The HUGIN AUV for Force Protection in the Littorals

Per Espen Hagen and **Nils J Størkersen**
Norwegian Defence Research Establishment (FFI)
P O Box 25
NO-2027 Kjeller
NORWAY

per-espen.hagen@ffi.no / nils-j.storkersen@ffi.no

ABSTRACT

With their low cost and large destructive power, sea mines have the potential to become a weapon of choice for terrorists and rogue nations. The post-cold war mine threat differs from the traditional in a number of ways. Devising ways of countering this threat, ideally without risking own personnel, should be seen as an important task.

As a small nation with a very strong dependence on the sea, Norway has always had a need for efficient systems to protect its maritime zone and assets. The HUGIN Autonomous Underwater Vehicle (AUV) programme was initiated in the 1990s to deliver an efficient capability for mine countermeasures (MCM). Since 2001/02, the Royal Norwegian Navy has operated HUGIN AUVs on a regular basis.

In order to correctly classify mine-like targets in highly cluttered environments (such as the Norwegian littorals), very high resolution imaging is required. Synthetic aperture sonar (SAS) is a key technology for obtaining good classification performance over a wide swath. With the emerging threat of terrorist mining, recognition of traditional mine shapes such as cylinders and truncated cones becomes insufficient. Very high resolution imagery will substantially improve the ability to detect and classify improvised explosive devices.

1.0   INTRODUCTION

1.1   The "new" mine threat

Sea mining has always been an asymmetric threat, in that the cost of procuring and laying one or even a large number of sea mines can be very small compared to the consequence to an opposing force. Probably the clearest example of this was the US Navy frigate USS *Samuel B Roberts*, which struck a $1,500 Iranian mine in 1988 and suffered major structural damages and injuries to 69 crew members. The repairs took more than a year and cost approximately $96 million [1].

Traditionally, the main purpose of mining is not to destroy ships, but to deny an adversary access to a given port or shipping lane or at least slow him down. With terrorist mining, this is no longer necessarily the case. While one strategy may be to disrupt commerce by e.g. placing a mine in a major port, the destruction of a random military vessel could also be seen as a major victory by the terrorists. The same can be true for rogue nations. There are many indications that terrorist organisations are acquiring this capability. Several terrorist groups have attempted to acquire mini-submarines, stealthy boats, and expertise in diving and underwater explosive handling [2]. Mine laying can also be as simple as dropping a mine from a bridge.

As terrorists are likely to deploy only a very small number of mines, such mining is most effective in confined areas or narrow straits. Furthermore, the minefield is likely not to be declared, meaning that the force seeking entry would need to rely on intelligence regarding possible terrorist mining – or perform a thorough survey of the area before entering with high-value assets.

A further complicating factor is that these devices may be quite different from ordinary sea mines. In the extreme, every oil drum, refrigerator or other piece of debris may be an improvised explosive device (IED). This emphasises the value of route surveying, where areas of interest are surveyed regularly. This technique immensely simplifies the detection of any new suspicious objects in the area.

1.2   Autonomous underwater vehicles

The state of the art of autonomous underwater vehicles (AUVs) has progressed tremendously over the last decade, and such systems have now successfully transitioned into several applications, civilian as well as military. Many of these involve searching relatively large areas with sensors that allow detection and classification of small objects – whether the application is seabed surveying to plan an oil pipeline route, mine hunting, or covert underwater reconnaissance.

Among the principal advantages of AUVs are their ability to collect a rich, high-quality data set covertly and rapidly, without risk to personnel. Bringing the sensors onboard a stable platform, away from the difficult surface layers and closer to the targets, means that AUV sensor data is often superior to that collected by even much more expensive near-surface sensors.

AUVs are often compared to unmanned aerial vehicles (UAVs), which perform a similar role in the air-land battlefield. Compared to their flying cousins however, AUVs require a high degree of onboard autonomy and intelligence, as real-time underwater communications is slow and restrictive and full remote control is thus not feasible.

2.0   THE HUGIN AUV PROGRAMME

Figure 1: HUGIN AUVs. Left: A HUGIN 3000 vehicle operated by Fugro NV, the Netherlands; right: A HUGIN 1000 vehicle operated by RNoN from the mine hunter HNoMS *Karmoy*.

The HUGIN AUVs have been developed by FFI and Kongsberg Maritime since the early 1990s, and 10 vehicles have been sold to civilian and military customers. Although the HUGIN programme initially

gained more momentum in the offshore oil and gas industry, military uses were taken into account from the beginning. A recognised national shortfall in deep water mine hunting led to the establishment of the HUGIN MRS programme, the primary goal of which is to deliver an efficient AUV capability for forward mine countermeasures (MCM) [3]. In the following years, the programme has expanded to include other applications such as rapid environmental assessment (REA). A preliminary capacity, the HUGIN 1000 pilot system, was delivered to the RNoN in early 2004, and a full-capability prototype called HUGIN 1000-MR is due for delivery in late 2006. Basic system specifications are listed in Table 1.

Table 1: Basic specifications of the HUGIN 1000 AUV.

Dimensions	Length 4.2 m, $\varnothing$ 0.75 m
Dry weight	650 kg
Depth rating	1000 m
Endurance	>20 hours @ 4 knots; >30 hours @ 3 knots
Speed range	1.5 – 6 knots

The main difference between the two RNoN vehicles is the payload. The pilot system features a side scan sonar or a simple synthetic aperture sonar (SAS). The SAS provides higher resolution imagery, but requires a time-consuming post-processing step. HUGIN 1000-MR will feature a very high resolution interferometric SAS. While post-processing is needed also for this system, it will be tightly integrated with the display and analysis system and should not slow down post-mission analysis [4]. Table 2 lists key performance figures for all three sonars.

Table 2: HUGIN 1000 main imaging sensor comparison.

Vehicle	HUGIN 1000 pilot		HUGIN 1000-MR
Sonar	EdgeTech 4300-MPX	EdgeTech 4400-SAS	Kongsberg HISAS 1030
Range resolution	4-8 cm	7 cm	2.5 cm
Along-track resolution	35-60 cm	14 cm	2.5 cm
Swath width at 4 knots speed	150-250 m	200-350 m	300-400 m
Area coverage rate (net)	0.5-1 km^2/h	0.7-1.4 km^2/h	1-2.5 km^2/h

2.1   Operational experience examples

A major component of the RNoN's AUV programme has been to evaluate the concept and technology through participation in national and international exercises and operations. The first operations took place in 2001, with the FFI-owned HUGIN I test and development AUV. The Navy's first dedicated HUGIN 1000 AUV took over after delivery in 2004. After the HUGIN 1000-MR vehicle (with the new HISAS sonar) is delivered late this year, the RNoN will operate both vehicles concurrently. In parallel, two RNoN MCMVs and one support vessel have been modified and upgraded for AUV operations. This includes a launch and recovery system (see Fig. 1) that facilitates safe handling at sea states up to 4.

Over the past 4-5 years, the RNoN has used HUGIN vehicles in more than 30 campaigns, adding up to well over 100 dives. Some examples are given in the following.

In September 2003, HNoMS Karmoy and HUGIN I performed an REA operation for the NATO exercise *Northern Light* in Luce Bay in southwestern Scotland. The task was to collect imagery, bathymetry and environmental data from a 12-nmi amphibious landing route. The operations took place in shallow water (10-15 metres water depth in half the area, 15-25 in the other half), with transverse currents of up to 2-3 knots. Due to tidal variations of around 5 metres, the HUGIN operations had to be performed during the periods of high tide. Within 48 hours, HUGIN performed four 6-hour missions, interspersed with 6-hour battery recharge bouts. The data was handed to a shore lab operated by NATO Undersea Research Centre (NURC) for immediate post-processing [5].
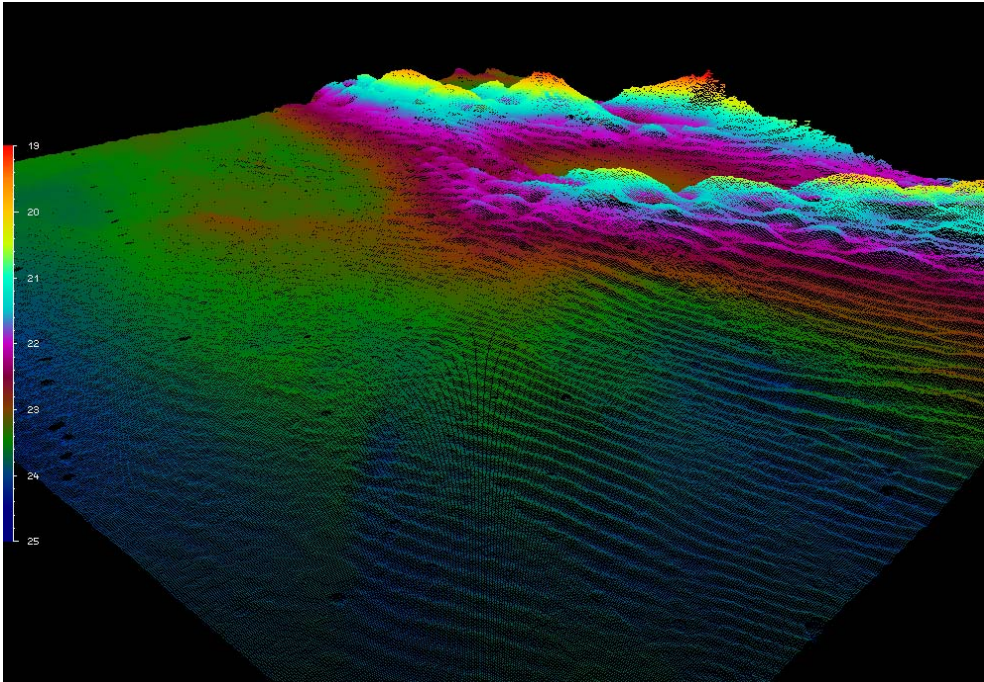

Figure 2: Multibeam bathymetry of a 300x300 m area with sand ripples, recorded by HUGIN I during Northern Light 2003. DTM cell size 30x30 cm, water depth 19-25 m. The depth has been exaggerated by a factor 5 for this display.

In May 2004, the newly delivered HUGIN 1000 was used in the *Blue Game 04* NATO exercise. One of the tasks completed was a harbour protection survey outside the town of Arendal in southern Norway. The survey took place in a narrow strait – in places just 100-200 metres wide – with water depths of 20-30 m, and numerous obstacles such as jetties, anchorages and buoys. The 15-nmi mission was executed autonomously in 4 hours at night, and the data processed and analysed onboard the following hours [5].

In late 2005, the RNoN HUGIN 1000 system was transported to Italy for participation in two sea trials with the NATO Undersea Research Centre (NURC); MX3 and SWIFT. During the MX3 trials, HUGIN was used in a Percentage Clearance trial in a 1.5 km^2 area at 20-45 m water depth. After a 3.5 hour survey and 2 hours of post-mission analysis, the RNoN crew had correctly classified all 8 exercise mines laid, with a handful of false calls [6].

While the bulk of the operations have used the AUV as a remote sensor platform organic to its host MCM vessel, experimentation has also started with using the AUV in a network based defence concept, where data is collected for and delivered to "customers" outside the MCM task group. Over-the-horizon delivery of AUV data in real time was first demonstrated at the 2005 Azalea Festival, when HUGIN data was transferred via acoustic links and satellite from a fjord in Norway to Norfolk, VA in the USA [7].
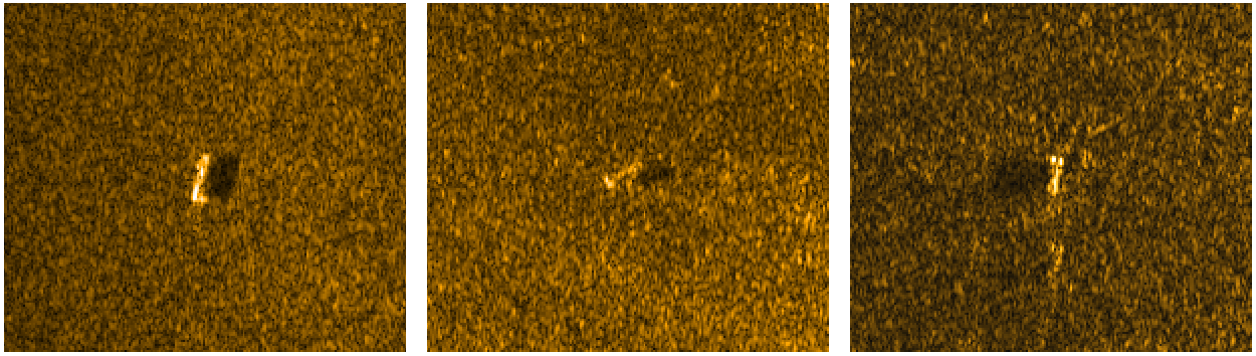
Figure 3: Example responses from 2 m long cylindrical exercise mines with EdgeTech SAS during NURC MX3 trial, November 2005. Range to targets 25, 66, and 69 m, resolution 7x14 cm.

More information on the HUGIN programme can be found in [8].

3.0   HIGH-RESOLUTION SAS

The Norwegian littorals are characterised by rocky seafloor and rough bathymetry. In order to correctly classify mine-like targets in highly cluttered environments, very high resolution sensors are required. High-resolution synthetic aperture sonar (SAS) is a key technology to obtain good classification performance over a wide swath, and SAS systems have been operated on HUGIN AUVs since 2003 [9].

With possible terrorist mining, recognition of traditional mine shapes such as cylinders and truncated cones becomes insufficient. However, any mine would need to contain a certain volume of explosives to be effective, which constrains its size. Very high resolution imagery will substantially improve the ability to detect and classify improvised explosive devices.

The following images illustrate the quality of data provided by a high-resolution synthetic aperture sonar. All data is recorded with a prototype HISAS sonar installed on a HUGIN AUV, configured to emulate the HISAS 1030 sonar intended for HUGIN 1000-MR [10].
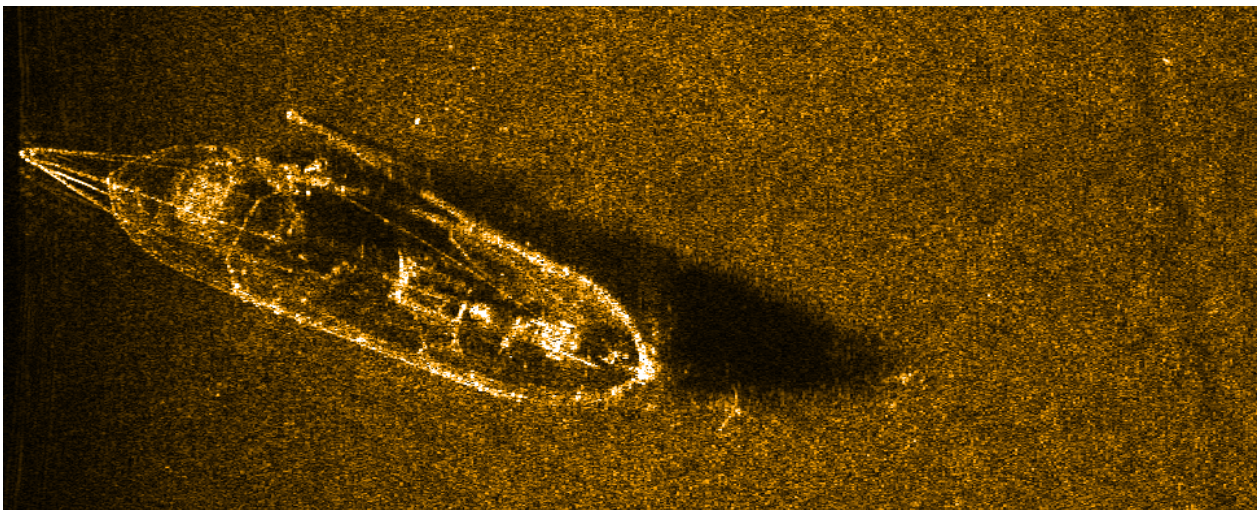

Figure 4: HISAS prototype SAS image of a fishing boat. AUV depth 175 m, altitude 20 m, range displayed 20-60 m, resolution 3x3 cm.
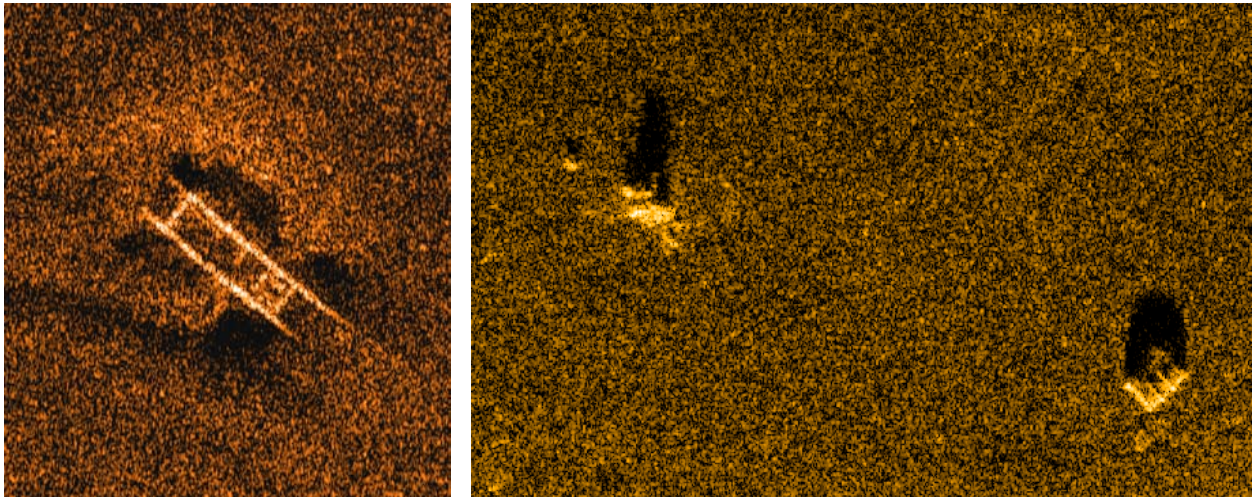
Figure 5: HISAS prototype SAS images of small objects.
Left: A ladder at 88 m range; right: A rock and an oil drum at 50-55 m range.

It is also important to note that a high-end interferometric SAS offers many data products in addition to high-resolution sonar images like those displayed here. Multi-aspect image sequences, decimetre-level bathymetry, acoustic colour and other techniques provide complementary information and will substantially improve target classification performance [4][10].

4.0   AUVS IN THE FORCE PROTECTION ROLE

AUVs can be deployed from a craft of opportunity with relative ease, or be an organic component of e.g. an MCMV or a submarine. Quay launch and recovery, using a crane or containerised L&R system, is also feasible.

As described earlier in this article, a HUGIN 1000-MR type vehicle can cover as much as 50 km^2 in a single mission. If covertness is required, the AUV can be launched e.g. 20 nmi away, transit to the operations area in 5 hours, cover a 25 km^2 area, and return to its base. The AUV mission is executed autonomously and can be repeated as often as necessary with little cost. Change detection techniques (manual, semi-automatic or fully automatic) can be used to locate any new objects in the area. In many cases, the SAS image quality will be sufficient to identify the objects. Otherwise, a second AUV mission may be executed to reacquire and visually identify a set of objects, typically using a still image camera or a laser scan system.

It was noted in Section 1.1 that terrorist groups would most likely be capable of laying only a very small number of mines. These are in turn likely to be relatively simple. Consequently, it may often be possible to plan a safe route around any suspicious objects found, and a mine disposal capability may not be necessary. Should clearance be required, an MCMV, clearance divers or some other appropriate unit can be called to the area. One such unit could then provide sufficient clearance capacity for a very large area.

Clearly, the AUV technology can be used also for other aspects of force protection; against more conventional threats. One example is de-risking of submarine operations: AUVs can be used to carry out covert precursor surveys, accurately mapping the sea floor, assessing any mine threat, etc. before a manned submarine enters the area. AUVs can also be equipped with radiation sensors to determine the safety of entering areas where radioactivity is suspected, etc.

5.0   CONCLUSIONS

Sea mines, always a dangerous weapon, can with relative ease be employed by terrorists or rogue nations not for its traditional purpose of sea denial, but to disrupt commercial shipping or to damage or sink naval vessels. AUVs with high-quality sensors provide a way to detect and classify mines and improvised explosive devices – without risking lives in the process. A very high resolution SAS can provide contact information bordering on inspection quality for a very wide swath, allowing sufficient coverage of areas of up to 2.5 km^2 per hour. If possible mines are detected, a viable strategy will often be to plan a safe route around them, as terrorist-laid mine fields would most likely consist of a very small number of mines. Thus, no mine *clearance* capability may be required. This makes it much easier to have the capability for protection against such a threat available within a force.

6.0   REFERENCES

[1]   U.S. Naval Mine Warfare Plan, 4th edition.
http://www.navy.mil/palib/cno/n75/Htm/ConceptDocs/Navy_USMC/MWP4thEd/splash.htm.

[2]   Kjøk, Å. (2004). *Motives for terror strikes against the Norwegian oil industry*. FFI rapport 2004/01682 (in Norwegian).

[3]   Hagen, P. E., Størkersen, N. & Vestgård, K. (2001). "The HUGIN Autonomous Underwater Vehicle for Forward Mine Hunting Operations." *UDT Europe 2001 Conference Proceedings*, Hamburg, Germany, June 2001.

[4]   Hagen, P. E., Hansen, R. E., Knutsen, K. D. & Langli, B. (2006). "Post-Mission Analysis with the HUGIN AUV and High-Resolution Interferometric SAS." *Proc. Oceans 2006 MTS/IEEE*, Boston, MA, USA, September 2006.

[5]   Hagen, P. E., Størkersen, N., Kartvedt, P. & Vestgård, K. (2004). "HUGIN MRS in the Royal Norwegian Navy." *UDT Hawaii 2004 Conference Proceedings*, Honolulu, HI, USA, October 2004.

[6]   Bovio, E. et al. (2006). *MX3 Trial Report: Percentage Clearance Trials with Autonomous Underwater Vehicles*. NATO Undersea Research Centre Technical Report NURC-FR-2006-007 (SR-445) (NATO RESTRICTED).

[7]   Hagen, P. E. & Størkersen, N. (2005). "Network Centric Warfare with Autonomous Underwater Vehicles – Results from Experimentation with HUGIN 1000." *Proc. Oceans 2005 MTS/IEEE*, Washington, DC, USA, September 2005.

[8]   FFI's HUGIN AUV web pages, http://www.ffi.no/hugin/.

[9]   Hansen, R. E. et al. (2005). "Synthetic Aperture Sonar Processing for the HUGIN AUV." *Proc. Oceans 05 Europe*, Brest, France, June 2005.

[10] Hagen, P. E., Hansen, R. E. & Langli, B. (2006). "Synthetic Aperture Sonar for the HUGIN 1000-MR AUV." *UDT Europe 2006 Conference Proceedings*, Hamburg, Germany, June 2006.