European Science Foundation

Exploratory Workshop Scheme

Scientific Review Group for Life, Earth and Environmental Sciences

Strategic Workshop on

Breakthrough Technologies To Advance Diving-Based Underwater Research In The Next Decade

HCMR, Crete 18-19 March 2014

Convened by:

Dr. Martin Sayer, Dr. Maria Salomidi and Prof. Dr. Philipp Fischer

SCIENTIFIC REPORT

1. Executive summary

An ESF Exploratory Workshop on “Breakthrough Technologies To Advance Diving-Based Underwater Research In The Next Decade” was convened at the HCMR facility on Crete on the 18th and 19th March 2014. There were 24 participants from 17 countries that demonstrated a good geographical spread across Europe. As well as end-users from the academic scientific and archaeological diving communities, there was also representation from SMEs engaged with developing some of the emerging technologies.

Scientific diving in Europe is a productive, cost-efficient research tool but lacks a co-ordinated approach to developing or adopting new technologies that would advance delivery of underwater science. The workshop explored emerging technologies: those that advance quality of diving-based science delivery; those that improve operational capability of international scientific dive teams; and those that are specific to science disciplines. The objective was to generate collaborations that adopt standardised methodologies for future initiatives based on breakthrough technologies that aim to enhance diving-based research over the coming decade.

The workshop was introduced through a discussion of the structure of the workshop, its main objectives, and the anticipated outcomes and deliverables. There was a brief introduction to the ESF plus a discussion on what mechanisms may be available to the group in the future for supporting related blue-skies collaborations. The main body of the workshop concentrated on the the three themes and for each theme there was an initial overview of the current status in the area, some highlighted examples of emerging technologies, a forward look into what may be possible, and then an open group discussion on the feasibility of existing and emerging techniques. The workshop concluded with an open discussion period, facilitated through a number of break-out groups examining the central themes but from the perspective of different user-groups.

It was considered by nearly all the workshop participants that the predominant technological development that would create the most significant advances in scientific diving would be low-cost accurate methods of geo-referencing the diving being undertaken. GPS signals do not penetrate underwater and so different techniques have to be adopted to enable the determination of accurate subtidal positioning. Long baseline (LBL), short baseline (SBL) and ultra-short baseline (USBL) techniques exist in the offshore industries for precisely placing divers and/or ROVs in three dimensions underwater. Although costly, these systems are of use to some underwater archaeology projects based on fixed sites. However, they are of limited use where there any significant movement is involved. There have been preliminary attempts to produce diving computers that are linked, through a surface buoy, to a GPS signal although any offset in the linking wire does affect accuracy. In development are systems that are based on the positioning technologies produced for Autonomous Underwater Vehicles (AUVs) and Underwater Gliders. These systems take a GPS position immediately before diving and immediately on resurfacing. The dive profile is then calculated through interpolating between the two GPS fixes using inbuilt compasses, gyros and accelerometers. A prototype unit centred on smart-phone technology has been produced but currently lacks consistent accuracy. Much larger and more expensive navigation boards for divers, based on the AUV/glider systems, are known to exist for military use.

Smart-phone and tablet technologies were perceived as being the platforms that will support most diving-based technological development in the coming years. There are already proprietary underwater cases available for most models with some permitting underwater touchscreen usage. Much of the potential for using "smart" technology underwater comes from the power of the computing available, the volume of data storage, and built-in cameras and video, GPS, accelerometers, and compasses. There are many potential applications with prototype underwater surveying tools (a combination of a smartphone and lasers), physico-chemical parameter loggers and even underwater routers that make use of the ability to transmit wirelessly underwater (although currently limited to about 1 metre distance).

Many terrestrial cutting edge methods for surveying are now being used underwater by divers. Three-dimensional mosaicking of camera or video stills permits the visualisation of large sites or objects that may not be obvious to the naked eye, particularly where underwater visibility is limited. The xyz point clouds generated during the visualisation processes also produce highly accurate methods of measurement (including volumetric quantification) in the laboratory. These methods are further optimising the time being spent underwater by the diver. Other developments are also contributing to increased optimisation of diving time. There are now a range of head-up displays available to the diver which means that a lot of the data that is necessary for the diving operation (such as depth, time, bearing, cylinder pressure) can be presented in a way that does not interrupt the main tasks being undertaken. Although scientific diving remains an extremely safe sector of the diving industry, there are technologies emerging that can provide remote safety cover for the diver underwater or improve operational capabilities with, for example, enhanced thermal protection technologies for diving in extreme environments.

The final discussions examined what immediate opportunites there were available, what emerging technologies were realistic, and what the "wish-list" was for technologies not yet developed. A major conclusion was that, even though it has a good record in terms of scientific productivity, diving was a science-support sector that currently lacked the critical mass, in terms of numbers and/or budgets, to influence the active developers of emerging technologies. In highlighting the needs of our own sector, there would always probably be a need to identify other user-groups outside of science who could either spread the research and development costs, or offer larger markets for the equipment developed. Ultimately, this could result in the main needs of scientific divers having to be modified to ensure that something of use was produced. It was considered necessary to broaden the potential user base for some of the emerging technologies with significant benefits being seen from engaging with the recreational and inshore commercial sectors. As a result of these concluding discussions, it was decided to try and facilitate the expansion of the portfolio of new and emerging technologies while also growing the potential user-base through a related COST Action application. An outline proposal was presented; this generated a final draft that was submitted for consideration on 28th March 2014.

2. Scientific content of the event

Theme 1: Technologies to advance the quality of diving-based science delivery

Presentation 1: "Diving in the cold – what makes it safe"; Piotr Kuklinski (Institute of Oceanology, Polish Academy of Sciences, PL)
The Polar regions are challenging environments subject to rapid and unpredictable weather changes. Scientific Diving is essential for diving under ice and it is a flexible, low-cost tool but its usefulness can be compromised when divers are exposed to the conditions. There

are a number of areas where product development would improve scientific delivery. Diving regulators need only to be tested to water temperatures of 4°C to adhere to CE marking as "cold-water regulators". However, polar water temperatures can be as low as -1.9°C. Although divers can use dry-suits for diving, new and emerging methods of active heating under the suits was considered beneficial. Reduced battery-life in extremely cold waters can be a limiting factor in some research areas. Some of the improvements are linked to the amount of thermal protection needed and the ease of operating standard equipment. For example, larger buttons on satelitte phones and EPIRBs would improve efficiency.

Presentation 2: "The CADDY, an electronic/electric diving buddy"; Donat Petricioli (D.I.I.V. d.o.o., Zagreb, HR)
There are a number of operational challenges in diving related to equipment and task overload. CADDY – Cognitive Autonomous Diving Buddy, makes use of micro-ROVs as light-sources and communication nodes between autonomous surface vehicles, autonomous underwater vehicles and divers. This can promote diving safety, enhance seabed surveys, act as a communication router, link with tablet-based applications and aid work in restricted environments.

Presentation 3: "GPS Diving Computer"; Arne Sieber (SEABEAR GmbH, Leoben, AT)
Underwater GPS mapping provides the potential for integrating cameras, dive computers and GPS units (presently surface buoy mounted), to generate a full geo-referencing capability for divers. The technology is all available and is relatively cheap and simple to achieve. There are already examples of methods that combine the depth profile from a dive computer with the GPS signal from a surface buoy to generate fully geo-referenced dive profile. However, there are problems with gaining good accuracy (particularly at greater depths) when using wired links to surface buoys.

Presentation 4: "The use of tablet computers for scientific underwater data collection"
Jouni Leinikki (Tvärminne zoological Station, Hanko, FI)
Stressed the importance of making use of "off the shelf" technologies and adapt for underwater use. Mobile touch screen devices are low price, wireless, have long battery life, and can link to multiple sensors. The technological limitations are that touchscreen technologies are disturbed by the water / ambient pressure and that wireless connectivity has poor range in water. Touchscreens require a dielectric fluid layer to work properly underwater. Tablets can be used for underwater positioning making use of data buoys with cables to wireless router. Data transfer through water is limited but there is the potential to establish wireless networks around the diver to permit communications or sensor matching with the tablet.

Discussion Theme 1:
The discussion emphasised the observation that obtaining accurate but cost-effective methods for geo-referencing divers and/or diving projects would be a major benefit for scientific diving. It was acknowledged that systems were available but either were too expensive (LBL, SBL, USBL), unobtainable (military swimboards), or were only in the early stages of development (a smartphone-based navigation system being developed by Marco Palma – UBICA). The workshop considered that widening the discussion group (possibly through a relevant COST Action) would allow better communications with other groups working on the problem of sub-surface geo-referencing but for different platforms. Getting insight into the potential for glider-based navigation systems would be of interest especially if that technology could be adapted for diving. However, it was acknowledged that budgets for scientific diving still lagged behind those for remote sensing technologies and any systems

that could be used by divers may have to be based on potential larger markets. Getting some form of links with the recreational sector may be of use for driving down costs through increasing the potential market for any endproducts. It was considered that recreational divers may buy equipment that logged their dives in 3-d (onto Google Earth for example?). Similarities between how mountain bikers and joggers currently can upload and store their journeys, and the potential for recreational divers to do the same were discussed. Likewise there was recognition of the potential for engaging more with "Citizen Science" initiatives if that resulted in access to lower-cost technologies.

In water data transfer, as well as data transfer to the surface, was also seen as a major area for future development, particularly if this could be integrated with relatively simple and robust loggers of a range of physico-chemical parameters. Small low-cost aquatic temperature loggers already exist; the range of measurable parameters needs increasing. Even so, the workshop considered there was already potential for wider engagement with Citizen Science projects that used recreational divers, or recreational diving schools for increasing the scope of data generation outside of what is attainable by the current scientific diving community.

Theme 2: Technologies to improve the operational capability of scientific divers

Presentation 1: "Potential of rebreather technology for scientific diving"; Alain Norro (Royal Belgian Institute of Natural Sciences, Brussels, BE)
The presentation highlighted the potential of using rebreathers to extend the current depth and duration capabilities of scientific diving. However, it was acknowledged that the utmost care should be taken when embracing this form of diving equipment. It would also be necessary for some Eurpean countries to alter legislationin order to adopt new equipment within existing regulations. Although there were a number of advantages to diving with rebreathers, such as: markedly lower gas usage; constant ppO_2 (advantages in reduced decompression loading); enhanced duration; silence (no bubbles); warm/moist breathing gas; there were also disadvantages that are still to be overcome: cost (unit & time); more complex / less reliability; more training; effectively limited to depths of no more than 100m.

Presentation 2: "Head-up displays"; Arne Sieber (SEABEAR GmbH, Leoben, AT)
Commercially-available head-up display (HUD) masks have limitations and are of little use for scientific diving. However, there are benefits to using HUD; they are good in low visibilities and also remove the need to keep monitoring a wrist-mounted unit (higher productivity). There is the capability to add dive computers into HUD (HUDC - diving computer integrated HUD) with each dive producing a data file in .csv file format.

Presentation 3: "Dive methods adaptation and technique development for use of close-circuit rebreathers (CCR) in Scientific Diving, to meet health and safety requirements"; Maria Asplund (Sven Lovén Centre for Marine Sciences- Kristineberg, Fiskebäckskil, SE)
This talk followed on from Presentation 1 in this second theme. It was a brief overview of CCR courses and how the units can be used within Swedish Health and Safety laws.

Presentation 4: "Future of rebreathers"; Arne Sieber (SEABEAR GmbH, Leoben, AT)
The dangers of CCR use were highlighted; recent data show that CCR use produces a ten-times higher accident rate than traditional open-circuit diving. In order to optimise diving as a research tool when using CCR there is a need to reduce the associated task-load. In particular there needs to be reductions in the time needed pre- and during-dives for constant checking of CCR functioning. The future for CCR is based on developing simple, non-

intervention units that are fail-safe. Units fitting these criteria are available but presently for military use only. These units require no set-up time, and have:
- automatic pre-dive validation; different types of sensors and monitoring.
- new and more reliable sensor technologies
- simple user interface; full automatization.

The release of these types of unit to the scientific diving community is dependent on other markets (recreational / military).

Discussion Theme 2:
There was overall agreement that HUD and HUDC were welcome additions to the equipment available for scientific diving. There were obvious advantages to moving the information available diver from the more traditional multiple locations around the diver into a single information source. The benefits for low visibility diving and increased productivity (and possibly safety with a more accessible method of viewing diver ascent rates) were obvious to the workshop. The ability to adapt HUDs to half-masks as well as full-face masks may be a further welcome development.

The discussion on rebreathers was based largely on the scientific applications that would benefit from their use. Although these were many, it was considered that the units would have to start to match open-circuit in terms of ease of use, portability, and cost, for their use to become more mainstream. However, the advantages in erms of science quality were welcomed. In particular the ability to remove the impact of noise and exhaust bubbles was considered beneficial for a range of potential applications: e.g. working under ice and in caves (not disturbing the related delicate ecosystems); working on delicate archaeological sites; and closer interactions with underwater life. Extending depth and duration may not be popular drivers for the technology in the science community but the warmer breathing gases did have potential for making cold-water diving more tolerable. Again, it was agreed that the recreational market was key to advancing this technology with the possibility of gaining input on lessons learnt from the military sector.

Topic 3: Technologies that are specific to science disciplines

Presentation 1: "Stereogrammetry in underwater assessments: a methological assessment"; Philipp Fischer & Christop Walchers (Alfred Wegener Institute (AWI), Helgoland, DE)
This presentation described a method of using two underwater cameras, mounted in a particular way to generate stereo images of animals that could be used for subsequent measurement. The method is non-invasive as it is possible to measure free-swimming fish, for example, in comlex habitats. There is a need to calibrate the method before use and there was some discussion on the problems associated with such calibrations.

Presentation 2a: "Simple 3-d imaging"; Martin Sayer (NFSD, Oban, UK)
The work described was based on transferring free-ware terrestrial 3-d mosaicking applications into the underwater environment. The application is based either on capturing screen grabs from video or a series of still photos and transforming them into an xyz pointcloud. This is achieved through estimating the 3-dimensional movement of selected points between successive frames. Parts of the original images can be stitched back onto the pointcloud to give the illusion of a 3-d image. The advantages of this technique is that it can help visualise relatively large areas of seabed or archaeological artefact that may not be visible to the naked eye in waters of low vivisibility. The scientific strength comes from using the pointcloud data to measure the volumes or slopes of complex habitats easily in the laboratory.

Presentation 2b: “Photogrammetry – photogrammetric reconstruction”; Yiannis Issaris (Hellenic Centre for Marine Research, Anavyssos, GR)
This presentation complemented presentation 2a by describing very similar methods for achieving the same photosynthing outcome. The methods described combined photos of different quality / different angles to produce large-scale 3-d photo mosaics. This has been used for calculating surfaces and volumes; growth rates in 3-d in situ (point-cloud compare); fine-scale habitat mapping; and the documentation of study sites. For archaeological projects, the method can be combined with software such as MeshLab to reconstruct damaged or missing areas of the target.

Presentation 3: “Potential use of hyperbaric chambers for empirical experiments and technology development in aquatic research”; Maria Asplund (Sven Lovén Centre for Marine Sciences- Kristineberg, Fiskebäckskil, SE)
This presentation was not given; presentations 2a and 2b were expanded to fill the time. Presentation 2b was introduced to substitute for presentation 3.

Presentation 4: “Technologies for ecology”; Massimo Ponti (Università di Bologna, Ravenna, IT)
A number of technological advances were described that have been developed specifically in support of ecological aplications. Calibrated 3-d reconstruction is now being used regularly in ecological surveying. This is being aided by the development of a classification system to permit ecologically-relevant predictions to be made from acoustic data only. Examples were given of synchronisation of different data sources using R. An example was combining a GPS track (from surface buoy information) with dive computer profiles to give a GIS track. 3-d reconstructions could then be overlain to add biotopes onto GIS track (xyz data).

Presentation 5: “Underwater iPhone to the rescue of field marine ecologists”; Yiannis Issaris (Hellenic Centre for Marine Research, Anavyssos, GR)
There is an increasing use of “smart” technologies underwater for scientific purposes. This example was of a prototype system that combined laser beams with a waterproofed smart-phone to produce a method for accurately measuring distances and targets underwater in real-time. The example given was for mapping animal distributions. The measurements were recorded digitally and significantly improved underwater productivity. In some cases, the increased speed of measurement reduced dive times and so removed any decompression obligations. The next version of the system described will examine using stronger and/or pulsing lasers with higher levels of computing power (i.e. moving to tablets).

Discussion: Theme 3
A lot of the discussion centred on this theme considered the potential uses of “smart” technologies such as smart phones and tablets. In particular there is increasing interest in developing systems that integrated specific measurements into fully georeferenced context. There was a real need to develop accurate depth gauging capabilities for any measurement devices (including dive computers) that corrected pressure readings for changes in water density and temperature. A significant advance for a wide range of diving –based research areas would be the capability for accurate underwater levelling.

There was also the potential to gather more data about the science divers themselves. It was considered that the scientific diving community was well placed to act as an experimental diving population; a lot of real-time physiology measuring devices could also be combined with science equipment for more detailed diving physiology research.

Looking to the future, there was some discussion about what potential uses could come from adapting the emerging “Google Glass” technology into diving. As with the HUDs, any device that presented the science diver with more real-time data in a format that was easy and safe to use, could significantly increase underwater productivity.

GENERAL DISCUSSION:
For the general discussion periods, the workshop was divided into five subgroups; membership of each group was determined by similar user needs and/or areas of expertise. Each group was asked to address the following five topics but in a way that was specific to their particular needs:

a. Identifying opportunities - now and the future
b. immediate opportunities
c. realistic emerging technologies
d. "wish list" for the next decade
e. opportunities for implementation

3. Assessment of the results, contribution to the future direction of the field, outcome
In general, researchers who were working on developing technologies view tablets and their related technologies as immediate opportunities for exploitation. The main constraint is how the wishes of the science community are being communicated to the developers. It was acknowledged that the science users may not always represent a viable commercial market, but with better communication, and with the potential for some shared costs and risks, there was the possibility of immediate evolution of some technologies.

It was felt that rebreathers provided immediate opportunities with only minor adaptions. Improved safety and reliability of rebreather units remains a major requirement of the science diving community as is improvement in how research time could be optimised (ease of use; lower decompression times). It was considered beneficial to examine developing rebreather training that was targeted specifically at scientific divers.

The user-groups saw a large number of potential developments (realistic and idealistic) based on the workshop presentations. Each group generated a long list of ideas and wishes but there was a large degree of commonality with some of the requirements. These were:

a. accurate, real-time georeferencing
b. 3-d scanning and associated applications
c. underwater data transfer
d. increased range of autonomous monitoring methods
e. improved accuracy in some available equipment
f. more standardisation of data collection
g. enhanced international collaboration / co-ordination, particularly where there is standardisation of techniques

There was some discussion on how to co-ordinate the user community and disseminate more widely some of the initiaives currently underway. It was agreed that it was unproductive to develop technologies and new techniques in isolation. There was immediate need for a co-ordinated approach which provided credibility of the size of the potential user community but also created the possibility of developing multi-use platforms based on common technologies. Some of this co-ordination could come via web-based discussion groups but the discussion concluded with the agreement of developing a COST Action proposal based on the outcomes of the workshop. That proposal was written and submitted to the 2014-1 open call.

4. Final programme

Monday 17th March 2014

Afternoon	*Arrival at workshop hotel (Your Memories Hotel)*
20.00	*Informal meal at Hotel if required*

Tuesday 18th March 2014

09.00-09.40	**Welcome by Convenor** **Martin Sayer** (NFSD, Oban, UK) *Introductions; Outline of the workshop; Timetable and objectives*
09.40-10.00	**Presentation of the European Science Foundation (ESF)** **Sonja Lojen** (Scientific Review Group for Life, Earth and Environmental Sciences)
10.00-14.30	**Topic 1: Technologies to advance the quality of diving-based science delivery**
10.00-10.15	**Presentation 1 "Diving in the cold – what makes it safe"** **Piotr Kuklinski** (Institute of Oceanology,Polish Academy of Sciences, Sopot, PL)
10.15-10.35	**Presentation 2 "The CUDDY, an electronic/electric diving buddy"** **Donat Petricioli** (D.I.I.V. d.o.o., Zagreb, HR)
10.35-11.05	*Coffee / Tea Break*
11.05-11.20	**Presentation 3 "GPS Diving Computer"** **Arne Sieber** (SEABEAR GmbH, Leoben, AT)
11.20-11.40	**Presentation 4 "The use of tablet computers for scientific underwater data collection"** **Jouni Leinikki** (Tvärminne zoological Station, Hanko, FI)
11.40-12.30	**Discussion of Presentations**
12.30-13.30	*Lunch*
13.30-14.10	**Discussion of Future Developments**
14.10-14.30	**Agreed conclusions and actions for this Topic**
14.30-18.10	**Topic 2: Technologies to improve the operational capability of scientific divers**
14.30-14.50	**Presentation 1 "Potential of rebreather technology for scientific diving"**

	Alain Norro (Royal Belgian Institute of Natural Sciences, Brussels, BE)
14.50-15.10	**Presentation 2 "Head up displays"** **Arne Sieber** (SEABEAR GmbH, Leoben, AT)
15.10-15.30	**Presentation 3 "Dive methods adaptation and technique development for use of close-circuit rebreathers in Scientific Diving, to meet health and safety requirements"** **Maria Asplund** (Sven Lovén Centre for Marine Sciences-Kristineberg, Fiskebäckskil, SE)
15.30-16.00	*Coffee / tea break*
16.00-16.20	**Presentation 4 "Future of rebreathers"** **Arne Sieber** (SEABEAR GmbH, Leoben, AT)
16.20-17.10	**Discussion of Presentations**
17.10-17.50	**Discussion of Future Developments**
17.50-18.10	**Agreed conclusions and actions for this Topic**
20.00	*Dinner at local taverna*

Wednesday 19th March 2014

08.30-12.30	**Topic 3: Technologies that are specific to science disciplines**
08.30-08.50	**Presentation 1 "Stereogrammetry in underwater assessments: a methological assessment"** **Philipp Fischer** (Alfred Wegener Institute (AWI), Helgoland, DE)
08.50-0905	**Presentation 2a "Simple 3-d imaging"** **Martin Sayer** (NFSD, Oban, UK)
0905-0925	**Presentation 2b "Photogrammetry – photogrammetric reconstruction"** **Yiannis Issaris** (Hellenic Centre for Marine Research, Anavyssos, GR)
0925-09.30	**Presentation 3 "Potential use of hyperbaric chambers for empirical experiments and technology development in aquatic research"** **Maria Asplund** (Sven Lovén Centre for Marine Sciences-Kristineberg, Fiskebäckskil, SE)
09.30-09.50	**Presentation 4 "Technologies for ecology"** **Massimo Ponti** (Università di Bologna, Ravenna, IT)
09.50-10.10	**Presentation 5 "Underwater iPhone to the rescue of field marine ecologists"** **Yiannis Issaris** (Hellenic Centre for Marine Research, Anavyssos, GR)
10.10-10.40	*Coffee / Tea Break*
10.40-12.10	**Discussion**
12.10-12.30	**Agreed conclusions and actions for this Topic**

12.30-13.30	*Lunch*
13.30-16.00	**GENERAL DISCUSSION: Identifying opportunities - now and the future**
13.30-14.00	**Discussion: immediate opportunities**
14.00-14.30	**Discussion: realistic emerging technologies**
14.30-15.00	**Discussion: "wish list" for the next decade**
15.00-15.30	Coffee / tea break
15.30-16.00	**Discussion: opportunities for implementation**
16.00-18.00	**GENERAL DISCUSSION: Follow-up activities**
16.00-16.30	**Discussion: identifying future research**
16.30-17.00	**Discussion: identifying future collaborations**
17.00-17.30	**Discussion: dissemination activity**
17.30-18.00	**Open discussion on any other issues**
20.00	*Dinner at local taverna; End of Workshop*

5. Final list of participants

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6. Statistical information on participants

17 countries were represented: Germany, Poland, Croatia, Bulgaria, UK, Greece, Austria, France, Belgium, Sweden, Portugal, Turkey, Italy, Cyprus, Finland, Norway, Ireland. The ESF representative was from Slovenia.

With the ESF and Marine Board observers there were 17 (68%) male and 8 (32%) female particiants.

Of the formal participants, 11 (48%) rated themselves as Early Career researchers and 12 (52%) rated themselves as establish researchers.