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The HUGIN Autonomous Underwater Vehicle for Forward Mine Hunting Operations

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Abstract

Autonomous underwater vehicle (AUV) technology holds great promise for many applications, in the military as well as the civilian communities. To maximise synergism, the Norwegian Defence Research Establishment (FFI) has teamed with civilian interests for its ambitious underwater vehicle program. This has led to a self-supporting industrial basis in Norway for commercial exploitation of the untethered underwater vehicle technology. Two generations of HUGIN systems have been developed by FFI in collaboration with Norwegian industry. The HUGIN vehicles have been operated commercially, primarily for the offshore oil and gas industry, since 1997, establishing daily operational real-life experience which is fed back to the development community to facilitate exploitation in a wide range of areas. The HUGIN Mine Reconnaissance System (HMRS) will be the first military realisation of the HUGIN AUV technology. This paper describes the concept of forward mine hunting, the technical solutions, and the capabilities of this application.

1. Introduction

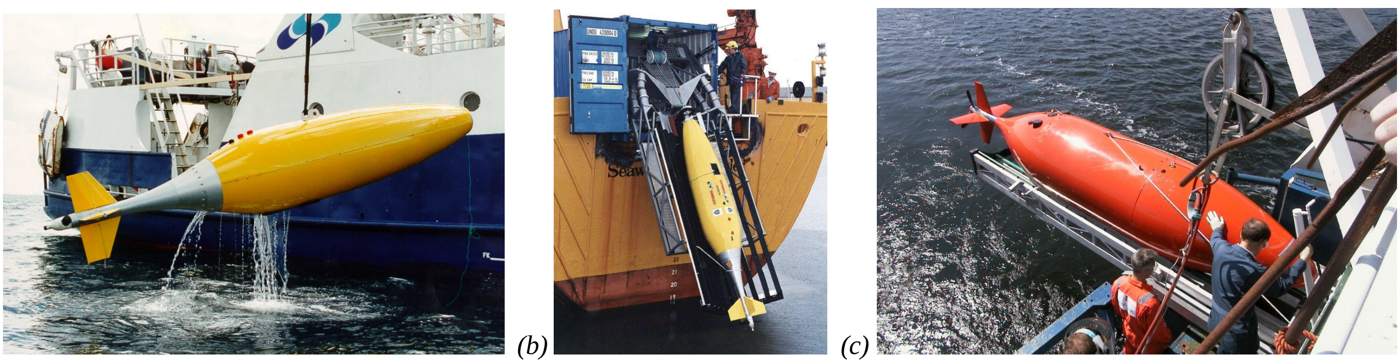
The Norwegian coastline presents unique difficulties to mine clearance. Long, narrow fjords with steep and rocky bottom, and water depths of several hundred metres even very close to shore, make conventional mine hunting very inefficient, in many cases impossible. With a coastline measuring thousands of kilometres, it also follows that a highly efficient mine clearance service is of utmost importance.

Historically, mine laying has been very effective in Norwegian waters, and mine countermeasures (MCM) is a priority area of the Royal Norwegian Navy (RNoN). In the 1990s, Norway developed and acquired a fleet of state of the art mine hunting and mine sweeping vessels (the *Oksøy* and *Alta* class MCMVs). Still, due to the difficulties of mine hunting in Norwegian waters, more and different resources are needed to fulfill the national mine clearance requirements.

In the post-cold war era, the focus of the Norwegian armed forces has shifted more towards participation in international operations. While the Norwegian MCMVs have shown excellent performance in such operations, conventional mine hunting operations by their nature place personnel and vessels at great risk. The loss of one out of only four mine hunting vessels or its crew is unacceptable in a situation where Norway is not at war, and this also raises the need for other, safer methods of mine clearance.

Autonomous underwater vehicle (AUV) technology has matured considerably in recent years, and AUV systems have already been used commercially in Norway and other countries for a few years. AUV technology may be a key component in the solution to the above problems.

2. The HUGIN development program



(a) (b) (c)

Fig. 1. HUGIN vehicles: (a) HUGIN I, (b) NUI Explorer, (c) HUGIN 3000.

The Norwegian Defence Research Establishment (FFI) initiated its AUV program in 1991 with the development of the *AUV-Demo* vehicle. Since then, three more vehicles have been designed and built by FFI and Kongsberg Simrad AS. Realising the complexity and magnitude of the effort necessary to build flexible and reliable AUVs, FFI has sought to pool the resources of the military and civilian communities. The offshore oil and gas industry and the fisheries being two of the main pillars of the Norwegian economy, this has led to a self-supporting AUV industry in Norway [Hagen (2000)].

Two of the vehicles built are currently operated commercially. Since its completion in 1998, *NUI Explorer* has performed a number of surveys for the oil companies Statoil and Norsk Hydro. The vehicle is owned and operated by Norwegian Underwater Intervention (NUI) [Størkersen et al. (1998), Hagen et al. (1999)]. The *HUGIN 3000* vehicle was delivered to the US survey company C&C Technologies (Lafayette, Louisiana) in July, 2000, and is currently being used for seabed mapping, imaging and sub-bottom profiling in the Gulf of Mexico [Chance et al. (2000), Vestgård et al. (2001)].

While the HUGIN vehicles can be operated fully autonomously, the main use of the vehicles (high-resolution seabed mapping) usually requires positioning accuracies that are currently unattainable by fully autonomous vehicles. Kongsberg Simrad's HiPAP super-short baseline (SSBL) acoustic positioning system is used to position the AUV relative to a surface vessel, and differential GPS satellite navigation for absolute positioning of the surface vessel. With this setup, absolute positioning accuracies around 2 metres have been demonstrated for bottom objects at 1300 metres depth in the Gulf of Mexico [Vestgård et al. (2001)]. Global position updates are transmitted from the surface vessel to the AUV at regular intervals to reset INS drift, enabling the vehicle to perform accurate waypoint navigation.

As this mode of operation dictates the presence of a surface vessel with near-continuous acoustic communication with the AUV, additional functionality has been added for manual override of the pre-programmed mission plan, and sensor data transmission for vehicle monitoring and quality control. This "acoustic tether" has significantly reduced the threshold for acceptance of the technology in the survey community.

The latest generation of HUGIN vehicles, represented by *HUGIN 3000*, is characterised by a high degree of flexibility. The vehicle can roughly be divided into four sections: The control and propulsion section (aft), the battery section (centre, top), the transducer bay (centre, bottom), and the payload control section (fore).

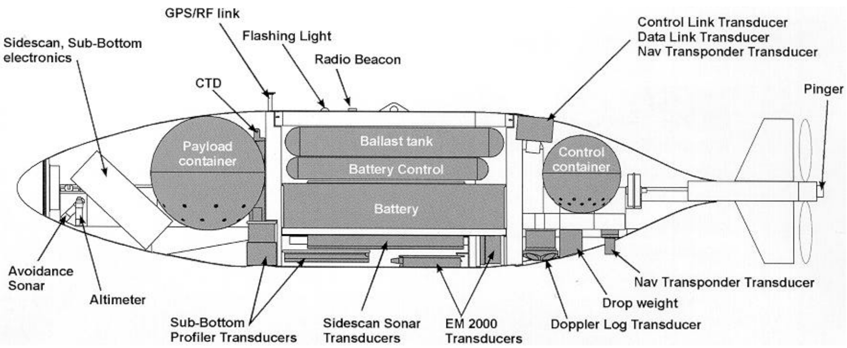


Fig. 2. Schematic view of the HUGIN 3000 vehicle

The main pressure container in the control section contains the Control Processor, the Navigation Processor, the Inertial Measurement Unit (IMU), and the electronics for the acoustic command and data links. The control processor handles guidance and control, general error checking and handling, multiplexing and demultiplexing of data to and from the acoustic links, and administers network services. The navigation processor runs a real-time aided inertial navigation system (AINS) developed by FFI, supplying position and attitude to the guidance system. The processors interact using CORBA [OMG (1995)] over a TCP/IP Ethernet, the Vehicle Network. The vehicle is equipped with a purpose-built, highly efficient direct drive motor enclosed in oil and working under ambient pressure.

In the *HUGIN 3000*, the battery section contains a 40 kWh alkaline aluminium/hydrogen peroxide semi fuel cell developed by FFI [Hasvold et al. (1999)]. Other HUGIN vehicles have been equipped with NiCd and Lithium Ion rechargeable batteries.

The transducer bay can be easily disconnected and replaced, to facilitate rapid re-configuration of the vehicle for different missions. The *HUGIN 3000* was delivered with a Kongsberg Simrad EM2000 multi-beam echo sounder, an EdgeTech dual frequency side scan sonar, and an EdgeTech sub-bottom profiler.

The payload control section is dominated by a pressurised titanium sphere with internal diameter 70 cm. This affords plenty of space for a main Payload Processor as well as electronics units for the various payload sensors. The payload processor is connected to the vehicle network.

The *HUGIN 3000* vehicle has a depth rating of 3000 metres, a nominal endurance of 48 hours, and a cruise speed of 4 knots.

The HUGIN vehicles are programmed and monitored from the HUGIN Operator Station, a workstation on the surface vessel. The means of communication varies with the phase of the mission – Ethernet on deck, RF link when the AUV is at the surface, acoustic command and data links when submerged. The same operator interface is used throughout these phases, giving the operator a sense of continuity and being in charge at all times [Hagen (2001)].

3. AUV based mine hunting

3.1. Concept

Mine hunting comprises two very different tasks: Mine detection, classification and positioning, which is essentially a survey task not unlike many civilian AUV operations, and mine neutralisation, which is an intervention task best carried out by means of more conventional ROV systems under complete manual control. In traditional mine hunting operations, these two tasks are carried out in parallel; each mine is neutralised as soon as it is detected and classified by an operator. This approach is necessary for safety reasons, but it is in no way an ideal mode of operation.

The quality of the data attainable by the MCMV mine hunting sonars is often insufficient, not least because a safe distance of several hundred metres to any mines must be maintained at all times. As a result, the number of false contacts (non-mines classified as possible mines) can be large. Whether or not a contact is a true target, each ROV launch halts the operation for a significant amount of time. With an expendable mine disposal weapon (EMDW), many false contacts will lead to excessive use of such weapons; with a recoverable ROV, the operation will typically be halted even longer while the ROV is being recovered.

AUV technology is an excellent remedy to this unfortunate situation. Using an AUV to perform the survey part of the operation, detection and classification data of superior quality can be gathered at higher speed and without any risk to MCMVs and personnel. An AUV can be sent out on an autonomous mission surveying all or part of the area to be cleared. The AUV will store all sensor data onboard, to be recovered when the vehicle returns. Alternatively, the vehicle can surface at regular intervals and relay the data back using a radio or satellite link.

To achieve the highest efficiency, fully automatic mine detection algorithms must be applied on the recorded data. A human operator should, however, perform the final classification of the computer detected objects. Following this, the MCMV can perform an informed assessment of the situation, and – if necessary and desirable – start mine neutralisation. The neutralisation phase will be much more streamlined than in the traditional scenario.

3.2. The HUGIN Mine Reconnaissance System

The HUGIN Mine Reconnaissance System (HMRS) builds on the proven HUGIN AUV technology in accomplishing the above method of operation. The vehicle will operate fully autonomously and independently of the MCMV, with endurance approximately 24 hours. The main sensor for mine detection and classification will either be a synthetic aperture sonar (SAS) or a commercial multi-beam focused side scan sonar. For accurate autonomous positioning, terrain-aided navigation will supply the traditional doppler-aided inertial navigation system.

With the HMRS system, AUV technology will be used to accurately map mine threat situation in an area of interest. The clearance operation will be performed by the Oksøy class MCMVs, using an EMDW such as the Minesniper. Optimal use of the system in Norwegian waters relies on route surveys for accurate mapping of bathymetry and existing bottom objects in peacetime. When such surveys cannot be performed, e.g. in urgent international operations, operational effectiveness will be somewhat reduced.

Fig. 2. An illustration of the HMRS concept: After an AUV has surveyed an area (bottom), clearance can be performed with an MCMV equipped with mine disposal weapons. At the same time, the AUV can be used to map another area of interest (top).

The first phase of this development program will be finalised in 2001, when an adapted version of the *HUGIN I* vehicle will be used to demonstrate autonomous mine detection, classification and positioning. A full capability prototype HMRS system can be completed and transferred to the RNoN in 2005 for testing and evaluation within the MCM organisation.

3.3. Enabling technologies

FFI's "dual use" development philosophy has meant that the bulk of the generic AUV technology development has been funded by civilian interests. This has allowed FFI to concentrate the limited military funding to the areas primarily of concern to military AUV applications. To realise the HMRS concept, three main areas have been focused:

Accurate autonomous navigation. FFI has developed a state of the art aided inertial navigation system which is now used in all HUGIN vehicles [Gade (1997), Mandt et al. (2001)]. This allows optimal integration with any new aiding sensors. FFI has also developed complementary navigation aids such as bathymetric navigation systems [Kloster and Heyerdahl (1998)]. For the HMRS scenario, the aim is to be able to maintain a position accuracy in the order of 10 metres for the duration of an AUV mission in areas where a pre-existing bathymetric map is available.

Synthetic aperture sonar. Last year, FFI started a collaboration with Kongsberg Simrad AS and Simrad AS to develop an interferometric wide-band synthetic aperture sonar and integrate it on the *HUGIN I* AUV by the end of 2002. Target specifications are 5x5 cm resolution in both imagery and bathymetry, with a swath width of 2x300 m. With a nominal AUV speed of 4 knots, this yields an area coverage rate of approximately 4 km^2/hr, with data quality suitable for reliable classification even in cluttered areas. The SAS system will be integrated with the inertial navigation system for optimal quality. FFI also participates in a Joint Research Program with SACLANTCEN (La Spezia, Italy) in this field [Hagen et al. (2001)].

Automatic mine detection and classification. Algorithms have been developed to automatically detect objects based on imagery and bathymetry. To ensure a detection rate close to 100%, a high false alarm rate must be tolerated. This is remedied by an automatic pre-classification algorithm, which uses a combination of physical characteristics and heuristics to assign a confidence to each detected object [Midtgaard et al. (2000)].

3.4. Current status

A technology demonstrator is currently nearing completion at FFI. This system aims to demonstrate the main elements of the HMRS concept, using off-the-shelf technology, within year 2001. As many of the technologies assumed by HMRS are still under development, only a strongly reduced coverage rate will be achieved with this system. The *HUGIN I* AUV is being equipped with an improved accuracy navigation system, features for enhanced autonomy, a high frequency side scan sonar and a multi-beam echo sounder.

4. Conclusions

Within a few years, AUV technology can tremendously increase the efficiency and safety of mine hunting operations. A key to the successful introduction of AUV technology in this field is to view mine hunting as composed of two distinct operations: detection/classification/localisation, and neutralisation. While AUVs may contribute to the former within a very short time, we believe that the latter is much better left to human-controlled systems such as ROVs in the foreseeable future. The HUGIN Mine Reconnaissance System (HMRS) aims to be a complete, efficient and safe mine surveying system for all water depths except very shallow water, and a full capability prototype system is scheduled to be completed by 2004-05.

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