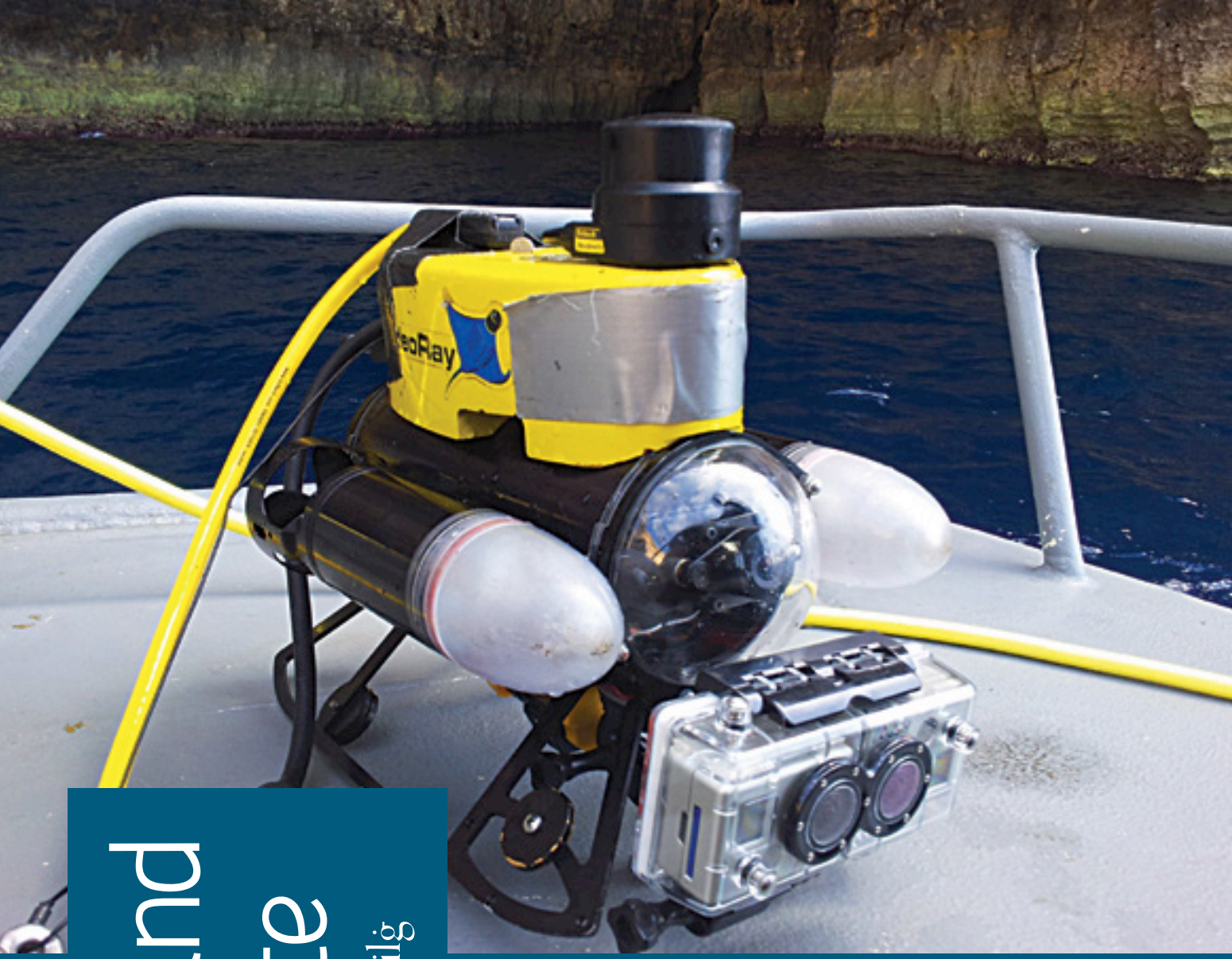


Maps, **Bots**, and a Neolithic Site

The underwater world beneath Tas-Silġ

A team of American and Maltese scientists has recently mapped the water system underneath the Neolithic temple site at Tas-Silġ. No picks and shovels were involved; instead, high-tech wizardry let the team create a 3D picture of this underground world. Words by The Editor.

The VideoRay Pro III dipped and slammed into the pool wall. I cringed and hoped I didn't break the robot, I quickly realised how tricky it is to manoeuvre these machines in murky water.

I was clumsily driving an American robot in the University of Malta's pool. This machine had just mapped the underground water cisterns at Tas-Silġ, a Neolithic temple around 4000 years old with a rich history that includes the Punic and Roman periods until around 400 AD. A team of American computer engineers is currently collaborating with Maltese archaeologists to explore Malta's underground wells and cisterns.

The number of people working on this project and the breadth of disciplines is remarkable. Here are their stories.

DR CHRISTOPHER CLARK

Mr SharkBot

"I'm just the robot guy"

It all started five or six years ago when Dr Christopher Clark (California Polytechnic State University [CalPoly] and Princeton University) met Christopher Olstad (Marine Resources Development Foundation) at a conference in America. Olstad was showing some gritty filming of an underwater site by robots, which Clark knew he could improve. Then, Olstad introduced him to a Maltese archaeologist called Timmy Gambin, who quickly arranged for a one-week trip to Malta. In that first year, they explored eight underground water cisterns in a week. This year they are on their fourth visit and brought 11 students to map over 30 cisterns and two caves.

For Dr Clark, using robots to map these underground places is a challenge. Before this collaboration, he used to map swimming pools, which are neither fun nor have much real world application. Mapping ancient cisterns is useful for archaeologists and helps him push robot technology to its limits. The researchers usually have no idea how large an underground space is. Above ground, all you will see is a small hole or two, when they lower the robot "you have no idea what it's going to be like [...] this is the exciting part" said Dr Clark. Exciting, but it poses many challenges.

The most obvious problem is the water itself. Everything is waterproofed. Dr Clark usually buys off-the-shelf equipment, "I want to buy the best stuff that doesn't break so often." He travels around the world and transportation tends to break robots. He does not want to fix broken equipment in a country whose language he does not understand and with little idea from where to source spare parts. Industry built robots have been tested repeatedly, they tend to last longer than lab-built ones.

Water also scatters light. Land based robots use lasers to quickly and efficiently scan an area. Underwater, lasers would not work since debris scatters light quickly. Instead, roboticists use sonar. Sound waves travel further and faster underwater, although "it's the speed of light versus the speed of sound." The robot has to move much slower to gather the same detail. »

Students using robots to explore Tas-Silġ, a site under the care of Heritage Malta.

Image: Flickr/joncrowell

SharkBot

Dr Chris Clark collaborates with the shark expert Dr Chris Lowe (California State University) to track sharks with robots. Clark uses a torpedo-shaped robot made by OceanServer called the Iver2. The process involves catching a shark, attaching an acoustic tag, then releasing it. The robot can now use the tag to track the shark using sonar.

Tracking sharks helps researchers know where a shark's location is to learn more about its behaviour. Biologists have traditionally followed sharks around for hours on a boat keeping their receivers within range, or had stationary receivers in areas they knew were visited by sharks. Neither solution is ideal. "A robot can last longer and follow the shark in a better way" said Chris Clark, the researchers just picks up the bot, collects, and interprets the data.

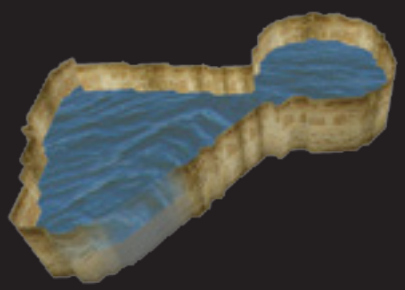
The next step is attaching more sensors on the robot like salinity, temperature, and so on. These will help "see if there is some correlation between the environment and what the shark is doing." The robots also need to last longer, move faster, with more manoeuvrability, "something super small, quick and with a long battery life" — that's Dr Clark's ideal SharkBot.

The biggest research challenge is for the robot to know its location. Without this knowledge, "there is no point in taking a scan." "There is no GPS down in the Cistern", so the researchers need to develop techniques like SLAM (Simultaneous localization and mapping) that help the robot scan and map itself at the same time. In a cistern, the robot can do this in two ways. One is a smart tether that links the robot to the joystick control (manual manoeuvring). Sensors along the line's length take measurements that can locate the robot. Another method uses computer algorithms to figure out location. The robot can send sound waves in multiple directions and use the overlapping waves to pinpoint itself. There are many different ways a robot can do this, but the result is the same: the robot measures where it is and where the walls of the cistern, well, or cave are, so how does this get transformed into a 3D map? ▪

Tas-Silġ is one of the most complicated cisterns Dr Wood and her team has mapped. "We never know what they [the cisterns] will look like. It's always very exciting. Is it a single chamber or a large complicated chamber like Tas-Silġ?" This neolithic site simply has three large entry points above ground. When they lowered the robot through these holes they discovered multiple chambers, tunnels and an immense networked area that could provide water to multiple areas on the temple site. An incredible early example of convenient water "on tap."

Being underwater complicated mapping, "on land they can do things they can't quite do in water." For Dr Wood to create these 3D maps, her team needs to take the sonar data collected by the robots and turn it into a geometric model. "Sonar is much less accurate than laser [...] there are problems with noise, gaps in the data and aligning everything."

The data they handle is essentially a number of dots surrounding the robot. The dots represent the distance between the robot and the nearby wall as determined by sound waves. As the robot is controlled around the chamber it gathers a bunch of other dots, by knowing the robot's location a computer programme can then join the dots to make a 3D map. The programme they use is called the marching cubes algorithm that was originally developed for medical data to "create 3D surfaces of the brain." This is a very novel application but means that the raw data needs to be filtered and adjusted to fit the model. The computer-generated map also needs smoothing and data gaps are filled using probability theory (pictured in red) to make everything look as it should. On top of this skeleton a texture is applied (usually camera images of the actual site), which gives an even closer approximation to the cave's actual appearance — they can even fill it up with water. ▪



Top: Cisterns of private homes in Gozo.
Below: Water system under Tas-Silġ.

MR KEITH BUHAGIAR

The Water Expert

"I identify which is which"

I suspect it is a well," said Keith Buhagiar nonchalantly. "What do you mean, are you saying that Tas-Silġ is a well not a cistern, should I change the title of my article?" I replied naively (previous title: *Using Underwater Robots To Explore The Cistern Under Tas-Silġ*). "Cisterns and wells can be confused," he replied. "Tas-Silġ has the appropriate geology" for a well, which could explain its ancient nature.

Trying to recover from my confusion I simply asked for definitions. "A cistern would be a subterranean or above ground reservoir, a water storage tank. [...] The first form of waterproofing was simply a mixture of cement with ground pottery and lime, which could retain water. [...] A well should be a shaft that taps an underground source," which is what they think occurred at Tas-Silġ.

More sensors on the robot would help Mr Buhagiar be certain. In particular, "an analysis of the actual water," would help identify the difference between a well and a cistern, since one collects rain runoff, while the other directly taps the water table. The tests would identify the water's source, for example, detection of high levels of chemicals like nitrates and calcite deposits identify wells. Apart from robotics, Mr Buhagiar believes that he will only be certain after going down there himself. "Being in the space would help me better detect the evidence, give me a better idea of the clay deposits [...] these clues would be difficult to detect using the [robot], for now human access should back up the data."

> "Being in the space would help me better detect the evidence"

The Tas-Silġ well system is also one of the most complex structures the team has ever seen. The team has theories but does not have all the answers. "It is still a work in progress [...] one of the concerns must have been to secure a water supply," the inhabitants could have tapped water from multiple locations. The well's entry points are from areas built in the Punic and Roman eras, which suggest that the well was expanded to its current size from those times. Timmy Gambin also suggests that "the complexity of the tunnels aimed to keep a flow of water throughout the system. [...] It must have been necessary to make them intricate, [...] to efficiently feed different areas, everything boils down to efficiency."

Advanced robotics and 3D mapping made this possible, but further sensors, high-definition photography, and sampling might give the archaeologists all the answers they need. ▪ »

DR ZOE WOOD

The 3D Map-Maker

"I do all the computer graphics"

DR TIMMY GAMBIN

The Maltese Connector

"I act as a catalyst"

Marine Biology and Robotics

"Another wonderful story of collaboration. We worked with Dr Joseph Borg from the Department of Biology and under his guidance we are starting to formulate a plan to go back to marine caves to gather data that he and his students could use. [...] The caves can be 100 meters deep with narrow entrances. It would be extremely difficult and dangerous for a diver to reach the inner depths of a cave. The robot is safer and more economical," explained Gambin. The potential is incredible. If they manage to retrofit robots to measure oxygen levels, salinity, temperature, and so on, then merge the data with the marine life present, the researchers could have a 3D picture of cave ecology.

Dr Timmy Gambin initiated the 'Ancient Cisterns Exploration Project', which brought this team of people together to explore the wells and cisterns of historic buildings around Malta and Gozo. He believes that "the archaeologist and roboticist can work on their own, but why reinvent the wheel when you both stand to benefit? [...] Dr Clark brings in the technological firepower. For him it was much more interesting and much more tangible because he was seeing the practical use of his computer codes. [...] Now he was working in a real environment."

Dr Gambin is also a researcher and collaborates with Keith Buhagiar. His research interest is on how to merge technology with archaeology. "Not just technology for the sake of technology, but how we can merge technology with a practical research use. [...] It is essential for technology and archaeology to move ahead together." Dr Gambin's out-of-the-box thinking has driven this innovative project.

Apart from bringing everyone together, Dr Gambin helps the US team hit the ground running. "I took care of logistics, daily transport, timetables, things that may sound trivial but are absolutely essential. They find two vans waiting for them with their project name, the vans take them to the apartment, the apartment has everything even grocery shopping, they find the timetable, I meet them at the apartment, I brief them as to what the timetable is [...] everything is taken care for them. I also need to organise access to the sites, requests for permits, and so on. We plan months ahead" ▪

The Research Question *and answer*

"In a nutshell, one of the research questions that we asked was: do the water management systems existing in modern day Rabat or Mdina reflect the architectural shell that surrounds them. What does that mean? Does a baroque palace in Mdina have a well or cistern that dates to the baroque period, or could it have something older? The only way to find out is to go into these wells. Some of these wellheads are too small, some of them are too dangerous. So we chose robots."

"The robots took videos and generated 3D maps. On the basis of these data, together with Keith Buhagiar, we were able to start deducing the different typologies. You have the standard bell-shaped well which is omnipresent in most houses that predate the 1950s, but then you have other shapes, you have rectangular, rectangular with tunnels, and shafts that tap straight into the water table. Some are recent, some are ancient" — Dr Timmy Gambin.

Mr Keith Buhagiar explained how before bell-shaped wells and cisterns there existed structures shaped like a bottle of wine or like a square, since they were converted from disused quarry sites. "The most impressive site is at Tal-Kaċċaturi close to Borġ In-Nadur in Birżebbuġa"

The most unexpected part of this project wasn't the age of the site, or complexity of the tunnel, but Dr Jane Lehr, a researcher in ethnic and gender studies. What did she have to do with robots and temples? "I study ways in which graduating engineers can be best prepared to interact in an international context, [...] by developing training specifically focused not only on cultural differences but also how these cultural differences might matter in a technical context."

At a conference on Engineering Education, a director from Boeing, which employs over 150,000 people, emphasised how "we need to tear down the walls of the disciplinary silos, so that the students can be prepared to work in agile organisations, where they can interact with engineers, customers, sales staff, accountants, and so on," reflected Dr Lehr. By teaching students skills to work with people from other engineering disciplines, backgrounds, and cultures, they are helping them get a job. That is why Dr Lehr ran a module on Maltese history for all the American students on this project. In Malta, the students had to juggle learning about a new culture, a technical project, and conduct research on the Maltese education system, attitudes towards climate change, or strategies on its water resources. Within three months of graduating, eighty-two percent of engineering students at CalPoly find a job. ▪ »

DR JANE LEHR

The Cultural Wizard

"What it means to be a global engineer"

Robot used to train students at the University of Malta.

PROF. SIMON FABRI

Robots 'r' Us

"Making the machine more intelligent"

Robotics in Malta has historically focused on making land machines more intelligent and less dependent on humans, "on this level we are at par with international research" emphasised Professor Simon Fabri from the Faculty of Engineering, University of Malta. The department is industry focused, and till now there is no industrial demand for underwater robots. Robots might be able to do much more than divers, but the initial capital investment has been off-putting for companies. By collaborating with the Americans, Maltese researchers might finally have a good reason to invest in underwater robotics explained Prof. Fabri.

Timmy Gambin shares this vision. He hopes that this collaboration will "kickstart a process of funding applications" for Malta. Prof. Fabri and Dr Clark are also eager to apply for funds together. Dr Gambin continued, "having our own robot would enable us to become more autonomous; autonomy not to isolate us, but for further collaborations." Gambin sees two possibilities, "one, we can collaborate with people who are already established. Look, we're building an ROV [remotely operated vehicle], you built one five years ago, but can we better yours? Two, hooking up with [for example] the University of Benghazi and saying: we have five years experience in geoscience, let's collaborate. They need geoscientists to see where mud is, where sand is, where underwater springs are" he clearly sees Malta taking a lead in this field.

Apart from the hardware, collaboration has also helped Maltese students. This year Maltese students from the Faculty of Engineering joined the expedition and were taught how to manoeuvre the robots. Attracting funds would also help fund much-needed Ph.D.s and postdocs, who usually do the bulk of research in science. As Prof. Fabri said, "you need to employ someone who is working full-time on research. [...] My role is that of mentor." Malta recently got over half a million euros from European Union ERDF funding to train the next generation of roboticists. After they graduate these students need to find research jobs.

The applications for robots, and the researchers that accompany them, are endless. The "technology starts in the lab, developing the algorithms, making them perform better," explained Prof. Fabri. "But, if it stops there I'm not happy, I would like to see them applied to real-life situations." Roboticists can collaborate with health practitioners using robotics for rehabilitation, or aiding physiotherapy, cleaning, or transporting goods around a large building. "In Malta, we rarely get this opportunity," normally industry buys its technology from abroad and does not research. "University could help specialise the robot for them and improve on it." When Simon saw this "new application in archaeology, [he was] all for it." ▪

Next year, should see the American team bring an even better robot, with better cameras, sensors, and software. It will help explore new underwater worlds and solve more research puzzles. I am really looking forward to driving the improved robot, hopefully not into a wall but into an unknown ancient cistern, or well. ●

FURTHER READING

- The Malta Cistern Mapping site: http://tinyurl.com/maltamapping
- The CalPoly and Princeton students' blog: http://tinyurl.com/gozocisterns
- The Aurora Trust: http://auroratrust.com
- Some stunning pictures of the new Engineering Lab at UoM (Warning: includes cute robots): http://www.um.edu.mt/eng/sce/facilities/control
- The American scientist's talk details: http://tinyurl.com/exptechs
- Dr Chris Clark's Robotics Lab: http://lair.calpoly.edu/
- Smart Tether technology tested to localise robots underwater: http://www.smarttether.com/
- If you want to buy your very own yellow robot: http://www.videoray.com/