply any window corrections. Finally, “No Corrections” does not apply any corrections or remove any data.

AUTO POWER OFF

The Caveatron will automatically turn off to save battery life when in the Main Menu screen or in the Utilities Menu screen. This setting adjusts the time until it turns off from the last touchscreen press and can be set to 1, 2, or 5 minutes. It can also be set to NEVER to prevent auto power off from activating.

LCD DIMMING

Certain Caveatron hardware configurations support adjusting the screen brightness. Reducing the screen brightness adds significantly to the battery life.

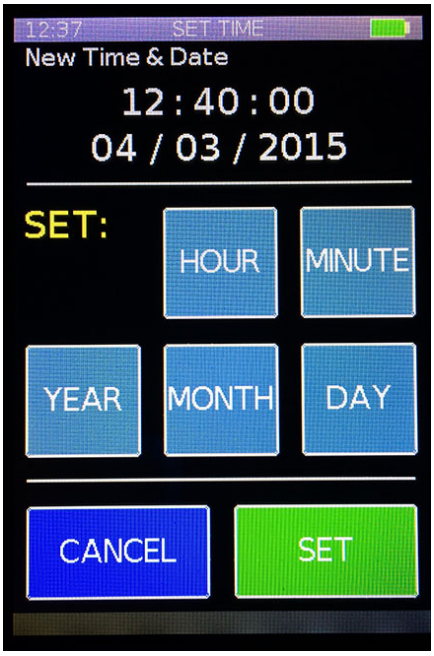
LCD Brightness
The screen brightness can be changed between 100%, 50%, 25%, and 12%.

LCD Dimming
The screen can be set to automatically dim after 1 minute of inactivity. After the screen dims, tapping it anywhere restores it to the set brightness level. The auto-dimming level is equivalent to 6% brightness. Auto-dimming can also be turned off.

SETTING THE DATE AND TIME

The internal clock can be set by going to **UTILITIES ➜ SETTINGS ➜ SET DATE & TIME**. A screen appears that shows the current date and time. The time is displayed in a 24 hr format. Select one of the buttons below to adjust the Year, Month, Date, Hour or Minute. Press-

ing one of these brings up a numerical keypad to enter a new value. After entering a new value, press **ENTER** to set the new value or press **CANCEL** to avoid changing any values. (See Keypad Usage sidebar on p. 7) After entering the new value, it returns to the main Set Date and Time screen which shows the new value. Additional adjustments can now be made to other values as needed. When done, press the **SET** button to set the clock the new time. **CANCEL** exits with out saving the new time.



Note that currently, daylight savings time is not automatically set, so the hour will have to be manually adjusted in the spring and fall.

MAGNETIC ANOMALY

These settings pertain to the detection of magnetic anomalies that can affect the compass azimuth readings. A checkbox allows you to enable or disable an audio alert if an anomaly is detected (a text alert is still displayed on screen in any case). The number boxes at the bottom allow you to set the upper and lower thresholds for the detection which may differ in different regions of the world. If the magnetic strength is outside of this threshold range, it triggers an anomaly alert. Use the **UP** and **DN** buttons beside the number box to increase or decrease the value. To help you set the values, you can use Manual Mode which shows the magnetic strength (MAG-STR) at the bottom. Take the Caveatron to an outside location away from any magnetic objects and turn it to various orientations, taking note of the highest and lowest MAG-STR values. Then take it indoor near objects that have stronger magnetic fields (like metal objects or object with motors, like refrigerators) and note the change in MAG-STR. Set the thresholds so that normal readings (like the ones you obtained outside) are between these limits but so that you can detect the anomalous values from placing the Caveatron near magnetic objects. You can adjust the thresholds at any time and they do not affect anything but when you get an alert.

Calibration

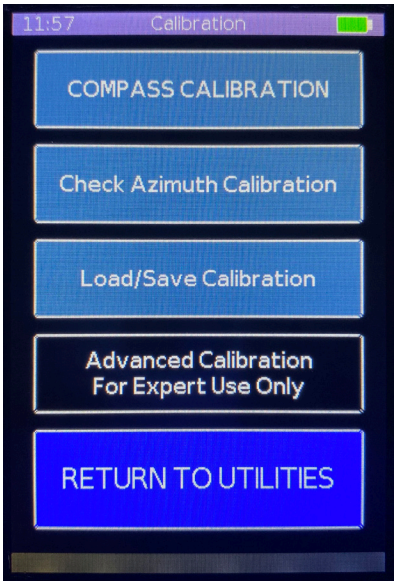
Detailed instructions for setting up and calibrating the Caveatron are provided in the "Caveatron Setup & Calibration Instructions" document along with instructions on how to use the calibration functions. Most of the calibrations need only to be done one time when the Caveatron is first assembled. The only calibration that should have to be performed on a regular basis is the User Compass Calibration, and those instructions are repeated in this section.

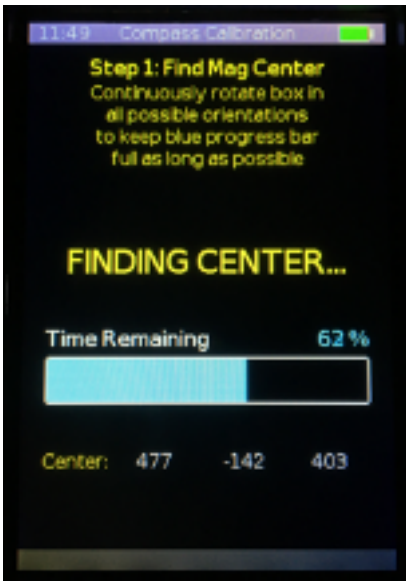
COMPASS CALIBRATION

The magnetometer sensor used for the compass drifts over the course of several days so needs occasional recalibration. Ideally, this should be done before each trip into a cave to get the best results.

This calibration is simple to perform and the steps are described below. First find an area well away from any buildings or major power lines. Be especially careful to stay far away from any motors such as compressors used in HVAC systems. Remember that roads and sidewalks are not good choices as they often contain rebar.

Under the **CALIBRATION** menu, select the **COMPASS CALIBRATION** function. There are two steps – first determining the approximate center of rotation of the calibration sphere and then calculating the coefficients. Both steps are done in approximately the same way. Hold the Caveatron out in front of you and when you are ready, press **START CALIBRATION** for Step #1 or **CONTINUE CALIBRATION** for Step #2. Continuously rotate the unit in all orientations so that each side points in every direction at some point. One way to do this is to spin the unit several times on one axis while you turn yourself around in a gradual complete 360º rotation and then switch to each of the other two rotation axes while you continue to turn around. Oftentimes the more upward pointed and downward pointed directions get missed, so you may need to spin and rotate the unit in these directions a few more times to complete the calibration. A progress bar is shown on the screen to indicate how many of the required points have been acquired. The unit intelligently acquires points to ensure that a relatively uniform distribution of points are collected around a sphere. If you were to just hold it in one or a few directions, the calibration would never complete as



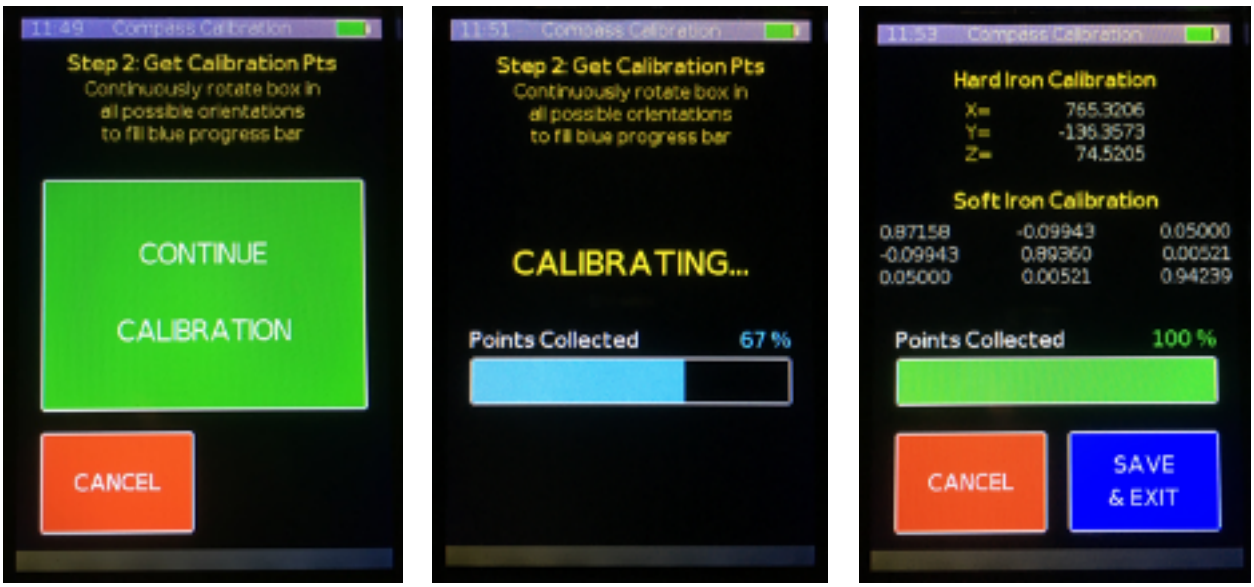


there would be an insufficient distribution of points.

In Step #1, the goal is to keep the progress bar as full as possible as long as possible while enough points are gathered to get an accurate center position for the magnetic sphere. If you hold it still, the progress bar drops rapidly, but as you spin the Caveatron to different angles, it will jump back up to full. The longer you keep it full, the more accurate the result. Eventually you will have gathered points from every direction and the progress bar will reach zero, completing step #1.

In Step #2, the goal it to fill the progress bar to full. As you spin to different angles and new data points are collected, it will gradually fill up. Spin the Caveatron as before. The last few percent may be a bit more difficult to get as you have to find the angles and orientations of the unit you have not yet covered.

Once the calibration is complete, the coefficients are immediately calculated and displayed on the screen. If you are satisfied, press **SAVE & EXIT** and they are stored in the EEPROM as the new Hard/Soft iron calibration parameters for that LIDAR configuration. They can be updated at any time by repeating the Compass Calibration. Note if you do not press **SAVE & EXIT**, the new coefficients are not stored and the existing coefficients remain in memory.



SAVE CALIBRATION PARAMETERS

This function saves the current calibration parameters to a file named “Cal_save.imu”, in the root of the SD card (not in a folder). This file can be downloaded to a computer by the normal file transfer process over USB. This file can also be reloaded if you take a new calibration that is unsatisfactory.

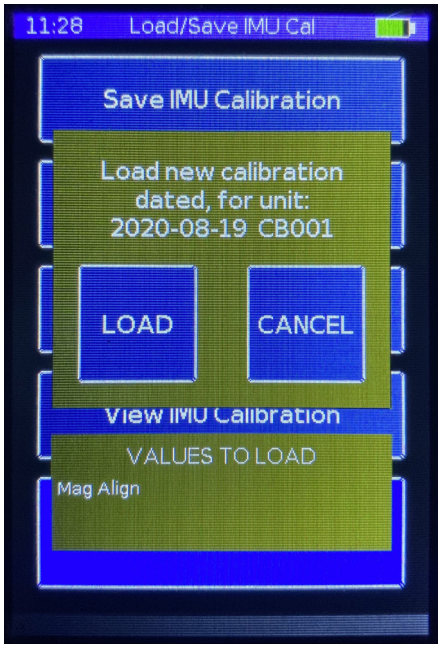
LOAD PREVIOUS CALIBRATION PARAMETERS

This function loads a previously saved calibration file (with the name “Cal_save.imu”.) All current calibration parameters are overwritten by the values in this file and a warning screen gives you the option to proceed or cancel. When selecting to proceed, wait several seconds until a message appears that the loading is complete. The Caveatron should be rebooted after performing this function to ensure the new parameters are applied.

LOAD NEW CALIBRATION PARAMETERS

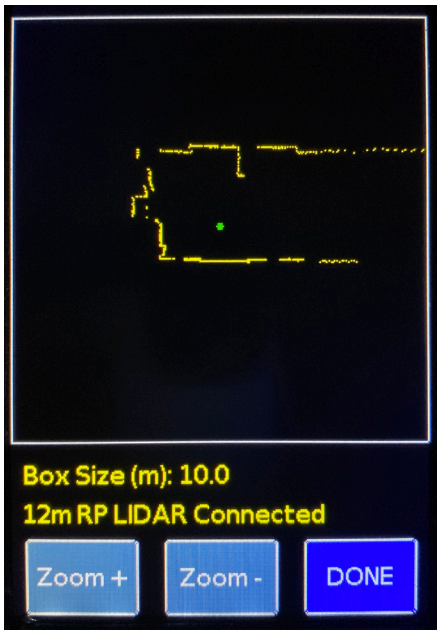
This function loads a subset of calibration parameters from a file named “Cal_new.imu” that a user uploads to the Caveatron SD card by the file transfer process over USB. This file must be placed in the root of the SD card (not in a folder). This is a special version of an IMU file that can contains a subset of the calibration parameters. If only one type of calibration parameter needs to be changed (for example, the magnetometer offsets), you would only place those parameters in this file and, when load, only those values are changed. A detailed description of the file format of a Cal_new.imu file can be found in the “Caveatron Setup & Calibration Instructions” document.

When running this function, a message appears showing the types of calibration parameters found in the file which will be overwritten and the date in the *.IMU* file to confirm that these are the correct parameters to load. After hitting ok, wait several seconds until a message appears that the loading is complete. The Caveatron should be rebooted after performing this function to ensure the new parameters are applied.



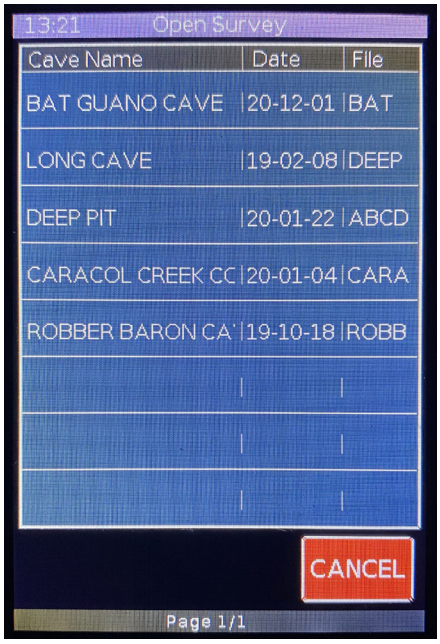
Utilities Menu

VIEWING A LIVE VIEW OF THE LIDAR OUTPUT



UTILITIES ➜ LIDAR provides a real time view of the LIDAR output. This is useful for checking what the LIDAR is actually seeing while in the cave and ensure you are picking up the walls, ceiling and other features you want. It can also be used for troubleshooting. The live LIDAR view is for visualization only and no data is recorded. It also runs at a reduced data rate of 2000 pts/sec since the screen resolution is limited. When starting this utility, the LIDAR initializes immediately. In the live LIDAR view, the large box shows the LIDAR output. The yellow dots show the LIDAR points while the central green dot is the Caveatron's position. The display accumulates the data from the previous 3 rotations of the LIDAR before refreshing. Below are controls to zoom in and out and the scale and LIDAR module type are shown.

REOPENING A PREVIOUS SURVEY



UTILITIES ➜ SD CARD ➜ OPEN OTHER SURVEY. A previously created survey can be reopened to continue adding shots and scans to it. A list of the surveys saved on the SD card is shown (up to a maximum of 32). Eight surveys are shown per page with the cave name, the survey start date, and the 4 letters used in the base file name. Move between pages by tapping **NEXT** or **PREV** or press **CANCEL** to exit. Tap on the survey's entry to open it and make it the current survey. A message box will briefly appear to confirm that the survey has been opened.

SD CARD INFO

UTILITIES ➜ SD CARD ➜ SD CARD INFO. This shows information about the SD card including its format, size, available space, and number of files.

ABOUT SCREEN

UTILITIES ➜ ABOUT This screen shows the current software revision installed and the serial number of the Caveatron (if applicable).

Theory of Operation

The Caveatron's ability to scan a cave is based on four key components – a LIDAR, a Laser Rangefinder (LRF), a magnetometer, and an accelerometer. In recent versions, a gyroscope has been added which is used to enhance the position accuracy. The general operating concept is that as the Caveatron is moved through space, it uses the LIDAR to scan cross-sections of the cave often enough to be able to generate a dense point cloud of the cave. Each rotation of the LIDAR needs to be located in space, both in terms of position and orientation. Orientation comes from the magnetometer and accelerometer which allow the pitch, roll, and yaw of the unit to be computed. The position is much more difficult since it requires some basis of reference. In developing the Caveatron, I chose to use the familiar concept of setting stations in the cave and using that as the framework for locating the scans. Stations are set, and shot measurements are performed in much the same way as has been standard cave survey practice for many years. In traditional survey, these stations are then used as the basis for drawing the sketch. In the case of the Caveatron, the concept is that shots between stations are taken by the device itself and the "sketch" is the LIDAR scan data, referenced to the stations.

Getting a continuous measurement of position with respect to a station requires some sort of marker so that the station is distinct from anything else. For the Caveatron, a thin retroreflective plastic card forms the marker. The LRF has been modified to add an optical fiber over its receiver so that its sensitivity is greatly reduced. As such, it will not obtain a measurement from normal cave surfaces under most circumstances (it is possible to get an LRF measurement from very light colored surfaces, such as a white painted wall, at short distances of a meter or so). The reflective card uses a retroreflective material that creates a very strong and concentrated reflection back only in the direction of the light source. Normally, an LRF would be saturated by such a strong reflection, but with the filter, this is the only signal it can see. The reflection from the card is strong enough that the filtered LRF can perform measurements to a distance of 40 meters.

When scanning with the Caveatron, it cannot be assumed that it will always be pointed at the reference station, but because of operator motion, the Caveatron orientation will move around somewhat. When a return is obtained from the card by the LRF, we know exactly where it is pointed, so that the Caveatron's orientation and position at that instant can be established as a fixed point relative to the station. In between these fixed points, the exact position of the Caveatron cannot be known, but can be estimated from the accelerometer, magnetometer and gyroscope data, which is done in post-processing. In general, position estimations from those type of sensors are prone to drift with error increasing rapidly. However, since the Caveatron typically gets an LRF measurement about once per second and is forcibly limited to no more than 12 seconds between LRF measurements, the duration is short enough between fixed points that the position drift error from the sensors can be kept to a minimum.

The LIDAR currently in use with the Caveatron (RPLIDAR) uses triangulation to determine its range. This means that a laser and detector are offset from each other and the detector uses a linear image sensor to observe the place where the laser spot is located. If it is toward one end of the sensor, the distance is closer and if it is toward the other end of the sensor, the distance is farther. The number of pixels and the size of the detector limit the resolution and range. There are other LIDARs that use the time-of-flight principal and can obtain more

range, but those are currently considerably more costly. A downside to a triangulation-based LIDAR is that it is necessary to pass the light through a flat window since a curved window will induce distortion in the distance reading. The LIDAR continuously rotates and outputs a stream of measurements with each one containing an angle and a distance. The angle is the direction the LIDAR is pointed when that distance was measured. The RPLIDAR has the ability to adjust the output data rate from 2000 measurements per second to 8000 measurements per second. The rotation speed can also be adjusted allowing for a denser set of points in each rotation, but with more spacing between rotations (slower speed), or tighter rotation spacing and fewer points per rotation (faster speed).

The LRF uses a red laser that produces a series of short pulses to measure the length of time it takes for the pulse to return from its target to compute the distance. In the Caveatron, the red laser serves double duty as the pointer and all sensors are calibrated to the direction of the red laser spot. The LRFs available for use with the Caveatron all have a small spot size, which allows it to be precisely pointed when taking measurements. To achieve its accuracy, the LRF must average a large number of points internally, limiting how often it can obtain a reading.

The magnetometer provides a measurement of the yaw angle of the Caveatron relative to magnetic north by measuring the Earth's magnetic field. As such, all readings by the Caveatron are not relative to true north, however they can be converted in the post-processing software by entering the magnetic declination of your location. Unfortunately, magnetometers can be affected by many other things than the Earth's magnetic field, yielding false readings. These can include ferromagnetic materials, such as iron and some steels, and electromagnetic currents from electricity and motors. In buildings it is difficult to get reliable magnetometer readings as there are many sources of magnetic fields such as refrigerators, heating/cooling systems, wiring in the walls, or rebar in concrete. Fortunately, caves do not usually contain anything that would affect the magnetometer, however there are some exceptions, such as cave gates and your helmet light. As such, the Caveatron should be kept away from gates as much as possible and you should not place your headlamp or battery pack directly next to the Caveatron. Some types of caves such as lava tubes may be located in rock containing ferromagnetic materials, but the effect of this has not been tested. Magnetometers are prone to internal drift so need to be recalibrated on a regular basis.

The accelerometer provides the tilt and roll angle of the Caveatron relative to Earth's gravity. As such, down is always a known direction. Accelerometers are also affected by movements so have the ability to be used to estimate how far and in what direction something has moved. However, the effect of gravity and the effect of movement cannot be readily separated without the use of a gyroscope. Accelerometers are fairly stable so do not need regular recalibration.

A gyroscope measures angular movement. If an object is stationary or moving purely side to side, a gyroscope provides no reading. The gyroscope allows the gravity acceleration component and linear acceleration component to be separated from each other in the accelerometer data. The original version of the Caveatron did not have a gyroscope so used a filtering and linear estimation method to determine its position between fixed points. With the gyroscope, the orientation can be definitively calculated and the linear velocity can be estimated at any point in time to provide a more accurate position computation.