

Lessons Learned

Military Ops with Hugin AUVs

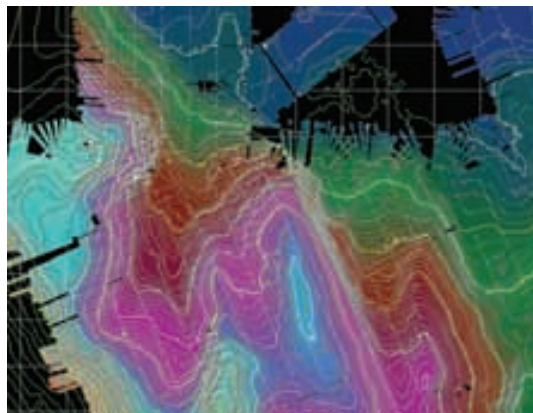
Since 2001, the Royal Norwegian Navy (RNoN) Mine Warfare Flotilla has used HUGIN autonomous underwater vehicles (AUVs) in a number of military operations around Europe. A dedicated military system, HUGIN 1000, was delivered to the Flotilla in January 2004. The AUV is operated from a RNoN mine hunter, and has been deployed in NATO's Immediate Reaction Force MCMFORNORTH from October 2004. Various types of operations have been performed, ranging from route surveys to covert mine reconnaissance and Rapid Environmental Assessment (REA) missions.

Equipped with side scan or synthetic aperture sonar, multibeam echo sounder, and a state of the art integrated inertial navigation system, the HUGIN AUVs provide high quality, high resolution imagery and bathymetry with excellent position accuracy. A proven launch and recovery system allows safe and efficient operation in high sea states. In parallel with the use of the HUGIN 1000 system in the RNoN, a new version with an improved capability is being developed. Lessons learned during four years of operational military use of HUGIN vehicles will help form the next generation, called HUGIN 1000-MR. The RNoN recently placed an order with Kongsberg Maritime for such as system, for delivery in 2006.

From the start of the HUGIN AUV program in the early 1990s, a dual use strategy has been followed where technologies and solutions have been developed for both the military and the civilian market. HUGIN has been developed jointly by the Norwegian Defence Research Establishment (FFI) and Kongsberg Maritime. A total of 10 vehicles have been built or are under production.

The HUGIN 3000 vehicles have enjoyed success in the commercial survey industry over the

Detail of EM3000 bathymetry data transferred in real time from HUGIN 1000 in Norway to Norfolk, VA. The gaps are caused by drop-outs in the acoustic data link from HUGIN. Note the near-perfect match between the real-time bathymetry contours (grey) and the 10-m contours from an earlier surface survey.



past eight years - the accumulated billed survey distance exceeds 50,000 km. Survey companies in Norway, USA, and The Netherlands currently own and operate HUGIN vehicles around the world. On the military side, the Royal Norwegian Navy Mine Warfare Flotilla has operated HUGIN vehicles since 2001. In response to a NATO initiative to accelerate national force goals, the RNoN in January 2003 instructed FFI to deliver a pre-production military version of HUGIN for MCM and REA operations. The vehicle, HUGIN 1000, was delivered in January 2004 and started operations shortly thereafter.

Before the dedicated military HUGIN 1000 AUV was delivered, the test and development platform HUGIN I was made available to the RNoN on several occasions. A permanent installation of the infrastructure necessary to run full-capability HUGIN missions from the mine hunter KNM Karmøy was completed in the summer of 2002. The limitations of the aging HUGIN I vehicle (short endurance, COTS survey sensors, etc) notwithstanding, this increased the Navy's understanding of AUV operations, and of the strengths and weaknesses of the civilian HUGIN versions. Thus, the Navy was able to assist in the specification of the HUGIN 1000 based on actual experience.

Operations

On several occasions in 2002 and 2003, KNM Karmøy performed route surveys in key areas around Norway. This was combined with testing of the HUGIN infrastructure and training of key personnel onboard the mine hunter. Bathymetric maps with sub-meter resolution were produced using data from the Kongsberg EM3000 multi-beam echo sounder onboard HUGIN I, and a low-cost side scan sonar from Sonar Equipment Services provided seabed imagery.

HUGIN played a role in an early CDE (Concept Development and Experimentation) operation in the preparatory phase of the Northern Light 03 NATO exercise. The objective was to survey a corridor

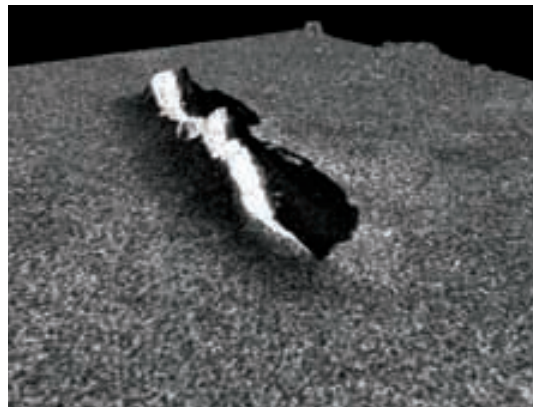


HUGIN 1000 being launched from KNM Karmøy in the Baltic Sea during its 2004 deployment in MCMFORNORTH.

500 m wide and 12 nautical miles long in Luce Bay, Scotland. The data collected was to be used to verify historic data and plan MCM operations before an amphibious landing. HUGIN I completed four successful missions in 48 hours, operating the vehicle on a tight schedule: To maximize area coverage in the shallow water (10-30 m), each mission was performed during the six hours of highest tide, while the batteries were recharged during the six hours of lowest tide. The vehicle also had to combat tidal currents of up to three knots. While the AUV primarily operated autonomously, the mine hunter was usually located within a few nautical miles of HUGIN I. Two-way acoustic communication was available at up to 2-3 nautical miles in very shallow water. Data from each mission was brought to shore for immediate processing on a provisional shore lab set up by NURC (NATO Undersea Research Center). In the days following the

AUV operations, data was processed further at FFI in Norway and NURC in Italy. The end result, a set of AML (Additional Military Layers) files, was then transferred to the exercise headquarters in Northwood, UK for use by MCMVs during the clearance operation.

Bathymetry of part of the amphibious landing route surveyed by HUGIN I for Northern Light 03. Grid spacing 1 x 0.5 ft., water depth 14-32 m. The green lines indicate the area to be surveyed, 6 nmi x 500 m; white lines indicate HUGIN's trajectory.



2003 MCM demo, Finland

Less than two weeks after Northern Light, KNM Karmøy

The US submarine Nautilus sunk outside Bergen in 1931. This image, using side scan imagery draped over multibeam bathymetry, was produced with the Triton Imaging post-processing software on the mine hunter and transmitted to the US 2-3 hours after AUV recovery.

and HUGIN performed a series of MCM demonstrations for the Finnish Navy outside Hanko, Finland. The AUV CONOPS demonstrated included route survey, mine mapping, and covert REA. Change detection was used to locate mine-like objects laid between two AUV missions. Some of the missions were performed fully autonomously, with the ship anchored outside the operations area. While the crew were asleep, HUGIN mapped a three sq. km area in approximately six hours. Challenges encountered in Finnish waters included operating in a low salinity environment (salinity approximately 7 parts per thousand).

2004 NATO exercises

Just six weeks after the delivery of the HUGIN 1000 pilot system, the mine hunter and the new AUV participated in the Joint Winter 04 NATO exercise outside Northern Norway. 13 AUV missions were completed, mainly covert REA and MCM surveys. In May 2004, HUGIN 1000 participated in the NATO exercise Blue Game 04. Missions executed included a survey of the narrow harbour areas around Arendal, Norway.

2004 MCMFORNORTH deployment

In 2004, KNM Karmøy and HUGIN 1000 were deployed in NATO's standing MCM Force North. AUV missions were executed in the waters of Lithuania, Latvia, Germany and Denmark. Among the missions performed were mine clearance operations in the Baltic Sea, which is littered with tens of thousands of mines and other unexploded ordnance from the last century.

Azalea Festival 2005

On April 20, 2005, HUGIN 1000 executed a mission outside Bergen, Norway with real-time data transmission to the U.S. In conjunction with the annual Azalea Festival in Norfolk, Va., a NERA F77 Inmarsat satcom system was installed on the mine hunter, providing 128 kbps data transfer rate and Internet access. Data was transmitted acoustically between HUGIN and the mine hunter, then via the Inmarsat system to a display computer in Norfolk. Visitors to the festival were thus able to see bathymetric maps of the seafloor being built in real time by an AUV on the other side of the Atlantic. As the connection was two-way, it was also possible to send commands from Norfolk to the AUV.

MCMOPLAT 2005, Latvia

In May-June 2005, KNM Karmøy and HUGIN 1000

were once again in the Baltic Sea. Two mine-like objects detected and classified from HUGIN 1000 sonar data were investigated by divers and turned out to be live mines, later neutralized.

Lessons Learned

From the very beginning, an important tenet of the HUGIN AUV program has been to use the sea as our laboratory. New concepts, new techniques and new subsystems are tested at sea early in the development cycle, instead of spending large amounts of time in simulations before the first sea trials. We believe that bringing the systems to the sea, while obviously not completely risk-free, results in a much steeper learning curve and frequently provides new insights that simulations cannot. By going to sea early, lessons learned from sea trials can be fed back to the development process at an early stage, while there is still room for major design changes. Kongsberg Maritime's development and manufacturing facility in Horten, Norway is set up so that HUGIN sea trials can be performed at modest cost and only a few days' notice.

The HUGIN MRS program has followed the same principles. HUGIN 1000 is the first HUGIN vehicle developed and produced specifically for a military customer. However, the deployments of the older HUGIN I vehicle with the Navy during the development provided extensive input as to what improvements were needed. Some improvements (e.g., to the operator system software) were made available to the Navy before the new vehicle was delivered, allowing Navy personnel to evaluate them at the earliest possible stage.

In addition to ensuring that the end product is well suited to the task, this process has the additional benefits that the Navy personnel feels ownership of the technology, and that they are able to follow the progress of the development closely.

A significant challenge encountered with the HUGIN 1000 development was with the main sensor, the EdgeTech 4400-SAS sonar. Early field experience identified some issues in the control system and SAS processor, many of which are now resolved. Furthermore, the sonar design limited the data quality of the SAS in some challenging conditions. Unfortunately, Norwegian coastal waters are among the most challenging areas in the world for SAS, and it has taken a substantial amount of work to get the sonar up to an acceptable level of performance.

Another issue with synthetic aperture sonar is that SAS images have some fundamental differences from high frequency side scan images. It takes time for a trained side



Visitors at the Azalea Festival watch the real-time HUGIN data, including US Secretary of the Navy Gordon England, Norwegian Minister of Defence Kristin Krohn Devold, and Norwegian Ambassador to the US, Knut Vollebæk.

scan sonar operator to get used to the characteristics of SAS images, and to be able to properly use SAS data.

A major part of the HUGIN MRS program has been to transition the deep-water technology designed for HUGIN 3000 to military operations, which generally take place in relatively shallower water. While it is generally true that deep-water operations are more difficult, the challenges unique to shallow-water operations should not be underestimated. This is especially the case for fully covert, fully autonomous operations in confined and/or unknown areas. The development model followed is rewarding, but also challenging. At times, it has been frustrating to the Navy operators that procedures and interfaces change several times. Even though a change is for the better, it can take time for users to adjust to the new situation, and it may hamper the desired "second nature" interaction. As a rule however, we find that the positive aspects of the development process more than compensates for this. An example of the difficulties of testing autonomous systems in real-world environments is the dangers imposed by fishing vessels. During the Joint Winter 04 exercise, a HUGIN mission had to be interrupted because a trawler was headed straight for the AUV - inside a military exercise area. The trawler ignored hails and warning flares from KNM Karmøy, HUGIN's mother ship. Such a situation would obviously not occur if the

area was mined, but it is difficult to fully avoid in times of peace.

The Future

In May 2005, the Royal Norwegian Navy ordered a next generation HUGIN 1000-MR system from Kongsberg Maritime. This will be a full capability system, compared to the reduced capability HUGIN 1000 pilot system delivered 2004. The most significant changes concern the payload suite. HUGIN 1000-MR will feature a more robust, more capable SAS as its main sensor. The design of this sonar is being verified with the high end SEN-SOTEK SAS sonar, which started sea trials in early 2005.

A principle of early testing of new developments at sea has been followed. As a consequence, many potential design flaws have been caught early. The close participation of the end customer in the development process has resulted in a common understanding of the issues and their relative priorities.

The preceding was authored by Per Espen Hagen and Nils Størkersen, Norwegian Defence Research Establishment (FFI); Bjørn-Erik Marthinsen, Royal Norwegian Navy Mine Warfare Flotilla; Geir Sten, Norwegian Defence Logistics Organization; and Karstein Vestgård, Kongsberg Maritime AS.