Planned research using autonomous underwater vehicles in Iceland

Gunnar Stefansson [1]
gunnar@hi.is
University of Iceland

Abstract

Several applications have been submitted for the purchase of a first autonomous underwater vehicle and for its use for various research purposes at universities and research institutes in Iceland.

The research to be conducted using the AUV is described in this paper along with the selection process and maintanance.

Obviously the AUV will be utilized for research in marine biology, particularly on the benthos but also for fish and various mapping projects, including hydrothermal vents. In addition the AUV will lead to extensive research in various fields of science and engineering, from mapping and stock assessments to methods of image processing and control theory. It is hoped that this and subsequent AUV-related research projects will become a catalyst for cross-discipline research cooperation and forge a link between science and industry.

[1] Note: Gunnar Stefansson is also chairman of the Board of Hafmynd

1 Introduction

This communication is a part of a grant application for funding an Autonomous Underwater Vehicle (AUV) for marine research. The AUV will immediately be used for research on the ecosystems of Faxa Bay, Breidafiord, Eyjafiord, Huna Bay and at the Vestman Islands. In addition a research project on automatic image processing will be based on images from the AUV and the AUV will be used for several projects currently on the drawing board. It is expected that this initial purchase will lead to further developments in AUV-based research as well as research on AUV technologies and thus that this initial application for AUV purchase is only the first of several such applications.

AUVs are used for marine research in several countries but also when searching for objects (and people) at sea, bathymetry and generally mapping the seabed. Specialized AUVs have been developed for Mine CounterMeasures (MCM) projects, others for underwater photography and still others are designed for hydrographic measurements. The emphasis in this proposal is on an AUV which will be suitable for photography and for general investigations of the seabed to a depth of up to 500m with a variety of choices of modules. Later options include hydrogaphic research, higher-quality photographs or sub-bottom profiling.

As seen from the list of research partners in this proposal the AUV will be of use for several research projects, strengthening some and starting others.

Figure 1: The Gavia AUV, total length 2.6m with the modules proposed here (counting from the right): Nose cone, battery module, GeoSwath, DVL, INS, control unit with tower, propolsion module.

The AUV in question has the product name Gavia and is produced in user-interchangable modules. Thus the used can put together different AUVs depending on the project. A basic AUV contains the propulsion unit, a control module (containing the central computer as well as communications with other modules and land station), battery module and nose cone (with optional camera). The control unit normally comes with a side scanning sonar since sonar images are generally more useful than photographs due to the poor transparency of sea water. Other project-dependent modules will be added in future projects.

This proposal contains a detailed justification for this purchase. An analysis of requirements is in the form of a short description of each research project (section 2) along with an explanation of why the particular instrument is required for the project.

The particular choice of modules (in Fig. 1) is described in section 3 and this is based on the research in section 2. Extra modules not needed in these particular projects are of course not described here. For example this proposal does not include accurate salinity or temperature measurements. It should be noted that this proposal only includes modules which have already been produced for other customers and are in use (in other countries). Thus there is no actual development work in the equipment per se.

Section 4 contains a comparison with other known technologies and an explanation of why this particular AUV needs to be used. In short this is of course because this particular vehicle is composed of the modules which can undertake precisely the tasks required by the research projects described.

Given the short summers in Iceland it is important that the AUV be in working order during the entire summer and thus one needs to consider reliability issues. Section 5 deals with reliability of the equipment package as a whole (the "system"), which includes spare parts - and justifies the purchase of additional modules as spares. A separate document on reliability issues is available.

Figures in this report are either courtesy of the producer of the equipment or from researchers using the Gavia. They are intended to illustrate that the features mentioned in this report are indeed available and the research indicated is feasible. In two places in the report it is suggested the research project indicated has a highly uncertain outcome and may not yield useful results and this is indicated. In all other cases the methodology has been tested but of course not on the species/ecosystem/geology/engineering task in question.

2 Research projects

The research which will initially be conducted using the AUV will be related to the bottom fauna in several areas around Iceland.

2.1 Benthos research on the Icelandic shelf

Knowledge of the ecosystem on the continental shelf has increased considerably as a result of a single large benthic research project (BIOICE) which is organized by the Ministry of the Environment with the participation of the Marine Research Institute, the Nature Research Institute, the University of Iceland and the village of Sandgerði along with experts from several countries as well as graduate students (150 persons). Samples were taken at almost 600 stations at depths ranging from 20m to 300m.

This research project has, however, mainly been based on samples taken off a soft bottom since it is more difficult to take samples off a hard bottom. Information is therefore lacking from areas where a hard sea floor is dominant.

Several interesting research projects[2] have started or are in preparation as a direct or indirect continuation of BIOICE where AUV technology will be very useful. This includes the Nordic project Deep-west, which aims at investigating the deep-sea community structure off Iceland with an emphasis on sponge bottoms and effects of fishing. The AUV will also be useful for the continued geothermal research in the Skjalfandi Bay, the community on a hard sea floor at Vestmannaeyjar to name only a few.

Another continuation of BIOICE will most likely consider the inshore ecosystem around Iceland. It is highly likely that the Gavia will be used extensively and be one of the main instruments in the project.

2.2 Crab research

A crab species of the *Cancer* genus was recently found for the first time in Icelandic waters, but this species has been utilized earlier in Scandinavia and around the British Isles. Research on this species in Icelandic waters started in 2007 and the research is founded by the Ministry of Fisheries. This research forms a part of two MSc projects at the Dept. of Biology at the Univ. of Iceland[3].

The AUV will most likely be important when investigating the distribution of this crab species off the south-west and west coasts, but this crab has so far been found off the Reykjanes peninsula, Hvalfiord and Breidafiord. The AUV will also permit estimation of crab density and from this estimates of sustainable yield will be obtained, since this is likely to become a harvested resource in the near future.

2.3 Stock assessment of scallop in Breidafiord

A ongoing pilot project[4] on assessment of scallops using an AUV has already been funded by two grant agencies. The possibilities of using side scanning sonar (SSS) and photograps from an AUV are being investigated in this project. The first photographs (Fig. 2) indicate that it is

[2] Coordinated by Jorundur Svavarsson
[3] Coordinated by Jorundur Svavarsson
[4] Coordinated by Gunnar Stefansson

indeed possible to use an AUV equipped with a camera to count animals from the photographs and thus obtain a stock estimate. The methodology of going from photographs to abundance is well-established (see e.g. Stokesbury (2002)).

It should be noted that the common assessment methodology of counting scallops from a scallop dredge will only give indices of abundance whereas photographs can in principle give absolute abundance under certain conditions.

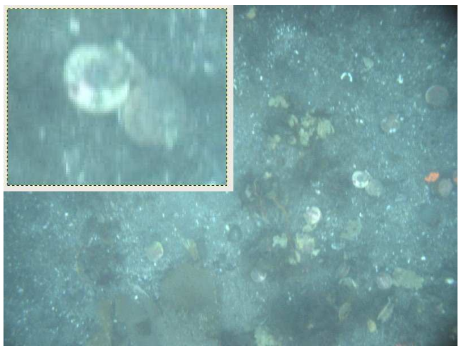

Figure 2: Scallops on a rocky bottom with an enlarged photograph of two animals, taken with standard Gavia equipment (color camera)

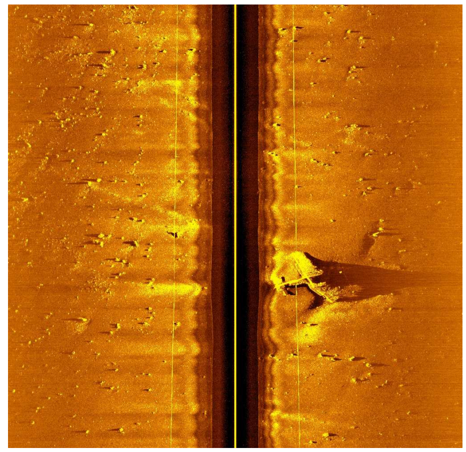

Figure 3: Typical sonar image taken with the Gavia 900 kHz side scanning sonar with a 30m range setting at approx. 3m altitude. Note the airplane wreck

Figure 2 of scallops on a rocky bottom shows that although scallops tend to be easily identified it would be desirable to have a high(er) quality camera in order to identify e.g. smaller scallops amongst rocks, not to mention dead scallops from live ones. This is a separate R&D project (selecting and mounting a new camera and flash in a Gavia AUV and connecting it to an on-board computer). The proposal under discussion is for the purchase of an off-the-shelf product so the development of a camera module is outside this proposal, but will be applied for separately.

Further research is needed to determine whether and how well scallops can be identified from the side scanning sonar. The SSS scans a much wider area than a camera and thus it would completely change the costs involved in an assessment. Equivalently, if the SSS can be used, a much more accurate assessment can be obtained at the same cost since the data collection is usually by far the greatest expense in any assessment. There are some indications that this may be a feasible approach (Kostylev et al. (2003)) and therefor such experiments are planned for scallops around Iceland. Although a SSS has been used in multiple projects such as when searching for people, sunken ships and airplanes (Fig. 3) such uses have usually been at low frequency and from the surface or high altitude. The use of a high-frequenccy SSS in an AUV sailing close to the ocean floor should be a feasible option to obtain the kind of precision required for species identification of shells on the bottom.

The AUVs considered here can not take biological samples, e.g. for age readings. However, for assessment purposes it has been found that scaled length distributions of the resource come close to providing the same information on abundance, particularly if the recruiting yearclasses are identifiable in the length distributions (Taylor et al., 2007).

The above first pilot study was undertaken using photography from an AUV over a "clean" area where scallops had been planted. The next step is to investigate how easy it is to identify live scallops from dead using a camera and/or a SSS on active fishing grounds. For this one needs access to an AUV over some time, but this can be done from land or from a small rubber dhingy.

2.4 Common whelk

The common whelk has been harvested in Breidafiord almost continuously for a decade. Considerable knowledge has been obtained on the biology and distribution of the common whelk in Breidafiord[5].

In 2007 research into the common whelk in Breidafiord was restarted[6] with the purpose of investigating in detail the life cycle of the animals, including the size at maturity, growth rate, stock identification, spawning seasons and regional variation in the biology of the common whelk. In addition research was initiated on the distribution and density of the common whelk in Breidafiord. During these investigations (funded by the Ministry of Fisheries) a camera mounted on an ROV (remote-operated vehicle) has been tested. It was found that this setup is not ideal for estimating the number of animals per unit area to any level of accuracy.

Other methods which have been used to obtain stock indices include counting the number of animals per trap. This may give reasonable indices which can be compared between areas and years. On the other hand the trap contains bait and hence it is difficult to convert such measurements to abundance measures since it is not clear what area should be attached to the catch.

The purpose of common whelk investigations using an AUV for photography in Breidafiord is to obtain density information independent of the mobility of the animals, currents or other outside factors. In addition to quantitative information on density, the photographs will be used to obtain information about the common whelk habitat.

2.5 Bottom structure of Breidafiord

Figure 4: Sandwaves on the ocean floor, picture taken with a Gavia camera.

Figure 5: Rocks on a sea bed, picture taken with a Gavia camera.

It is of considerable interest to investigate the sea floor structure in Breidafiord in order to better understand the distribution of species such as the common whelk and scallops.

[5]From eaerleir research conducted by Solmundur Tr. Einarssonar in the shallower part of the fiord in 1993 as well as analyses of the catches in the fiord during the years 1998-1999

[6]Coordinated by Erla Bjork Ornolfsdottir

Investigations of bottom structure are of interest for several reasons, but here the main reason is the desire to classify the bottom into groups corresponding to the habitat of different species.

Many techniques can be used to classify the sea floor, but the technically simplest is to take photographs and hand-classify each picture. This technology clearly exists and there is no uncertainty in this being possible (cf. Figs. 4-5). For a large collection of photographs the classification could e.g. be based on a subset of these or be based on automatic methods using measured properties using the entire collection.

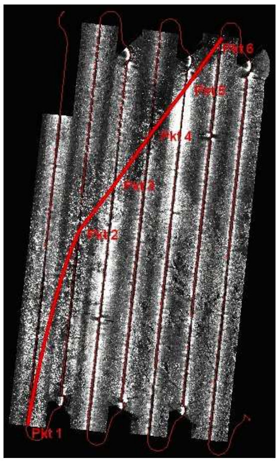

Figure 6: Example of complete coverage using a side scanning sonar: The bottoom of the Ulfljotsvatn lake, scanned with the Gavia SSS.

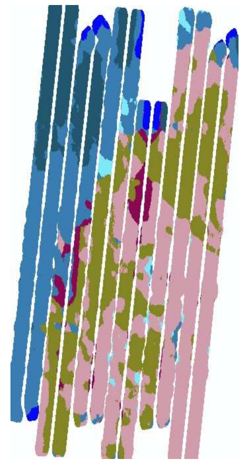

Figure 7: Example of the use of a classification algorithm on SSS data: Classification of bottom areas in the Ulfljotsvatn lake. Courtesy of Questar Tangent.

It is considerably more interesting to use methods which use side scanning sonar data since the SSS continuously scans a much wider area than the camera (cf Fig. 3). If a high-frequency SSS is used from an AUV, this will result in much more detailed images (cf Fig. 6) than those normally obtained from the surface.

Such images can be put through a classification algorithm[7] in order to classify habitat (mynd 7). Several such algorithms are commercially available but they are also a standard part of any statistical package[8]. This can be done after some preprocessing of the original images to obtain numerical measures from subregions of each image.

When used alone an "unsupervised learning" or statistical "clustering" algorithm is used. However, when used with data on species occurrence (from photographic images) a "supervised learning" or statistical "discrimination" algorithm can be used.

2.6 Geothermal vents in Eyjafiord

Marine research at the University of Akureyri has mainly focussed on the biology of Eyjafiord. Research projects include geothermal vents in the fiord within the inlet of Arnarnesvik. It is likely that these vents are a part of a system crossing the fiord past the town of Grenivik.

Individual small parts of this system have been mapped using a multibeam echo sounder on board

[7] Commercially available from http://www.questertangent.com/default.aspx?PageID=1023

[8] Freely available in the R package, http://www.r-project.org

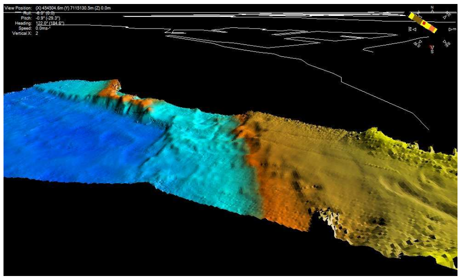

Figure 8: A part of Reykjavik harbor mapped using the GeoSwath in a Gavia.

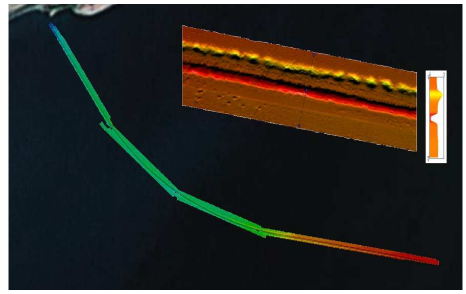

Figure 9: A submarine trench, dug out for an oil pipeline in the Caspian Sea. Measured during a pre pipe-lay survey for an oil pipeline in the Caspian Sea mapped from a Gavia-mounted 500 kHz GeoSwath Plus.

large vessels. The resulting images give indications of the bottom topography in the fiord but so far there is a lack of coverage with respect to the entire system of vents in the bay. The plan is therefore to have the AUV sail back and forth across the bay to map the entire system of vents.[9]

It is fairly easy to obtain three dimensional images of a region of the type mentioned here. In fact this is fairly comparable to excercises such as when images were obtained of a long ditch in the Caspian Sea (Fig. 9) and Reykjavik harbor (Fig. 8) as well as several other locations such as Baku harbor and the underside of an ice berg in Alaska.

The technology is thus ready and the investigations should be possible without technical development.

2.7 Cod spawning behaviour

A project on cod spawning behaviour is currently funded by two grant agencies. This project will use the Gavia to investigate the bottom topography and attempt to investigate cod spawning behavior in Thistilfiord as well as off the south-west coast of Iceland.[10]

This project is intended to map the biological diversity of cod with an emphasis on behavior in relation to spawning and migration.

For investigation the bottom topography the Gavia can be used with either method described earlier, i.e. the GeoSwath or using a traditional SSS as described above along with a classification algorithm. The implementation depends on whether the emphasis is to be on graphical representation or classfying habitat. In either case the methodology is fairly well established.

In addition to this a known spawning ground will be selected and investigations will be undertaken on whether it is possible to photograph spawning cod using an AUV. Of the projects in this report, this is the most uncertain one and the one with the most novelty. It is likely that the AUV will need to be sent in the direction of a spawning aggregation and sail over the aggregation, under it (upside down) and even on the side, taking pictures continuously.

Methods for sailing on the side and upside down have been developed earlier, cf fig 10. The risk here is not mainly technical but rather with regard to fish behaviour in the presence of an approaching AUV,.

[9]Coordinated by Hreidar Thor Valtysson
[10]Coordinated by Gudrun Marteinsdottir

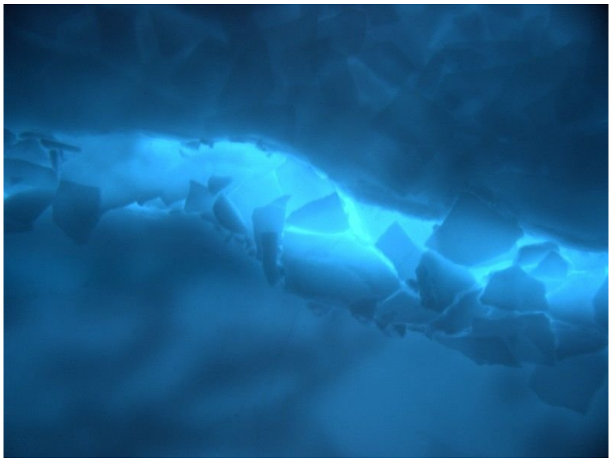

Figure 10: Photograph, taken upwards from a Gavia sailing upside down under ice.

2.8 Increasing the profitability of the nephrops fishery

A project designed to increase the profits of the nephrops fishery in Iceland currently recieves grants with the goal of finding factors which affect the quality of the shells, muscles, stock size and habitat.[11] The habitat will be inspected using the AUV in a manner similar to that used for scallops and the common whelk.

Underwater photography is a well-known technique for investigating nephrops areas (Tuck et al., 1997; Morello et al., 2007) but the camera which is traditionally on a sled, tether or frame will here be in an AUV.

2.9 Image processing

An AUV with a camera can collect images of considerable quality, almost continuously or at least in such a manner that every object appears on at least two pictures. Such data gives the options of investigating and seeing objects on the sea floorin several ways. Notably it is possible to used classical techniques from geography to make "three-dimensional" (steroscopic) visualisation(Axelsson, 1998; Petrovic, 2001), viewing two images simultaneously through special glasses.

In this project[12] the emphasis will be on methods to identify objects of a specific type from a sequence of photographs taken from an AUV. Initially the emphasis will be on scallops since these shellfish are readily recognized by their shape. The project is aimed at developing methods which can be used in real-time within the AUV. These idea are not new (Johannsson et al., 2006) but have not been carried through into fully developed algorithms.

A grant application will be filed for a PhD student to take on this project.

[11] Coordinated by Gudrun Marteinsdottir

[12] Coordinated by Thordis Linda Thorarinsdottir

2.10 Lumpsucker research in Huna Bay

A separate grant application has been submitted for the use of an AUV for investigating the lumpsucker spawning grounds in Huna Bay off northern Iceland.[13] As described above, the techniques in this project have been fairly well established.

In addition to investigating the spawning grounds the AUV will be used to photograph large parts of the lumpsucker spawning grounds in the bay. As with the cod spawning investigations, this part of the lumpsucker project is highly risky as it is not at all clear whether reasonable images can be obtained in this manner. Similarly it is not obvious whether the lumpsucker will be identifiable in the SSS images. This will be the first attempt to obtain measures of density of a fish stock using a camera and a side scanning sonar on board an AUV. If the results are positive, the potential arises for automatic and non-intrusive monitoring of non-benthic species at a much lower cost than normally seen with marine surveys using acoustics or demersal trawling.

2.11 Control theory

The control theory for an AUV is a very interesting area of research as witnessed by the activity in this field (Antonelli, 2004). This is an ongoing project[14] and further grant applications will be submitted to continue earlier research at the University of Iceland (Thorgilsson et al., 2006).

2.12 On the AUV technology and the use of the Gavia as a basis for research

AUV technology has been investigated quite a bit as a vehicle for marine research. (Fernandes et al., 2002, 2003; Desa et al., 2006), including bottom topography (Johannsson et al., 2006). The suggested use of the AUVs is as wide-ranging in the litterature as is seen in this proposal,

In addition to marine research it is of interest to use an AUV for engineering research. Several universities already do this and it is commonly considered useful to have an AUV to study it. develop and test new techniques as seen e.g. by Griffiths and Edwards (2003) who investigate the next generation of AUVs, Lee et al. (2007) investigate the potential of AUVs in aquaculture and Madhan et al. (2007) who design a new AUV.

Once an AUV is available several specialized issues become research projects such as methods regarding image processing (Smith and Rumohr, 2005) along many other fields and the AUV even enters the arena in astrobiology (Bruhn et al., 2005).

The AUV discussed here has already been used in a variety of situations and its properties have been discussed in most of the above references (but see also Thorhallsson and Hardason (2003)).

From this it should be clear that it is a very interesting option for the research community in Iceland to have its own AUV. This is not only for the purpose of solving the research issues mentioned in this proposal but also to have the AUV as a general basis for pulling forward methodologies in statistical image analysis and software development, control theory etc. It is highly likely that this technology will become a catalyst for new research in several different fields and lead to novel cooperation of research groups.

This approach will also lead to increased cooperation amongst researchers at different universities as well as further link university research to the private sector. Indications have already been seen

[13] Coordinated by Halldor Gunnar Olafsson
[14] Coordinated by Anna Soffia Hauksdottir

of this (Thorgilsson et al., 2006).

3 The choice of modules

The research projects decribed in section 2 have several issues in common. They are best conducted with an instrument which can cover a fairly large area, but normally smaller than an entire bay. Better precision or resolution tends to be obtained with equipment which is close to the bottom rather than at the surface and large vessels or long sailing distances are not required. All the projects can be handled through the use of an AUV. In spite of the common issues the projects require different instruments on board the AUV.

Only one AUV on the market is designed so that the end user can use different modules depending on the task at hand - this being the Gavia produced by Hafmynd. Thus, depending on the project different modules are selected, such as the GeoSwath sonar (giving three-dimensional views), a camera, salinity measurements etc. The following therefore gives a description of how one can select modules to handle the projects in this proposal (section 2). Section 4 subsequently gives a comparison with other technologies and other producers.

The choice of spare modules is described in a later section.

3.1 The base AUV

A base AUV needs to have a nose cone, battery module, control unit and propusion moduls in order to function.

The nose cone contains a camera but the corresponding strobe is attached near the rear of the AUV in order to diminish reflection from silt or floating organisms.

The battery module stores the charge required for 4-6 hours of operation, depending on the activity.

The control module contains computers, communications equipment and the side scanning sonar. The computers coordinate the planned cruise, the various pieces of equipment and communication with land or between modules.

At the surface the AUV communicates with home base using a wireles LAN unless the distances are too great in which case text messages using an Iridium phone are used. An acoustic modem is used for communicating underwater, if desired.

Positioning while at the surface is obtained using GPS, but the vessel subsequently sails between points using a compass unless more accurate positioning equipment is placed in the vessel.

The propulsion module contains the electric motors, gears etc for propulsion, steering and so forth.

3.2 More accurate positioning and three-dimensional maps

Investigations into bottom structuree or special underwater formations require three-dimensional information. The GeoSwath [15] is specially developed for this purpose. The same piece of equipment is commonly used from a surface vessel, but by placing it in a AUV one can obtain more accurate images since the AUV sails closer to the bottom for higher resolution.

The GeoSwath requires highly accurate positioning, e.g. since bands from different swaths need to be joined, but also since corrections need to be made for any drift in the AUV. A composite

[15] from GeoAcoustics, http://www.geoacoustics.com

technology, INS/DVL is used for this purpose and this comes in a specially designed module. The interferometric methodology used in the Gavia, GeoSwath, appears to be accurate enough for general high-quality bathymetric measurements (Gostnell et al., 2006)), although this kind of accuracy is not required for the projects described here.

The AUV described in this proposal is to be used for three-dimensional mapping and hence one INS/DVL module and one GeoSwath module will be included.

3.3 Additional modules

The only "additional module" in this proposal is an extra battery module. This module will be used in order to be able to charge one module while another is in operation. With this one can obtain full working days with the AUV, considerably enhancing its potential.

The two battery modules will be used interchangably. Naturally this also implies that each is a spare for the other and one will not encounter weeks of delay even if one breaks down.

3.4 Spares

The single greatest concern is related to malfunctions due to handling or sailing into hard objects (see section 5), since these are sensitive instruments and it is known that the failure rates of AUVs can not be ignored (this appears to apply to all products from all suppliers). The effect of failures can be made negligible by having spares of those modules with the highest failure rates. For this reason it is proposed that in addition to the basic outfit described above, a control module, nose cone and propulsion module will be purchased as spares (see section 5).

With this choice of modules there will always be spares unless the GeoSwath or DVL/INS modules fail when they are to be used. These modules are simply too expensive to justify their purchase as spares, particularly since they are only essential for one specific type of research, i.e. when three-dimensional images are required. Given their reduced use compared to the other modules, these should also have a lower failure rate.

The control module is the most complex module of the entire set and the battery modules by its nature is under considerable stress, not to mention the propulsion module with its moving parts and the nose cone which is the first point of impact. Finally, these modules need to be available for all projects making them mission-critical and high-use, advocating the existence of spares.

4 Competitive options

This section compares the different technologies available and justifies the use of an AUV in general and the Gavia in particular.

The research projects described in this document will use photographs or sonar images (side-scann or interferometric) to investigate living creatures on the sea floor or the bottom topography on fairly large areas. A variety of technologies has been used for these and similar uses but only one technology applies for regions of the size in question.

Sonar and photographic images are captured by instruments on board surface vessels or underwater equipment. Unmanned underwater vehicles are mainly of two types, remote operated vehicles (ROVs) or autonomous underwater vehicles (AUVs). Each of these approaches has it virtues and problems and each is optimal in specific circumstances.

4.1 ROV

In order to photograph a small area at some depth far from shore one first needs to get to the location using a surface vessel and subsequently to send down a camera (and a flash/strobe). ROV-technology is specially developed for this scenario and is generally applicable when the purpose is to obtain high-quality photographs of very small areas. The ROV is connected by cable with a vessel or land and needs considerable power but precisely for this reason it is possible to attach power-consuming instruments such as a powerful strobe.

An ROV is not usually applicable when investigating a larger region or if an accurate position is required for measurements at sea or if the instrument needs to be stable at sea (e.g. precisely vertical). The reasons for this are the tether and the steering mechanisms. An ROV does not normally include positioning equipment except as obtained from the surface vesses[16]. This usually implies that if the camera is sent away from the surface vessel then the accurate position is lost. On top of this one needs to add problems associated with keeping the surface vessel steady and not drifting. The result is that it is exceedingly difficult to obtain highly accurate positioning as is required for some applications (e.g. anything related to bathymetry, including three-dimensional mapping) unless a very expensive ROV is used.

If the location of a specific geothermal vent is well known the ROV approach is of course applicable. Thus a surface vessel will carry the ROV to the appropriate location, the ROV is sent down and high-quality pictures are taken while the equipment is manually kept in a specific position using to a live camera feed. On the other hand if the task at hand is to scan a typical fiord or large part of it (e.g. the geothermal vent system of Eyjafiord), the ROV is not the right piece of equipment since the typical ROV does not have any means of following a specified track, knowing its exact position while travelling or maintaining a fixed height above the sea floor.

For the same reasons an ROV is not the instrument of choice for stock assessment of benthos (or fish), whether with a camera or acoustic means. In this case, in addition to positioning issues, the cameras on an ROV generally point forward, i.e. in the direction of travel, but for assessment purpopses it is crucial to take pictures in a downwards-facing direction in order to count animals within a rectangle of a known size.

The use of a camera attached to an ROV has been tried for stock assessment of the common whelk and it turned out that the ROV was not suitable due to instability combined with the forward-facing camera. This is easiest to see if one considers a camera which can photograph with a 90 degree angle. If the camera normally tilts forward at 30 degrees and the inaccurary in this tilt can

[16] In some this can be obtained as additional equipment

be 15 degrees, then the camera sometimes takes a picture straight forward with an infinite-size image. A downwards-facing camera will be much more stable with regard to the size of the image.

The conclusion of this comparison is that although ROV technology is optimal for some projects it is not applicable for the research projects in this proposal.

4.2 Surface vessels

Three-dimensional images have been obtained using acoustical methods (Tonchia, 1994), e.g. using a multibeam echo sounder, (Hammerstad et al., 1993) or interferometric techniques (Mallace, 2002) and used e.g. for imaging large portions of the Reykjanes Ridge (Keeton et al., 1997). In order to obtain images of very large areas such as the Reykjanes Ridge, it is fairly obvious that one needs large apparatus such as a large research vessel or a large (e.g. manned) submarine. The multibeam sonar in a research vessel is a well-known technology and it is also well-known that this is a fairly expensive technology. The base cost of the research vessels is typically measured in tens of millions of dollars and the cost of the instruments alone can easily be over a million dollars. The result is an extremely powerful technology for mapping large areas but at a cost which dwarfs the cost of the AUVs considered here.

The large vessels are inappropriate for coastal investigations for the same reasons: They are too large and expensive to run and tend to be difficult to operate in the coastal zone.

4.3 The choice of an AUV

The above implies that an AUV is by far best suited for the projects under discussion. A few companies manufacturee AUVs and they vary greatly in size, shape and capabilities. For example SAAB manufactures an AUV which weighs in at 620kg and AUVs may weigh up to two tonnes to reach a depth of 6km. For the research in this proposal, however, an instrument which can reach 500m is more than sufficient and it is highly desirable to have the option of transporting the equipment e.g. in an SUV and launch it from a pier, the shore or a small boat.

Two producers make such AUVs commercially, Hydroid[17] and Hafmynd[18]. The smallest Remus vehicles from hydroid are somewhat cheaper than the Gavia from Hafmynd but they are sold in fixed implementations and the equipment under consideration here is not all available for the Remus.

The choice of equipment must take into consideration several factors, starting with the type of investigation to be conducted but also the costs involved, maintenance and reliability. The price, maintenance and reliability is discussed elsewhere, but a comparison of the Gavia and the Remus quickly shows that the GeoSwath+INS/DVL combination is not available for the smaller Remus vehicles. The Remus vehicles become very expensive if they are designed for depths greater than 100m which is important for some of the projects here. Remus vehicles which can handle greater depths and can carry a GeoSwath are closer to weighing two tonnes and priced accordingly.

The single factor which clinches the choice of a Gavia over the Remus is the modularity of the Gavia: The Gavia is the only AUV which permits the user to insert modules appropriate to each task.

[17] http://www.hydroidinc.com/
[18] http://www.gavia.is/

4.4 Rentals

In place of purchase it is often possible to rent instruments and AUVs are no exception.

The daily rate of an AUV with an operator from Hafmynd is considerable. In fact, with this day rate it would take about six months of use to reach the price of the system proposed here. At the current time the company only has one vehicle for internal use, though several are under construction. This vehicle is used for all purposes, i.e. rentals, sales and marketing in addition to development.

Attempts to conduct individual smaller research projects in cooperation with Hafmynd, based on good-will or for payment have to date not been very successful. It is clear that projects can not be completed in any other manner than through hard contracts, either for rentals or purchase. The reason is simply that short periods of research can never have priority over a several-week rental agreement or a military exhibit with a potential sale of a dozen vehicles. In addition it should be noted that a vessel which is also used for development is not ideal for a short research project since a development vessel is by nature an unstable AUV.

The rental rates of Hafmynd are of course the rates which the company can use for general rentals. This is therefore also the lost revenue if the company were to conduct experiments with a research organisation. The rental rates are of such a nature that it is obviously beneficial to purchase a vessel rather than rent it. Given that the rental rate is comparable to the rates of other companies it is unlikely that one may be able to obtain better rates - apart from the fact that other companies simply do not have the equipment required with the GeoSwath being the obvious example.

4.5 Extensions

In addition to the above list one should note the extensibility. If a Remus or similar vehicle is purchased there are no options of modifications or extensions. On the other hand one can add modules for the Gavia to conduct new investigations. In particular one can purchase equipment for accurate salinity and temperature readings for hydrographic research. Similarly one can purchase a single control module for experimental work on control theory or a new nose cone to develop a different technology for photography. None of this is possible except with this specific choice of an AUV.

5 Reliability

The choice of equipment naturally needs to take into account the type of research to be conducted but also equipment reliability. The research to be conducted in this proposal will mostly be done from shore or from small research boats such as rubber dhingys. Such investigations can in some cases be done during winter but in Iceland it is imperative that one can utilise the equipment throughout the summer months when it is much more likely that weather will be favorable. It is therefore important that the entire collection of instruments (“system”) be chosen in such a manner that there is a minimal probability of e.g. losing several weeks to repair.

An AUV of the type described here is a very complicated piece of equipment. It is in the nature of complicated equipment that these break down, i.e. have a high failure rate. These instruments are commonly compared to helicopters and it is well known that if helicopter operators want reliability they tend to want to have more than one machine in order to guarantee the uptime of the “system”. The “system” is the collection of instruments available, including spare parts and/or spare modules and “reliability” (or “availability”) is the probability that an experiment can be conducted satisfactorily at the desired time.

The failures which will come up will be of a multitude of types. Some are simple and cause little inconvenience, e.g. routine replacement of movable steering fins. Such failures (which should probably be classified as wear and tear rather than a failure) are therefore not an issue regarding system uptime. Other failures are more of an issue and need to be taken into account.

Considerable experience has been accumulated on the AUVs sold by Hafmynd as several have been sold to end-users in addition to Hafmynd’s own use of vessesls for demonstration, in-house use and rentals. This use implies considerable transport using planes, cars and ships and a wide variety of uses on-site. In addition to general handling issues, the handling of delicate instruments by shipping companies is notorious and equipment may well arrive broken on-site just like other luggage. All of these issues will arise also with the equipment in this proposal and therefore this experience will be used when planning for increased reliability

Failures due to handling can be quite problematic and it is important to show considerable care in packaging. Although the AUV looks robust it must be kept in mind that the internals are basically a collection of delicate computers. Even with such care instrument breakdowns will always come as a part of shipping and handling including launch and recovery of the AUV. The important issue here is therefore to plan for failure and make sure that a three-week repair cycle does not stop research for three weeks.

A separate document details the reliability of different systems, with a variety of modules and different AUV constructs. It turns out the there is an enormous difference in uptime if there are two modules of the types which are mainly used. The difference is much greater than that which one would observe merely by having a spare of a non-modular AUV and the document explains the probabilities involved.

For these reasons it is suggested here that three modules be added for the sole purpose of ensuring reliability. With this addition (along with the extra battery module) the reliability is much greater and for this reason these three extra modules are considered a very important part of the system proposed here.

6 Operations

6.1 General

An AUV similar to the one considered here is used in a research environment at the University of British Columbia (UBC) and considerable experience has already been obtained from this use. The research is mainly conducted by a professor and a graduate student. This experience suggests that a reasonable model is to instruct graduate students in the use of the AUV and subsequently make them responsible for the instrument (along with the advisor).

The suggested projects for the instruments described here are more variable than at UBC and more researchers will need access to the AUV. It is therefore prudent to ensure that at least one knowledgable person is normally available to tend to the AUV. The general rule will be that this individual will be able to go with the AUV to those who require its use. A post-doc, hired at the Univ. of Iceland (at UI expense), will take on this task.

Courses in the use of the AUV are included in the purchase and all parties (post-docs, students and selected instructors/researchers) will attend these courses.

6.2 Utilisation

It is assumed that the AUV will be of direct use to several researchers in Iceland and many more will be able to use data collected on its missions.

As the AUV becomes used more intensively the partners in this proposal will come to an agreement on the share in its utilisation in accordance with the amount of funding raised for its purchase. For example, the University of Iceland and the University of Akureyri are assumed to raise equal funding and are therefore expected to have the same access to the AUV.

It should also be noted that due to the modularity it will be possible to add relatively few modules to obtain two or more usable AUVs. It is to be expected that individual modules will be bought annually as parts of other research proposals.

7 Maintenance

The equipment is sold with a warranty and modules needing repair under the warranty will of course be shipped back to the manufacturer. Given the spares, it is assumed that in by far most cases a module needing repair can be exchanged for another and thus there will be no delays due to such repairs. This type of repair is expected to be rare in any case.

Initially there will not be much maintenance except of a general type due to handling and accidents such as ramming into hard objects while sailing. This is not to imply that the AUVs will be handled carelessly. Rather one needs to acknowledge that accidents will happen no matter what the precautions. These instruments are delicate and it is inevitable that malfunctions will come up on occasion during transport, launch, recovery or while in the sea. It will be assumed that most such repairs can be undertaken by switching modules and sending one back for repair.

Regular maintenance is minor but includes renewing O-rings and such. This is sufficiently minor that the operator deals with this during vehicle use, before it is launched. Directions on maintenance are a part of a course on handling the AUV.

In the longer run (2-5 years) it is likely that more modules will be purchased resulting in more complete AUVs. These will then be financed with individual research proposals. The prices involved will be much lower than in this proposal since usually only individual modules will be purchased and usually not nearly as expensive modules as the ones under consideration here.

In general broken modules will be sent back for repair and it is assumed that the University of Iceland (Science Institute and/or the Institute of Biology) will foot the bill, at least for the first two years.

It is not considered important to include a special maintenance or update agreement in the initial purchase. If this is to be done later the consortium will decide on the cost recovery in accordance with the relative use of the modules by each partner at that time.

8 Financing

It is assumed that the National Research Foundation of Iceland will provide 50% of the capital required. Other costs are covered by the partners, either through their own contribution or through other grant applications which will be submitted during the coming months.

Partners within the umbrella of The University Iceland (Univ. Iceland Science Institute, Institute of Biology and Vestman Islands Research Institute) have guaranteed 22% of the funding needed and The University of Akureyri will raise another 22%. Other partners will raise the funds needed to cover remaining costs

References

G. Antonelli. Open control problems in underwater robotics. *Robot Motion and Control, 2004. RoMoCo'04. Proceedings of the Fourth International Workshop on*, pages 219–229, 2004.

P. Axelsson. Integrated sensors for improved 3D interpretation. *International Archives of Photogrammetry and Remote Sensing*, 32(4):27–34, 1998.

FC Bruhn, FD Carsey, J. Kohler, M. Mowlem, CR German, and AE Behar. MEMS enablement and analysis of the miniature autonomous submersible explorer. *Oceanic Engineering, IEEE Journal of*, 30(1):165–178, 2005.

E. Desa, R. Madhan, and P. Maurya. Potential of autonomous underwater vehicles as new generation ocean data platforms. *Current Science*, 90(9):1202–1209, 2006.

P.G. Fernandes, P. Stevenson, and A.S. Brierley. AUVs as research vessels: the pros and cons. *ICES CM*, 2002.

P.G. Fernandes, P. Stevenson, A.S. Brierley, F. Armstrong, and E.J. Simmonds. Autonomous underwater vehicles: future platforms for fisheries acoustics. *ICES Journal of Marine Science*, 60(3):684, 2003.

C. Gostnell, J. Yoos, and S. Brodet. NOAA TEST AND EVALUATION OF PHASE DIFFERENCING BATHYMETRIC SONAR TECHNOLOGY, 2006.

G. Griffiths and I. Edwards. AUVs: designing and operating next generation vehicles. *Proceedings of the 3rd EUROGOOS Conference, Elsevier*, 2003.

E. Hammerstad, S. Asheim, K. Nilsen, and H. Bodholt. Advances in multibeam echo sounder technology Oceans 93. *Eng. Harmony Ocean IEEE*, 1, 1993.

H. Johannsson, T. Thorhallsson, and H. Hafsteinsson. An efficient method of combining detection and identification of seafloor objects using Gavia AUV. *OCEANS 2006*, pages 1–6, 2006.

JA Keeton, RC Searle, C. Peirce, B. Parsons, RS White, MC Sinha, BJ Murton, and LM Parson. Bathymetry of the Reykjanes Ridge. *Marine Geophysical Researches*, 19(1):55–64, 1997.

V.E. Kostylev, R.C. Courtney, G. Robert, and B.J. Todd. Stock evaluation of giant scallop (Placopecten magellanicus) using high-resolution acoustics for seabed mapping. *Fisheries Research*, 60(2-3):479–492, 2003.

J.A. Lee, M.T. Roh, K.M. Kim, and D. Lee. Design of Autonomous Underwater Vehicles for Cage Aquafarms. *Proceedings of the IEEE Intelligent Vehicles Symposium*, 2007.

R. Madhan, E. Desa, S. Prabhudesai, L. Sebastiao, A. Pascoal, E. Desa, A. Mascarenhas, P. Maurya, G. Navelkar, S. Afzulpurkar, et al. MECHANICAL DESIGN AND DEVELOPMENT ASPECTS OF A SMALL AUV–MAYA, 2007.

D. Mallace. A Comparison of Shallow Water Multibeam Systems from a Commercial Viewpoint. *SPECIAL PUBLICATION-HYDROGRAPHIC SOCIETY*, 48:2–2, 2002.

E.B. Morello, C. Froglia, and RJA Atkinson. Underwater television as a fishery-independent method for stock assessment of Norway lobster (Nephrops norvegicus) in the central Adriatic Sea (Italy). *ICES Journal of Marine Science: Journal du Conseil*, 64(6):1116, 2007.

D. Petrovic. Three-Dimensional Mountain Map. *Proceedings of the 20th International Cartographic Conference, Beijing*, 5:3392–3399, 2001.

CJ Smith and H. Rumohr. Imaging Techniques. *In Eleftheriou A. & A. MacIntyre. Methods for the Study of Marine Benthos. Blackwell, pp.87-112*, 2005.

K.D.E. Stokesbury. Estimation of Sea Scallop Abundance in Closed Areas of Georges Bank, USA. *Transactions of the American Fisheries Society*, 131(6):1081–1092, 2002.

L. A. Taylor, J. Begley, V. Kupca, and G. Stefansson. A simple implementation of the statistical modelling framework gadget for cod in icelandic waters. *African J. Mar. Sci.*, 1:1–40, 2007.

H. Thorgilsson, G. Herjolfsson, AS Hauksdottir, and ST Sigurdsson. Scheduled Control of a Small Unmanned Underwater Vehicle Using Zero Optimization. *Decision and Control, 2006 45th IEEE Conference on*, pages 5900–5905, 2006.

T. Thorhallsson and H. Hardason. GAVIA–a modular compact AUV for deep and shallow waters. *Proc. Unmanned Underwater Vehicle Showcase*, pages 45–58, 2003.

H. Tonchia. Evaluation of a deep water wide swath echo sounder for hydrographicsurveys. *OCEANS'94.'Oceans Engineering for Today's Technology and Tomorrow's Preservation.'Proceedings*, 3, 1994.

ID Tuck, CJ Chapman, and RJA Atkinson. Population biology of the Norway lobster, Nephrops norvegicus (L.) in the Firth of Clyde, Scotland-I: Growth and density. *ICES Journal of Marine Science*, 54(1):125, 1997.