Airborne Lidar Hydrography: Vision for Tomorrow

Robert W. Pope[1], LCDR Peter Johnson[2], Ulf Lejdebrink[3], W. Jeff Lillycrop[4]

Airborne Lidar Hydrography (ALH) was first conceived in the mid-1960's, and prototype systems, like the United States' Airborne Oceanographic Lidar, the Canadian Larsen 500, the Australian WRELADS, and the Swedish FLASH, were fielded in the 1980's. However, it was not until the early 1990's that technology came of age and operational systems were fielded, including the Royal Australian Navy's Laser Airborne Depth Sounder (LADS), the U.S. Army Corps of Engineers' Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS), and the Swedish Maritime Administration's HawkEye. These systems were developed to meet specific requirements for nautical charting and port and harbor surveying for their respective governments.

Although these operational ALH systems have now matured and are available from industry, it has been national governments, namely Australia, Sweden, and the US, that have driven the requirements. With up to 8 years of operational experience and thousands of system hours, these same national governments are currently re-evaluating their needs and formulating new requirements that go well beyond the capabilities of the first ALH systems. However, industry will be quite challenged to meet these requirements for new data collection capabilities, unit cost, system size constraints, and the ability to integrate with complementary sensors.

This paper provides a comprehensive, multi-nation view of what has been learned regarding ALH with a direct view to where the technology and systems must be in 5 to 10 years to meet anticipated requirements. These requirements include, but are not limited to, nautical charting, port and harbor mapping, coastal zone management, and military rapid environmental assessment for site characterization.

1/ Program Manager, Joint Airborne Lidar Bathymetry Technical Center of Expertise, U.S. Naval Oceanographic Office
2/ Manager, Hydrographic System Development, Australian Hydrographic Service
3/ Senior Advisor, Swedish Maritime Administration
4/ Director, Joint Airborne Lidar Bathymetry Technical Center of Expertise, U.S. Army Corps of Engineers

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Introduction

The airborne lidar hydrographic survey systems operating in the world today are the products of Australian, Swedish, and United States government programs, each developed based on different survey requirements and program goals. Each program has traveled a different path and each experienced different successes and failures, but as the authors sat down and collaborated on this paper, it became strangely clear that we all share the exact same vision for the future.

Existing Systems

Before considering the future, we look at the existing systems that are in use today. For a complete history of airborne lidar hydrography (ALH), see Guenther, et al. 1996 and Steinvall et al. 1996.

<u>Canada & Larsen 500</u>. The Larsen 500 was developed in the early to middle 1980's by the Canadian Centre for Remote Sensing, the Canadian Hydrographic Service, Terra Surveys Ltd, and Optech, Inc (Casey, et al. 1985) to support nautical charting missions in the Arctic during the few weeks a year the region is ice-free. However, since Larsen preceded the systems described below by nearly 10 years, it does not have the same performance capabilities. Lessons learned from Larsen were incorporated into the Swedish and US programs and it has performed a variety of survey missions, including nautical charting, coral reef mapping and coastal zone monitoring. However, since it is still in limited operation today, it certainly deserves recognition. Since the Larsen program, the Canadian government is no longer actively involved in ALH.

<u>Australia, LADS & LADS MkII</u>. In 1946, the Royal Australian Navy (RAN) Hydrographic Service was established as the national charting authority. By 1971 only about 15 percent of the continental shelf, the most critical area for safe navigation was actually charted to modern standards. In 1972 the RAN Hydrographer approached the Department of Defence's Weapons Research Establishment to evaluate whether lasers could be used for high speed surveying in shallow water. In 1989 a contract was awarded to BHP Engineering and Vision Systems Limited of Australia to develop an operational system. In October 1993 the Laser Airborne Depth Sounder (LADS), (figure 1) entered operations (Nairn, 1994) and to-date, has surveyed over 15,000 square nautical miles. LADS is operated by the RAN LADS Flight with logistics support from the system


Figure 1. RAN LADS

manufacturer Tenix (formerly Visions Systems). A next generation LADS, named the LADS MkII, was developed as a commercial system by Vision System's LADS Corporation, owned now by Tenix, and this system has been operational for several years. As a newer generation system, it includes many of the lessons learned from operating the RAN LADS, coupled with newer technology.

U.S. (Army & Navy) SHOALS. The U.S. Army Corps of Engineers (USACE) operates and maintains thousands of miles of navigation channels throughout the US. In the middle 1980's it initiated a development program to produce the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system (Lillycrop, et al. 1996). Developed by Optech Inc., SHOALS (figure 2) was initially developed for navigation channel condition surveying, but quickly evolved into a coastal zone mapping system as well. Today, SHOALS is operated through the Joint Airborne Lidar Bathymetry Technical Center of Expertise, a partnership with the U.S. Naval Meteorology and Oceanography Command and the Naval Oceanographic Office. Because of this relationship, SHOALS has conducted several large nautical charting missions and rapid environmental assessment for military training exercises.

Figure 2. SHOALS

Sweden & HawkEye. In the middle 1980's the Swedish Defense Research and Development Agency worked with Optech Inc., to develop the FLASH airborne lidar system to evaluate object detection and the emerging lidar technology. The success of this program lead to development of two HawkEye systems (figure 3) in the early 1990's by Saab Dynamics and Optech Inc, for the Swedish Navy and Swedish Maritime Administration. Two systems were deployed in 1994 for dual use, hydrography and submarine detection (Steinvall et. al., 1996). Not long after delivery, the Swedish Maritime Administration sold their system to Indonesia and began sharing the remaining system with the Swedish Navy. Today, the Swedish HawkEye system typically operates in Spring and Fall conducting nautical charting missions and Navy operations within the national waters of Sweden.

Figure 3. HawkEye 1 & 2

Airborne Lidar Applications

Each airborne lidar system began with a specific concept of operations, but through use and experience, new applications have evolved or been identified as well suited for airborne lidar. Described below are today's missions and ideas for tomorrow.

Today's Missions

Nautical Charting. Since its inception, nautical charting has been the primary survey requirement for most of the airborne lidar survey systems. This is due to the enormous backlog in the production of modern charts needed for safe navigation worldwide. A large percent of the backlog areas are shallow, less than 50 m, and in relatively clear waters, which are well suited for ALH. This mission requirement is not likely to diminish over the next 20 years because even though thousands of square nautical miles have been survey with Larsen 500, LADS, SHOALS, and HawkEye, many more times this area is in critical need of surveying.

Port & Harbor Surveys. A similar survey requirement to charting is port and harbor surveying to define navigation channel conditions for safe navigation and to determine and quantify potential dredging requirements. These surveys are typically concerned with harbor approaches and the condition of the navigation channel as related to sediment shoaling. The most successful surveys are in harbors that have good flushing and mixing with clearer ocean waters. This mission requirement is not expected to diminish over the next 20 years as the pressure for deeper navigation channels and resulting channel shoaling is expected to grow.

Coastal Zone Mapping. Perhaps one of the more rapidly growing survey requirements is for large regional surveys to map and monitor the conditions of coastal shorelines. This is particularly the case along sandy shorelines that are subjected to severe storms, such as hurricanes, but also along more stable, even rocky shorelines where the effects of storms waves and flooding are of concern. Also, global warming and sea level rise are seriously eroding national boundaries as entire land masses disappear. Over the past few years, these requirements have emerged in Canada, Italy, Mariana Islands, Middle East, Puerto Rico and the United States, to name a few locations. This survey requirement is expected to increase over the next 20 years, driven by increased population along the coasts of the world and the resulting increased potential for property damage and loss of life from extreme storms. The need for responsible shoreline growth and management will fuel these requirements.

Military Operations. Although nautical charting was the primary requirement instigating ALH, military needs and potentials were quickly realized. There have been non-ALH systems developed worldwide exclusively for mine and submarine detection using lasers in one of several approaches including laser ranging and imaging. These applications are extremely complex and difficult representing a major challenge for the future because the requirement is expected to continue to increase as it has in Sweden.

Two military applications for airborne lidar are antisubmarine warfare (ASW) and rapid environmental assessment (REA).

Antisubmarine Warfare. The most well known ALH system for ASW was developed for the Swedish Navy. HawkEye is a dual use system for bathymetry and ASW. The survey and search requirements will not diminish over the next 20 years because regional threats are not expected to diminish and airborne lidar technology is expected to become more capable for object detection.

Rapid Environmental Assessment. Since the decline of the Soviet Union, NATO and European militaries have transitioned to smaller more mobile forces capable of force projection anywhere in the world on a moment's notice. Additionally, other countries, such as Australia, are looking beyond their own defense to combined operations in its area of strategic military interest. Worldwide, this trend is growing, driven in part by a perceived lessening of the US's willingness to enter regional conflicts. However, when existing data are too dated, or non-existent, REA includes sending in military assets to collect data to characterize potential amphibious landing sites. Sites may be denied areas and may be a few kilometers to hundreds of kilometers in size. This is an emerging requirement and airborne lidar has great potential to support rapid regional reconnaissance and surveying.

Tomorrow's Missions

The missions described above are expected to continue to be primary missions over the next 10 years. However, the emphasis must be on greater flexibility with respect to using aircraft of opportunity, lower cost and smaller size of the lidar sensor, integrated survey planning and automated data processing, and utilization of commercial off the shelf equipment making it easier to maintain. These characteristics will reduce the cost per square kilometer of survey by reducing flight costs, field crew size and training, and data processing complexity.

Also during the next 10 years, more information about the environment should be extracted from the raw lidar return signals to better quantify the environment and add value to the already existing elevations produced by the lidar system. Once the cost has been expended to operate an airborne platform for lidar elevations, any additional information about the area or environment becomes very valuable at a very low cost.

Beyond this 10 year time period, the ability of lidar to fuse with complementary sensors to produce more precise, and a broader range of environmental information will lead to new applications and missions. As an example, it has been demonstrated that fusing lidar depths with hyperspectral imagery leads to improved ability to determine sea bottom type (sand, mud, grass, etc). These combined technologies could also produce high-resolution information on coral reef health; improved over what either sensor could produce as a stand-alone sensor. There are other sensors that lidar could complement and fuse with to improve our ability to rapidly and accurately characterize and quantify the coastal zone.

As lidar sensors and complementary sensors improve, difficult applications such as mine counter measures and submarine detection will fall within the typical applications of ALH systems. In addition to military operations, these sensors, of suite of sensors should be able to locate and identify oil spills and possibly humans in support of maritime rescues. The potential applications are broad, but require ALH systems that are flexible and easy to operate and integrate with a variety of other systems.

Sensor Performance

To support the applications described above the ALH system of today must evolve. This section lists some of the performance characteristics associated with ALH systems and identifies directions needed to enhance today's sensors and systems.

Lasers. Since airborne lidar hydrography began, a primary performance metric has been laser pulse repetition rate. Then, as in the future, the faster the laser, the better it will be for ALH because more area can be covered in a given time period with denser spot densities. Over the coming years, faster lasers are very desirable, and repetition rates should approach 10,000 Hz, with 5 mJ/pulse and 1 – 2 ns pulse widths. Conversely, as these specifications change, the resulting laser size, weight, and power requirements must decrease in order to produce smaller more flexible systems. Additionally, tunable lasers (wavelength and energy) capable of adjusting to maximize performance under given environmental conditions would improve maximum depth performance and possibly extend the locations and missions where ALH systems are capable of operating.

System Operation. Existing systems perform best in non-direct sunlight because sun glint becomes a noise source to the receivers. Improved receivers and associated optics which produce greater signal to noise ratios could improve performance across the board. As performance improves, the locations and types of applications will increase. However, the airborne sensor must be capable to operating in a variety of configurations to match the survey with the requirement, such as altering sounding densities (sub-1 m x 1 m up to 10 m x 10 m) and using different positioning systems (PGPS, GPS, DGPS, and KGPS). These and other flight parameters must be able to change for each survey line and even to add and alter survey lines while in the conduct of a mission.

Airborne Sensor and Platform. To increase operational flexibility with respect to mission type, sensor fusion, and survey cost, systems of the future must be small, portable, and modular in design. Regardless of application, these three criteria will ensure that future systems can utilize standard photogrammetric aircraft of opportunity or utility helicopter, be easily shipped worldwide to utilize these aircraft, and be capable of operating integrated with other sensors. The size must also be reduced so that lidar can become a viable sensor for unmanned aerial vehicles (UAV). This is important to the military of the future, one that must project itself in a moments notice around a region or around the world. Finally, the level of automation and operator control must advance such that the system is capable of monitoring the progress of the mission and assessing the quality of the data to reduce the needed expertise level of the operator, on in the case of a UAV application, operate autonomously.

Ground-Based Processing. Existing ALH systems appeared before conventional shallow-water acoustic multibeam survey systems became wide spread, but this acoustic technology has already significantly helped ALH. Shallow-water acoustic multibeam systems produce can many times more data than ALH systems and this has caused a boom in tools to manage, edit, and visualize large spatial data sets. These tools, and generations thereafter, must be integrated into future ALH systems in order to improve depth extraction and processing. Today many weeks of additional training in lidar technology is required to process data accurately. Only through an integrated approach that processes ALH data simultaneously considering raw lidar signals, nearest neighbors, and statistical variations along with survey mission parameters and historic survey data, can the amount of additional training be reduced and typical hydrographer conduct ALH processing. Finally, to maximize the incorporation of ALH into commercial visualization and editing packages, an open architecture must be adopted by the lidar manufactures so that existing software manufacturers and universities can evolve this capability.

Logistics. Existing systems are rather large and require several specially trained personnel to mobilize them into the aircraft and once installed, they require complex procedures to calibrate. Future systems must be small and require fewer, and less specially trained personnel to mobilize and initiate survey missions. A target size and level of training should be similar to acoustic multibeam survey systems. In addition, system maintenance should be modular and self-diagnosing, again reducing the amount of specialty training required of the field survey crew.

Enabling Capabilities

To meet many of the needs describe above there are enabling capabilities that will significantly improve or expand ALH operations and applications.

Bottom Type. There is much more information contained in the raw lidar return signal, which is digitized and recorded, than only water depth. Development of algorithms to extract this information is possible for applications such as, delineating bottom type in gross terms (i.e., sand, sea grass, mud, etc), however, research and development is needed.

Water Clarity. As with bottom type, information is contained in the raw lidar signal that should yield a quantification of water clarity, such as the diffuse attenuation coefficient (Billard, et al. 1986 and Steinvall et al. 1993).

Sediment Concentration. Once water clarity can be determined, the next step is to quantify, or at a minimum, qualify spatial concentration of suspended material, such as sediment. This information could be used to evaluate dredging operations and measure effluents impact on a region.

Wave Climate. The size and direction of waves is important for many coastal engineering applications, such as measuring sediment transport rates, and in military operations, such as determining limiting conditions for safe ingress and egress routes. If an airborne lidar system is surveying an area, then to gather ancillary information adds value to the mission.

Other similar regional environmental measurements from an airborne platform that could support both military and civil applications include water temperature, sound velocity and surf zone depth measurements. The technology advancements necessary to make these measurements are medium risk. However, the benefits may be substantial and help to form a bigger picture of a coastal zone or battle space.

Land/Water Interface. Shoreline surveying, whether for rapid environmental assessment or coastal zone management, can become very difficult when delineating where the land ends and the water begins. An accurate, repeatable methodology is required and should be achievable with more aggressive use of existing raw data.

Digital Imagery. The most basic form of imagery is digital, geo-referenced, photographs that can be incorporated into a product such as in a Geographic Information System or simply as a base photograph on an elevation/depth contour plot. Existing lidar data have been used on many occasions with aerial photographs or even satellite imagery, however, if the capability is mounted and deployed on the lidar aircraft, the information becomes synoptic, and inexpensive. This concept can be extended to other imagers, such as hyperspectral, which then provides an entirely new dimension to data collection and combining with lidar data to extract information the other two sensors alone could not produce.

Topographic Elevations. Land elevations are being collected on a regular basis by existing systems, but they lack the resolution necessary to fully define topographical features such as small structures, dune lines, seawall break points, and other detail. High-resolution data provided by existing topographic lidar systems are capable of merging these shoreline structures and coastal features with ALH underwater data, thus producing a seamless product.

Sensor Fusion

As lidar sensors continue to evolve and mature, they should be combined with other airborne sensors because there is economy in collecting as much information from as many sensors on a single airborne platform and more importantly, one sensor can often help to extract additional environmental information from another sensor.

We have seen proof of concept studies and tests that have brought together lidar and hyperspectral data, lidar and digital photographs, lidar and electromagnetic sensors, lidar and interferometric synthetic aperture radar and lidar (hydro) and lidar (topo). In all cases, the combination yielded more than the two separately could. Airborne electromagnetic sensors, for instance, can extend data acquisition in areas beyond ALH capabilities, e.g., in turbid water and detecting small features beneath the sea floor. The ALH systems of the future must make this fusion practice and be capable of sharing a single airborne platform with other complementary sensors.

Summary

The ALH systems of the future must be small, low cost, and able to operate on a wide variety of aircraft. Systems must require a minimum of additional training to operate because lessons learned from existing systems and programs are incorporated and automated into these new ALH systems. More information that is currently collected must be utilized to better quantify the environment. Finally, the systems of the future must be extremely flexible to meet the changing requirements of the survey community.

Until these characteristics are adopted by industry, government programs will be the only method of evolving airborne lidar hydrography. It is the authors goal and vision that if the above criteria are met, the entire survey community, both industry and governments, will add ALH to their capabilities. Only then will systems mature and evolve based on the needs of the many.

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