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PREVIEW
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Underwater robotics:

Is a human maintenance and repair team a thing of the past?

Engine maintenance: Caterpillar Marine reveals a brand-new solution that enables an engineer to predict a component failure 30 days before it happens

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IRATA wants to minimize accidents among rope access technicians

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Man vs machine

A number of programs are underway to develop autonomous robots that are capable of carrying out inspections and maintenance of ships, which could offer huge cost and efficiency savings compared with similar work carried out by humans

by George Coupe

Robots have been sent into space and even used to perform operations on the human body – so it is probably only a matter of time before they are fully embraced by the very conservative international shipping industry.

Conservative for good reason: the loss of a single day's sailing to an operator of the giant bulk carriers that relentlessly ply the world's oceans can be measured in hundreds of thousands of dollars. The introduction of new technology naturally introduces the risk of unexpected delays – about as welcome as pirates on the port bow.

And yet autonomous robots, capable of carrying out inspection, maintenance and even some repairs while a ship is still at sea, offer huge potential cost savings – particularly in terms of improving running efficiency and reducing the number of days spent in dry dock. It is possible, according to some robotics experts, that advances made in other sectors will lead robots capable of most maintenance and repair tasks, both inside the hull and on the outside, underwater.

"In the next 10 years, we will see more research and development of underwater repair and maintenance robots, and I believe in the next 15-20 years most of the underwater repair and maintenance will be performed by semi- or fully automated robots," says Prof. Kenji Shimada, who runs the Computational Engineering and Robotics Laboratory (CERLAB) at Carnegie Mellon University, in Pittsburgh.

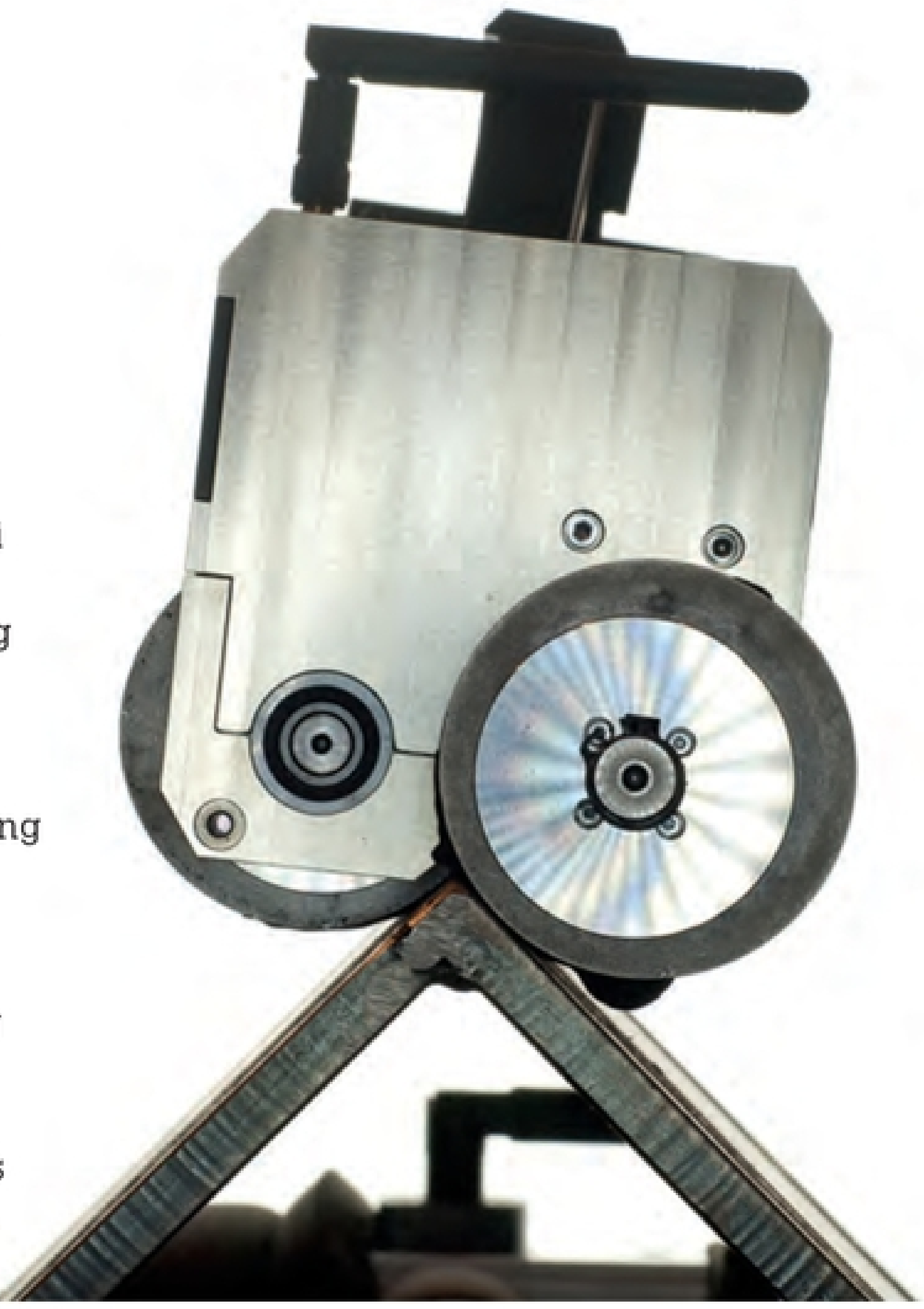
"This is similar to what has been going on recently with the research and development of unmanned cars and unmanned aerial vehicles, or drones. Many upcoming technical advances in unmanned cars and drones will also be useful for underwater repair and maintenance robots."

Prof. Shimada established CERLAB in 1996; areas of research include the optimization of robot motion, motion planning for redundant degree of freedom robots, and their application in product development and medicine. It is funded by NASA and Sandia National Labs, among others. However, in a new departure, CERLAB has embarked on a phase of research in partnership with the Tsuneishi Shipbuilding Company to develop robotic technologies to "revolutionize" the shipping industry.

One of the projects to be funded by the US$1.6m grant from Tsuneishi is the development of an autonomous hull-cleaning robot system.

Hull cleaning

Most tankers and bulk carriers spend long periods at sea, during which time they accumulate a large amount of biofilm and debris on their hulls. This debris increases friction and produces resistance, which in turn leads to increased fuel consumption.



BELOW: **SIR's innovative overlapping wheelbase design and detachment mechanism allows it to successfully navigate the internal hull stiffener profiles**

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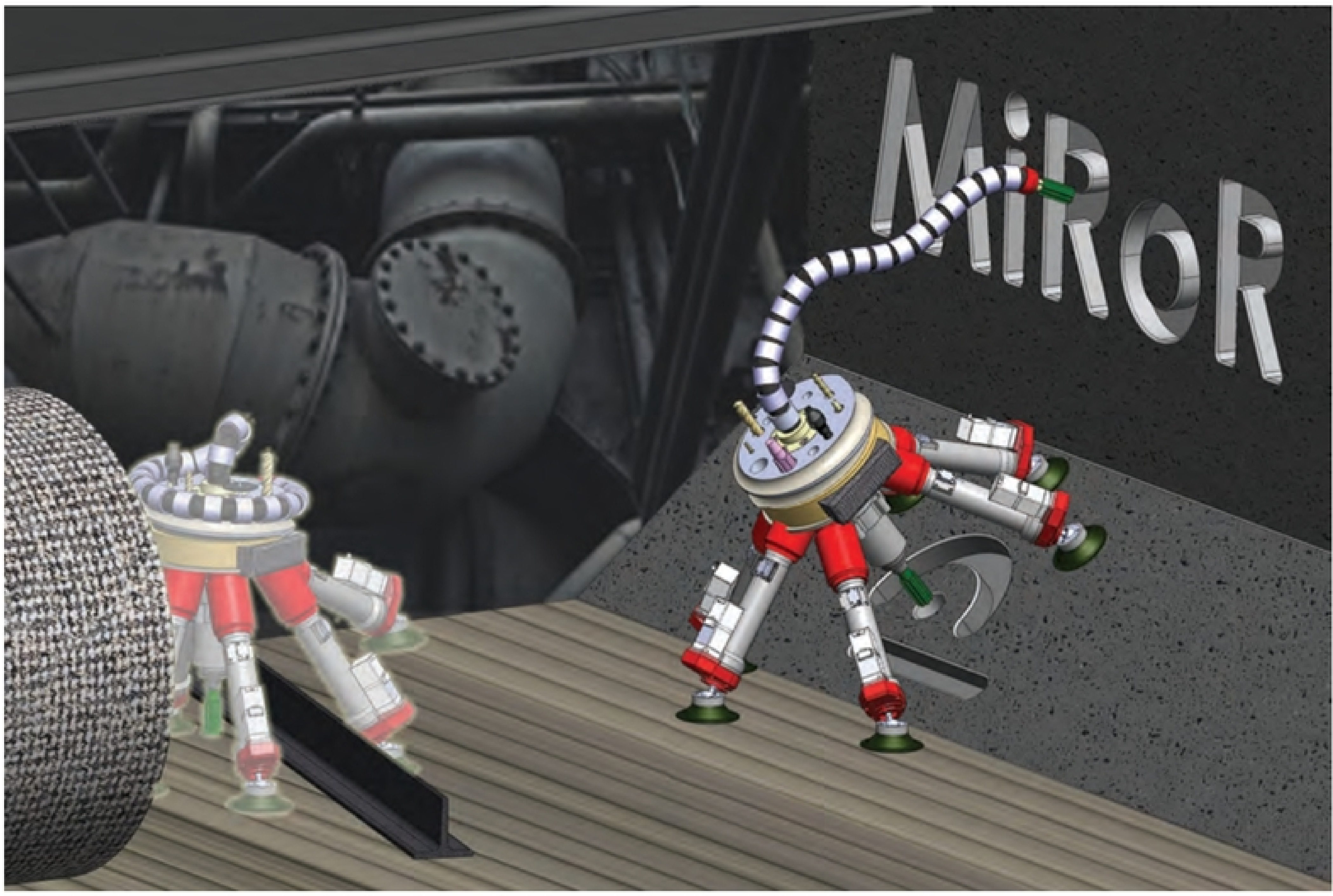
Prof. Kenji Shimada, Computational Engineering and Robotics Laboratory (CERLAB), Carnegie Mellon University, Pittsburgh.



Current methods of cleaning might only be applied every two years, but an automated robot capable of operating underwater would enable the task to be performed more regularly. This would mean cost savings, better fuel economy and a greener planet, says Shimada.

"We have just finished the first six months of a four-year project period. We are developing a robotic system that is capable of mapping biofouling of a ship hull, and cleaning the hull. The ultimate goal is to develop a fully autonomous system by using an underwater vehicle with positioning sensors, inspection sensors, and cleaning tools.

"This robotic inspection and cleaning system will be equipped on a ship and deployed regularly to avoid biofouling from degrading the performance of a ship and its fuel efficiency. Using our robotic system, we can keep a ship healthy."

Shimada says underwater operation presents challenges in the design of all three essential components of the robotic system: locomotion and manipulation, positioning and sensing, and motion planning and control.

"For example, the robot has to sense its position and maneuver itself under some water flow," he says. "Sometimes the water is not clear and the visibility can be less than a couple feet. It would also be a challenge to come up with the optimal task sequence and generate the most efficient cleaning motion path."

But a robot that could regularly clean the hull of a large bulk carrier would offer potential cost savings of many thousands of dollars a month.

"The fuel consumption is affected heavily by the surface condition of a ship. For example, when a ship is parked for a week or two, a layer of biofoul can grow between 0.5in and 1in, and this can degrade the fuel efficiency by 5-10%. Suppose that the monthly fuel cost of a large tanker is US$2m, removing biofouling regularly can save between US$100,000 and US$200,000 per month," says Shimada. "Biofouling can also add additional stress to the engine, and in the worst cases it may lead to a broken cam shaft, which is very expensive to repair. This can be avoided by keeping the ship hull clean."

In addition to the underwater cleaning robot, the four-year partnership with Tsuneishi also aims to develop robotic welders to work in confined spaces, a retrofit sensor network, and a part tracking system for the shipyard.

A robot that can carry out tasks in the hard-to-reach spaces inside a ship's hull was also the focus of another prototyping project that has recently been completed by a team at ETH Zurich University in Switzerland. Working in partnership with Alstom Inspection Robotics, the team of 10 students built a prototype robot to carry out visual inspections in the narrow and highly constrained spaces of a ship's ballast tanks, between the outer and inner hulls.

Ship inspection

The Ship Inspection Robot, SIR, is also intended to be used while a ship is sailing in order to reduce the time spent in dry dock, and minimize the loss of income to ship operators.

"In a future user case, several autonomous low-cost SIRs might constantly estimate the ship's condition and contribute to safer operations and more efficient maintenance," says Florian Berlinger, the project manager on the team at ETH Zurich.

The mechanical stress of loading and unloading, and the corrosive properties of seawater, all take their toll on a vessel's structure. This is especially true for a ship's ballast tanks, which are filled with seawater to compensate for load changes. Since the ballast tanks are located deep inside the ship, they are the most susceptible to unseen corrosion.

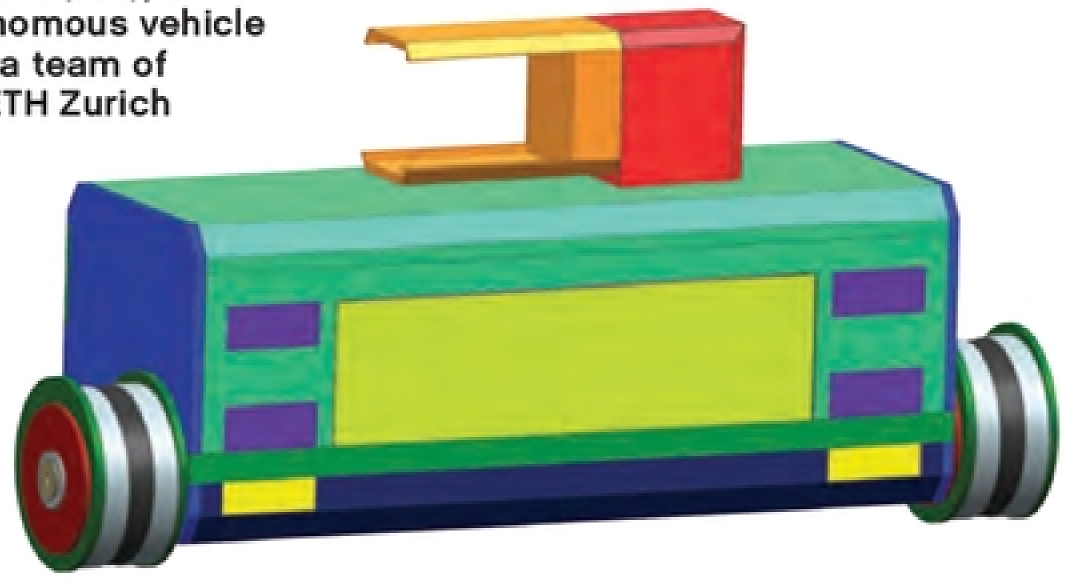
Ballast tanks, however, offer some considerable obstacles to an autonomous robot – in particular the hull stiffeners. Alstom Inspection Robotics specializes in developing robots for powerplant inspection – that is, pipework and other tubular profiles. When considering a move into the ship inspection market, it became clear that navigating the hull stiffeners, which typically have an I-shaped profile, would be the main challenge.

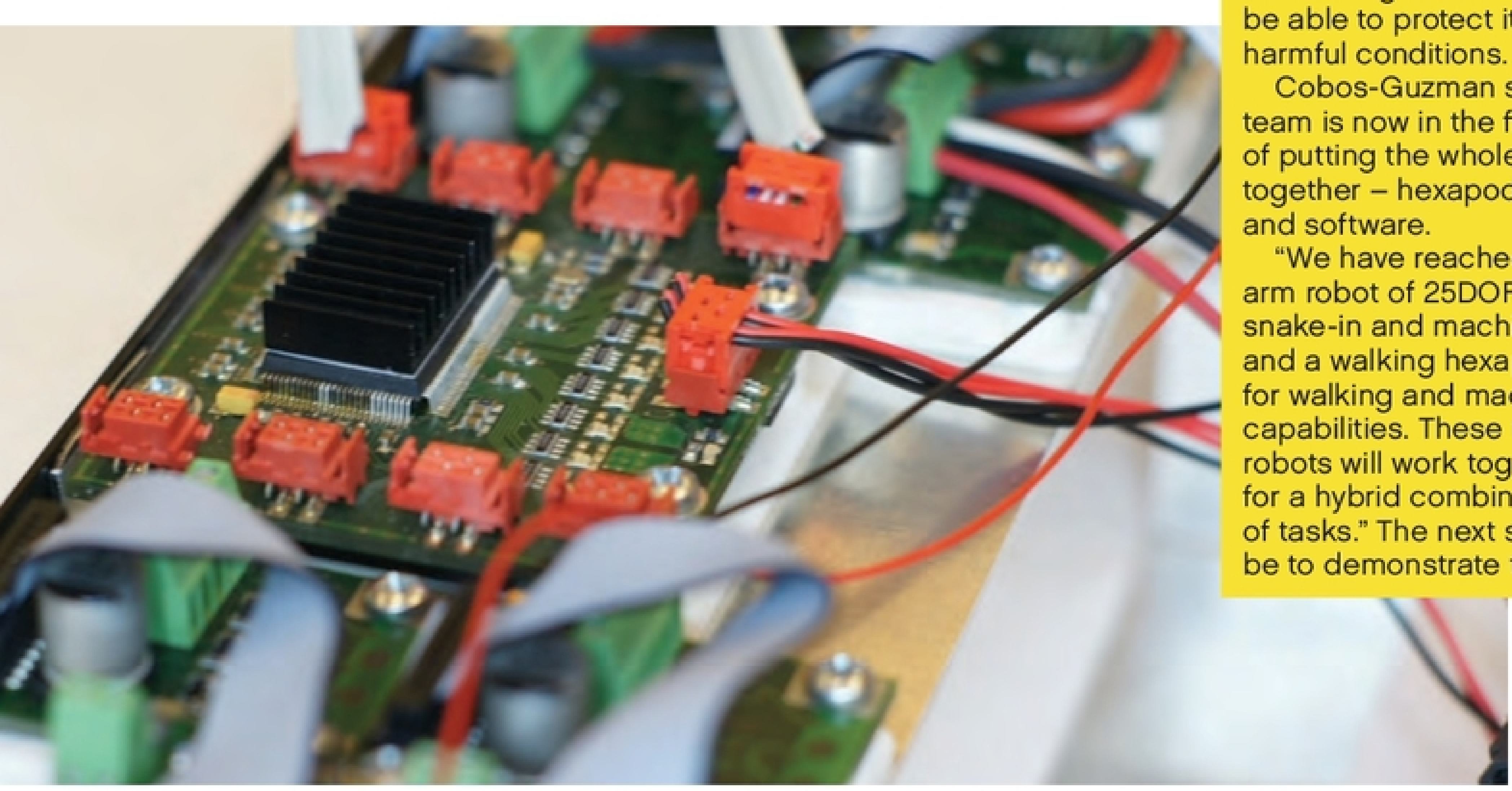
ABOVE: **A European consortium is developing a six-legged repair and maintenance robot for conducting on-site CNC machining in dangerous or hard-to-access environments (Photo: MiRoR)**

RIGHT: **The SIR prototype was developed for Alstom Inspection Robotics over a period of just nine months**

"Alstom Inspection Robotics was looking for ideas, so they came to ETH and said they needed a team to help develop a prototype for such a robot. This was done as part of a one-year project, which is one way to conclude a Bachelors degree at ETH," says Berlinger.

After just nine months, the multidisciplinary team of 10 students, RIGHT AND BELOW: **The Ship Inspection Robot (SIR), a low-cost autonomous vehicle developed by a team of engineers at ETH Zurich University**





MIROR PROJECT

A walking and snaking robot capable of planning its own movements and workload could reduce daily ship maintenance costs by up to £3,000 (US$4,644) per day.

The Mini-RoboMach is the product of a four-year European Commission-funded program known as MiRoR. The aim of the project was to develop a novel miniaturized robotic machine capable of walking and snaking into constrained or hazardous environments and carrying out useful machining and inspection tasks.

Dr Salvador Cobos-Guzman, the MiRoR project manager, says Mini-RoboMach will consist of a 'free-leg hexapod' capable of 6-axis processing and a snake arm capable of light processing tasks. The robot will also be able to operate autonomously: navigating and deciding on methods of reaching a working area and scheduling tasks. It will also be able to protect itself in harmful conditions.

Cobos-Guzman says his team is now in the final stages of putting the whole system together – hexapod, snake arm and software.

"We have reached a snake-arm robot of 25DOF for snake-in and machining tasks, and a walking hexapod robot for walking and machining capabilities. These two robots will work together for a hybrid combination of tasks." The next stage will be to demonstrate the robot in a variety of industrial settings, including mock-ups of an aero-engine, nuclear reactor and an offshore pipeline.

"The objective is to perform in-situ repair, inspection and navigation tasks using the snake arm and a walking hex robot," says Cobos-Guzman.

The main technical challenges were to incorporate all the components of the mechatronic system, such as actuators, electronics and mechanical transmissions in a highly compact device. The second challenge was the design of a mathematical model for a hyper-redundant system for navigation and machining.

Cobos-Guzman said regular use of a robot such as Mini-RoboMach to carry out maintenance and repair on a ship could help to extend a vessel's service life and minimize costly human intervention.

"The autonomous maintenance service that the robot can provide will extend the service life of installations such as a ship. Ships are built for a specified design life, for example, 10, 20 or 25 years, without maintenance. However, the ship service life may be longer if effective ship maintenance is carried out every 2.5 years.

"For example, this type of autonomous operation can eliminate normal operating expenses by £2,000 to £3,000 per day."

including mechanical and electrical engineers and industrial designers, came up with SIR. The remotely operated robot uses a system of magnetic wheels to traverse the various planes and surfaces in the ballast tank, and provides visual images to the controller via a video link.

Clemens Clausen, who worked on SIR's drivetrain, says the I-shape sections presented a particular problem for the magnetic wheels: "The main challenge is the geometry of the profiles. We are driving with magnetic wheels and in the narrow corners you get a kind of magnetic saturation effect, which means the wheels do not stick very well. You also have the issue of acceleration and deceleration; these are additional forces that have an effect on how well the wheels hold to the surface."

> **Biofouling can also add additional stress to the engine, and in the worst cases it may lead to a broken cam shaft, which is very expensive to repair. This can be avoided by keeping the ship hull clean**
>
> **Prof. Kenji Shimada**, Carnegie Mellon University

BELOW: **Inspection robots could be used to help to plan and target maintenance and repair work**

ABOVE: **The multidisciplinary team of 10 students at Zurich University included mechanical and electrical engineers and industrial designers**

Concave corners are similarly problematic, but the team came up with an innovative wheelbase design and a now-patented detachment mechanism, or lever, on the underside of the robot, to prevent it from getting stuck.

"The key feature of our innovation is the overlapping wheelbase. The wheels are not only very close together, but they are overlapped. This wheel alignment enables us to overcome profiles like I-shapes and, together with the detachment mechanism for concave corners, it enables us to overcome the obstacles," says Berlinger.

The intention is that SIR would enable operators to gather enough information while at sea to plan more precisely and target maintenance work, thus reducing the time a ship spends out of the water.

"A full ship inspection involves putting the ship in dry dock and erecting scaffolding around the outer hull so that it can be viewed at close quarters. This costs a lot of time and the estimates for losses of income for a ship operator can amount to US$100,000 per day. So that is why the idea came up to operate an inspection robot inside the ship while it is sailing," says Berlinger.

But could a compact inspection robot such as SIR eventually carry out some repair work as well? Clemens Clausen says this might be possible in the future, but the industry is not rushing to experiment with new technologies.

"The motivation for building a small robot rather than a big robot was actually that the whole industry is very conservative. If you want to make big changes, you need to start small."

Clausen says that even when it comes to inspection, operators are still likely to be reluctant to trust a robot: "They still want to build the scaffolding and look at it [the hull] with their own eyes. But maybe we can at least enhance this process and help them to be more precise about where they need to build that scaffolding.

"Thinking about the future of these robots, the first step will be purely visual inspection, then maybe non-destructive testing such as ultrasonic testing, then maybe in the future, you might get a bigger robot that can do minor tasks, such as welding. The whole industry is very conservative, and doesn't want changes happening too quickly because it costs time and money; they don't want to experiment, they want to earn money."

While SIR is still officially in the prototype phase, the ETH team is confident Alstom Inspection Robotics will eventually take the design forward.

Developments in robotics, particularly in the field of intelligence driven and autonomous machines, means the capability to take on inspection and repair tasks in the challenging conditions of the shipping sector is always growing. Dr Salvador Cobos-Guzman, a senior research fellow at Nottingham University in the UK, says progress made in a variety of fields could be harnessed to produce robots that are effective in marine environments.

"There are different research lines that can be combined in an interdisciplinary way to produce efficient robots for marine repair, such as material science, mechanical design, hydraulic systems, visual servoing controls for underwater autonomous tasks, tele-robotic systems for underwater activities, autonomous navigation algorithms, artificial intelligence, and so on."

Cobos-Guzman is the project manager for MiRoR (Miniaturized Robotic systems for holistic in-situ Repair and maintenance in restrained and hazardous environments – see sidebar). He says that while there have been several advances in underwater autonomous vehicles and the interfaces needed to control them, there is actually a lack of systems actually capable of carrying out complex tasks underwater.

"For example, there are hydraulic arms with tweezers that can manipulate objects with very poor manipulation dexterity. Therefore, complex robotic hands or complex end-effectors could be designed to perform complex manipulations. The challenges are in terms of design, that the new robots have to support high pressures and corrosion environments, and that the design must also protect the internal mechatronic system."

It is possible that in the future robots could even work together to carry out underwater repair tasks, he says: "A collaboration of several underwater robots with powerful robotic arms and/or special end-effectors can be used to repair ships or underwater structures using techniques of artificial intelligence for autonomous maintenance." \\