SeaFox IQ/SeaWolf
- new mini and midi AUVs for security and inspection –

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ABSTRACT

The Autonomous Underwater Vehicles (AUV's) *SeaFox IQ and SeaWolf* are nearing the completion of their development at ATLAS ELEKTRONIK.

The possible mission spectra of these low (40kg) and medium (110kg) weight versatile vehicles includes inspection of 2-D and 3-D underwater facilities, maritime security and maritime science applications.

SeaFox IQ and *SeaWolf*

- are in the category of high performance AUV's
- have a high payload capacity relative to vehicle weight
- are capable of several hours endurance
- are capable of maximum speeds up to 6 and 8 knots respectively
- are highly manoeuvrable including hover capability
- may be also equipped with long lengths of fibre optic cable for broad band on-line data transmission during autonomous operation.

The AUVs are able to execute multiple types of inspection, surveillance and reconnaissance tasks partly or completely autonomously. Further, the vehicles are capable of operation in waters of high current. In the inspection role, extremely complex structures can be detected and examined with or without human support. This applies moreover not only to objects with heavy marine growth (mussels, barnacles, etc.) but also in underwater regions of minimal visibility.

To match the vehicles' impressive hydrodynamic characteristics and to meet these challenging missions, the standard payload configuration features a multi-sensor package complete with an advanced image processing software suite and precision navigation capabilities both in the long range and close to target domains. The highly accurate short range navigation sub-system provides vehicle guidance such that a constant distance from the target object is maintained whilst ensuring complete coverage of the inspected scenario.

In order to further enhance inspection efficiency, the UUV's are able to execute the inspection with the aid of existing CAD data from the relevant object. If such data are not available, the vehicles will create the data file by themselves on the basis of the actual inspection mission. In case of a repeated inspection, a so called "Change Detection" algorithm is activated to specifically detect a "difference" in the pre-recorded scenario. This is particularly effective in a cluttered sea bottom picture, often prevalent in port and harbour areas.

The scope of this paper is to present these emerging high performance

ATLAS AUV’s *SeaFox IQ* and *SeaWolf* with a brief description of their respective performance characteristics and mission applications, and to introduce the discussion of future growth potential

INTRODUCTION

The development environment at ATLAS ELEKTRONIK for Unmanned Underwater Vehicles (UUV’s), including ROV’s, AUVs and Hybrid AUVs (HAUV’s), focuses, insofar as is possible, on the synergies between the individual systems. At the top strategic mission level, today’s UUVs are based substantially on dual use in that they are suitable for both military and commercial applications. Consequent to such a philosophy are greater serial production efficiency for the basic systems and higher performance/price ratios to the benefit of customer budgets.

The ATLAS UUV family concept is shown in Fig. 1. All vehicles are based on the same design principles of high manoeuvrability and payload versatility, resulting in a large degree of synergy across the product range.

A further design characteristic of the ATLAS UUV family is the modularity which, depending on the specific payload capacity, is realized by the possibility of plug and play integration of various payloads. Finally all ATLAS UUVs can be mission-specifically equipped by the user with a fiber-optic cable (FOC), so that a wide-band, real time transmission to the surface (or to underwater communication nodes) of all sensor and status information can take place. Such hybrid AUVs (HAUVs) open wider and completely new application possibilities.

Fig. 1: ATLAS UUV Family

SEAFOX AND SEAWOLF

The UUVs SeaFox and SeaWolf are characterised by flexibility both to the user community and areas of application, including the following core capability missions for:

- Mine Counter Measures
- Damage Assessment
- Intelligence
- REA
- Route Survey
- Maritime Border Control
- Waterways and Port Surveillance
- Passenger Terminal Protection.

Among many users are:

- Defence Forces
- Coast Guard
- Maritime Administration
- Customs and Immigration
- Port Authorities
- Environmental Agencies
- Commercial Operators
- Maritime Scientific Institutes.

Depending on payload capacity, the following features are realized in the systems:

- Autonomous or operator supported inspection and classification of all types of underwater areas, structures and objects
- Adaptive autonomy in relation of the mission
- On line data link via fibre optic cable on request (hybrid)
- Operation in confined and tidal areas
- Inspection sensors of latest technologies in underwater vehicles
- Navigation/positioning of highest accuracy
- Standard interfaces for simple integration of customer specified sensors and software (plug and play)
- High-performance multi sensor image processing on board or in the surface console
- 100% inspection of selected object assured
- CAD base inspection on request
- CAD object data creation during the inspection
- Alarm function in relation to the identified anomaly
- Prepared for team operation
- Object oriented mission planning and control.

The SeaFox UUV

The UUV *SeaFox IQ,* represented in Fig 2, is a small and lightweight (see Tab. 1) unmanned underwater vehicle with an endurance of more than one hour. The vehicle can be equipped with an inertial navigation system, supported by GPS and DoLog for highest routing precision. Due to its modularity, mission-adapted sensor suits include 360° and side looking sonar as well as a tiltable TV system as shown in Fig. 2.

Fig. 2: The SeaFox UUV

Parameter	SeaFox IQ
Length [m]	1.3
Width [m]	Ø 0.4 (max)
Weight [kg]	40
Speed [ktd] • Max • Min	 6 0.5 (backwards)
Diving depth [m]	300
Duration [h]	approx. 2
Payload [kg]	5
Obstacle avoidance	yes
Hover capability	yes

Tab. 1: *SeaFox* key data characteristics

The SeaWolf UUV

Fig. 3 shows the *SeaWolf* design and Fig. 4 possible sensor suits, comparable to the *SeaFox* in Fig. 2. Tab. 2 presents the *SeaWolf* key data characteristics.
A variety of sensor combinations are available:

- IMU, GPS receiver and DVL belong to the basic navigation unit
- Transponder/Responder are basic equipment to use if a client wishes to use an underwater tracking system
- TV on a pan/tilt-platform, side scan and the obstacle avoidance sonar comprise a basic sensor suite

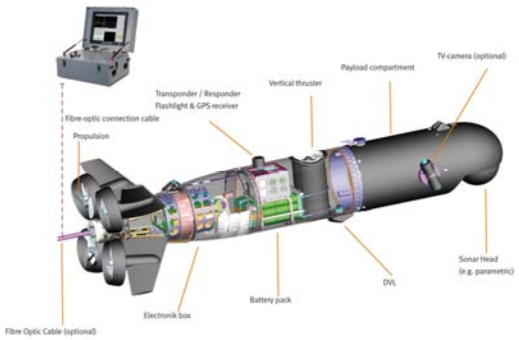

Fig. 3: *SeaWolf* design

Fig. 4: The *SeaWolf* UUV

- High resolution multi beam sonar, sub bottom profiler, parametric sonar and a laser unit are options able to be installed and integrated on client request.

Parameter	*SeaWolf*
Length [m]	2.0
Width [m]	Ø 0.5 (max)
Weight [kg]	110
Speed [kts] Max min	 8 Minus 0.5
Turn radius	< 3 m
Diving depth [m]	3 to 300
Duration [h]	3 @ 4 kts
Payload [kg]	> 30
Obstacle avoidance	yes
Hover capability	yes
Navigation	INS + DVL + (D)GPS + pressure sensor + compass (+ CML)

Tab. 2: *SeaWolf* key data characteristics

Vehicles' Design and Features

- Propulsion
  For reasons of minimum drag, the hulls of *SeaFox* and *SeaWolf* are designed as a torpedo shape. Hydrodynamic stabilization in heading direction takes place via four fins at the tail, which are also the carriers for the main drives. To increase the manoeuvrability of the larger *SeaWolf* vehicle, these four drives are slightly outwardly aligned. For both vehicles, the drives are very powerful in relation to the vehicle's size and mass.
  A crucial advantage of the four-propeller thrust compared to UUVs with control surfaces is the retention of agility and good manoeuvrability even at low speed. The rollock of the vehicles is guaranteed passively by a sufficient metacentric height. A high performance vertical thruster is integrated in the middle of the vehicles. In summary, this propulsion unit results in fast and agile vehicles, driven in four degrees of freedom (vehicle fixed X- and Z-axis, yaw and nick). The vehicles are designed and constructed with a high degree of mechanical robustness and are able therefore to operate in unfavourable environmental conditions such as high currents and near surface turbulence.
  The vehicles are able to carry a practical payload size up to approximately 5 kg resp. 30 kg (*SeaFox/SeaWolf*) in weight.

- Navigation
  Any accurate underwater object inspection requires a highly precise and reliable navigation system, not only for an initial inspection but also for object/anomaly re-location for possible repeat observations including, from other aspect angles or with lower vehicle speed to increase the resolution. Just as important is the use of previous

knowledge concerning the structures which shall be examined and the possible anomalies. This is only realisable with an appropriately accurate navigation capability.

In the autonomous mode, the course is managed by the autopilot. The navigation system is controlled by an IMU and the sensors GPS, DOLOG, Compass, Pressure and – if required – CTD.

The quality of navigation can be further improved by the use of sea bottom information like objects with known positions.

The rationale for the basic requirement of a high navigational and positional accuracy is that for any inspection task, the crucial ability of the system is to re-locate a detected anomaly at any time in the future. High quality and expensive and expensive doppler-supported inertial navigation systems, today used in large AUVs, have a position drift of few meters per hour mission time. For the type of missions envisaged for *SeaFox IQ* and *SeaWolf*, as discussed here, a higher accuracy level is required. This is achieved by the integration of further sensor information. A natural kind of the data enrichment is a bottom picture-supported navigation (on basis of acoustic and optical sensor technology). This support to this higher level of positional accuracy is available with high probability as the vehicles move predominantly in areas with a multiplicity of very characteristic objects. Picture-supported navigation is applicable in gradations of different quality of the a priori information. The presence of a detailed electronic map of the area to be inspected with characteristic objects and its known absolute position approaches an optimal solution. Such a detailed bottom picture may only be available for high traffic areas such as port and harbour approaches, port and harbour infrastructure, (piers, berthing areas, jetties, etc.). For other lesser-used and lesser-charted scenarios, a clear increase of the navigation accuracy (short and long-term) may be attained even for a priori completely unknown (absolute) object positions. These are the so called SLAM (Simultaneous Localization and Mapping) or CML (Concurrent Mapping and Localization) procedures. The application of these procedures requires prior knowledge and input of the detailed characteristics and performance of the imaging sensors.

- Automatic Anomaly Detection and Classification

  As previously mentioned, the UUVs *SeaFox* and *SeaWolf* may be equipped with a fibre-optic cable and therefore used as hybrid AUVs, in that they operate autonomously, as in a fully automatic mission, but with on line data transfer. The optimum mode of operation, total autonomous or hybrid, for the best results of any particular scenario, may not always be obvious. With increasing complexity of the mission, as in the case of an inspection of complex three-dimensional structures, the risks for a successful autonomous mission will increase substantially. To overcome this uncertainty in mission planning and potential of unsatisfactory results, it is possible to use a fibre-optic cable connection whereby the employment of an adaptive autonomy can be beneficial in ensuring mission success. This means that the level of the autonomy is adjusted during mission planning on the basis of mission tasks and the environmental situation. Such adaptive autonomy missions naturally require varying degrees of operator support dependent on the actual situation. This is shown in principle in Fig. 5.

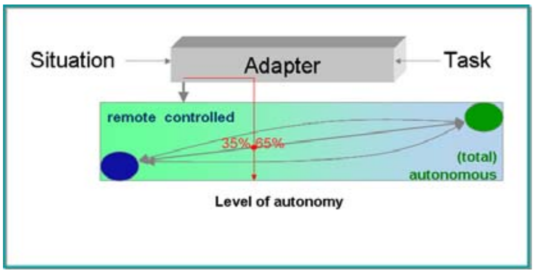

Fig. 5: Adaptive Autonomy

The principle of the onboard Automatic Detection and Classification system (ADAC) is shown in Fig. 6. The ADAC module consists of the components

- generation of geo-referenced sonar images
- detection and pre-selection of relevant objects,
- feature extraction and
- classification.

Input to the ADAC system are the raw, unprocessed sonar sensor data such as side scan sonar. In the first step, a geo-referenced sonar image is generated. It serves as the basis for the following detection and pre-selection steps. Pre-selection is implemented in order to reduce the number of detected objects and thus to limit the computational efforts and time consumption for the successive steps. After feature extraction and classification, the contact data for each classified object, namely:

- features
- position
- classification result and
- the sonar image of the classified object

are stored and transferred to the vehicle's guidance system. The contact data will also serve as input for mission re-planning measures.

- Co-operation Capability
  Today, scientific and military users demand systems composed of multiple underwater vehicles. Each vehicle has to be able to play a different role during the progress of the mission.

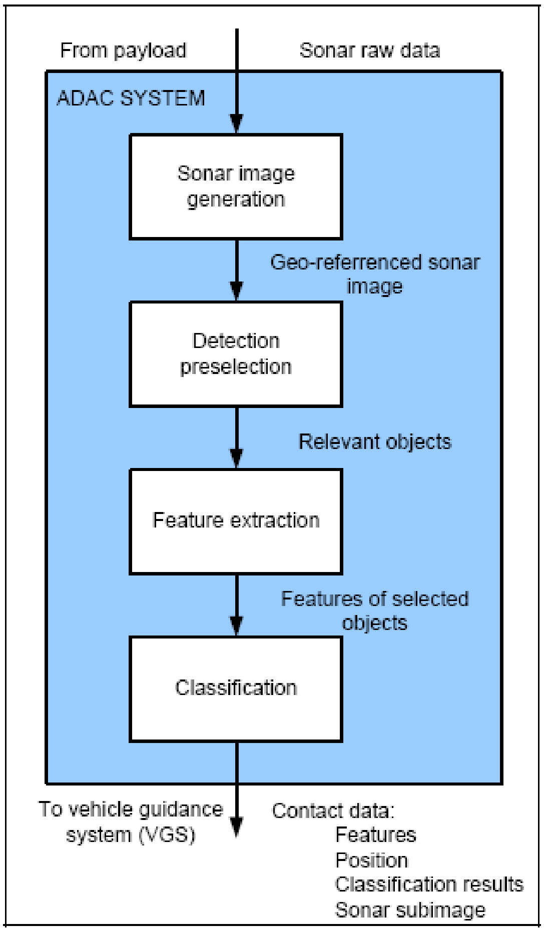

Fig. 6: ADAC system concept

They form specific nodes in a network with its own sensors, processing, and communication capabilities, thus combining the properties of heterogeneous systems into a more capable team, such as:

- vehicles intended for searching operations could re-direct vehicles equipped with manipulators to extend their scope of activity to rescuing missions;
- some vehicles could monitor other systems at work to record the operations using video; or
- some vehicles could serve as navigation aids or communication relay stations.
- Multiple vehicles also allow surveying larger areas in less

time, simultaneously obtaining time and space resolutions that are otherwise unachievable.
- Combining vehicles into a team will make research more effective and will lead to completely new applications.

Such a cooperative capability for the presented UUVs is currently under development at ATLAS Elektronik. The challenge of this project is to establish and realize technologies for networked and co-operating heterogeneous unmanned vehicles:

- A user-interface with underlying middleware to plan, check and distribute a co-ordinated mission and for post mission analysis
- A generic control system for coordinated control of multiple objects in an uncertain environment including aspects of mission alterations on the fly and triggered action
- A swarm navigation solution which enables team members to estimate the position within the swarm as basis for coordinated control and communication network
- A generic communication middleware, which enables heterogeneous vehicles to communicate with each other by LAN, radio and underwater acoustic communication.

Fig. 7 shows the relevant software modules.

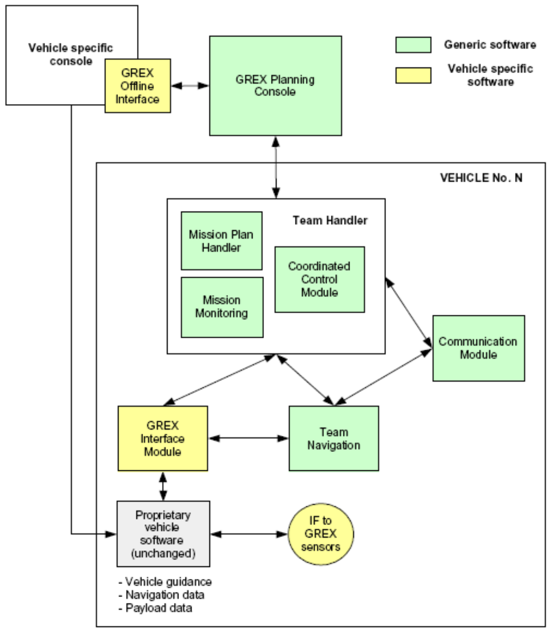

Fig. 7: Software modules overview

THE UUV SURFACE STATION

For the necessary performance of mission planning and control, the *SeaFox* and *SeaWolf* systems use a comprehensive and special software package to realise the following features:

- An optimum mission route usually along complex 3D-structures.
- Obstacles, and/or anomalies within the investigated area which have to be inspected at a necessary closest range, mapped and avoided.
- Visualization of the received and suitably processed inspection images for the observer. This serves different purposes;
  - on the one hand the observer has to be able to evaluate the inspection results and the discovered anomalies. Therefore he has to have the capability to move as freely as possible through the 3D- scenario in order to take a suitable point of view and distance to the object or the anomaly.
  - Secondly it must be possible to arrange and present the object/anomaly in the total scene. Only this combination of

visualisation presentation gives the observer the possibility for a definitive anomaly evaluation.

- Finally, support for the creation of a database of the detected objects and anomalies.

Fig. 8 shows the fold-out, transportable and splash proof operator console usable for all ATLAS UUVs shown in Fig. 1.

Fig. 8: Surface station

MISSION EXAMPLE – HARBOUR SECURITY

Introduction

Ports and their serving waterways are the nerve centres of the international logistics networks. More than 90% of the world trade is carried by sea transportation and more than 80% is accomplished with 46,000 ships operating in some 4,000 ports. The smooth operation of this critical transportation network is seriously dependent on the technical functionality and security of its terminal nodes, the ports and harbours. In the underwater domain, today's controls and inspections are accomplished predominantly by divers. Frequently encountered poor visibility and cold water conditions and other underwater hazards make the diver’s task very difficult, sometimes incomplete and sometimes, not at all possible.

Fig. 9 shows a typical port scenario with its complex and widely-dispersed structures, more or less not possible to be fully inspected by divers.

Fig. 9: Typical harbour scenario

Port and harbour underwater areas requiring constant attention are:

- Ships, vessels, cruise liners, etc.
  - investigation of damage and marine growth
  - searches for the attempted transportation of illegal goods
  - searches for attached explosive items
- Harbour facilities
  - sheet pile walls
  - floodgates incl. rails
- Neighbouring areas susceptible to damage and attempted terrorist attacks are
  - drilling platforms, both active and in the decommissioning phase
  - offshore wind-powered devices and dams
  - facilities in rivers and channels
  - tidal and current-driven power stations.

Potential underwater intruders are e.g.:

- Swimmer and diver
- Diver with scooter

- Vessels, ships, etc. with explosive devices/weapons
- Unmanned Underwater Vehicles (ROVs/AUVs)
- Trained Mammals etc. with IEDs
- Mines (drifting, moored, bottom, proud, buried, limped).

The difficulty to detect such a dangerous object is shown as Fig. 11. Here a relative big object, a Manta mine is shown after one week in the water. The detection is not easy, even as depicted here in clear water conditions.

Fig. 10: Manta mine after one week on the sea bottom

Moreover, the signature of potential intruders which are able to deliver such explosive agents, is not always high enough for easy detection as shown in Tab. 3.

Characteristic	SDV	Assisted Diver	Free Diver	Marine Mammal	UUV
Speed	6kts	2kts	.5	15kts	6kts
Manoeuvrability	Medium	high	high	Very high	high
UWnoise	medium	low	low	low	medium
Target Strength	-15dB	-20dB	-25dB	-25dB	-15dB
Magnetic Signature (@ 6m)	20nT	10nT	0	0	20nT
Electric Signature (@ 1m)	90mA	60mA	0	0	120mA

SDV:= Swimmer Delivery Vehicle

Tab. 3: Typical intruders

Inspection Examples

All segments of the underwater investigation challenge are important, but a most critical task is the inspection of 3 dimensional objects pertaining to ships or harbour facilities. Fig. 11 shows two submarines, laying in the water since some years on the same place and equipped with improvised explosive devices (IED) at unknown positions.

Fig. 11: Submarines, ready for hull inspection

The underwater situation is clearly shown in the following pictures. Fig. 12 presents a part of a submarine propeller, taken by *SeaFox's* TV camera, not cleaned for many years and overgrown with mussels.

Fig. 12: Part of the propeller

Fig. 13 shows the same propeller with an anomaly (marked). The distance between the TV camera and the anomaly has been closed to less than 2 m due to the underwater visibility. It is clear, that an automatic detection of such an object is extremely difficult and can be achieved only with multi sensor processing by using in this case, TV with laser and 3d high resolution sonar.

Fig. 13: Attached anomaly

The same anomaly, recorded at a very short distance is shown in Fig. 14.

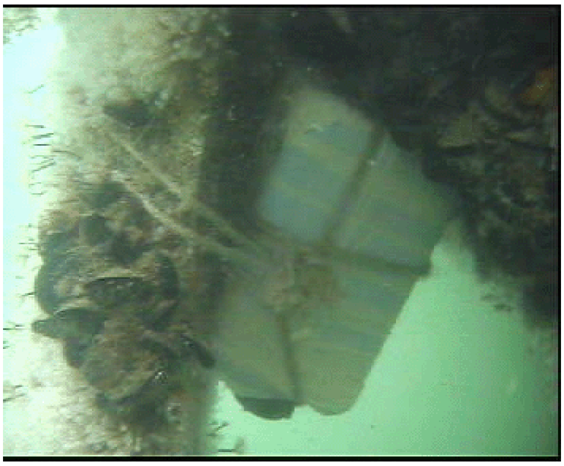

Fig. 14: Identified anomaly

Equally problematic is the detection of dangerous objects on the sea bottom in port and harbour areas. An example for this shows Fig. 15. The challenge in such areas is that they normally contain large quantities of unknown objects in which dangerous objects can be easily hidden. A sea bottom search using the "change detection algorithms" is a practical solution to enhancing performance for a successful inspection in such situations.

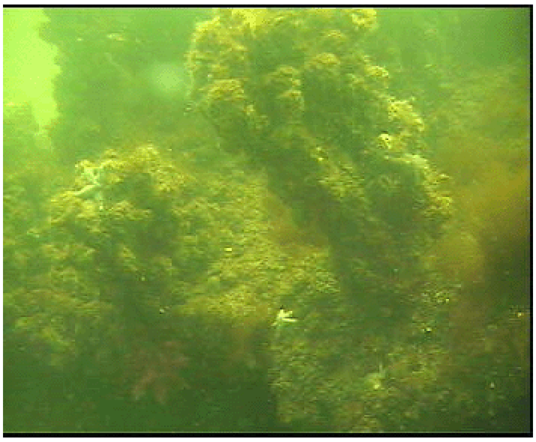

Fig. 15: Unknown object on harbour bottom

CONCLUSION

The environment for harbour inspection is extremely non cooperative. Major difficulties which have to be taken into account and solved include at least:

- High traffic density, high probability of collision
- Confined operating space
- Sea bottom sand ⇔ silt
- Changing tides and varying currents
- Uncharted obstacles or unknown objects potentially in large quantities
- Noise
- Visibility
- Plant life.

Hence, a successful underwater inspection for autonomous detection of anomalies in such an environment is an extremely challenging task, for which ATLAS ELEKTRONIK has developed the *SeaWolf* AUV. The vehicle has the possibility to carry the appropriate sensors for this environment, provide the high manoeuvrability and navigational accuracy as well as the software for vehicle guidance, intelligent mission management and multi sensor processing .The *SeaWolf* highlights are:

- Relatively light weight and highly-modular UW vehicle
- Efficient propulsion and hover capability
- High speed and excellent manoeuvrability

- Mission planning on digital sea chart
- Execution of any defined missions
- CML navigation (under development)
- Terrain following or flight in constant depth/height above ground
- Data logging on board and replay on surface console
- Flexibility to use different sensors suites
- Optional HAUV function.

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