The HUGIN 1000 Autonomous Underwater Vehicle for Military Applications

Per Espen Hagen and Nils Størkersen
Norwegian Defence Research Establishment (FFI)
P O Box 25, NO-2027 Kjeller, Norway
peh@ffi.no - njs@ffi.no

Karstein Vestgård
Kongsberg Simrad AS
P O Box 111, NO-3191 Horten, Norway
karstein.vestgard@kongsberg-simrad.com

Per Kartvedt
Royal Norwegian Navy Mine Warfare Flotilla
P O Box 24 Haakonsvern, NO-5886 Bergen, Norway
pkartvedt@mil.no

***Abstract* – In January 2003, the Royal Norwegian Navy (RNoN) directed the Norwegian Defence Research Establishment (FFI) to deliver a prototype AUV suitable for various military applications by the end of the year. The vehicle, developed by FFI and Kongsberg Simrad AS, will be the first of the new HUGIN 1000 AUV class, and builds extensively on technologies and solutions from the larger HUGIN 3000 vehicle class. Primary applications for HUGIN 1000 include mine reconnaissance, depth independent mine detection, classification and localisation, MCM route survey, as well as overt and covert Rapid Environmental Assessment (REA). HUGIN 1000 is highly modular, and in its standard configuration will have an endurance of approximately 24 hours. A substantially similar version will also be available for civilian customers.**

I. INTRODUCTION

The HUGIN autonomous underwater vehicles (AUVs) have enjoyed great success in the civilian survey industry over the past six years [1], [2]. Commercial operations have been successfully performed off the coast of four continents, in environments ranging from arctic winter to tropical summer. The accumulated billed survey distance is approaching 40,000 km – once around Earth along equator. This amount of commercial experience is unparalleled among AUV manufacturers in the world today.

The HUGIN vehicles have been developed jointly by the Norwegian Defence Research Establishment (FFI) and Kongsberg Simrad. Following an early technology demonstrator built 1991-93, the first HUGIN vehicle started sea trials in 1996. Four HUGIN vehicles are currently in operational use. The current model, HUGIN 3000, has a depth rating of 3,000 metres and an endurance of 50-60 hours using a semi fuel-cell power source [3]. HUGIN 3000 customers have operated at depths exceeding 2,900 metres [4], and have completed missions with endurance up to 61 hours [5].

Fig. 1. The HUGIN 3000-GC AUV during launch

II. THE NORWEGIAN MILITARY AUV PROGRAM

In parallel with the commercial AUV program, FFI has conducted a development and evaluation program for military AUVs and their applications. To a large extent, the two programs have overlapped. This includes ensuring that technology developed for civilian users will also be applicable, with a minimum of modifications, to military users. One of the benefits of this is that thousands of hours of real-life operational experience had been gathered before the first military AUV was built.

In 2001, FFI and Kongsberg Simrad demonstrated a range of military AUV operations from the Royal Norwegian Navy (RNoN) mine hunter *KNM Karmøy*. Operations included route surveying, rapid environmental assessment (REA), and forward, autonomous, deep water mine detection, classification and localisation [6]. These demonstrations concluded several years of research and development in areas such as high quality autonomous navigation, computer aided mine detection and classification, and sensor and data fusion. The demonstrations showcased the maturity of the AUV technology, and marked the transition to a new phase in the Norwegian military AUV program.

Fig. 2. HUGIN I immediately after launch from the RNoN mine hunter KNM Karmøy in December 2001

The same mine hunter has later been upgraded with a permanent installation of the infrastructure necessary for full quality HUGIN AUV missions. This has enabled the RNoN to carry out several series of AUV missions in areas of vital national interest, while at the same time training the crew in AUV operations.

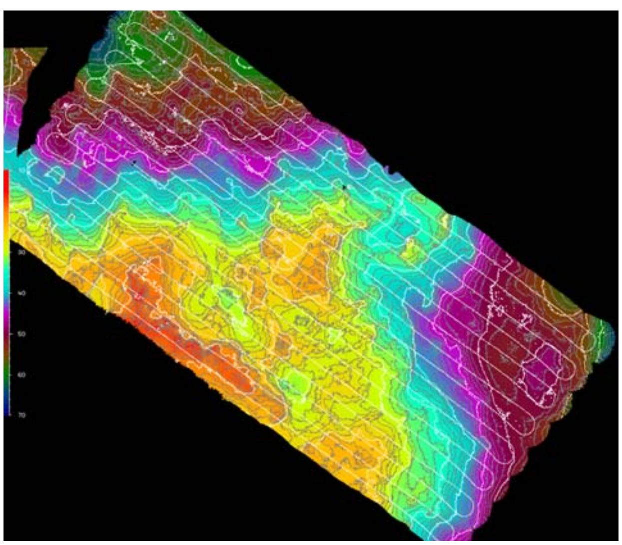

Fig. 3. Multibeam bathymetry from an MCMV survey operation with HUGIN I on KNM Karmøy, May 2003. Water depth 10-60 m.

As a dedicated Navy AUV was not available, missions have been carried out using FFI's test and development AUV HUGIN I. This vehicle, which was built 1995-96, was not designed for the harsh environment encountered onboard an MCMV (e.g., long transits at 20 knots in high sea states, operating in the vicinity of mine detonations, etc.). However, the system has exceeded all expectations, and outstanding MCM survey results have been obtained [7]. Current plans include participation in the NATO exercise *Northern Light* in the UK, and a series of MCM missions in Finland; both in September 2003.

The HUGIN Mine Reconnaissance System (HUGIN MRS) program aims to deliver a next-generation military AUV on commercial terms in early 2005. This system will feature a very high resolution interferometric synthetic aperture sonar (SAS) as its primary sensor [8], a wide range of traditional and non-traditional navigation aids [9], and endurance exceeding 24 hours with rechargeable batteries.

As a stopgap measure before this system is available, the RNoN in early 2003 directed FFI to deliver a pilot HUGIN MRS vehicle within year 2003. This system is unofficially called "HUGIN MRS version 0", as it represents a reduced capability for many of the envisioned applications. Nevertheless, it is a significant step forward compared to the current state of the art in AUVs. The vehicle is currently in production, and sea trials are scheduled to begin in early October 2003.

The "version 0" HUGIN MRS contains the world's first commercial SAS, facilitating 10x10 cm resolution with a swath width of up to 500 m. The SAS for the full-capability HUGIN MRS will have substantially increased performance, allowing "super-classification" of mine-like objects as well as very high resolution bathymetry.

III. THE HUGIN 1000 VEHICLE

As the existing HUGIN 3000 vehicle class was considered too large for comfortable handling onboard an MCMV, the HUGIN MRS program led to the birth of a new AUV class. Both the HUGIN MRS vehicles described above will be of the new HUGIN 1000 class. HUGIN 1000 represents a reduction in weight and volume of up to 50% compared to HUGIN 3000.

A. Mechanical design

HUGIN 1000 was designed for a very high degree of configurability, to make it suitable for a wide range of applications – in the military, commercial and scientific domains [10].

AUVs are available in a wide range of sizes today – from man-launchable vehicles weighing less than 50 kg, to systems weighing several tons. Increasing the size of an AUV will always increase its capability. While a small AUV can often be perfectly adequate for covering very small areas, larger AUVs offer longer endurance, higher speed and/or better payload sensors, which can reduce the total time needed to complete a task by as much as 90%. It was therefore decided that the size of the HUGIN MRS AUV should be determined by the handling capability of an MCMV such as the Norwegian *Oksøy* class of dual hull surface effect ships.

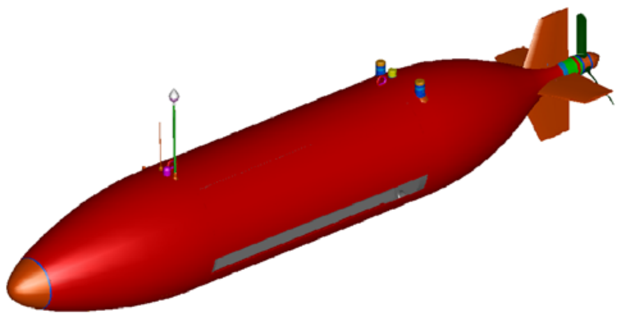

Fig. 4. HUGIN 1000

Furthermore, the new vehicle class had to be modular in size, partly because the specifications of the final HUGIN MRS could not be fully anticipated at the start of the project. HUGIN 1000 is therefore built up of three sections. The centre section is cylindrical and can be built in different lengths, varying the total volume of the vehicle by approximately 500 litres. The centre section can also be built with different internal structure, allowing optimal integration of any payload type that fits inside the outer diameter of 75 cm.

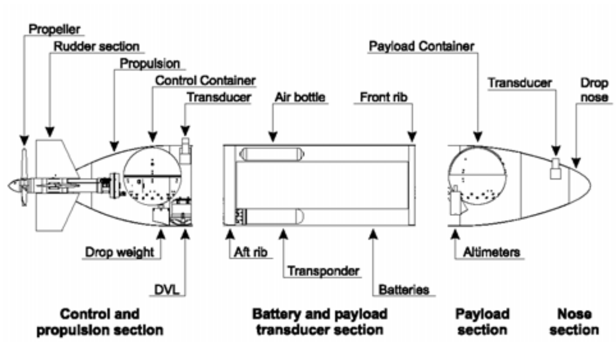

Fig. 5. HUGIN 1000 mechanical design, shown here with a centre section of 1.65 m

The design of the HUGIN 1000 retains much of the inherent stability, hydrodynamic efficiency and excellent manoeuvrability of the original HUGIN I vehicle, while at the same time affording an unprecedented level of modularity and flexibility.

As in HUGIN 3000, the vehicle frame is built in carbon fibre laminate and high performance syntactic foam. The buoyant frame significantly increases the ability to carry heavy equipment such as batteries and transducers. Two main frames in the aft and front section of the vehicle provide a stiff and torsion free hull structure, ideal for precise sensor installation and alignment accuracy.

Dry weight of the vehicle is typically 600-800 kg.

B. Energy and propulsion

HUGIN 1000 features a scalable power system allowing multiple smart battery modules to be connected. The standard version is equipped with three pressure tolerant, rechargeable Lithium polymer battery modules, providing a total of approximately 15 kWh. Primary Lithium batteries may also be used; this will more than double the amount of energy available. One or two battery containers may be replaced by payload systems.

A high efficiency, high torque synchronous motor allows direct drive of a long bladed propeller, optimised for high electrical to hydrodynamic efficiency and low acoustic noise. Four individually controlled rudder blades are used for heading, pitch and roll control.

C. System architecture

HUGIN 1000 is built on the same technology base as HUGIN 3000; the software, electronics and system design are mostly identical. Both systems will co-exist on the same technology base, mutually benefiting from the advances made for their various applications.

Like HUGIN 3000, HUGIN 1000 employs a distributed software system featuring three or more main computers. The *Control Processor* (CP) is responsible for running the vehicle according to the pre-programmed mission plan, and for error/emergency detection and handling [11]. The CP also handles communication to the surface and interfaces most navigation sensors. The *Navigation Processor* (NavP) runs the real-time integrated inertial navigation system [9], and the *Payload Processor* (PP) manages all payload systems, using a "plug and play" device driver system to handle any combination of payloads [12]. The CORBA based open architecture enables customers to integrate additional computers on the vehicle network, implement new modules for the Payload Processor, add new payloads, and run third-party guidance and mission management systems.

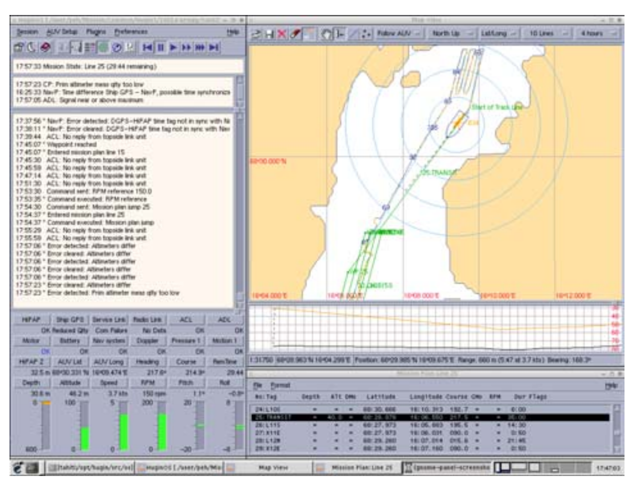

Fig. 6. Screenshot of HuginOS

On the surface vessel, the *HUGIN Operator Station* (HuginOS) is used to control HUGIN, during configuration, maintenance and missions [13]. Several different facilities are available for communication between HUGIN and the surface vessel – a Fast Ethernet connection on deck, up to three different RF and satellite links at the surface, and three different acoustic links when submerged. Compared to HUGIN 3000, acoustic communications have been upgraded for long-range communications in very shallow water. Approximately 1 nmi range in 10-15 m water depth has been demonstrated in military missions.

D. Specifications

Table I lists some of the key ratings and specifications for the HUGIN 1000 vehicle. More information can be found in [10].

The endurance figures apply with 3 pressure tolerant Lithium polymer battery modules, and 250 W power available for payloads.

TABLE I.
HUGIN 1000 BASIC SPECIFICATIONS

Dimensions	
Length	3.85 – 5.0 m
Maximum diameter	0.75 m (29.5")
Volume	1.1 – 1.6 m^3
Depth rating	600 m
Dynamics	
Speed range	2-6 knots
Nominal speed	3-4 knots
Turn radius	10 m at 4 knots
Motion stability	< 0.5º at 4 knots
Maximum pitch angle	±50º
Battery	
Energy capacity	5-15 kWh
Maximum power	2 kW
Endurance	Up to 24 hours at 3 knots Up to 18 hours at 4 knots

IV. APPLICATIONS

HUGIN 1000 can be outfitted with a variety of payloads, to address a wide range of applications. This chapter lists some typical applications.

A. Mine countermeasures

HUGIN 1000 is designed to fill multiple roles in MCM: Peace-time route survey, mine reconnaissance (an exploratory operation to determine whether an area is mined or not), and mine detection, classification and localisation (a clearance operation where the objective is to find all mines in an area).

The Royal Norwegian Navy has requirements to do mine hunting in water depths from very shallow water down to several hundred metres, and the HUGIN MRS program is a key element in achieving this.

To effectively detect and classify ground mines in cluttered environments, very high resolution imaging is needed. Another sensor is needed to detect tethered (in-volume) mines. Furthermore, for high quality route surveys, a hydrographic instrument will be needed.

The sensor suite for MCM consists of:

- Interferometric synthetic aperture sonar, capable of imaging and bathymetry down to 2x2 cm resolution
- Volume search sonar
- Multibeam echo sounder

Typical area coverage rate will be 2-5 km^2/h for route survey, 0.5-4 km^2/h for mine reconnaissance and mine classification missions.

To preserve the speed advantage gained by this rapid area coverage, fast evaluation of the collected data set is imperative. The HUGIN Mine Reconnaissance System includes tools for automatic mine detection, computer aided mine classification, sensor and data fusion, and visualisation of AUV sensor data. These tools will allow the analyst to manually classify the contacts, normally starting with the ones deemed most mine-like by the computer [14].

FFI and the RNoN are currently defining concepts of operation for the various types of MCM missions.

B. Rapid environmental assessment

HUGIN 1000 is suitable for category 2, 3 and 4 REA operations. In category 2 REA, the objective is to perform a rapid, overt collection of a variety of sensor data for environmental assessment. Typical data available from HUGIN 1000 include:

- Very high resolution seafloor imagery
- Very high resolution bathymetry
- Seafloor classification
- Sea currents
- Sound speed profile
- Water temperature

In category 3 REA, the objective is to collect the same types of data, covertly. The actual covertness requirements will determine if the AUV can surface periodically for GPS position fixes and RF/satellite communications. This will mainly affect the positioning accuracy.

In category 4 REA, the data collection is performed in-stride with deployment of own forces. For this type of operations, the collected data will normally be transmitted to the surface vessel in near real time using acoustic, RF and/or satellite links.

The data types listed above will be available with a sensor suite similar to that used for MCM operations, with the possible exception of the volume search sonar. Seafloor classification can be performed based on both SAS and multibeam echo sounder data; sea currents are available from the Doppler velocity log/Acoustic Doppler current profiler; and sound speed and water temperature are available from the high quality CTD sensor which is part of HUGIN 1000's basic sensor suite.

Typical area coverage will be 2-5 km^2/h.

The HUGIN MRS vehicles are designed for REA applications in addition to their primary role in MCM operations [15].

C. Anti-Submarine Warfare (ASW)

For ASW training operations, HUGIN 1000 can be equipped with a towed array and powerful low frequency transducers, enabling it to "respond" to an active ASW sonar, mimicking the signature of a large submarine. Using the acoustic links, it is even possible for a "submarine team" to perform various tactics and manoeuvres in real-time during the training operation.

Another possible use is submarine search in the littoral using active sensors, typically in conjunction with surface vessels and helicopters.

D. Other applications

The current threat of terrorist attacks has raised the need for routine surveillance of strategically important areas and objects, such as ports, offshore oil installations, subsea cables, and various military installations. In times of peace, a HUGIN 1000 system primarily designed for REA and/or MCM applications will have excellent capability for such surveillance tasks. While many of these surveillance tasks may perhaps be performed equally well by other means, using an existing AUV system removes the need for investing in one or more other systems.

Needless to say, HUGIN 1000 is also very well suited for a range of civilian tasks, both commercial and scientific – search and survey operations, marine archaeology, oceanography and fishery research, to name but a few.

V. CONCLUSIONS

Due mainly to the "dual use" development strategy employed in the HUGIN development program, the time to develop a military grade HUGIN AUV has been remarkably short. The HUGIN development program differs significantly from many COTS projects, where civilian technology is applied directly to military applications. Instead, the requirements of the military customer are recognized from the outset. This ensures that the technology will work in a military environment with a minimum of modifications.

As this paper has demonstrated, HUGIN 1000 is suitable for a wide range of military applications. The Royal Norwegian Navy will have an operational pilot system built around the HUGIN 1000 vehicle from the end of 2003, and most likely a second, more capable system from early 2005. Like the HUGIN I vehicle has already been used in several military operations [7], the new systems will be used heavily in the years to come.

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