Sandec Department of
Sanitation, Water and Solid
Waste for Development

Volaser

a faecal sludge measuring device

Assembly and users' guide

eawag
aquatic research

Volaser: a faecal sludge measuring device

Assembly and users' guide

Nienke Andriessen
Linda Strande

Impressum

Authors:	Nienke Andriessen & Linda Strande
Publisher:	Eawag – Swiss Federal Institute of Aquatic Science and Technology Department of Sanitation, Water and Solid Waste for Development (Sandec) Überlandstrasse 133, 8600 Dübendorf, Switzerland
Cover:	A Volaser being used to measure the volume of faecal sludge in a septic tank in Lusaka, Zambia. Nienke Andriessen
Photos:	Tribecraft AG and Eawag (unless stated otherwise)
Layout:	Carlijn Andriessen
Review:	Arno Lenzi, Tribecraft AG, Binzstrasse 7, 8045 Zürich, Switzerland
Published:	2023
Bibliographic reference:	Andriessen, N. & Strande, L. (2023). Volaser: a faecal sludge measuring device - Assembly and users' guide. Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland

Table of contents

Introduction

The Volaser is a measuring instrument that measures the volume of onsite sanitation containments and in situ volumes of faecal sludge, without the need for emptying. It consists of a tripod, a tube with a laser distance sensor, a depth probe, and is operated with a smartphone application (Figure 1). The device can be used in a variety of settings, for example to know sludge volume that needs to be emptied and increase transparency during emptying, design scheduled emptying campaigns, or make better estimations for city or community-wide quantities of faecal sludge that need to be managed and treated

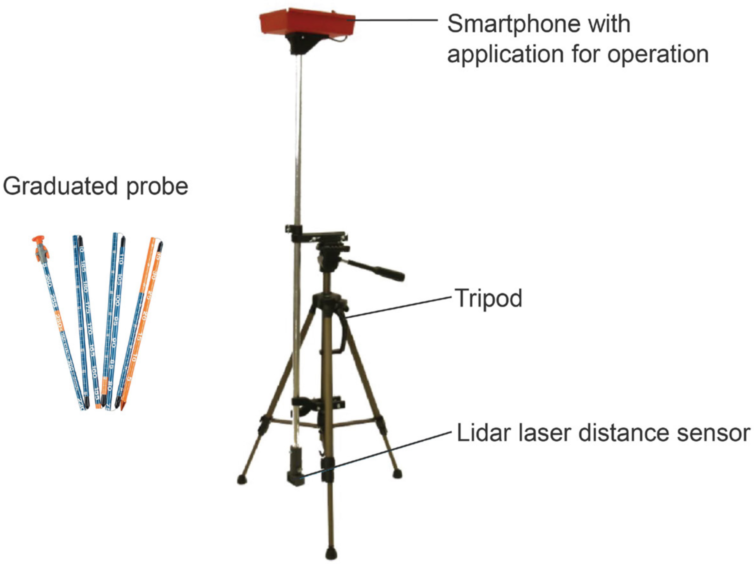


Figure 1: A Volaser device (Andriessen et al., 2023).

To take a measurement, the Volaser is set up over an access port to the containment. A graduated probe is used to measure containment depth. Then, a lidar laser distance sensor is inserted into the empty space of the containment. While turning the device, the laser sensor measures the distance to the containment walls inside the containment and the angle of rotation to calculate area. The empty volume inside a containment is calculated as *area × depth to sludge layer* (Figure 2), and the total volume of a containment is calculated as *area × containment depth* (Figure 3). Finally, faecal sludge volume is calculated as total *volume - empty volume*. While executing the measurements, the smartphone application also takes the GPS coordinates of the measuring point, and allows to take notes and photos. To determine accumulation rates, the Volaser can be used by monitoring the volume of faecal sludge in the same containment over time. A measurement interval of at least 6 months is recommended (Prasad et al., 2021).

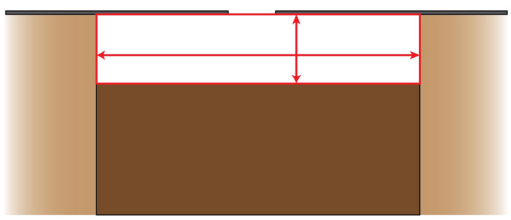


Figure 2: The Volaser uses the area and distance to the sludge layer to calculate the empty volume inside a containment.

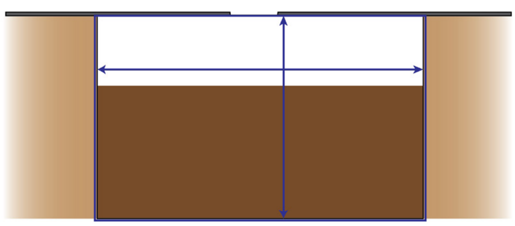


Figure 3: The depth of the containment is measured with a probe. The Volaser then calculates the total containment volume as area x depth.

Sustainable management of faecal sludge requires reasonable estimates of the quantities and qualities (Q&Q) that are accumulating at community to city-wide scales. In situ volumes are difficult to determine, as faecal sludge is often stored underground in containments, records frequently do not exist, and construction is not standardized. However, estimates are necessary for planning scenarios as it represents the total amount of faecal sludge that needs to be managed. Determining accumulation rate over time is even more difficult, with no records of emptying events, illegal emptying, or time-intensive research projects. Previous attempts to measure accumulated faecal sludge quantities have used questionnaires to ask homeowners the size of their containment and when it was last emptied, asking emptiers how much they emptied, or using the gauge on a vacuum truck. However, these methods are problematic, as they rely on people's memory and/or availability of an emptying service. Eawag developed the Volaser measuring device to address the need for an affordable, accurate and easy to use device for measuring volumes of faecal sludge in situ.

A Volaser can be constructed anywhere in the world, and consists of 3D printed parts and parts that can be bought locally or online. Costs will vary per location, but the device was developed to be constructed for a maximum of 350 USD.

Specifications of the Volaser are presented in Box 1. During the development of the Volaser a trade-off between achieving higher accuracy and lower price was considered. This means that the Volaser cannot measure extreme cases (e.g. containments deeper than 3m, or extremely large containments). Precision and accuracy were determined as reported in Andriessen et al. (2023). Relative error in precision is <10%, and average deviation from accuracy is 2.6cm, which in practice will mean there is a slightly higher effect of error on small containments than in large ones.

Box 1: Volaser specifications

- Since the Volaser measures empty containment volume, at least 10cm free space is needed at the top of the containment.
- The containment needs to have a vertical access port to the containment that is possible to open.
- The smartphone needs to have an Android operating system, with a gyroscope and a USB-C charging port.
- The TF Mini Plus lidar laser that is used to measure distance has a range between 0.1-12 m. Measurements outside of that range might have a higher error, for example when a containment opening is <10cm from the containment wall.
- The length of the probe dictates how deep the Volaser can measure total containment depth. Realistically, the probe is maximum 3m long (see section 'List of required materials'. For scenarios where the containment is deeper than the probe, see section 'The depth of the containment is deeper than the length of the probe' under 'Trouble shooting'.
- For containments with a baffle or multiple chambers, each chamber will have to be measured separately. Depending on the situation, only the first chamber could be measured (e.g. when the only the first chamber of a septic tank is emptied).
- A measurement assumes that the containment has uniform walls along its entire depth. In reality, this might not always be the case (for example where the walls of a pit latrine are dug around rock) (Figure 4). However, this will in most cases fall within the error margin of the device.

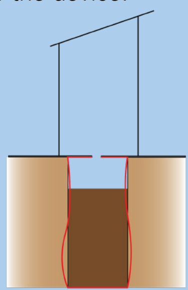


Figure 4: An example of containment walls that are straight, versus walls that are not straight (red line).

How to use this guide

This guide is a step-by-step instruction for anyone who wants to construct and/or operate a Volaser device. The first half of this guide provides a comprehensive explanation on how to order and construct a Volaser yourself. There is a list of all parts needed, and a step-by-step explanation of how to assemble them. All parts described in the text are numbered and cross-referenced with Table 1 and the technical drawings on our website (www.sandec.ch/volaser). An accompanying assembly video can also be found on our website. It is possible to use alternative brands or materials than the ones listed in this manual, for example because they cannot be obtained in your desired location. However, accuracy and precision specifications are based on assembly and operation done exactly as described in this manual.

The second half of this manual provides user guidelines on how to operate and store a Volaser, and provides tips for trouble shooting. An accompanying operation video can be found on www.sandec.ch/volaser.

The complete Volaser design and 3D printing files are available open source under the CC-BY 4.0 license. The smartphone app is published under and open source MIT license.

Contact information

For inquiries regarding the Volaser, please contact info@sandec.ch. If you make a Volaser yourself, or make adjustments to the Volaser design or software, please be in contact and send us a picture! We are happy to receive your feedback.

Acknowledgements

Design and production of the Volaser and publication of this manual would not have been possible without the help of all people who contributed to its design, construction and testing: the Design and Technology Lab from ETH Zürich and ZHdK, Clara Pedrini and Ammandip Duggal, who designed the first prototype; Matt Grau contributed to further refinement; Tribecraft AG and JLS Digital played an essential role in transforming the prototype into a robust product; CubeX SAL, Sanivation Limited, GOAL, University of Zambia, Makerere University, Kwame Nkrumah University of Science and Technology, Consortium for DEWATS Dissemination Society, 500B Solutions, and Harold Chirwa (WES Management), who were testing partners. Funding for the development of the Volaser was provided by the Swiss Agency for Development and Cooperation (SDC) and Eawag.

Assembly manual

List of required materials

Table 1 provides a complete list of all Volaser parts that need to be purchase or 3D-printed. This list of parts can also be downloaded from www.sandec.ch/volaser, where links to example suppliers are also provided. For several parts, technical drawings containing detailed part measurements are available, and these drawings should be consulted before 3D printing and during assembly (Figure 5). .stl files for the 3D-printed parts are also available on the website.

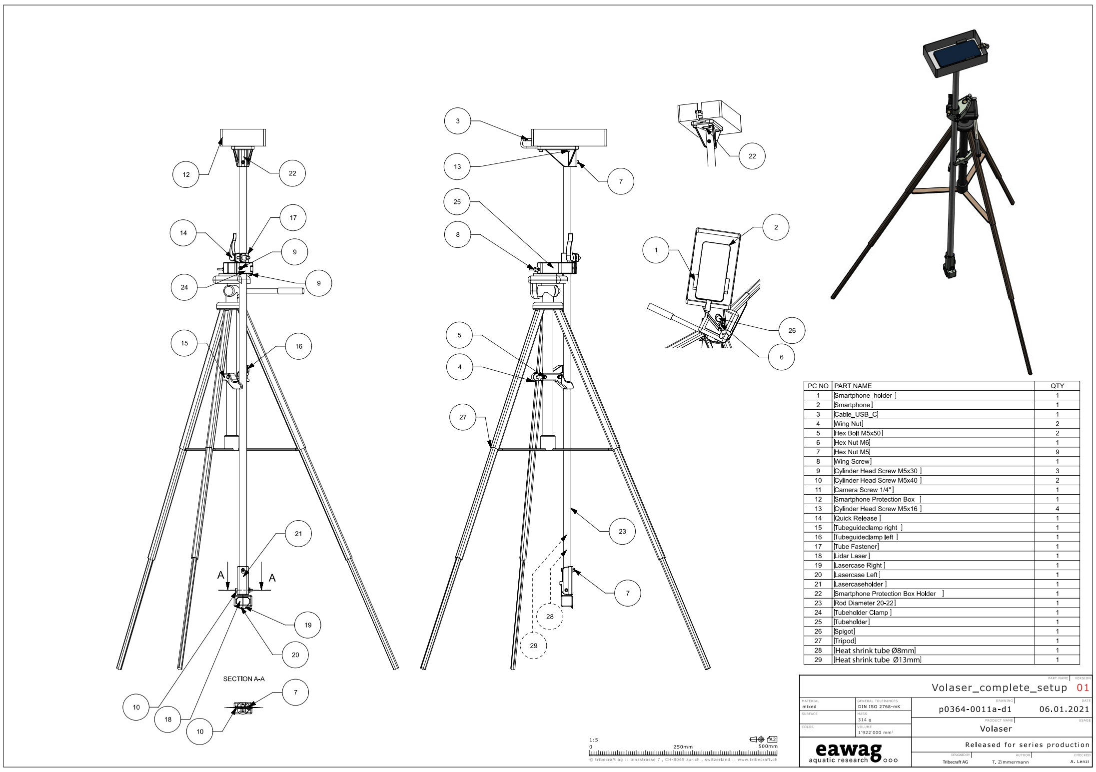
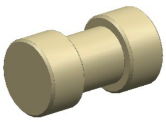
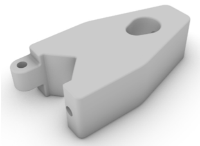
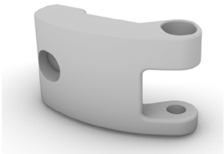
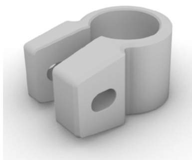
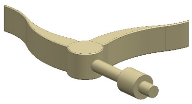
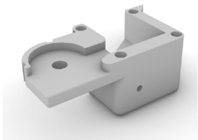
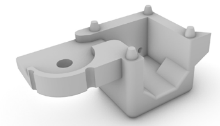
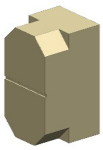
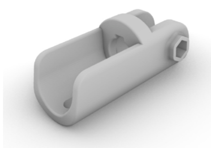
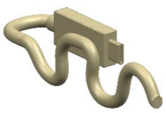
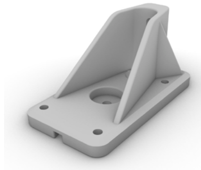
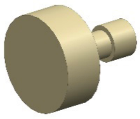
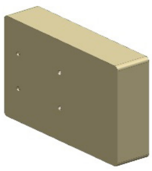
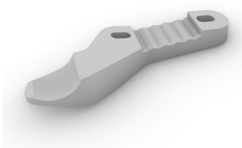
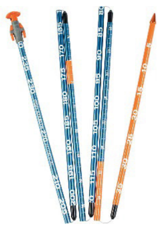


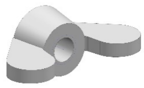
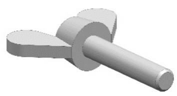
Figure 5: ✎ Technical drawing Volaser complete setup. All technical drawings can be found on www.sandec.ch/volaser and should be consulted before 3D printing and during assembly.

Table 1: All Volaser parts. Specific example suppliers can be found in the list provided on www.sandec.ch/volaser.

No.	Name	Picture	Quantity	Purchase / 3D-print	Description	Example suppliers
1	**Tripod**		1	Purchase	Could be any common photography tripod.	Local photo shop or online
2	**Smart-phone**		1	Purchase	Must have a gyroscope and Android operating system. A list of tested phones that work with the app can be found here: https://github.com/volaser/volaser-app#tested-hardware-android-devices, but other phones could also be used.	Phone store
3	**Spigot**		1	Purchase	1/4 inch to 3/8 inch, with inside threads on both ends.	Specific item, can be purchased for example via www.banggood.com
4	**Tripod mount**		1	3D-print	See technical drawing *Tripod mount*.	
5	**Tripod mount clamp**		1	3D-print	See technical drawing *Tripod mount clamp*.	
6	**Metal tube**		1	Purchase	See technical drawing *Metal tube*. 1.15m length, outer diameter 20-22mm, inner diameter minimum 17mm. Ideally from a light material such as aluminum, but other materials could also be used.	Hardware store or via a local welder/ metal worker.

No.	Name	Picture	Quantity	Purchase / 3D-print	Description	Example suppliers
7	**Tube fastener**		1	3D-print	See technical drawing ✎ *Tube fastener*.	
8	**Quick release**		1	Purchase	Quick release commonly used for the seat post of a bicycle.	Could be purchased at bicycle suppliers/ manufacturers or online.
9	**Lasercase – Right**		1	3D-print	See technical drawing ✎ *Lasercase_right.*	
10	**Lasercase – Left**		1	3D-print	See technical drawing ✎ *Lasercase_left*.	
11	**Lidar laser**		1	Purchase	Benewake TF mini plus.	Specific item, can be purchased for example via www.banggood.com.
12	**Connection piece laser-case**		1	3D-print	See technical drawing ✎ *Connection piece lasercase*	
13	**Phone connection cable**		1	Purchase	Name: Adafruit FTDI SERIAL TTL-232 USB C CBL 5V Important: Voltage is 5V, length 1 m	Specific item, can be purchased for example via www.digikey.com.

No.	Name	Picture	Quantity	Purchase / 3D-print	Description	Example suppliers
14	**Protection box base**		1	3D-print	See technical drawing *Protection box base*	
15	**1/4 inch quick release screw**		1	Purchase	Shaft Length: at least 9.5mm (incl. thread).	Specific item, can be purchased for example via www.banggood.com.
16	**Smart phone clip**		1	Purchase	Needs to have an inward screw thread on its backside (which most common smartphone clips will have).	Phone store or department store.
17	**Protection box**		1	Purchase	See technical drawing *Protection box*. Any plastic (Tupperware-style) box that easily fits the phone can be used. Recommended dimensions are approximately 22 x 15 x 5 cm (L x W x H).	Supermarket, stationary shop.
18	**Tubeguide – Right**		1	3D-print	See technical drawing *Tubeguide_right*.	
19	**Tubeguide – Left**		1	3D-print	See technical drawing *Tubeguide_left*.	
20	**Depth probe**		1	Purchase or manufacture locally	Graduated. Length dependent on what is available or practical. 3m has been tested and is a useful length.	Outdoor shops, online, or locally manufactured by an artisan.

No.	Name	Picture	Quantity	Purchase / 3D-print	Description	Example suppliers
21	**Wing nut**		2	Purchase	M5 (5mm diameter).	Local hardware store.
22	**Hex bolt M5x50mm**		2	Purchase	Hexagonal head, M5 (5mm diameter), 50mm long.	Local hardware store.
23	**Hex nut M6**		1	Purchase	Hexagonal nut, M6 (6mm diameter).	Local hardware store.
24	**Hex nut M5**		9	Purchase	Hexagonal nut, M5 (5mm diameter).	Local hardware store.
25	**Wing screw**		1	Purchase	M6 (6mm diameter), 30mm long.	Local hardware store.
26	**Cylinder head screw M5x30mm**		3	Purchase	Cylindrical head, M5 (5mm diameter), 30mm long.	Local hardware store.
27	**Cylinder head screw M5x40mm**		2	Purchase	Cylindrical head, M5 (5mm diameter), 40mm long.	Local hardware store.
28	**Cylinder head screw M5x16mm**		4	Purchase	Cylindrical head, M5 (5mm diameter), 16mm long.	Local hardware store.

- (20) ***Depth probe***: Probe length can vary based on what is locally available and how it will be transported. A modular or collapsible probe is ideal, but a simple metal or wooden rod can also be used. Realistically, the probe is maximum 3m long, as this could be transported (depending on mode of transportation) and can still be inserted when there is a roof overhead. In general, 3m is long enough to measure containment depths. In situations where containment depth is deeper than 3m, a longer modular probe could be fabricated, but this is only useful when only measuring outside without a roof overhead (e.g. toilet superstructure). For scenarios where the containment is deeper than the probe, see section 'The depth of the containment is deeper than the length of the probe' under 'Trouble shooting'.

- We have used a 3m long standard collapsible avalanche probe, which might not be available everywhere. However, any locally constructed design can be used, for example multiple 1m long metal rods with an inside screw thread on one end and outside screw thread on the other side, that can be screwed together to form a longer probe of desired length. A core sampling device could also be used for measuring containment depth, especially if taking faecal sludge samples at the same time (Koottatep et al., 2021). If the probe is not graduated, add a graduation to it with a waterproof marker.

- The (13) ***Phone connection cable*** and (11) ***Lidar laser*** need to be 5 Volts. In the current Volaser model, the phone connection cable has a USB-C connector, and is only compatible with smartphones with a USB-C port. If another phone is to be used (e.g. with a micro USB or lightning port), another phone connection cable will be needed. Take note that such a cable should be 5 Volts and 1m long.

  If you do not have access to a (25) ***Wing screw***, a standard hexagonal screw can also be used, or use a wing nut and a standard cylinder screw to create a wing screw (Figure 6).

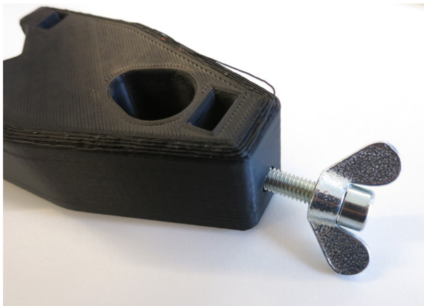


Figure 6: An alternative wing screw made with a wing nut and cylinder head screw.

3D-printed parts

The Volaser contains nine parts that need to be 3D printed, which can be done either with a local 3D printer on site, or by ordering the 3D prints from a 3D printing service. We have listed some common 3D printing services in Box 2, which ship to many locations worldwide. It is recommended to use a strong, heat/UV resistant material, such as ABS, ASA or similar. PLA is not recommended.

Box 2: 3D-printing services

If local 3D-printing services are not available, these are some common 3D-printing services that ship to many locations worldwide (there are many additional suppliers, and you might need to search for the one that best fits your location):

- 3D Hubs (www.3dhubs.com)
- Craftcloud (www.craftcloud3d.com)
- Shapeways (www.shapeways.com)
- Weerg (www.weerg.com)

When uploading the 3D-printing files (.stp) into the printing software, double-check that the printing direction is correct, which is provided on the technical drawing for each part (the direction of printing should be correct by default).

Tools needed

- Electric drill with a 5.5mm or 6mm drill bit (whichever is available to you), and a 7mm drill bit
- Flathead screwdriver
- Wrench 8mm
- Allen key 4mm
- Marker
- Coping saw
- Cardboard, wooden, or plastic spacer, approximately 2x10mm
- Duct tape (approximately 10cm)
- Electrical tape (approximately 80cm)
- Sand paper or a rasp (optional)
- Thread locker adhesive (e.g. Loctite) (optional)

Assembly instructions

1. Check all parts (technical drawing Volaser complete setup)

Before assembly, check that all required parts are present, and are not damaged (Figure 7). Check that the 3D-printed parts are the correct size (same size as listed on the respective technical drawings). Check that the (11) ***Lidar laser*** and (13) ***Phone connection cable*** are 5V.

*Figure 7: It could be helpful to lay out all parts when checking them ((1) **Tripod**, tape, spacer and (2) **Smartphone** are missing in this picture).*

2. Preparing the tripod mount (technical drawing Tripod mount and Tripod mount clamp)

Take parts (4) ***Tripod mount*** and (5) ***Tripod mount clamp***. Connect the clamp and tripod mount with a (26) ***Cylinder head screw M5 x 30mm*** and (24) ***Hex nut M5*** (Figure 8 Left). Loctite can be used here if available. The protruding section of the tripod mount should fit exactly in the recess of the tripod mount clamp (Figure 8 Right). The cylindrical top of the screw should fit in the embedding in the hole. Do not tighten the nut completely: the screw should be fastened, but the clamp should still be able to open and close.

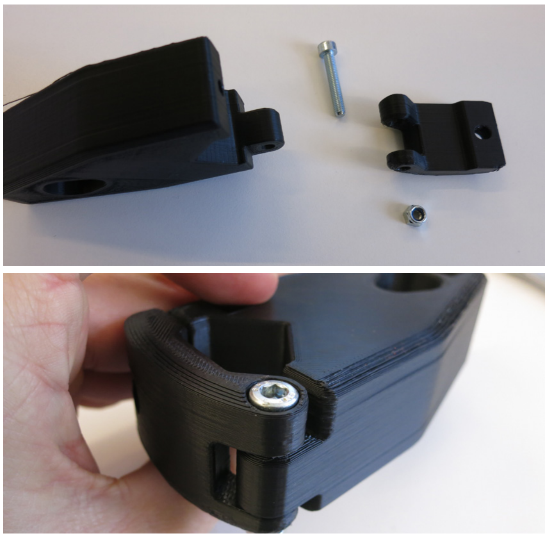


*Figure 8: Above: Connect the (4) **Tripod mount** with (5) **Tripod mount clamp**. Below: The protruding section of the (4) **Tripod mount** fits exactly in the recess on the (5) **Tripod mount clamp**.*

3. Installing the tripod mount

Unfold the tripod (part 1 ***Tripod***) and set it up with its legs fully extended. Screw the 1/4 inch side of part 3 ***Spigot*** onto the tripod (with Loctite, if available) (Figure 9 Left). Place the oval-shaped opening of the tripod mount over the spigot (Figure 9 Right).

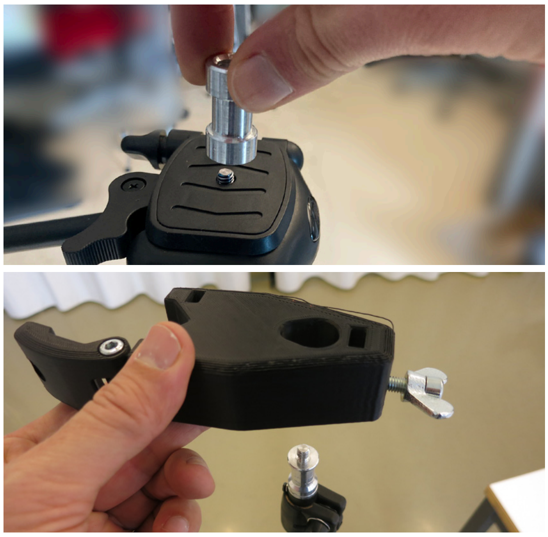


Figure 9: Above: Screwing the spigot onto the tripod. Below: Adding the tripod mount over the spigot.

Put a 23 ***Hex nut M6*** in the rectangular opening on the narrow part of the tripod mount (Figure 10 Left) (you might need to push it down with a flathead screwdriver). Insert the 25 ***Wing screw*** on the narrow end and tighten it (Figure 10 Right).

*Figure 10: Above: Put a 23 **Hex nut M6** in the rectangular opening on the narrow part of the tripod mount. Below: Insert the wing screw on the narrow end of the tripod mount and tighten it.*

4. Preparing the metal tube (technical drawing ✎ [Metal tube])

Drill two holes in the 6 ***Metal tube*** all the way through, facing same direction. Both should be 23mm from each end of the tube, 6mm in diameter, as shown on technical drawing ✎ *Metal tube* (Figure 11). Optionally, smoothen the holes with sand paper or a rasp to avoid sharp edges.

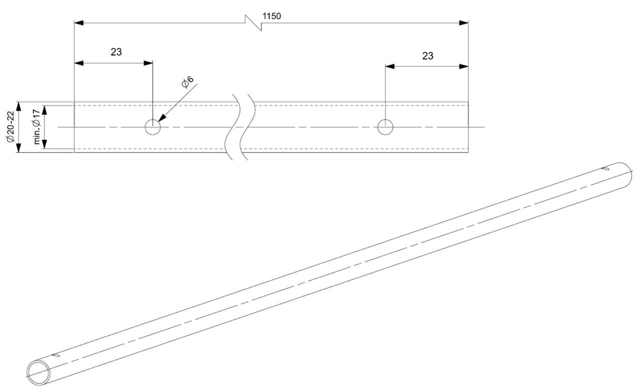


Figure 11: Excerpt from technical drawing Metal tube, showing the position of the holes in the metal tube.

5. Mounting the tube fastener (technical drawing ✎ Tube fastener)

Take the nut off the (8) ***Quick release***. Insert the screw of the quick release into the hole of the (7) ***Tube fastener*** (Figure 12), and slide the tube fastener over the metal tube. Tighten the nut, and then fasten the quick release. How tight the nut should be depends on the diameter of your metal tube. It should be tight enough that when you close the quick release, the tube fastener should stay on the tube so that it cannot be moved up or down (Figure 13).

Figure 12: Take the nut off the quick release screw, and stick it through the tube fastener.

Figure 13: The quick release on the metal tube.

Open the tripod mount clamp, and hang the metal tube inside (as shown in Figure 15), with the quick release above the mount. Put a (24) ***Hex nut M5*** in the last opening on the tripod mount (you might need to push it down with a screwdriver (Figure 14: Left: Insert a M5 nut into the last hole on the tripod mount. Right: You might need to push it down.Figure 14 right)), and close the tripod mount clamp by screwing a (26) ***Cylinder head screw M5 x 30mm*** into the hole on the tripod mount clamp (Figure 15). The tube should still be able to move up and down.

Figure 14: Above: Insert a M5 nut into the last hole on the tripod mount. Below: You might need to push it down.

Figure 15: Insert the screw into the hole on the tripod mount clamp.

6. Assembling the laser case (technical drawing ✎ *Laser case_right* and ✎ *Laser case_left*)

Connect the JST connectors for the cable that comes with the (11) ***Lidar laser*** (Figure 16). Then, take the lidar laser and (9) ***Laser case - right*** and (10) ***Laser case - left***. Insert one end of the laser into its case. Then, twist the cable coming from the laser once, so that there is a loop in the cable, following the groove of the laser case (Figure 17). This is needed to reduce tension on the cable while the laser case moves.

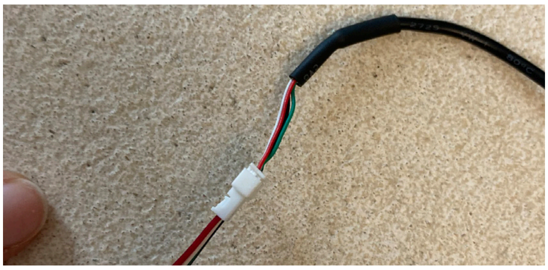


Figure 16: Connect the white JST connectors that come with the (11) ***Lidar laser****.*

Figure 17: The loop in the laser cable to prevent tension.

While holding the loop in place, close the other side of the laser case, so that the laser case surrounds the laser (Figure 18). Make sure the cable is not in front of the screw hole. Insert the cable through the hole in the (12) ***Laser case connection piece*** (Figure 19), and slide the laser case into the connection piece, with the rounded corners towards each other. Attach the connection piece to the laser case with a (27) ***Cylinder head screw M5x40mm M5*** and (24) ***Hex nut M5*** (Loctite optional) (Figure 20). The M5 nut fits exactly in the hexagonal opening. The screw should not be too tight; the laser case should still be able to move.

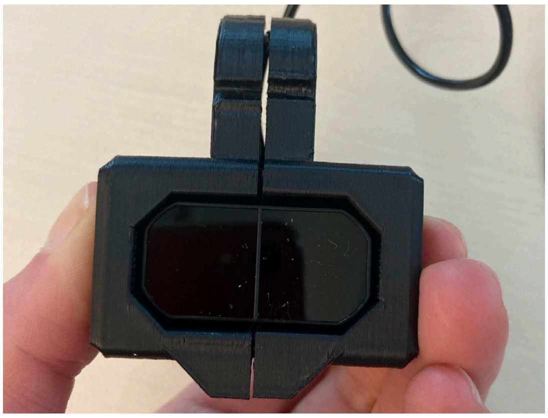


Figure 18: Close both sides of the laser case so that the case surrounds the laser.

Figure 19: The laser cable winds through the hole in the (12) ***Laser case connection piece****.*

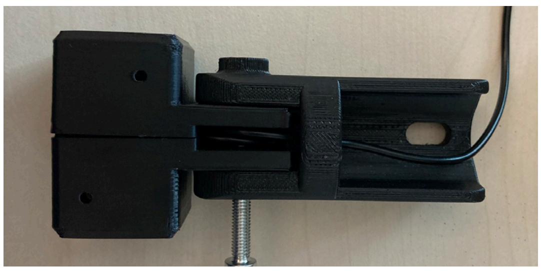


Figure 20: Connect the laser case connection piece to the laser case with a 40mm M5 screw. Make sure that the cable is not in front of the screw hole.

7. Securing the connections

Take the (13) ***Phone connection cable*** and the laser sensor in its casing. To connect the phone connection cable with a 6-pin FTDI serial TTL connector to the laser with 4 pins, you should build a connection using a spacer (Figure 21). For the spacer, any type of material can be used, for example cardboard or a piece of wood or plastic.

Connect the black pin to the black plug, the red pin to the red plug, the white pin to the orange plug, and the green pin to the yellow plug (Table 2). Slide the spacer between the black and red pins, and then secure all pins with a strong tape (for example duct tape, as used in Figure 21 - left).

Laser cable	Phone connection cable
Black	Black
- (Spacer)	Brown
Red	Red
White	Orange
Green	Yellow
-	Green

Table 2: The correct sequence of connecting the pins of the laser cable to the plugs of the phone connection cable.

Wrap electrical tape or heat shrink around this connector and the JST connector so that both are joined securely and protected against movement and moisture (Figure 22).

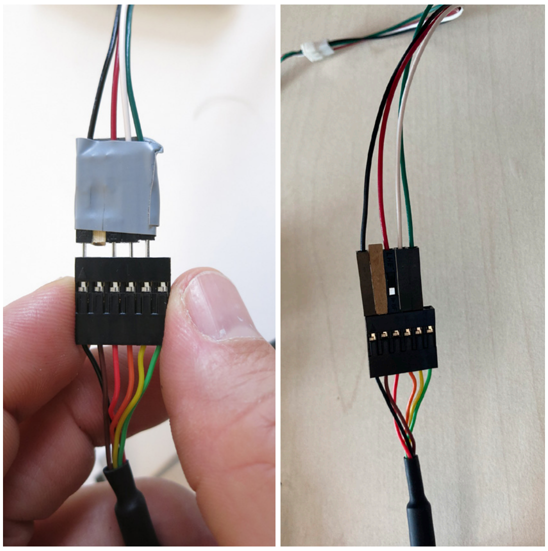


*Figure 21: Photo left: The (6) **pin FTDI serial TTL connector** (left connector), with the (4) **pin connector** to the lidar laser sensor (right connector). Photo right: A cardboard spacer (in brown) to structure the connection between the pins.*

Figure 22: The connector should be securely wrapped in electrical tape.

Afterwards, insert the USB-C cable into the metal tube until it comes out at the other end. Attach the (12) ***Laser case connection piece*** to the (6) ***Metal tube*** with a (26) ***30 mm M5 screw*** and (24) ***Hex nut M5***. Be careful not to trap the cable when pushing the screw through the tube. Then, guide the USB-C cable through the largest hole of the (14) ***Protection box base*** (Figure 23 left). Lightly pull on the cable to straighten it, and wind the cable through the designated groove (Figure 23 right). Attach the protection box base to the rod with a (27) ***Cylinder head screw M5x40mm*** and (24) ***Hex nut M5***: screw head on the outside, nut on the inside of the protection box base. Do not tighten it too much; the top surface of the protection box base should be level (as in Figure 23 Left).

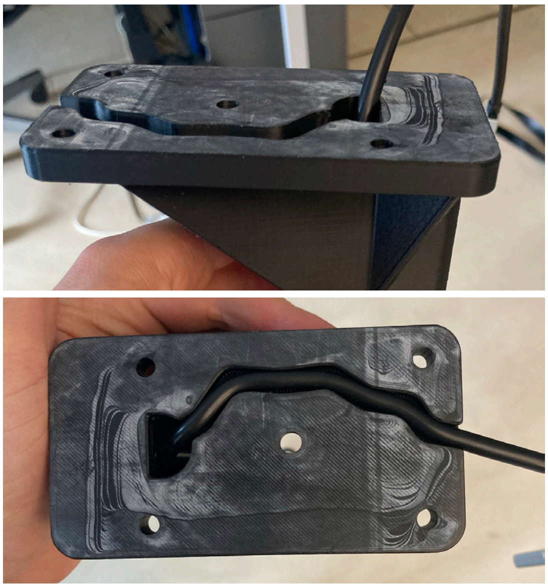


Figure 23: Above: The phone connection cable goes through the large hole in the protection box base. Below: Then wind the phone connection cable through the designated groove.

8. Preparing the protection box (technical drawing ✎ [Protection box](#))

To prepare the (17) ***Protection box***, it is necessary to drill five holes and saw a cable slot into the protection box. The position of the holes will depend of the size of the protection box and phone that will be used. An easy method to determine the position of the holes is to print the technical drawing of the protection box true to size (Figure 24), cut out the top view, determine the position of the holes according to the size of the smart phone you are using, and then mark the position of the holes with a marker onto the protection box, or alternatively, tape the cut out into the correct position and drill through the paper. The middle hole should be 7mm in diameter, the four corner holes between 5 and 6mm, depending on the drill size available (we used a 5.5mm drill). Then, identify and saw the position of the cable slot in the center of the short end of the protection box (Figure 25).

Figure 24: Use a print out of the protection box technical drawing to help place the position of the drill holes

Insert the (15) ***1/4 inch quick release screw*** from the bottom of the protection box base in the designated slot (Figure 26). Place the protection box on top through the 7mm center hole, and screw the (16) ***Smart phone clip*** onto the quick release screw. Then, secure the protection box to the base with four (28) ***Cylinder head screw M5x16mm*** and four (24) ***Hex nut M5*** in the four smaller holes.

Figure 25: Sawing the cable slot in the short end of the protection box.

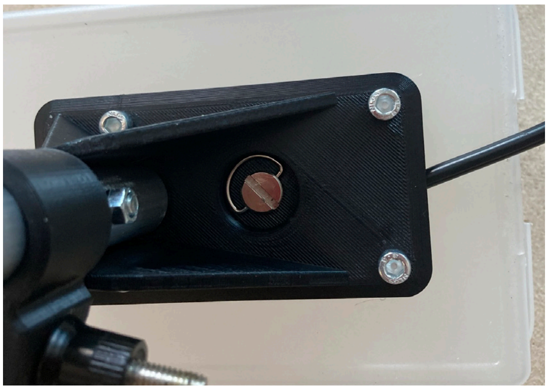


Figure 26: Inserting the quick release screw into the designated slot on the protection box base.

9. Tube guides (technical drawings Tubeguide_left and Tubeguide_right)

Take part (18) ***Tubeguide - Right*** and (19) ***Tubeguide - Left***. Insert two (22) ***Hex bolt M5x50mm*** in the designated hex slots on (18) ***Tubeguide – right*** (Figure 27). Place the ribbed surfaces of the tube guides on either side of the center shaft of the tripod (Figure 28 left), so that the guides hold the metal tube in place. Insert the screws through the holes in (19) ***Tubeguide - left***. Start by slightly tightening one of the bolts with a (21) ***Wing nut*** so that it says in place. Then slightly tighten the second bolt with another (21) ***Wing nut***. Continue alternately tightening both wing nuts until the tube guides hold the tube in place, but do not restrict the rotation of the tube (Figure 28 right).

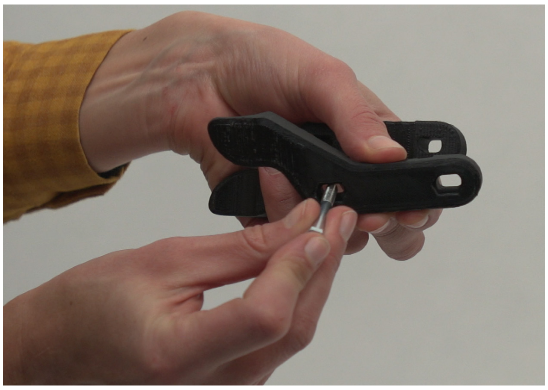


Figure 27: Insert the hex bolts into the designated slots on the Tubeguide - right.

10. Lastly, connect the (2) *Smartphone* to the phone connection cable, and place it in the phone clamp. Now your Volaser is finished!

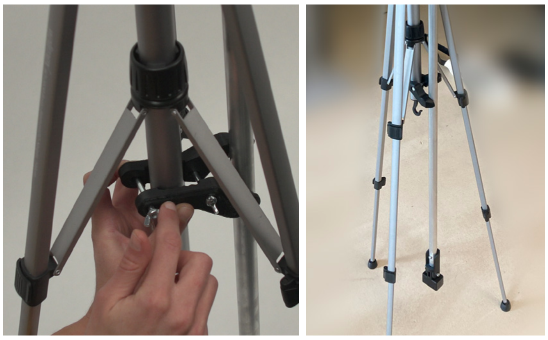


Figure 28: Left: Correct mounting of the tubeguides. Right: The tubeguides hold the metal tube in place.

Installing the smartphone app

Download the latest version of the Volaser application from www.github.com/volaser onto the smartphone that will be used for measurements. You can find the .apk file of the latest app version under "volaser-app", and then scroll down to "Releases" (Figure 29). In some smartphones, you might need to manually allow your phone to open applications from third party developers.

The Volaser smartphone application has three tabs at the bottom: 'Measure', 'Data', and 'Settings' (Figure 30). In the 'Measure' tab, you can take a new measurement. In the 'Data' tab, 29 you can find all saved measurements. The 'Settings' tab contains functions to test the device and adjust the measurement resolution. On the 'Test Laser and Gyroscope' page, USB should show 'Connected' when a phone is connected to the phone connection cable. When moving the phone, the arrow on the gyroscope ('Angle') should move, while the angle changes. It also contains a 'Test Laser' function, where the lidar laser makes a single measurement and reports the results. With the phone connected to the laser, a measurement should appear under 'Range' and 'Strength' when pressing the 'Test Laser' button. Range indicates the distance (in meters) that the laser measures, Strength indicates the strength of the returned signal (the fraction of laser light that is emitted from the laser, reflected on the walls of the containment and then measured by the sensor). A higher number for Strength means that a larger fraction of laser light is reflected, which indicates a stronger signal often caused by a lighter reflection surface.

The measurement period (the time between laser measurements, meaning the number of beams that the sensor shoots per second) can be manually adjusted in the 'Settings' page. It is automatically set to 100ms (10 beams/second). However, this setting should generally not be changed.

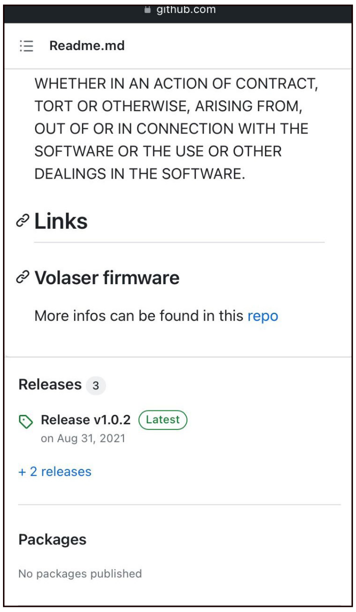


Figure 29: Scroll down under "volaser-app" to find "Releases".

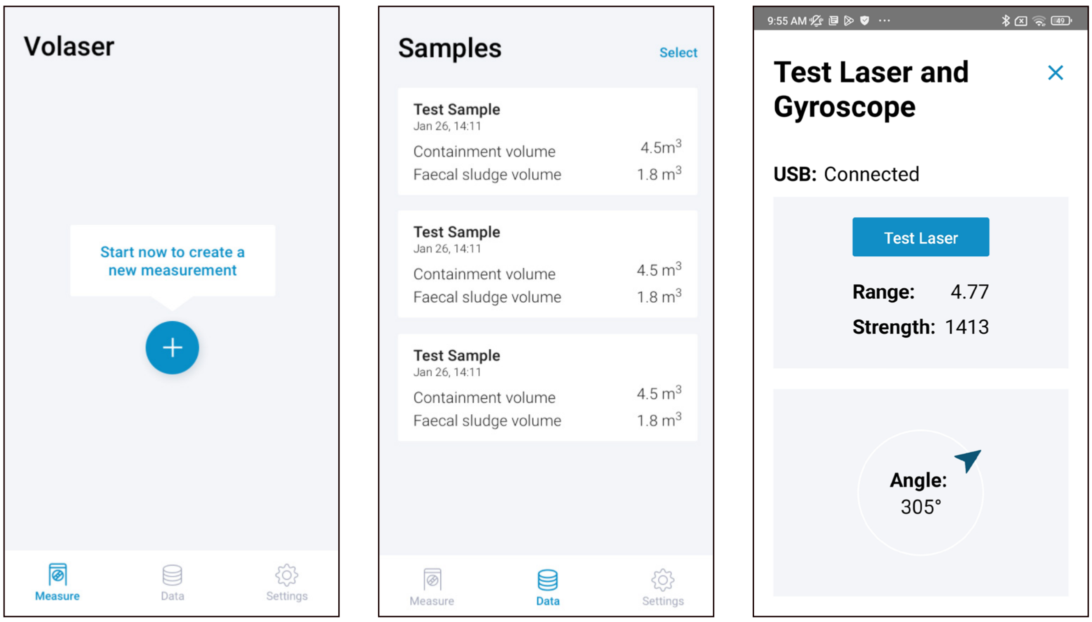


Figure 30: The Volaser smartphone application interface. Left: The 'Measure' tab. Middle: The 'Data' tab. Right: the 'Test Laser and Gyroscope' page.

Testing accuracy and precision

To ensure that the Volaser is functioning as desired, it is important to test the precision and accuracy before use.

- First, navigate to the ‘Settings’ tab in the bottom right corner of the app, and open the ‘Test Laser and Gyroscope’ page. Check that: 1) The USB is “Connected”; 2) When turning the phone, the arrow on the gyroscope (‘Angle’) should move, while the angle changes; 3) When pressing the ‘Test Laser’ button, a measurement should appear under ‘Range’ and ‘Strength’. Range indicates the distance (in meters) that the laser measures, Strength indicates the strength of the returned signal (the fraction of laser light that is emitted from the laser, reflected on the walls of the containment and then measured by the sensor). A higher number for Strength means that a larger fraction of laser light is reflected, which indicates a stronger signal often caused by a lighter reflection surface. If any of these three functions is not functioning, refer to the trouble shooting section in this manual.

- Secondly, take a tape measure and place the lidar laser at 30cm from a wall, with the ‘window’ of the laser pointing towards the wall. Press the ‘Test laser’ button in the ‘Test laser and gyroscope’ page. Compare the distance measured by the laser under ‘Range’ with the distance set by the tape measure. Do this four times. Then, repeat this procedure at distances of 50cm,100cm, and 300cm. More can be added if desired. To calculate precision: Compare multiple measurements of same distance with each other and calculate the percent deviation from their average. To assess accuracy, compare the measurement with the standard distance and calculate the standard error:

  $$\frac{(\text{measurement - standard distance})}{\text{standard distance}} \times 100\%$$

- Finally, measure the dimensions of a known object (e.g. a cardboard box, crate, pond) with a tape measure and calculate the area. Then, position the Volaser over the object and measure the area of the object (by creating a new measurement according to the steps below) and compare to the area measured by the tape measure.

Operation manual

Before use

- Switch on location sharing on your smartphone and allow your GPS location to be shared with the Volaser app.
- Appropriate Personal Protective Equipment (PPE) should be worn while working with faecal sludge or wastewater (Velkushanova et al, 2021). For working with a Volaser, especially when taking a depth measurement with the probe, a work suit, examination gloves (preferably nitrile), and rubber boots are the minimum recommended PPE attire.
- It is useful to have the following cleaning equipment within reach when using the Volaser: a cleaning cloth, absorbent paper towels, garbage bag, and a container or spray of water with soap or disinfectant.

Storage

For quick storage, adjust the legs of the tripod to their longest position and set the distance between the legs to a narrow stance, so that the tripod is stable, but the laser unit does not touch the floor. This is the 'storage position' (Figure 31). Ideally, place it next to a wall or in a corner where it will not be knocked over. During use outside, heat and UV radiation from the sun can affect the 3D printed parts. Therefore, store the Volaser in the shade if possible, as soon as you have completed the measurement. For longer-term storage in the office, it is ideal to store the laser in a cupboard away from people, to keep it from getting knocked over.

In some tripod models, the tripod mount and metal tube with the protection box and laser might be able to decouple from the tripod through a quick release system (Figure 32). This eases storage and transportation. However, whether this is possible will depend on the tripod model, and is not essential for the functioning of the Volaser.

Figure 31: A Volaser in the storage position: legs fully extended, and in a narrow stance so that the laser does not touch the ground.

Figure 32: Some tripod models might have a quick release that allows the metal tube and tripod mount to be easily separated from the tripod.

Taking a measurement

Follow these steps in the specified order for every measurement:

1. Preparation
Hold the tripod by its handle grip for an easy hold (if available) (Figure 33). Always keep the device upright.

To set-up the tripod, extend all three legs. The width between the legs can be adjusted by turning the cylinder on the central shaft clockwise, moving it up or down, and closing it by turning anticlockwise. (Note: this might vary slightly between different models/brands of tripods).

Once the tripod is set up, place the phone in the protection box and clip it into the phone clip, if using. If a phone clip is not used, the phone needs to be placed horizontally in the protection box while taking a measurement (Figure 34). Do not hold the phone while taking the measurement, as it will cause an error! Connect the USB-C cable to the phone, and open the Volaser app on the phone. When opening the app, a message might pop-up asking "Allow USB device to connect?" or something similar. Allow this.

Figure 33: Hold the tripod by its handle grip.

2. Create a new measurement
To start a new measurement, press the + button next to 'Create a new measurement' in the 'Measure' tab. A new measurement form opens, and the app will automatically guide you through a measurement. First, write the name of the sample you are measuring (e.g. a location name or unique sample ID number) in the 'Sample Name' box that pops up, and submit.

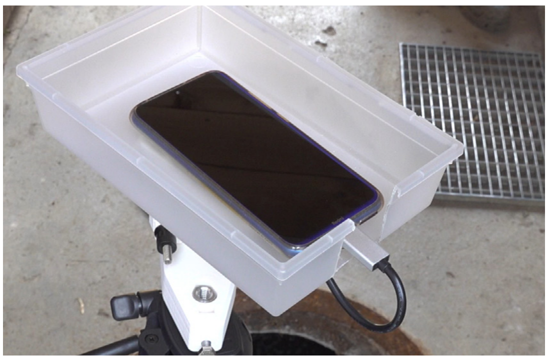


Figure 34: The smartphone needs to be placed horizontally in the protection box and/or smartphone clip.

3. Location
Tap 'Get location' to get the GPS location. If possible, get the GPS coordinates from the phone by pressing 'Get GPS location'. If for any reason it is not possible to automatically get the GPS location from the phone, you can manually add information on the location in the textbox. Press 'Save'.

4. Distance to bottom

Then, measure the depth of the containment with the depth probe. Assemble the probe (specific assembly instructions might differ depending on the probe used). Make sure you have some space around you as you do this.
To measure the depth of the containment, insert the probe vertically into the containment until you reach the bottom, or until the probe is fully inserted into the containment (so that the top of the probe reaches the opening of the access point (red line in Figure 35). Read the depth of the containment at the top of the containment (Figure 35).

Clean the probe with a piece of absorbent paper towel as you remove it from the containment. Dispose of the paper towel appropriately. Afterwards, clean the probe with a cloth or sponge and water with soap/disinfectant (Figure 36).

Type the measured depth of the containment in meters in the 'Record depth' button on the 'Distance to bottom' page and save.

Note: Probe length can vary based on what is locally available and how it will be transported. A modular or collapsible probe is ideal, but a simple metal or wooden rod can also be used. Realistically, the probe is maximum 3m long, as this could be transported (depending on mode of transportation) and can still be opened when there is a roof overhead. In general, 3m is long enough to measure containment depths. In situations where containment depth is deeper than 3m, a longer modular probe could be fabricated, but this is only useful when only measuring outside without a roof overhead (e.g. toilet superstructure). For scenarios where the containment is deeper than the probe, see section 'The depth of the containment is deeper than the length of the probe' under 'Trouble shooting'.

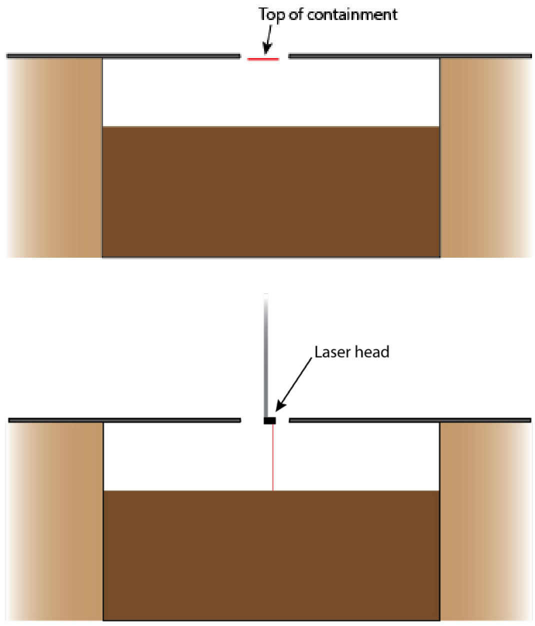


Figure 35: Measure the depth of the containment and the distance to the sludge at the top of the containment.

Figure 36: After taking a measurement, clean the probe with a cleaning cloth or sponge.

5. Distance to sludge
Measure the distance from the top of the containment to the sludge layer (used to calculate the empty space in the containment). Place the tripod over the open access port to the containment. Make sure that the tripod is level by either watching the bubble level on the top of the tripod (Figure 37), or by visual observation. Position the laser head so that it is at the top of the containment (Figure 35, same point as where the depth of the tank was measured). This can be done by opening the quick release and moving the metal tube up or down, and/or by shortening the legs of the tripod. Flip the laser so that it points downwards (Figure 38), the black 'window' of the laser should point downwards). Once the laser is in position, press 'Measure sludge' on the app. You can read the result on the screen at 'Distance to sludge'.

Figure 37: Above: Checking the bubble level on a tripod. Below: The top of the tripod with the protection box should be level while taking a measurement.

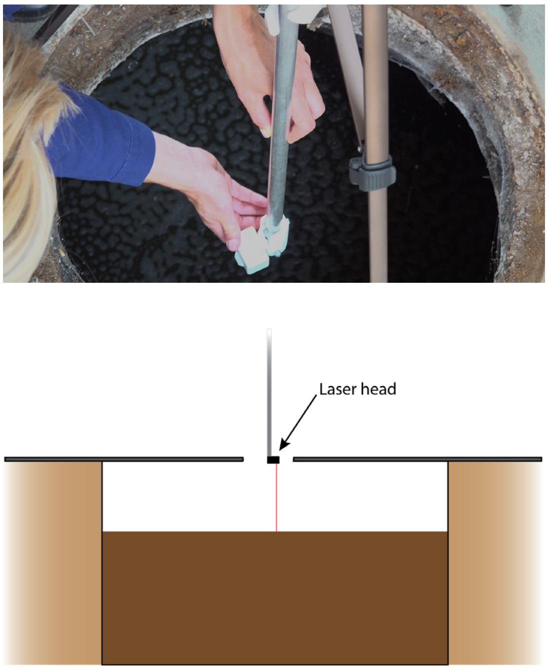


Figure 38: The laser sensor pointing downward.

6. Area
To measure the area of the containment, flip the laser so that it points to the side (Figure 39, the black 'window' of the laser should point sideways) and lower it into the containment, so that the laser unit is fully inside the empty containment space, but does not touch the sludge. The laser can be lowered by adjusting the length of the legs of the tripod. **The laser should never touch the sludge!**

Once the laser is correctly placed inside the containment, tap 'Measure area' and slowly start rotating the top part of the Volaser (protection box, including the phone) 360 degrees. The laser and metal tube will turn along. On the screen, you will see the shape of the measurement appear as you measure. Normally, one 360 degree round should suffice. However, if an erroneous measurement is observed in the shape displayed on the app (Figure 40), you can keep turning the Volaser until you are confident that the measurement shows the correct containment shape. Every new revolution will overwrite the previous measurements, so once you are satisfied with the shape you see on the screen, tap 'Done'. Only after pressing 'Done' should you remove the Volaser from the containment, otherwise it will keep measuring!

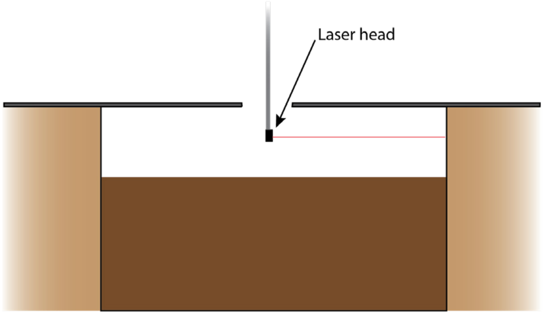


Figure 39: The laser sensor pointing sideward.

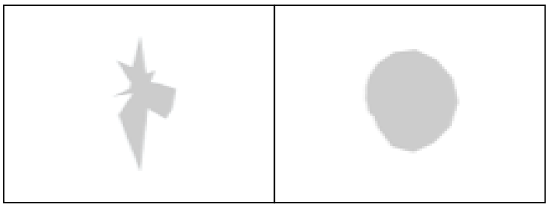


Figure 40: An example of an erroneous measurement of a round pit (left) versus a correct measurement (right).

7. Save data
After taking all measurements, tap 'Save' to save the data.

8. Data tab
All saved measurements can be found in the 'Data' tab. Tap on a measurement to open and review its data. Once opened, photos (e.g. of the containment that was measured) and notes (e.g. any irregularities) can be added.
To export and share data points, click on 'Select' in the top right corner in the 'Data' tab. Tick boxes will appear to select the data points to export. Either 'Select all' to export all measurements, or select specific measurements to share. Once selected, click on the triangular icon to share. A new window will pop up where you can choose how to share the data.

Maintenance

- Check that there are no dirt, fingerprints, or scratches on window of the laser lidar sensor. If the window is dirty, clean it with a damp cloth and some and dry it with a clean cloth.
- It is important to keep the USB-C phone connector clean. During use, try to protect the connector from soil, dust or water. Clean after use with air or a brush if needed.
- Check that all screws are in place and tighten any screws that need tightening.

Trouble shooting

Following are the most common problems that have been encountered and how to trouble shoot them:

The app is frozen
Completely close the application on your phone and restart the app (exact procedure might differ per phone brand). If this does not work, try restarting the phone.

The device is not measuring the area
While the phone is connected to the laser, navigate to the 'Settings' tab in the bottom right corner, and open the 'Test Laser and Gyroscope' page. Check that: 1) The USB is "Connected"; 2) When moving the phone, the arrow on the gyroscope ('Angle') should move, while the angle changes; 3) When pressing the 'Test Laser' button, a measurement should appear under 'Range' and 'Strength'. Range indicates the distance (in meters) that the laser measures, Strength indicates the strength of the returned signal (the fraction of laser light that is emitted from the laser, reflected on the walls of the containment and then measured by the sensor). A higher number for Strength means that a larger fraction of laser light is reflected, which indicates a stronger signal often caused by a lighter reflection surface.

If all three points are functioning as described, but the device is still not able to measure the area, there is a possibility that your phone is not compatible with the smartphone app. To test this, borrow a different phone and try if it functions with another phone. A list of phones that have been successfully used with the Volaser app is available on www.github.com/volaser.

The app indicates "Laser not found!"
This means that the phone and the laser are not connected. This could be either because the phone connection cable or laser is broken, or because there is a loose connection. To find out, follow the procedure described under 'Loose connection'.

Loose connection
If a loose connection is suspected, the (13) ***phone connection cable*** will need to be checked, specifically the connection points, and be re-secured. To do this, remove the cable from the curved slot on the protection box base. Unscrew the screw between the (12) ***Connection piece lasercase*** and the (7) ***Metal tube*** (see Figure 20) and remove. Carefully pull on the cable at the laser end, and pull it through the (14) ***Protection box base*** and metal tube until it comes out fully. Be very gentle, removing the cable might aggravate any existing loose connections. Check the entire cable and the self-constructed connections between the laser and phone connection cable for breakages. Push the two sides of the connection towards each other, or reconstruct the connector if needed. Before reinserting the cable back into the metal rod, do a quick test if the connection was reestablished. Connect the phone to the phone connection cable, go to the 'Test Laser and Gyroscope' page, and check that: 1) The USB is "Connected"; 2) When turning the phone, the arrow on the gyroscope ('Angle') should move, while the angle changes; 3) When pressing the 'Test Laser' button, a measurement should appear under 'Range' and 'Strength'.

The depth of the containment is deeper than the length of the probe
If a containment is deeper than the length of the probe, there are two options. Either use the maximum length of the probe as the input for 'Distance to bottom'. This means that the containment volume and faecal sludge volume will be slightly underestimated. Alternatively, if the user of the containment knows its depth, this value can be used. However, this might not increase accuracy of the reading, since many users do not know exact containment depth. Depending on the study purpose, one option may be preferable over the other.

References

Andriessen, N., Appiah-Effah, E., Browne, S. J. I., al Jahjah, R., Kabika, J., Kinobe, J. R., Korir, N., Nishimwe, P., Niwagaba, C. B., Pradeep, R., Prasad, P., Tembo, J. M., William, A., Ambuehl, B., & Strande, L. (2023). Quantities and qualities of faecal sludge: Experiences from field implementation with a Volaser in 7 countries during a pandemic. *Frontiers in Water, **5**(1130081).* doi:10.3389/frwa.2023.1130081

Koottatep, T., Ferré, A., Chapagain, S., Fakkaew, K., & Strande, L. (2021). Faecal sludge sample collection and handling. In K. Velkushanova, L. Strande, M. Ronteltap, T. Koottatep, D. Brdjanovic, & C. Buckley (Eds.), *Methods for Faecal Sludge Analysis*. London, UK: IWA Publishing.

Prasad, P., Andriessen, N., Moorthy, A., Das, A., Coppens, K., Pradeep, R., & Strande, L. (2021). Methods for estimating quantities and qualities (Q&Q) of faecal sludge: field evaluation in Sircilla, India. *Journal of Water, Sanitation and Hygiene for Development, **11**(3),* 494-504. doi:10.2166/washdev.2021.269

Velkushanova, K., Reddy, M., Zikalala, T., Gumbi, B., Archer, C., Ward, B. J., Andriessen, N., Sam, S., & Strande, L. (2021). Laboratory procedures and methods for characterisation of faecal sludge. In K. Velkushanova, L. Strande, M. Ronteltap, T. Koottatep, D. Brdjanovic, & C. Buckley (Eds.), *Methods for Faecal Sludge Analysis.* IWA Publishing.