Removing Man From Minefield

Single-minded, one-shot autonomous vehicle closes gap on mine neutralization

By EDWARD LUNDQUIST, Special Correspondent

Robotic Solution

The NATO Undersea Research Centre is "exploring ways to perform maritime mine neutralization more safely, efficiently and cost-effectively," said Warren Fox, program manager for the overall autonomous naval mine countermeasures program at the center.

- The effort involves collaboration between a highly capable autonomous surface vehicle (ASV) and a low-cost, disposable, mine-intervention unmanned underwater vehicle (UUV).
- The ASV guides the UUV to the target.
- The testing platforms were developed from modified commercial, off-the-shelf components.

Unmanned systems — particularly naval systems used for mine countermeasures (MCM) — are growing in sophistication and in numbers.

"These systems are currently limited to human-guided systems or systems that execute preplanned missions. Human operators must intervene to observe events, make decisions and guide the vehicle," said Warren Fox, program manager for the autonomous naval mine countermeasures program at the NATO Undersea Research Centre (NURC) in La Spezia, Italy.

Minehunting is inherently dangerous, Fox said.

"We have to send very expensive ships into mined areas with a lot of people onboard," he said. "Sometimes we have to send divers down to dispose of individual mines. The mantra in the minehunting community as we move into the future is to 'remove the man from the minefield.' Our objective is to demonstrate an end-to-end system that can go all the way from detection/classification/localization to neutralization with completely robotic solutions."

Fox said there are existing one-shot neutralization weapons currently available that are typically operator-controlled from a surface ship somewhere near the mine using a fiber-optic cable.

"They have sonar and cameras and are very operator-intensive. With robotics, we're trying to eliminate tethers [and] hopefully bring about a more automated solution," he said.

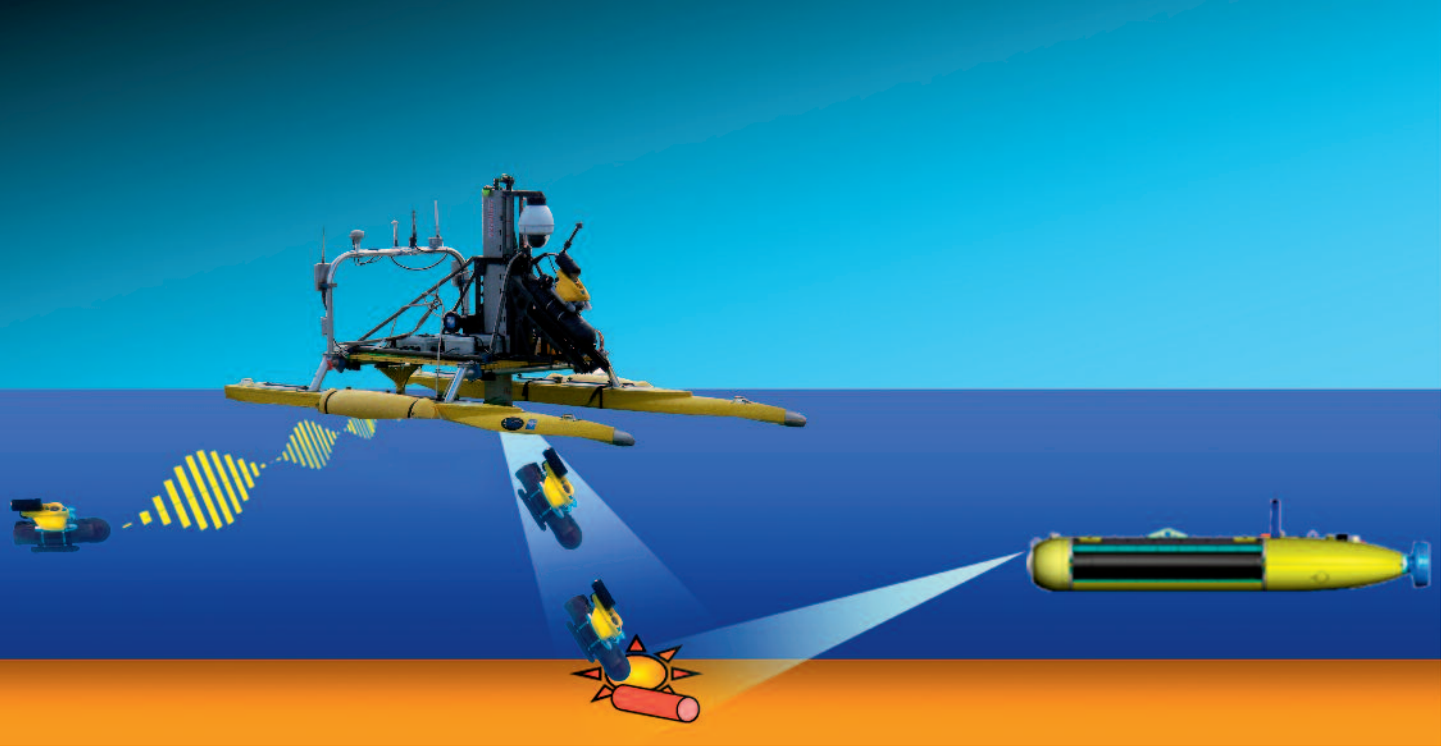
"We're trying to find robotic means to do mine disposal with the required performance to remove divers and have less operator requirements," said Dr. Vladimir Djapic, a research scientist in the systems technology department at NURC. "We're not just trying to introduce robots; we are trying to introduce a robust solution with robots."

Collaborative autonomous vehicles have the potential to provide a safer and more effective way to conduct MCM missions. Instead of legacy systems deployed from surface ships working in the middle of a minefield, a quickly deployable off-board autonomous system can be scalable to the needs of the operation, offer an increase in the operations tempo and deal with danger at a significant distance from any manned platform. A main advantage of true autonomous platforms is minimal operator workload or intervention, especially on long, tedious searches.

Djapic said the goal is a cost-effective one-shot vehicle.

"They need to be inexpensive — because they will be detonated at the mine — so we removed the sensors. We've introduced a 'master platform' that helps the one-shot vehicle navigate using sonar-based navigation aiding," he said.

"For our master platform prototype, we are using an autonomous unmanned catamaran surface vehicle with a top speed of 8 knots, and equipped with forward-looking sonar — with high resolution on the order of 1 or 2 inches — to image the bottom and area ahead," Fox said. "We're not trying to develop a final solution with this ASV [autonomous surface vehicle] prototype, but the final solution might be like this.



NATO UNDERSEA RESEARCH CENTRE ILLUSTRATION

The NATO Undersea Research Centre in La Spezia, Italy, is working to develop an end-to-end mine countermeasures system that can go from detection, classification and localization to neutralization with completely robotic solutions. The collaborative autonomous vehicle system illustrated here includes a catamaran surface vehicle, forward-looking sonar system and one-shot mine-neutralization vehicle.

"We start with the premise that the mine has been detected, classified and localized, so we know where it is, but to within some level of error," he said. "Our detection and classification system is an autonomous underwater vehicle, and the navigation is accurate up to a point. We can't use GPS [Global Positioning System satellite navigation] underwater, so we rely on an inertial navigation system. We might have a location with uncertainty on the order of 10 meters. We'll have some center point to head to, but we will have to reacquire the target to neutralize it."

"You cannot take that location for granted, because that address is given to you by an autonomous platform that does not have high-accuracy positioning sensors," Djapic said. "It has some inertial drift. So, we need to do some reacquisition. In our solution, we have an autonomous surface craft with GPS, and the forward-looking sonar reacquires the target and determines distance, range and bearing to the bottom object — it's a 2-D sonar, so it doesn't give depth. The system translates that information from the forward-looking sonar to a location on the bottom that is a projected GPS location.

"If it is a bottom mine, you know the depth from the fathometer. However, the same strategy applies for a mine that is in the water column," Djapic said. "Using an equation, the system determines the position of that mine.

"We can deploy the mine-disposal weapon, either by our ASV, or by some other means, such as an aircraft," he said. "The small underwater platform has just a compass and a simple depth sensor onboard. But combined with the aiding information that comes from the top, it can calculate its 3-D position and drive itself. It has enough battery power to take the detonation charge to the mine."

The forward-looking sonar determines the range and bearing to the object in the sonar image. A small, 40-bit acoustic message tells the mine-disposal vehicle where it is relative to the surface vehicle, having already been sent the position of the mine.

"It knows those two points in space and it's then drawing a line from where it is down to the mine. The vehicle then attempts to follow that line," Fox said.

"Since you're trailing it with the surface vehicle and constantly updating the high-resolution sonar data, the navigation updates arrive frequently enough and at a high enough resolution so that the vehicle is really following that line and arrives at the target within the accuracy that is needed," Djapic said.

Communications Challenge

While underwater communications is challenging (NURC has a number of research projects in this area), the range-limiting factor is not the communications.

"We have shown that the range of the forward-looking sonar is less than the distance the acoustic messages can travel," Djapic said. "We are using the technology that is available now."

"With underwater communications, you don't have as much bandwidth as above water communication, so you have to make that message as short as possible," Fox said. "A study showed that the minimal message we needed was 40 bits of information. We're sending that short message as often as possible to make the control problem easier on the underwater vehicle."

The NURC concept of operations for this system is to deploy the master platform perhaps as much as five nau-

NATO UNDERSEA RESEARCH CENTRE

An autonomous catamaran surface vehicle with a mine-neutralizer prototype mounted in the launcher is lowered into the water during testing by the NATO Undersea Research Centre in October.

tical miles from the host ship. Using an ASV instead of a USV as the master platform has its advantages.

"They can get to the area much faster than an underwater vehicle, and may not have the power requirement limitations," Djapic said

The ASV would come within 50 to 100 meters of the estimated target position — almost on top of the target — then reacquire the target and launch the mine-disposal vehicle.

"You might have a number of mines that need to be neutralized, so you could have a system with multiple neutralizers on it," Fox said. "After launch, the ASV neutralizes one mine and then moves on to the next, in serial fashion. Or, it could deliver all of the charges first, and then detonate them together."

In order to determine the limitations of the current system, Djapic said the NURC team has had good results with the surface vehicle in reacquiring and determining the position of the target, and then moving to a position away from the target.

"We have purposely moved 100 meters away from the target to demonstrate that we don't need to see the target at all times during the guiding operation," he said. "The ASV moved 100 meters away from the target, deployed the underwater vehicle, and then the ASV moved 50 meters away — which is the effective range of the forward-looking sonar — and started the mission. The underwater vehicle then traveled 100 meters to the mine, being trailed by the surface vehicle which was 50 meters away from it, and it arrived to within a desired range of the target.

"So far, we have looked for ways to deliver the neutralization charge," Djapic said. "Right now, we're talking about delivering something within an effective range, not necessarily a range where it can attach itself. There is a requirement that the neutralization charge stay there for some time in the presence of currents and wave surge, because the mine could be close to the shore. We're considering some kind of anchoring or attachment mechanism. That is something that needs to be developed."

Both the surface vehicle and sonar are prototypes, and with the sonar's limited range, Djapic said so far the system cannot be demonstrated to be effective for mines that are at 50 or 100 meters depth.

"What we argue is that our system can easily be integrated on an autonomous underwater vehicle. Instead of a surface vehicle, we could use an autonomous underwater vehicle for deeper mines," he said.

"With an AUV, the level of autonomy needs to be greater, because the surface vehicle has an option of operator intervention that you do not necessarily have with an AUV. But the concept of operation would be similar for the underwater vehicle to reacquire the target, the neutralization vehicle or mine-disposal vehicle would be introduced in that area, and the processing of the imagery would go in the same fashion. The acoustic message would be sent in the same way, and the underwater vehicle should arrive at the target," Djapic said.

The Prototype

Djapic said the NURC's expendable underwater neutralization vehicle prototype is currently a commercial, off-the-shelf VideoRay Pro4, a small, remotely operated vehicle (ROV) modified for autonomous operation. The Pro4 has two thrusters for propulsion and steering and a vertical thruster for depth control.

"We removed the tether from it, and added a box containing essential components, including batteries for power [ROVs are usually powered from the surface via the tether]; depth sensor and compass; an onboard computer to process the information from the pressure sensor and compass as well as from the ASV [this information is used to form the navigation solution]; and an acoustic receiver, which so far is just receiving those messages," he said. "Because the acoustic communications are one way and short range, it's more robust.

"There are software algorithms running onboard that are blending the sensory information, and also control algorithms that are sending the appropriate commands to the thruster," Djapic said. "If the vehicle lacks position updates for any reason, the computer would dead reckon itself into where it thinks it should go based on its last known position."

Eventually, he said, the components can be made more compact and the majority of the infrastructure will be the charge to detonate the mine.

"Our position has been that by removing the complex sensors, we have room to add a charge, more battery power for additional range or mission duration, and keep this vehicle fairly inexpensive, which was one of the requirements of our work," Djapic said.

Half-jokingly, Fox said the neutralization vehicle is "slightly bigger than a bread box."

"It's quite small," Djapic added. "So you could carry quite a few of them."

Important to NATO

NURC has had industry and academic partners in this project.

"We have been responsible for the underwater part of this system to include navigation, guidance and control of the small AUV," said professor Zoran Vukic, head of the Underwater Systems and Technologies Laboratory at the University of Zagreb, Croatia. "The autonomization of the small VideoRay ROV was realized here in Zagreb as a master's thesis, and later improved on and professionally built by NURC."

"Once we prove that it works, there is always a challenge with these robotic and autonomous solutions as far as getting the operational community to accept them," Fox said.

He said the NURC team has been interacting with some of the NATO minehunting groups during exercises.

"We've been able to take our minehunting synthetic aperture sonar system out in the field and operate alongside them, and provide them with results very quickly to show what this high-resolution imagery can bring to their operations," said Fox. "We'd like to do the same thing with the neutralization systems, to show what they can bring to their operations."

Djapic said this interaction is where the success stories come from.

"Robotic systems are introduced to the operators. They give feedback. The scientists and engineers improve the platform based on that advice, and improve the system. When they see equivalent or better results than a minehunter, they get very excited," Djapic said. ■