Underwater Robot for Minimally-invasive Cave Research

***Michael Ross** reports on his use of the commercial Navatics Mito underwater robot for exploring flooded caves.*

Background

Exploration of sumps is always a challenge. Availability of divers is limited, diving is always risky, transportation of a diver's heavy gear needs support from 'sherpas'.

Sending a camera-equipped robot down the sump beforehand would help to assess the nature and minimum length of the sump to help prepare a later dive. In some cases, visual inspection may even reveal that the sump is short enough to be dived without SCUBA equipment, or it may reveal obstacles which do not warrant sending a diver at all.

A further advantage of inspection by a robot, rather than by a person, is the size of the robot versus the size of a diver including gear. A smaller object that does not exhale air and stirs up less mud if handled carefully thus provides better visual contact to the unknown. When performing bio-speleological inspections, small animals might be shied away or overlooked by a human diver. In narrow sumps, the diver may not be able to see much of the ceiling, possibly overlooking chimneys or interesting artifacts. Last but not least, when diving a sump for the first time, there is usually not much opportunity for taking pictures or videos, because tackling the sump requires the undivided attention of the diver.

Using a robotic vehicle to explore sumps is not a new idea. DIY devices were built decades ago. However, the technology at that time (camera resolution, size of batteries, lighting) did not deliver good results. Nowadays, it is possible to construct much better devices. As we know from other areas of technology, however, this can take quite a long time, the prototype device always being in the state of 'nearly ready'. Hence, in our group, we opted for an off-the-shelf commercial device, despite it not being designed for use in caves.

The initial device that we purchased, the *Powerray*, which is made in China, did not satisfy our requirements: its three small rotors stirred up too much sediment, the robot was not able to tilt, and parts (battery, rotors) were not replaceable.

The alternative device, the *Navatics Mito*, which is presented here, is much more promising. Navatics is a spin-off from the Hong Kong University of Science and Technology. The team has an impressive track record of research in the area of underwater vehicles (Liyanto, 2017; Widy, 2017).

The Robot

The Navatics Mito robot weighs 3kg, and measures 41 × 31 × 13cm. It is delivered with the following useful accessories: replacement rotors, spare 80Wh LiPo battery, and a protective lens cap. The specification says it can be used to a depth of 40m. A 50m-long 4.2mm Kevlar-reinforced tether with length marks provides H.264-encoded communication between the robot and a terminal device, called a buoy, out of the water, which houses a wireless access point.

The buoy is designed to float on open water. It even has a solar panel for charging the battery, and a built-in fan to keep it cool – features which we really do not need in the cave.

The buoy relays the communication via WLAN using a custom protocol, operating at 2.4GHz, to a re-purposed gaming console (manufactured by Chinese company Senseplay), from which the robot is operated. To display what the robot sees, a smartphone or small tablet is required, but is not included. This is attached to the control unit via an OTG interface cable and a plastic bracket. The entire infrastructure is, therefore, a combination of four components.

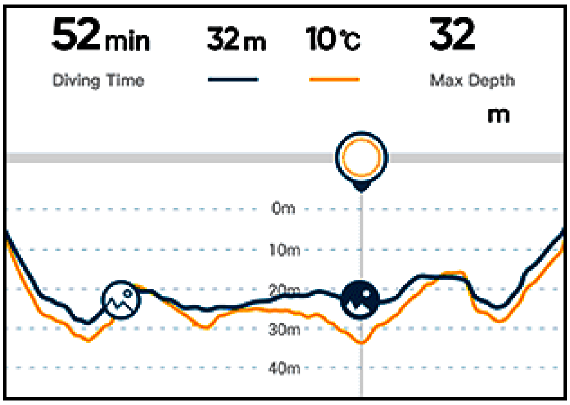
A definitive advantage of this particular robot is its four rotors, allowing the robot to move in four axes, i.e. to be able to look up or down at an angle of up to 45 degrees. This is very useful for inspecting the floor and ceiling of the sump. Compared to those of competitors' cheaper products, the rotors are relatively large. As a result, they do not have to rotate as fast, thereby creating less turbulence in the water.

The robot is programmed to maintain its orientation and vertical position, thanks to the built-in compass, as there is no GPS available underground. The pilot sets the depth as an absolute value on the

Piloting the robot in a cave environment.

Exploded view of the Navatics Mito robot.

Sample of display on the smartphone.



Sample of data log.

control unit, for example -1m, which is then kept steady by the robot, until the pilot sets a different depth. The same applies to the tilt angle.

The LEDs are manufactured by Cree. Their colour temperature is 5700K and they attain a colour rendering index (CRI) of 80. The brightness can be set in three steps, up to 2 × 1000 lumens. The lowest setting of 33% proved to be sufficient in most cases, particularly in murky water, therefore saving battery power.

The camera has a 1/1.7 inch CMOS chip, a lens with an f/2.0 aperture and a FOV (Field of View) of 120°. For recording, there is the choice between high-res images (12MP) or video (3840 × 2160). A colour correction facility is built-in. The media is written to the robot's storage in the selected resolution for later retrieval via an interface cable. During the dive, the video stream is also transmitted in compressed (1920 × 1080) quality to the app on the smartphone attached to the control unit.

The following live indicators are displayed on the smartphone for the operator: battery levels of the robot, buoy, and control unit; the selected and actual tilt angle; the selected and actual depth; compass reading; brightness setting; water temperature, and state of the rotors.

There is a page for advanced settings, where parameters for video recording and the sensitivity of the control pads can be adjusted.

Initial Results

Configuring the app was cumbersome, despite the printed user instructions and tutorial videos. The app needs to be registered and uses a protocol that requires mutual authentication of the devices. With the help of the responsive support team, this obstacle was quickly overcome. Before the robot becomes operational, it requires a brief calibration procedure.

We then tested the robot first in a bathtub using an iPhone SE, and later a Xiaomi Redmi Note 7 Android smartphone, to become familiar with its operation. It turned out that the iOS version of the app lags behind the Android version in capabilities and updates. A metallic bathtub appears to confuse the robot's built-in compass and the software that tries to keep the robot stable. The robot is specified to be 0.1kg positively buoyant but it wasn't. The manufacturer does not say whether the stated buoyancy applies to saltwater or freshwater. Some more buoyancy could be achieved by stuffing bubble wrap into the battery compartment, but when going deep, the bubbles will be compressed. More buoyancy will also be required when attaching additional payload to the robot. According to the specs, the robot can lift up to an extra 500g.

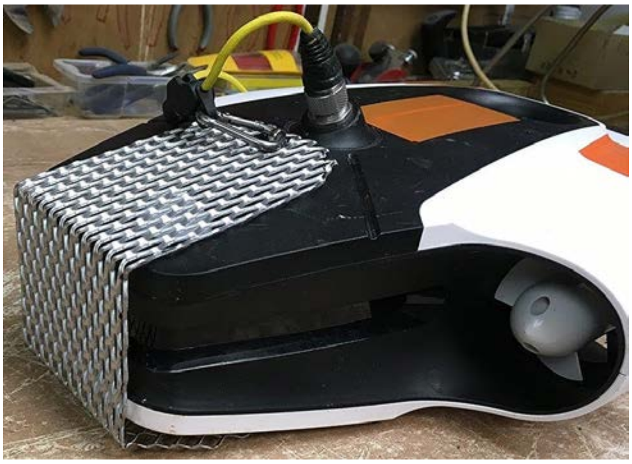
We tested the device first in benign and later in more challenging environments. Needless to say, the robot does not see much in murky water. Moreover, the compression algorithm used for video transmission gets confused in foggy water. In clear water, the results are most impressive. Even the smallest pebbles and artefacts can be seen.

In a behind-the-sump scenario, we could make the robot stick its lens out of the water to obtain a view of the ceiling.

The robot's battery life of approximately two hours – when used intensively – was sufficient in most cases. Fortunately, the robot's battery is swappable, so that a second dive of the underwater passage can be undertaken. The maximum duration of a dive is determined by the weakest battery of all four components (robot, buoy, control unit and smartphone). It is advisable to have power packs at hand for recharging those devices. Once a third of the available power is spent, one should navigate the robot back to the origin, because problems may occur underway which delay the return. For example, the robot may get temporarily stuck or the

Components left to right: robot, buoy and control unit with smartphone.

View from camera looking directly into the sump.



Mesh wire fitted to protect rotors from debris.

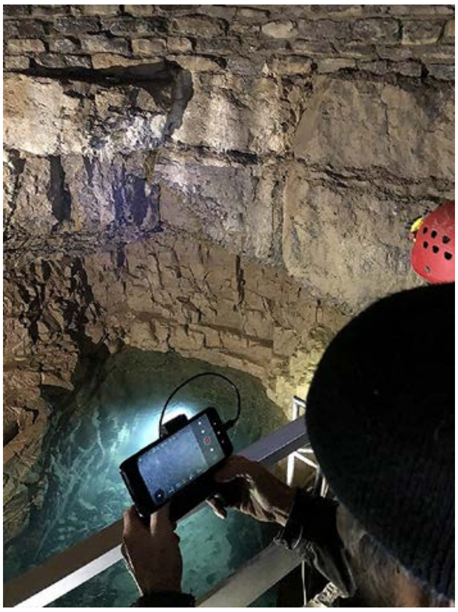
Inside the buoy. For cave use, the fan can be disconnected.

visibility can make it difficult to find the way out.

The power consumption of the buoy could be reduced substantially by disconnecting its internal fan, as there is no danger of overheating in a +10°C humid cave environment.

Piloting the Robot

Piloting the robot requires lots of practice to avoid getting it stuck or stirring up mud. It is essential to set the sensitivity of the controls to minimum in the app's configuration page. The robot must be kept away from passage walls, ceiling and floor. The vertical movement in particular needs to be performed carefully by adjusting the target depth in small steps. If the robot hits the wall after changing direction, one needs to immediately undo the direction change and retry with a smaller increment. Otherwise, the robot's stabilization mechanism tries to push the wall away with full force, leading to significant turbulence, which obstructs the view. The same applies to the floor and ceiling.



Piloting the robot. Photo: U. Gehbauer.

The two major obstacles we faced were: a) blocking of the rotors by leaves or other debris in the water, b) navigating the device in a way to not entangle the tether.

The blocking of rotors is indicated on the display by a warning pop-up, followed by the automatic shutdown of the motors. The robot will then drift according to its buoyancy and the direction of the water flow until the pilot hits the 'motors on' key. Then the robot will attempt to return to the previously set depth and direction as quickly as possible, which can cause significant turbulence. It is always good to set the target depth to the actual depth *before* switching on the motor.

Going into the reverse direction, also vertically, can help to free the rotors from debris. Severe blockage leads to a temporary power failure in the robot, combined with a temporary loss of communication, followed by a reboot of the internal circuitry. After approximately 30 tense seconds, the robot is operational again and communication is restored. As an unfortunate side-effect, the currently recorded video in the robot is lost, but the lower-resolution copy in the smartphone is be maintained. Therefore, it is good to end and restart the video recording every couple of minutes, so that several smaller video files are produced. In practice, however, a pilot, who is busy with navigating, sometimes forgets to reactivate recording, resulting in a dive without any footage.

To protect at least the vertical rotors, we have fitted metallic mesh (normally used for plastering) to the robot.

To prevent entanglement of the tether, a second person is required to manage the cable, while the pilot's undivided attention is dedicated to navigating the robot. The tether should be kept loosely, without any loops. There should be no strong pulling on the tether, as it may get stuck behind a rock or in a groove in the wall.

Video recording of the smartphone's screen by a third person is useful for later reviewing of the dive, as the displayed indicators (depth, direction, status of rotors) are not recorded by the app.

Outlook

It is apparent that the robot was not designed for use in caves. Having two components instead of four would be preferable, but we did not want to wait until such a device became available, be it DIY or commercial.

The robot's capabilities in its current state are already helpful for entering the era of 'minimally-invasive cave exploration'. There are also many more applications on the horizon, for example, in cave rescue and photogrammetry.

Enhancements to the device have been discussed with the manufacturer. Included here were protectors for the rotors, and a bracket for two parallel laser pointers to provide size information. The support team is open to suggestions for software update and we have discussed, for example, methods of improving the behavior of the robot in the event of it getting into difficulties.

References

Liyanto, H. (2017) *Modeling and Control of a 6 Degree-of-freedom Observation Class Autonomous Underwater Vehicle*, (Doctoral dissertation, Hong Kong University of Science and Technology).

A. Widy and K. T. Woo (2017) *Robust attitude estimation method for underwater vehicles with external and internal magnetic noise rejection using Adaptive Indirect Kalman Filter*, 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, BC, pp. 2595-2600.