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# The Six Million Dollar Hand:
# A Robotic Hand for Remotely Operated Deep Archaeology

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**Abstract**

Today, underwater robotics allows access to deep-water wreck sites for analysis and, sometimes, for their exhaustive study. If we want to achieve this, we have to do better than operating light touches on the upper archaeological layer, or just picking up an isolated artefact as the only evidence of a cargo. Indeed, it is important to consider the exhaustive study of these wrecks that are so rich in information for archaeologists. However, the issues of dealing with remote artefacts on deep wrecks are far from being resolved. During the last five years, DRASSM has performed a large number of tests in order to develop robotic devices able to remotely mimic the gesture of an archaeologist and has then focused on the whole study of abyssal shipwrecks. On this experimental basis, in 2015, the ANR 'SeaHand' Project was born, involving DRASSM, the P' Institute (CNRS), the Montpellier Laboratory of Informatics, Robotics and Microelectronics (LIRMM, University of Montpellier) and industrial partners. Project SeaHand aims to develop a haptically controlled underwater robotic hand designed to perform archaeological work in deep water. 'Haptically' means that this hand provides the pilot with the sense of touch, allowing the handling of fragile artefacts.

This paper is about the technologies that we used and their results in our most recent work.

**Keywords**

Robotics, deep-sea archaeology, DRASSM, France, ROV, abyss

## Introduction

Since its creation in 1966, the French Underwater Archaeology Research Department (DRASSM) has made a point of keeping up to speed with the various technological revolutions that have marked the history of our discipline, and it is for this reason that French archaeologists have endeavoured, since the early 1980s, to develop techniques for the study of wrecks lying at great depths. For many years such research was carried out with the help of large industrial groups and several research laboratories, but the results of these various experiments have often turned out to be disappointing.

In 2006 DRASSM decided to refocus its strategy concerning deep-water wrecks by developing its very own underwater vehicles and new methods. Moving steadily towards its goal, DRASSM has in the last five years surveyed nearly 50 wrecks at depths ranging from 300 to 1200m below the surface.

## 1980–2011: back to the pioneer age

In 1980, the Bénat 4 wreck, lying at a depth of 328m off Toulon, enjoyed the honour of being the subject of the first deep-water excavation in France. Initial results were promising and DRASSM has continued to research deep-water wrecks ever since because of their strong scientific potential, namely that ships sinking to such depths are always very well preserved. Even if the events leading to their wrecking were violent in nature, perhaps a storm or a battle, once the tumult and turmoil subside, the vast distance from the water's surface ensures little or no human intervention. Another benefit of the deep is the absence of waves, oxidation and, most of all, *teredo navalis* or naval shipworm, a tiny mollusc with a devastating appetite for wood.

Back in 1980, we did not realise the strategic importance of at least inventorying the deep-water components of our collective history—but we do now! A combination of improved diving technology (such as the development of rebreathers for SCUBA divers), exploration, commercial treasure-hunting and the expansion of fishing activities (to make the most of a diminishing resource) means that deep-water wrecks are now, more than ever before, under threat from deterioration and destruction. In short, in the preceding ten years the pillage and destruction of deep-water wrecks have become so widespread that we cannot expect this underwater heritage to survive unscathed. At the bottom of the sea lies a vast repository of artefacts that must at all costs be protected so we may study them and realise their scientific potential.

Using the submersible *Cyana* on these early excavations rendered abundantly clear to us the pressing need for developing archaeological methods specific to the deep. So in 1990, on the *Sainte Dorothea*, the wreck of a Danish 17th-century merchant ship, which lies off the south coast of France, DRASSM's archaeologists began the research and development necessary to achieve this goal. First of all, COMEX, a French robotics firm specialising in deep-water work, helped survey the wreck.

Then many tests took place through the 1990s to try out new methods and explore the intricacies of using mechanical excavating tools, sometimes on deep-sea wrecks but also on remains lying in shallower and, therefore, more accessible waters. In 1993 and 1995, DRASSM carried out much work in the Mediterranean on wrecks situated, respectively, at 660 and 450m below sea level. This time DRASSM used IFREMER's submersible, *Nautile*, which the French oceanography institute had developed to survey the remains of that world-famous wreck, the *Titanic*.

However, year after year, DRASSM's archaeologists realised that using third-party equipment in conjunction with scientists who were new to the field of archaeology created its own set of intrinsic problems. Basically, although institutions, industrialists and armies were happy to help archaeologists when they could by making their equipment available, it soon became apparent that they had their own ideas on how operations should be conducted and archaeologists would often find themselves relegated to the sidelines despite it being their show. Indeed, the owners of the equipment, robotic or otherwise, would retain direct control and all the external scientists were invited to do was to give an opinion. That said, these companies and organisations with whom we worked in the 1990s did help us develop suitable and innovative methods, such as using imaging and photogrammetry to build a representation of what we were finding on the seabed.

**2012–2016: towards technical independence**

Slowly but surely, DRASSM has worked ever since towards acquiring its technological independence so that it can carry out its own operations with its own equipment. In 2012, the launch of our scientific research vessel the *André Malraux* certainly gave a boost to its endeavours, but she is not the whole story when it comes to developing and trialling devices for use in surveying and excavating artefacts preserved in the deep. Therefore, earmarking an authentic archaeological site in the south of France for this purpose became unavoidable. The site features the *Lune*, a French naval vessel that sank off Toulon in 1664. The wreck lies 90m down and, being extremely well preserved, is an ideal subject for these studies.

The *Lune* was built over three years from 1639, had two decks, and carried 54 guns. On 6 November 1664, she set out from Toulon during a ferocious storm and, five nautical miles south of the coast, soon foundered. Her sinking was so sudden that the few witnesses who survived the tragedy reported that she 'sank like a stone'. Only a handful of the 800 aboard survived, probably no more than 40 people.

For the following three centuries, the story of the *Lune* was be forgotten until, in May 1993, her remains were brought to light. The *Nautile*, IFREMER's underwater exploration vehicle, came across the site quite by accident. DRASSM soon surveyed the old two-decker in her final resting place off the port of Carqueiranne, in 91m of water, and produced a detailed plan of the site. With the survey complete, it was decided that the great depth and the remarkable preservation of the wreck were two very good reasons for holding the site in reserve until such time as suitable technology and techniques became available for its comprehensive excavation and study.

With 20 years' experience in developing and testing innovative methods for excavating deep-sea wrecks under their belt, the archaeologists at DRASSM started planning works on the *Lune* in 2010, and two survey campaigns followed in 2012 and 2013. Our primary goal has always been to develop methods and machines for excavating deep-water wrecks, and to study them with as much scientific integrity as can be afforded for shallow-water sites.

A large part of the work undertaken on this test site has been devoted to the question of recovering artefacts. This remains one of our biggest challenges, and an altogether more complicated one was replicating human touch through the intermediary of a robotic device. Standard robotic equipment is, unsurprisingly, designed for industrial or military purposes and, for the most part, ill suited to specialist archaeologists wishing to deploy it underwater.

Hydraulic arms, which are a common feature of ROVs, are powerful but not particularly suitable for handling fragile objects because every attempt to move an object places it at risk. In 2013, we performed tests with a hydraulic arm fitted to a crawler, aiming to try out a device which could raise heavy objects, but we had to abandon this idea because the crawlers turned out to be very clumsy, and were quickly blinded by the sediment they disturbed as they moved.

Suction-cup devices like those used by the COMEX on the Grand Ribaud F shipwreck in 1988, are still an interesting idea but only work with one type of object that has to be hard enough to be held by its surface, and sufficiently smooth for the suction to gain a hold. Many other tests have been carried out during these few years, involving sophisticated equipment such as the French Navy's Newtsuit, which was developed by Nuytco Research and used in 2012 on the site of the *Lune*. However, while it is very impressive, it still requires a human operator.

Finally, the best result obtained during this first exploration period was certainly the shovel method, already used on the Mardi-Gras site in the Gulf of Mexico in 2007, and in Corsica at a depth of 360m. This method is worth exploring because it is the only way of recovering an object by supporting it from underneath. First of all, it includes the claw system designed by our brilliant 'mad scientist' Vincent Creuze of the Montpellier Laboratory of Informatics, Robotics and Microelectronics. Basically, it is a simple gripper, comprising two comb-like appendages mounted on an axle that can gently recover objects situated directly underneath it (Figure 1).

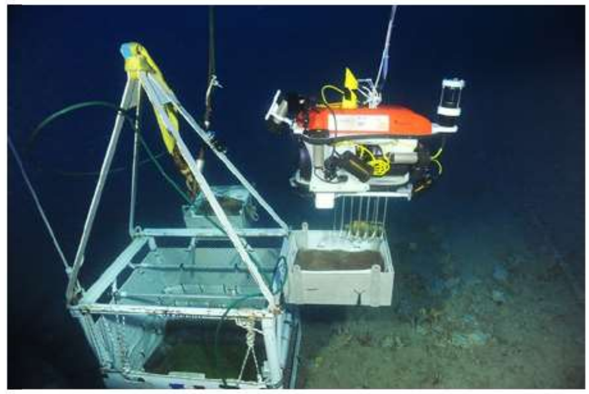

Figure 1. LIRMM's ROV fitted with sampling claws deposits an artefact in the deep-sea sampling case (F. Osada and T. Seguin, 2014 © DRASSM).

The combs are a perfect grab mechanism because they slide under the targeted object, and they also protect the recovered object by forming a sort of cage around it. We obtained very good results with this claw and so decided to develop a version for more powerful robots that would be capable of lifting heavier objects. So the next model moves under its own power and should be able to raise objects of up to 20kg (Figure 2).

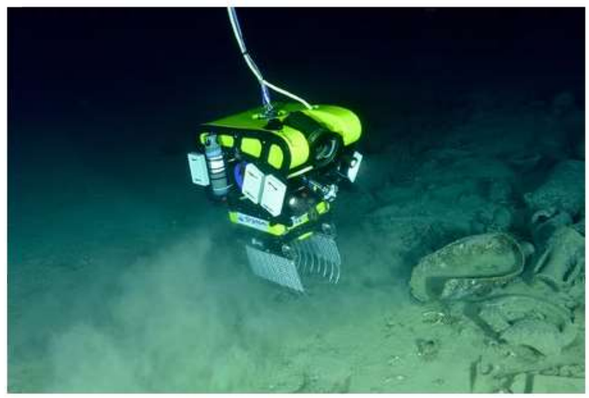

Figure 2. DRASSM'S ROV *Hilarion*, fitted with heavy sampling claws (F. Osada and T. Seguin, 2015 © DRASSM).

However, the claw system is not at all suitable for raising objects that lie in awkward places or are so fragile that they require more refined gripping systems. In 2014, once again on the site of the *Lune*, we tested a gripping prototype designed and built by Gilles Lopez, founder and director of the French company Techno-Concept (Figure 3).

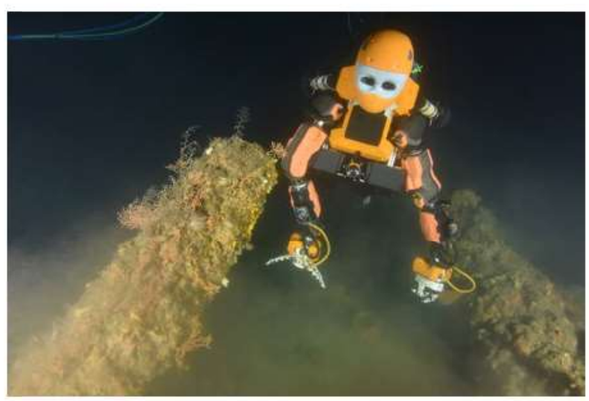

Figure 3. Trials of Techno-Concept's robotic hand off Toulon (F. Osada and T. Seguin, 2014 © DRASSM).

This robotic hand features the capacity to determine, by itself, at what point it has to stop squeezing when seizing an object. It does this through an ingenious self-adapting system, which is purely mechanical. The phalanges, which are jointed and activated by a complex system of cables and springs can adapt themselves with great ease to a wide variety of shapes. Once the object has been seized, the hand locks in position and maintains a secure hold on the object without compromising its shape or integrity. Tests on this very first version of the Techno-Concept hand have shown

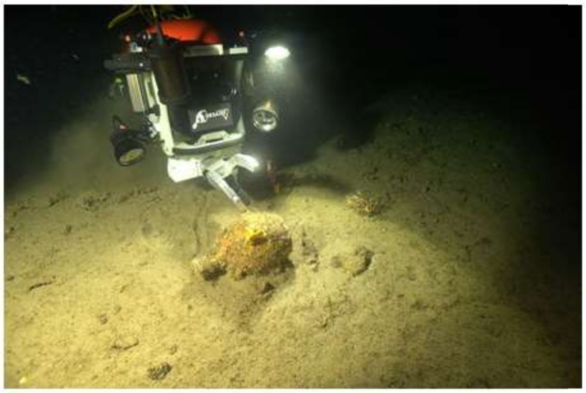

Figure 4. Techno-Concept's robotic hand on the *Lune* shipwreck (F. Osada and T. Seguin, 2014 © DRASSM).

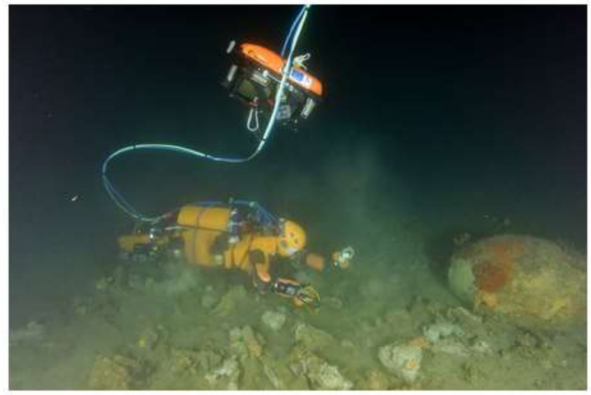

Figure 5. Stanford's humanoid robotic diver 'Ocean One' on the *Lune* shipwreck (F. Osada and T. Seguin, 2014 © DRASSM).

it to be fragile, but the concept has been proven sound, and work to improve its design is in progress (Figure 4).

## 2016: Ocean One: 'sci-fi' trials in the deep

However, the biggest event for French's submarine archaeologists in the last few years remains the meeting with Oussama Khatib, a professor at the Stanford Robotic Laboratory to whom the archaeological projects of DRASSM were duly presented.

Professor Khatib was already aware of these works and he immediately told us about a program that he and his team were working on. Called 'Ocean One', Professor Khatib's project was to create a human-looking robot capable of moving and undertaking complex tasks underwater while providing its human pilot with the essential sensations of touch and three-dimensional sight, two senses that are incredibly important to archaeologists. This project clearly occupied the same field, and at that initial meeting, the DRASSM and Stanford University teams took the decision to collaborate.

Ocean One's first trial campaign took place in April 2016 on the site of the *Lune*. Despite never having left its test tank at Stanford University in California, Ocean One was capable of working at a depth of almost 90m, collecting archaeological artefacts from the wreck and putting them in a basket, which had been placed nearby by another robot (Figure 5).

This first operation has allowed us to validate the various technological choices that have been explored these last four years and has shown that this field enjoys a vast potential for improvement. Most importantly, it demonstrates that the chosen research route—that of building a humanoid—a genuine avatar of an underwater archaeologist, has infinite promise. As a result of our experiments on the *Lune* excavation, Ocean One should be undergoing in the following months a series of improvements. We had planned to undertake in 2017 the next trial on a wreck dating from the Roman period, probably 2nd century BC, lying in French waters at a depth of almost 400m.

## The next stage: Project SeaHand

Officially launched a few days after the completion of Ocean One's field trials in 2016, Project SeaHand is supported and financed by the French National Research Agency (ANR), which includes the Institute Prime, LIRMM, DRASSM and industrial partners. It is an innovative project, which aims to develop a seagoing hand and its associated command system, and to experiment using this hand for the specific purpose of recovering artefacts. In the first instance, the researchers and engineers in charge of developing SeaHand are using as the starting point for their work the latest developments in robotic hands and haptic devices. They have extensive knowledge of such devices, which have been developed for numerous experimental applications.

The final version of the specifications and objectives for the project is, essentially, the fruit of feedback and analysis generated during previous trials in the field.

Without going into too much detail on the specifications, SeaHand must be able to:

- Function under electric power, in the sea and under extreme pressure;
- Seize objects of a size ranging from a coin up to a dish, weighing up to 1kg in the water, under the command of an operator;
- Adapt to the shape of the targeted object without damaging it;

- Measure the force it employs so the surface operator can assess the nature of the object and the risk of breaking it during handling;
- Function in excavation conditions where sediment, such as sand and silt, present a risk of abrasion; and
- Assist the surface operator in controlling the hand through, for example, visual relays and force indicators.

In order to better understand the constraints of the human archaeologist, we recorded movements and gestures in the lab. An operator's hands and arms were fitted with sensors and then filmed by a set of cameras while he simulated numerous ways of excavating and recovering archaeological objects. This technology, which has much in common with the 'motion capture' used in animated films, allowed us to record movements in great detail, to model them and, as a result, to reproduce them.

It is, in our opinion, absolutely essential for the archaeologist to be able to feel, through the intermediary of the robot, the object as if he or she were actually present, diving on the wreck in person. He or she has to be able to detect immediately the nature of an object, what it is made of and how resilient it is.

Our intention is not to design a robot like the ones used by industrial operators or the military, but one that would be a genuine avatar of the underwater archaeologist. In other words, the robot has to be able to take the place of a human diver, and allow the pilot to control its movements and analyse the nature or the condition of the objects discovered. Our goal is, therefore, to invent a robot that would be nothing less than the underwater projection of the archaeologist at the water's surface, to such a degree that the human pilot would forget he or she was not actually on the sea bed working on the site himself or herself.

Last but not least, we inserted into the specifications a clause that we believe fundamental for the future of marine archaeology: we made it clear that archaeologists would have to be able to pilot this robotic device themselves without having to take a long training course or specialise in the piloting of such machines. Our stated aim was that any archaeologist should be able to learn within a matter of hours how to use the robotic device so they can carry out the excavation work themselves rather than, as is so often the case, giving instructions to a professional pilot who then does the work in their stead. In our experience, not only is the work completed quicker and more efficiently when done by the archaeologist, it spares that period of time taken to communicate information to the pilot, and the time it then takes the pilot to assimilate and act upon that information: such delays, however short, can place an artefact in danger (Figure 6).

Figure 6. Aleria I shipwreck (1st-2nd century AD) 350m deep (F. Osada, 2013 © DRASSM).

Project SeaHand should, by 2019, bring us closer to realising this dream... of having deep-sea archaeology 'at our fingertips'.

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