

SCIENTIFIC MANIFEST 2

UNDERWATER **ACOUSTIC** **POSITIONING SYSTEM**

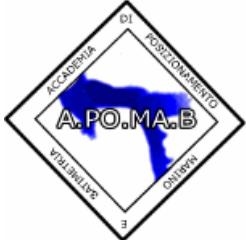
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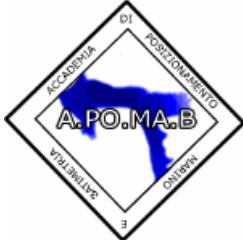


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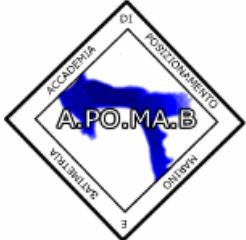


OBJECT: Underwater Acoustic Positioning System

An Vessel is a system for the tracking and navigation of underwater vehicles or divers by means of acoustic distance and/or direction measurements, and subsequent position triangulation. Underwater Acoustic Positioning Systems are commonly used in a wide variety of underwater work, including oil and gas exploration, ocean sciences, salvage operations, marine archaeology, law enforcement and military activities.

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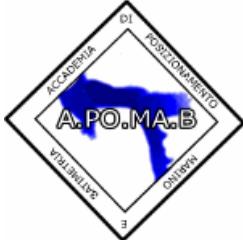


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1) Method of Operation

Figure 1 describes the general method of operation of an acoustic positioning system, this is an example of a long baseline (LBL) positioning system for ROV

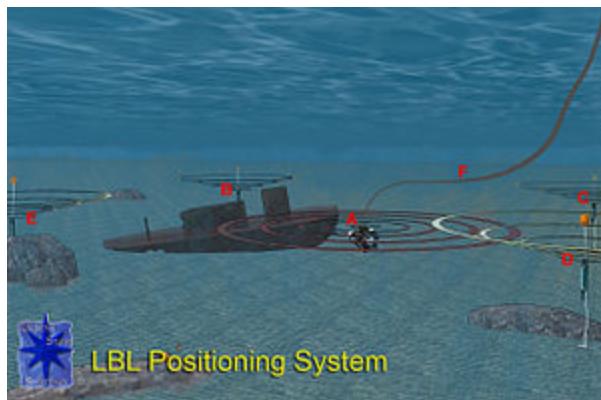
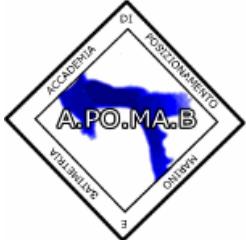


Figure 1: Method of the operation of a Long Baseline (LBL) acoustic positioning system for ROV

Baseline station deployment and survey: Acoustic positioning systems measure positions relative to a framework of **baseline stations**, which must be deployed prior to operations. In the case of a **long baseline (LBL)** system, a set of three or more baseline transponders are deployed on the sea floor. The location of the baseline transponders either relative to each other or in global coordinates must then be measured precisely. Some systems assist this task with an automated **acoustic self-survey**, and in other cases GPS is used to establish the position of each baseline transponder as it is deployed or after deployment.

Tracking or Navigation Operations: Following the baseline deployment and survey, the acoustic positioning system is ready for operations. In the long baseline example (see figure 1), an interrogator (A) is mounted on the ROV that is to be tracked. The interrogator transmits an acoustic signal that is received by the baseline transponders (B, C, D, E). The reply of the baseline transponders is received again at the ROV. The signal time-of-flight or the corresponding distances A-B, A-C, A-D and A-E are transmitted via the ROV umbilical (F) to the surface, where the ROV position is computed and displayed on a tracking screen. The acoustic distance measurements may be augmented by depth sensor data to obtain better positioning accuracy in the three-dimensional underwater space. Acoustic positioning systems can yield an accuracy of a few centimeters to tens of meters and can be used over operating distance from tens of meters to tens of kilometers.



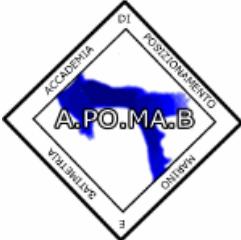
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Performance depends strongly on the type and model of the positioning system, its configuration for a particular job, and the characteristics of the underwater acoustic environment at the work site.

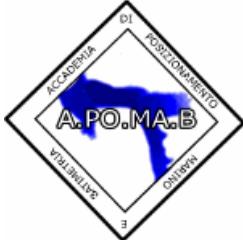


2) Underwater Acoustic Positioning System Classes

Underwater acoustic positioning systems are generally categorized into three broad types or classes

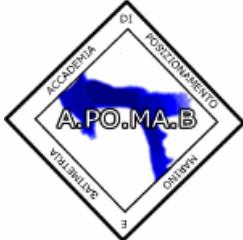
Long Baseline (LBL) Systems: Long baseline systems, as in figure 1 above, use a sea-floor baseline transponder network. The transponders are typically mounted in the corners of the operations site. LBL systems yield very high accuracy of generally better than 1 m and sometimes as good as 0.01m along with very robust positions. This is due to the fact that the transponders are installed in the reference frame of the work site itself (i.e. on the sea floor), the wide transponder spacing results in an ideal geometry for position computations, and the LBL system operates without an acoustic path to the (potentially distant) sea surface.

Ultra Short Baseline (USBL) Systems: USBL systems and the related super short baseline (SSBL) systems rely on a small (ex. 230 mm across), tightly integrated transducer array that is typically mounted on the bottom end of a strong, rigid transducer pole which is installed either on the side or in some cases on the bottom of a surface vessel^{[8][9]}. Unlike LBL and SBL systems, which determine position by measuring multiple distances, the USBL transducer array is used to measure the target *distance* from the transducer pole by using signal run time, and the target *direction* by measuring the phase shift of the reply signal as seen by the individual elements of the transducer array. The combination of distance and direction fixes the position of the tracked target relative to the surface vessel. Additional sensors including GPS, a gyro or electronic compass and a vertical reference unit are then used to compensate for the changing position and orientation (pitch, roll, bearing) of the surface vessel and its transducer pole. USBL systems offer the advantage of not requiring a sea floor transponder array. The disadvantage is that positioning accuracy and robustness is not as good as for LBL systems. The reason is that the fixed angle resolved by a USBL system translates to a larger position error at greater distance. Also, the multiple sensors needed for the USBL transducer pole position and orientation compensation each introduce additional errors. Finally, the non-uniformity of the underwater acoustic environment cause signal refractions and reflections that have a greater impact on USBL positioning than is the case for the LBL geometry.



Short Baseline (SBL) Systems: Short baseline systems use a baseline consisting of three or more individual sonar transducers that are connected by wire to a central control box. Accuracy depends on transducer spacing and mounting method. When a wider spacing is employed as when working from a large working barge or when operating from a dock or other fixed platform, the performance can be similar to LBL systems. When operating from a small boat where transducer spacing is tight, accuracy is reduced. Like USBL systems, SBL systems are frequently mounted on boats and ships, but specialized modes of deployment are common too. For example, the Woods Hole Oceanographic Institution uses a SBL system to position the Jason deep-ocean ROV relative to its associated MEDEA depressor weight with a reported accuracy of 9 cm.

GPS Intelligent Buoys (GIB): GIB systems are inverted LBL devices where the transducers are replaced by floating buoys, self-positionned by GPS. The tracked position is calculated in realtime at the surface from the Time-Of-Arrival (TOAs) of the acoustic signals sent by the underwater device, and acquired by the buoys. Such configuration allow fast, calibration-free deployment with an accuracy similar to LBL systems. At the opposite of LBL, SBL ou USBL systems, GIB systems use one-way acoustic signals from the emitter to the buoys, making it less sensible to surface or wall reflections. GIB systems are used to track AUVs, torpedoes, or divers, may be used to localize airplanes black-boxes, and may be used to determine the impact coordinates of inert or live weapons for weapon testing and training purposes references: Sharm-El-Sheih, 2004; Sotchi, 2006; Kayers, 2005; Kayser, 2006; Cardoza, 2006 and others...).



3) History and Examples of Use

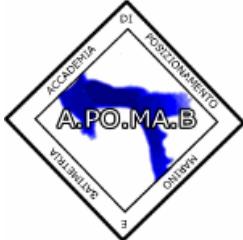


Figure 2a: An acoustic short baseline (SBL) positioning system was installed on the USNS Mizar during the search dives to the wreckage of the submarine USS Thresher



Figure 2b: The bathyscaphe Trieste was guided by that acoustic positioning system to the Thresher

An early use of underwater acoustic positioning systems, credited with initiating the modern day development of these systems, involved the loss of the American nuclear submarine USS *Thresher* on 10 April 1963 in a water depth of 2560m. An acoustic short baseline (SBL) positioning system was installed on the oceanographic vessel USNS *Mizar*. This system was used to guide the bathyscaphe *Trieste* 1 to the wreck site. Yet, the state of the technology was still so poor that out of ten search dives by *Trieste* 1, visual contact was only made once with the wreckage^[16]. Acoustic positioning was again used in 1966, to aid in the search and subsequent recovery of a nuclear bomb lost during the crash of a B-52 bomber at sea off the coast of Spain.

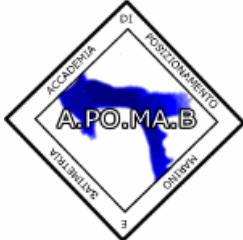


In the 1970s, oil and gas exploration in deeper waters required improved underwater positioning accuracy to place drill strings into the exact position referenced earlier thorough seismic instrumentation and to perform other underwater construction tasks.

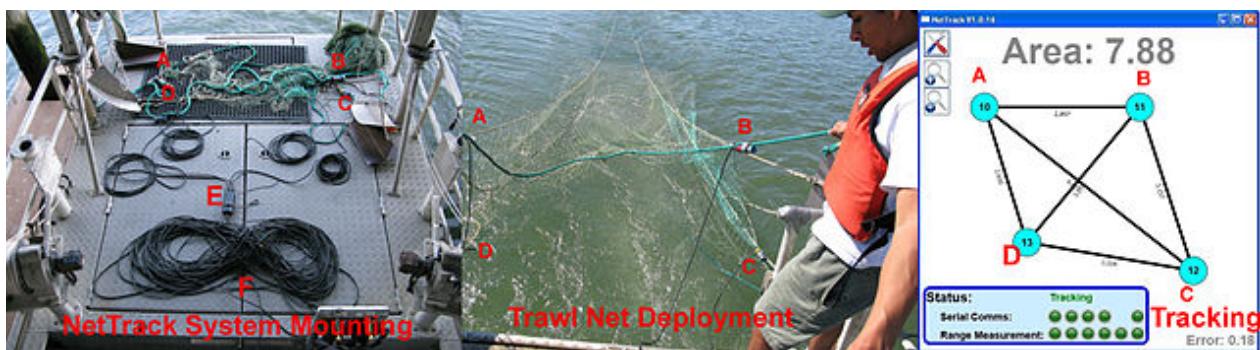


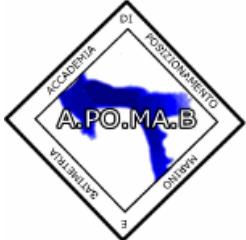
Figure 3: The Russian deep sea submersibles MIR-1 and MIR-2 searched the wreck site of the Japanese submarine I-52 in 1998. A LBL positioning system was used to guide and document the progressing search over multiple dives.

But, the technology also started to be used in other applications. In 1998, salvager Paul Tidwell and his company Cape Verde Explorations led an expedition to the wreck site of the World War 2 Japanese cargo submarine I-52 in the mid-Atlantic^[18]. Resting at a depth of 5240 meters, it had been located and then identified using side scan sonar and an underwater tow sled in 1995. War-time records indicated the I-52 was bound for Germany, with a cargo including 146 gold bars in 49 metal boxes. This time, Mr. Tidwell's company had hired the Russian oceanographic vessel, the *Akademik Mstislav Keldysh* with its two manned deep-ocean submersibles *MIR-1* and *MIR-2* (figure 3). In order to facilitate precise navigation across the debris field and assure a thorough search, *MIR-1* deployed a long baseline transponder network on the first dive. Over a series of seven dives by each submersible, the debris field was progressively searched. The LBL positioning record indicated the broadening search coverage after each dive, allowing the team to concentrate on yet unsearched areas during the following dive. No gold was found, but the positioning system had documented the extend of the search.



In recent years, several trends in underwater acoustic positioning have emerged. One is the introduction of compound systems such the combination of LBL and USBL in a so-called LUSBL^T configuration to enhance performance. These systems are generally used in the offshore oil & gas sector and other high-end applications. Another trend is the introduction of compact, task optimized systems for a variety of specialized purposes. For example the California Department of Fish and Game commissioned a system (figure 4), which continually measures the opening area and geometry of a fish sampling net during a trawl. That information helps the department improve the accuracy of their fish stock assessments in the Sacramento River Delta.



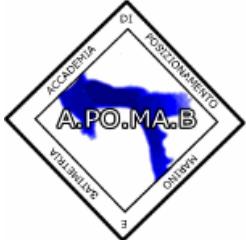


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Long Baseline Acoustic Positioning System

A **Long Baseline (LBL) Acoustic Positioning System** is one of three broad classes of underwater acoustic positioning systems that are used to track underwater vehicles and divers. The other two classes are Ultra Short Baseline Systems (USBL) and Short Baseline Systems (SBL). LBL systems are unique in that they use networks of sea-floor mounted baseline transponders as reference points for navigation. These are generally deployed around the perimeter of a work site. The LBL technique results in very high positioning accuracy and position stability that is independent of water depth. It is generally better than 1-meter and can reach a few centimeters accuracy. LBL systems are generally employed for precision underwater survey work where the accuracy or position stability of ship-based (SBL, USBL) positioning systems does not suffice.



4) Method of Operation and Performance Characteristics

Figure 1 describes the general method of operation of a long baseline system.

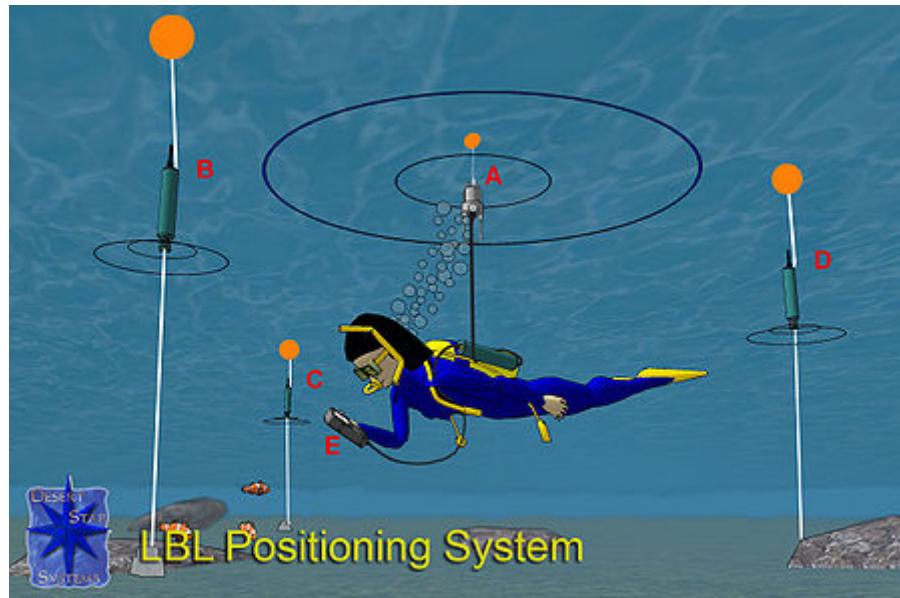
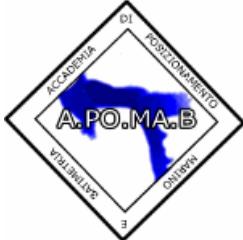


Figure 1: Method of the operation of a Long Baseline (LBL) acoustic positioning system

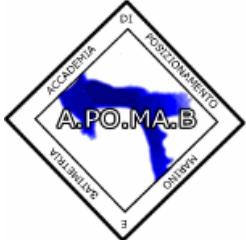


Figure 2: A dive team (Envirotech Diving) with their AquaMap LBL acoustic underwater positioning system including three baseline transponders (B) and diver stations (A) mounted on scooters. The baseline stations are first deployed in the corners of a work site. Their relative position is then precisely measured using the AquaMap system's automatic acoustic self-survey capability. For geo-referenced operations, the baseline positions are surveyed by differential GPS or a laser positioning equipment (total station). During a dive, the diver station interrogates the baseline stations to measure the distances, which are then converted to positions.



Long baseline systems determine the position of a vehicle or diver by acoustically measuring the distance from a vehicle or diver interrogator to three or more seafloor deployed baseline transponders. These range measurements, which are often supplemented by depth data from pressure sensors on the devices, are then used to triangulate the position of the vehicle or diver. In figure 1, a diver mounted interrogator (A) sends a signal, which is received by the baseline transponders (B, C, D). The transponders reply, and the replies are received again by the diver station (A). Signal run time measurements now yield the distances A-B, A-C and A-D, which are used to compute the diver position by triangulation or position search algorithms. The resulting positions are relative to the location of the baseline transducers. These can be readily converted to a geo-referenced coordinate system such as latitude/longitude or UTM if the geo-positions of the baseline stations are first established.

Long baseline systems get their name from the fact that the spacing of the baseline transponders is long or similar to the distance between the diver or vehicle and the transponders. That is, the baseline transponders are typically mounted in the corners of an underwater work site within which the vehicle or diver operates. This method yields an ideal geometry for positioning, in which any given error in acoustic range measurements produce only about an equivalent position error. This compares to SBL and USBL systems with shorter baselines where ranging disturbances of a given amount can result in much larger position errors. Further, the mounting of the baseline transponders on the sea floor eliminates the need for converting between reference frames, as is the case for USBL or SBL positioning systems mounted on moving vessels. Finally, sea floor mounting makes the positioning accuracy independent of water depth. For these reasons LBL systems are generally applied to tasks where the required standard of positioning accuracy or reliability exceeds the capabilities of USBL and SBL systems.

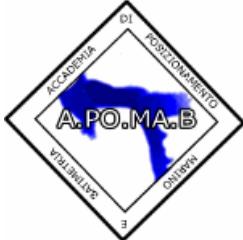


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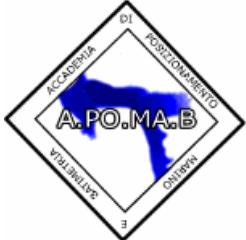
5) History and Examples of Use



Figure 3: Precisely establishing the position of nuclear submarines prior to missile launches was an early application of long baseline acoustic positioning systems. Covert networks of sea floor transponders could survive and provide a precision navigation capability even after GPS satellites had been knocked out.

The search and inspection of the lost nuclear submarine USS Thresher by the U.S. Navy oceanographic vessel USNS Mizar in 1963 is frequently credited as the origin of modern underwater acoustic navigation systems. Mizar primarily used a short baseline (SBL) system to track the bathyscaphe Trieste 1. However, its capability also included seafloor transponders, which in conjunction with early navigation satellites supported station keeping with a precision of about 300 feet, considered remarkable at the time.

By the mid 1960's and possibly earlier, the Soviets were developing underwater navigation systems including seafloor transponders to allow nuclear submarines to operate precisely while staying submerged. Besides navigating through canyons and other difficult underwater terrain, there was also a need to establish the position of the submarine prior to the launch of a nuclear missile (ICBM). In 1981, acoustic positioning was proposed as part of the MX missile system. A network of 150 covert transponder fields was envisioned. Submarines typically are guided by inertial navigation systems, but these dead reckoning systems develop position drift which must be corrected by occasional position fixes from a GPS system. If the enemy were to knock out the GPS satellites, the submarine could rely on the covert transponder network to establish its position and program the missile's own inertial navigation system for launch.



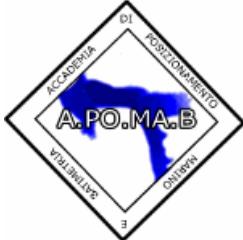
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5.1) Offshore

LBL diver technology has continued to advance, and the DS-3 terminal (figure 5) includes graphic information similar to that of mapping GPS receivers.



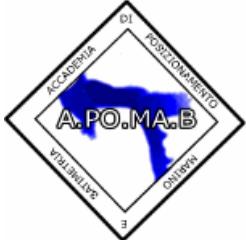
6) Ultra-short baseline

USBL (**Ultra-short baseline**) is a method of underwater acoustic positioning. A complete USBL system consists of a transceiver, which is mounted on a pole under a ship, and a transponder/responder on the seafloor, a towfish, or on a ROV. A computer, or "topside unit", is used to calculate a position from the ranges and bearings measured by the transceiver.

An acoustic pulse is transmitted by the transceiver and detected by the subsea transponder, which replies with its own acoustic pulse. This return pulse is detected by the shipboard transceiver. The time from the transmission of the initial acoustic pulse until the reply is detected is measured by the USBL system and is converted into a range.

To calculate a subsea position, the USBL calculates both a range and an angle from the transceiver to the subsea beacon. Angles are measured by the transceiver, which contains an array of transducers. The transceiver head normally contains three or more transducers separated by a baseline of 10 cm or less. A method called “phase-differencing” within this transducer array is used to calculate the angle to the subsea transponder.

USBLs have also begun to find use in "inverted" (iUSBL) configurations, with the transceiver mounted on an autonomous underwater vehicle, and the transponder on the target. In this case, the "topside" processing happens inside the vehicle to allow it to locate the transponder for applications such as automatic docking and target tracking.

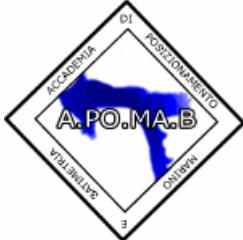


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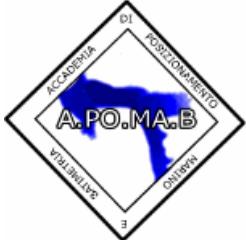


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Short Baseline Acoustic Positioning System

A **Short Baseline (SBL) Acoustic Positioning System** is one of three broad classes of underwater acoustic positioning systems that are used to track underwater vehicles and divers. The other two classes are Ultra Short Baseline Systems (USBL) and Long Baseline Systems (LBL). Like USBL systems, SBL systems do not require any seafloor mounted transponders or equipment and are thus suitable for tracking underwater targets from boats or ships that are either anchored or under way. However, unlike USBL systems, which offer a fixed accuracy, SBL positioning accuracy improves with transducer spacing. Thus, where space permits, such as when operating from larger vessels or a dock, the SBL system can achieve a precision and position robustness that is similar to that of sea floor mounted LBL systems, making the system suitable for high-accuracy survey work. When operating from a smaller vessel where transducer spacing is limited (i.e. when the baseline is short), the SBL system will exhibit reduced precision.

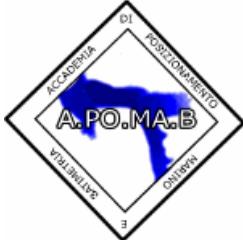


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7) Method of Operation and Performance Characteristics

Figure 1 describes the general method of operation of a short baseline system system.

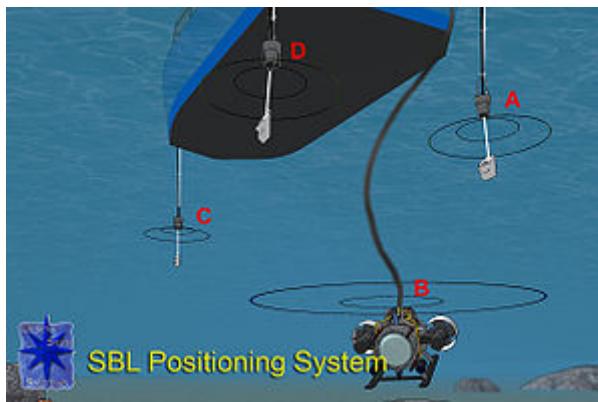
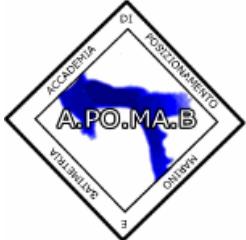


Figure 1: Method of the operation of a Short Baseline (SBL) acoustic positioning system for ROV

Short baseline systems determine the position of a tracked target such as a ROV by measuring the target's distance from three or more transducers that are, for example, lowered over the side of the surface vessel from which tracking operations take place. These range measurements, which are often supplemented by depth data from a pressure sensor, are then used to triangulate the position of the target. In figure 1, baseline transducer (A) sends a signal, which is received by a transponder (B) on the tracked target. The transponder replies, and the reply is received by the three baseline transducers (A, C, D). Signal run time measurements now yield the distances B-A, B-C and B-D. The resulting target positions are always relative to the location of the baseline transducers. In cases where tracking is conducted from a moving boat but the target position must be known in earth coordinates such as latitude/longitude or UTM, the SBL positioning system is combined with a GPS receiver and an electronic compass, both mounted on the boat. These instruments determine the location and orientation of the boat, which are combined with the relative position data from the SBL system to establish the position of the tracked target in earth coordinates. Short baseline systems get their name from the fact that the spacing of the baseline transducers (on a boat for example) is usually much less than the distance to the target, such as a robotic vehicle or diver venturing far from the boat. As with any acoustic positioning system, a larger baseline yields better positioning accuracy. SBL systems use this concept to an advantage by adjusting transducer spacing for best results. When operating from larger ships, from docks or from the sea ice where greater

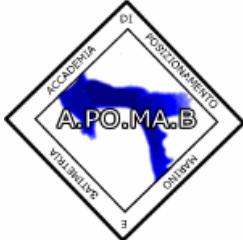


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transducer spacing can be used, SBL systems can yield a positioning accuracy and robustness approaching that of sea-floor mounted LBL systems.



8) History and Examples of Use

SBL systems are found employed in a variety of often specialized applications. Perhaps the first implementation of any underwater acoustic positioning system was a SBL system installed on the U.S. Navy oceanographic vessel USNS Mizar. In 1963, this system guided the bathyscaphe Trieste 1 to the wreck site of the American nuclear submarine USS Thresher. However, performance was still so poor that out of ten search dives by Trieste 1, visual contact was only made once with the wreckage.

The Woods Hole Oceanographic Institution is using a SHARPS SBL system to guide their JASON tethered deep ocean robotic vehicle relative to the MEDEA depressor weight and docking station associated with the vehicle. Rather than tracking both vehicles with a positioning system from the surface which would result in degraded accuracy as the pair's deployment distance , the SBL baseline transducers are mounted on MEDEA. yielding the position of JASON relative to MEDEA with good accuracy independent of the system's deployment depth. The reported accuracy is 0.09m

8.1) Example of SBL System Use: Under-The-Ice Surveying by ROV in Antarctica



Figure 2: The SCINI ROV next to its dive hole at Heald Island, Antarctica

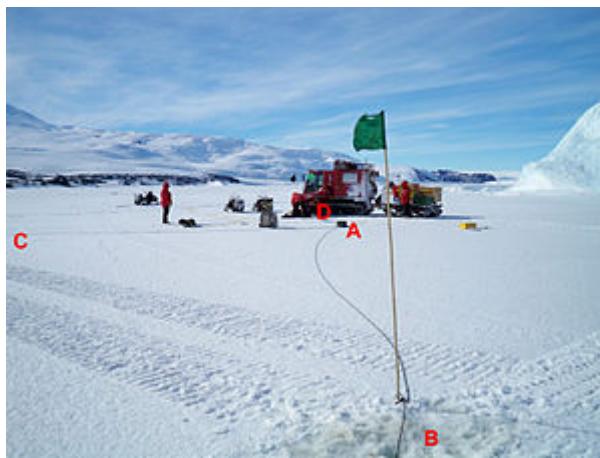


Figure 3: SBL positioning system deployment at Cape Evans. Maximizing the spacing of the baseline sonar transducers (A, B, C) and arranging them in an equilateral triangle yields best accuracy

An illustrative use of SBL technology is currently (since 2007) underway in Antarctica, where the Moss Landing Marine Laboratory is using a PILOT SBL system to guide the SCINI remotely operated vehicle. SCINI (figure 2) is a small, torpedo-shaped tethered vehicle (ROV) designed for rapid and uncomplicated deployment and exploration of remote sites around Antarctica, including Heald Island, Cape Evans and Bay of Sails. SCINI system is designed to be compact and light-weight so as to facilitate rapid deployment by helicopter, tracked vehicle and even man-hauled sleds. Once on site, its torpedo shaped body allows it to access the ocean through small (20 cm dia.) holes drilled into the sea ice. The mission's science goals however demand high accuracy in navigation, to support tasks including running 10-m video transects (straight lines), providing precise positions for still images to document the distribution and population density of benthic organisms and marking and re-visiting sites for further investigation.

The SBL navigation system (figure 3) consists of three small, 5 cm diameter sonar baseline transducers (A, B, C) that are linked by cable to a control box (D). A small (13.5cm L x 4 cm D), cylinder shaped transponder is mounted on the SCINI vehicle. Accuracy is optimized by making use of the flat sea ice to place the baseline transducers well apart; approx. 35m for most SCINI deployments.

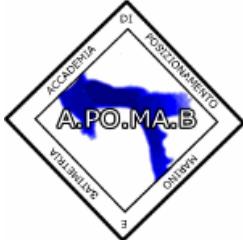


Figure 4 reviews SCINI operations guided by the SBL system. Figure 4A is an improvised ROV control room, in this case in a cabin hauled on top of an ice hole at Cape Armitage. From left, the displays are the ROV controls screen (A), the main camera view (B), the navigation screen (C) and the science display (D). The ROV pilot will generally watch the main camera view. He will glance at the navigation screen (C), which shows the current ROV position and track overlaid on a chart, for orientation and to guide the ROV to the location instructed by the scientist. The scientist, shown here seated on the right is provided with the science display (D), which combines the ROV imagery with position, depth and time data in real time. The scientist types written or speaks audible observations into the computer to provide a context for the data, note objects or events of interest or designate the start or conclusion of a video transect (figure 4B). A typical investigation of a site will span several dives, as tasks such as initial investigation, still image acquisition and video transects are gradually completed. A critical element in these dive series is to show prior-dive search coverage, so that a successive dive can be targeted at a previously unvisited area. This is done by producing a cumulative coverage plot of the dive site (figure 4C). The plot, which is updated after every dive, is displayed as a background map on the navigation screen thus providing guidance for the ongoing dive. It shows the prior ROV tracks with color used to indicate depth. Analysis of the track data displayed here yields the quality of positioning to provide a margin of error for measurements. In this case, the typical precision has been established as 0.54m.



Figure 4A: SCINI control room with four display screens for ROV control (A), main camera view (B), SBL navigation display (C) and image annotation or science screen (D)

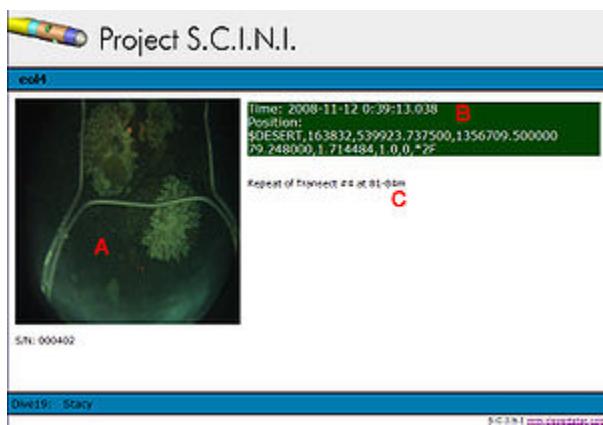
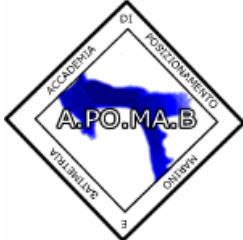


Figure 4B: Imagery, associated position, time and the scientist's observation or statement are combined into a single record

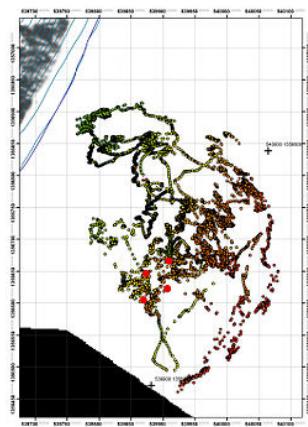
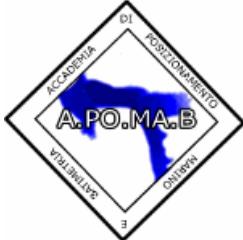


Figure 4C: A site coverage plot of multiple SCINI dives at Cape Armitage. The colored dots are the depth coded position traces of the vehicle



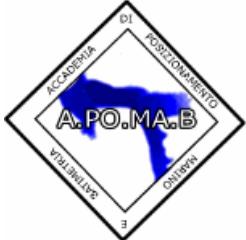
GPS Intelligent Buoys

GPS Intelligent Buoy (GIB) systems may be classified as inverted LBL devices where the transducers are installed on GPS equipped sonobuoys that are either drifting or moored. GIBs may be used in conjunction with an active underwater device (such as a pinger equipped torpedo), or with a passive acoustic sound source (such as an inert bomb striking the surface of the water). Typically the sound source or impact event is tracked or localized using a time of arrival (TOA) technique. Typically several GIBs are deployed over a given area of operation; with the total number determined by the size of the test area and the accuracy of the results desired. Different methods of GPS positioning may be used for positioning the array of GIBs, with accuracies of cm to meter level in realtime possible.

The system is patent protected and products are manufactured by the French company ACSA-underwater-GPS (subsidiary of the ALCEN group). Three off-the shelf products are available from the small portable GIB-Lite system to the large torpedo tracking GIB-FT, and including the medium-size,medium-range GIB-Plus system.

9) History and Examples of Use

Use of GIBs for underwater tracking and weapon scoring have been in use by the Navy since the early to mid 1990's. Early GIBs were created for broad ocean area weapons testing by modifying conventional Navy sonobuoys with small OEM-grade GPS receivers and deploying them from a helicopter or from P-3 Orion aircraft. The GPS data captured by the GIB was modulated over the analog VHF acoustic data stream using frequency-shift keying (FSK). This allows the GPS measurement data to be transmitted and received on legacy VHF sonobuoy receiver equipment. A drifting array of twelve or more GIBs would be deployed in a concentric circular array approximately 7 nm in diameter. Weapon strikes within the array emitted acoustic signatures that were captured by the GIBs and transmitted up to the orbiting aircraft. Post-mission the GPS and acoustic data from the GIBs would be combined to determine an absolute coordinate for the impact location in WGS 84 coordinates.

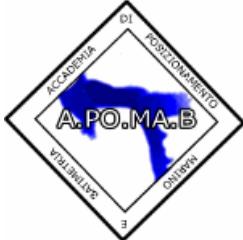


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10) Example of Underwater Acoustic-based Weapon Scoring

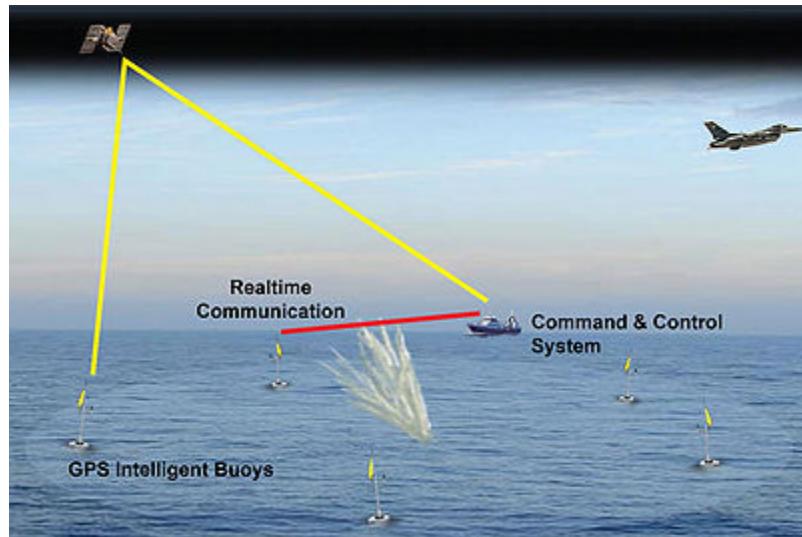
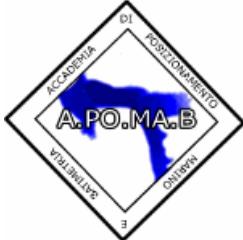


Figure 1: An array of GIBs positioned around a test area to provide weapon impact coordinates from weapon testing or training. Upon striking the water, acoustic signatures are captured and processed by each GIB, and relayed to the shipboard or a land based command and control system for realtime processing



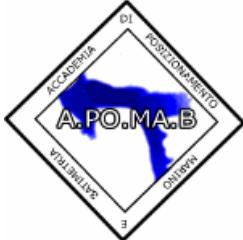
Figure 2: Photograph of the TARGT GIB



GIB type systems have been developed for a variety of specialized applications. An illustrative use of GIBs for underwater positioning is the TARGT weapon scoring and training system.

The system concept (Figure 1) utilizes an array eight to ten GIBs (Figure 2) moored in a 2 km by 2 km array. In the case of the TARGT GIB, the GPS and RF antennas are located on top of the sensor and the hydrophone, or underwater acoustic transducer, is located on the bottom. The device is approximately 6 ft tall and weighs 35 lbs.

Inert weapon releases from military aircraft strike the surface of the water within the array, emitting an acoustic signature that is captured by each of the GIBs. Each GIB determines the precise time of the received signal and transmits this time to the deployment ship in near real time. A command and control system located on the deployment and recovery ship combines the GPS data and acoustic timing information to triangulate the impact location and determine the exact impact time in near realtime. Several methods may be used, the most common being a time difference of arrival (TDOA) least-squares solution algorithm. Post-mission data processing is performed to further refine the results, with two-dimensional positioning accuracies of 1 to 2 meters and impact timing accuracies of 1-2 milliseconds demonstrated.



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