Experimental Results of an Inexpensive Short Baseline Acoustic Positioning System for AUV Navigation

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Abstract — The Ocean Engineering Department at Florida Atlantic University and the Naval Postgraduate have implemented AUV acoustic positioning systems based on the Desert Star Dive Tracker short base line (SBL) system. The motivation for these implementation efforts was to develop a short range, inexpensive, but relatively high precision navigation system for each institutions autonomous underwater vehicles (AUVs). In the NPS case the SBL system is to support navigation of their Phoenix vehicle in mine reconnaissance type missions where the vehicle needs to more precisely locate obstacles and mine like objects. In the FAU case the SBL system is to support guidance of the Ocean Explorer (OEX) vehicle in rendezvous and docking maneuvers. The Dive Tracker SBL can produce supposed positioning accuracies on the order of 6" rms.

FAU has build a portable easily deployed collapsible frame for supporting 3 SBL transducers or beacons. The frame is arranged in star that is anchored to the bottom. The baseline between transducers is approximately 20 ft. The OEX carries a transducer and electronics that compute its position relative to the baseline. A docking target placed near the baseline and anchored to the bottom. The location of the target is then determined by manually positioning the AUV transducer at the target and taking SBL fixes. A series of at-sea tests of this system have been conducted. This paper will present results of the at sea tests of this positioning system off the coast of Boca Raton Florida. The analysis will comment on the efficacy of this type of system for guidance of small AUVs in docking maneuvers.

I. Introduction

Recently various small Autonomous Underwater Vehicles (AUVs) such as WHOI's ABE and REMUS, MIT SeaGrant's Odyssey, and FAU's Ocean Explorer (OEX) have demonstrated the capability to perform oceanographic sampling and survey missions of varying depths, ranges, and durations [1,6,3]. The small size of these vehicles, however, constrains the energy and data storage capacity of these vehicles. The maximum projected mission duration for any of these vehicles under continuous operation is no more than 12 hours. While this is more than sufficient for a wide range of tasks there still remain significant oceanographic processes that require longer time scales over which sampling is performed. For example it may be better to perform several short surveys, each on a different day than to perform one long survey all on one day. Episodic events such as storm passage are difficult to capture unless the AUV can be pre-inserted and waits for the storm to occur. One solution to these problems is to somehow "dock" the AUV to a platform that restrains the vehicle while it sleeps between sampling episodes. If that platform can also recharge the AUVs batteries then much longer mission durations would be possible. ONR has identified docking, recharge, and data upload as A key enabling technology for the Autonomous Oceanographic Sampling Network [2].

MIT (Odyssey) and WHOI (REMUS) are developing docking approaches where the vehicle homes to a target using an Ultra Short Baseline sonar array mounted in the nose of the vehicle. The vehicle docks nose first with a power recharge system also mounted in the nose. A nose mounted approach is not desirable for the FAU Ocean Explorer (OEX) [4,8,3]. The OEX AUV has a unique physical arrangement that supports multiple payloads. The tail of the OEX contains all the dedicated components needed for navigation, propulsion, and control. This leaves the forward half of the vehicle free for mission specific payloads. Using this approach a dedicated nosecone is constructed for each different payload configuration. A quick connect bayonet mounting system and distributed power and control systems allow payload modules to be easily exchanged. A nose mounted docking and navigation system would severely decrease the modularity of the OEX concept, since each payload would have to include a docking system. Moreover some of the payload sensors are incompatible with a nose mounted docking system such as the turbulence probe. Consequently, FAU is developing a docking system that can be mounted in mid-section of the vehicle.

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The vehicle docks using a belly mounted stinger and navigation is performed using a short baseline system. The short baseline consists of 3 transducer attached to a portable, collapsible frame mounted on the sea floor. The AUV carries a belly mounted transducer.

The docking system is being developed for two different applications. One is to dock an Ocean Explorer vehicle while free swimming. That is the Ocean Explorer is moving at some speed under fin control as it swims into the dock. The second application is to dock an AUV with hover or station keeping capability. The hovering vehicle can slowly swim up to the dock. The hovering vehicle is currently under development.

The SBL system has some advantages and disadvantages relative to homing type systems. The SBL gives the XY position of the vehicle relative to the dock. the accuracy does not change significantly in the vicinity of the dock. This allows navigation around obstacles and approach paths to the dock that are not direct homing runs. Moreover the AUV can be tracked by the dock. This provides the capability to remotely monitor docking efforts of the vehicle. The SBL system is relatively inexpensive. One disadvantage of an SBL system is that the dock's location must be precisely determined beforehand relative to the baseline. If the dock is subsequently displaced the AUV won't be able to find it. In addition as the vehicle gets close to the dock the navigation accuracy does not get any better. Depending on the pinging protocol the SBL accuracy can be sensitive to vehicle motion.

This paper will present results of at sea tests of an inexpensive Desert Star SBL navigation system for docking navigation.

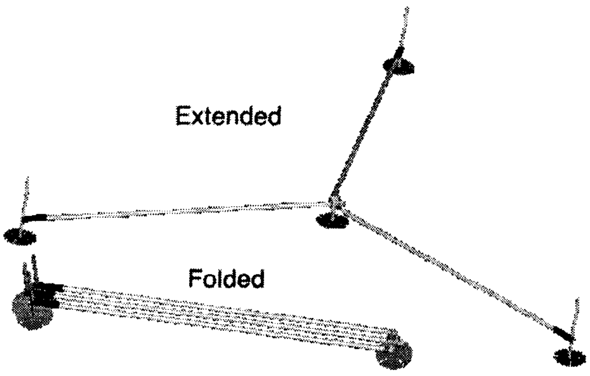

Figure 1: Portable collapsible SBL baseline fixture

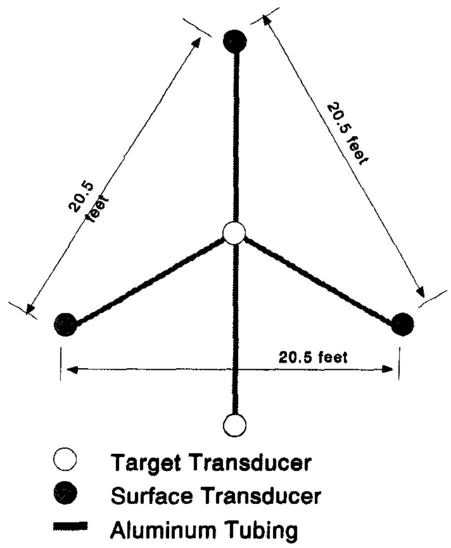

Figure 2: Baseline arrangement

II. Baseline Fixture

In order to facilitate rapid deployment and minimize operations costs, a portable collapsible baseline fixture was developed. Up to a point the longer the baseline the better the accuracy, however, this system needed to be easily deployed from a small vessel. As a compromise a 20.5 ft. baseline was selected using ~12 ft. poles in a star configuration. The poles are attached to a center hub on hinges. Feet at the end of the poles are used to anchor the baseline to the bottom. Cross bars with locking pins precisely constrain the geometry of the baseline. The whole system can be deployed on the ocean bottom in about 30 minutes. Figure 1 shows the collapsed and extended versions. Figure 2 gives the base line dimensions and Figure 3 shows the ranges and coordinate system used to calculate AUV positions.

III. DiveTracker SBL System

The DiveTracker™ system is designed and produced by Desert Star Systems and is commercially available in several models. The unit consists of hardware with built in software to control the transducers, calculate pinging times, and perform other functions such as computing decompression tables for divers. The model chosen for AUV application will provide a method for monitoring step by step, the progressive tests towards the ultimate goal of navigating the AUV to a dock. It will be used as a three transducer short baseline sonar system, capable of giving position information up to 3000 feet with a 6 inch repeatability depending on the noise present in the environment and the length of the baseline. The uniqueness of this system is its relatively low cost and ease of use while giving extremely accurate results. The system uses two identical main electronics boards which are configured to act as desired.

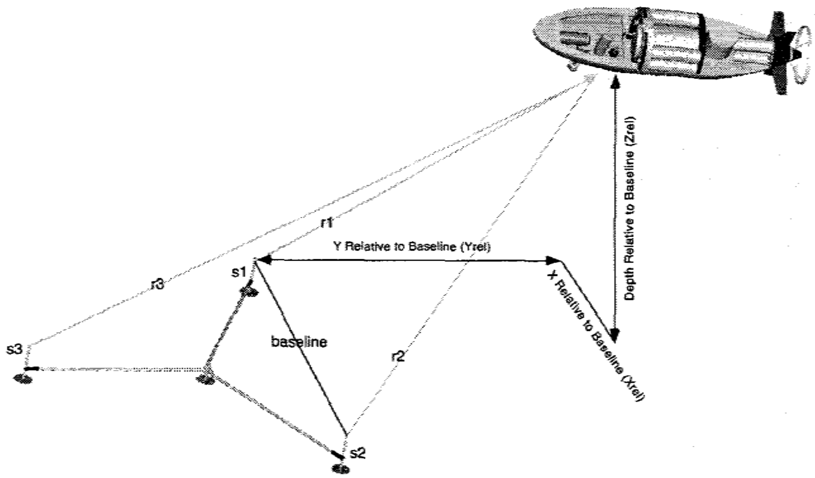

Figure 3: Baseline coordinate system

For the system in use, one will act as a surface station controlling the baseline transducers and one will act as a mobile station controlling one transducer on the AUV. The electronics is enhanced by the software design of the system. The software which operates on the HC11-based board is called DiveCode. This DiveCode is the program which controls the pinging and calculates the return times and ranges. The DiveCode is written in'C' and can be modified for specific uses. Another software program called DiveBase runs on a PC and is used in conjunction with the surface station. Also, a utility program called DiveTerm is used on a PC for downloading the configuration file, DiveBase.par to the mobile station.

(a) Components

The hardware for the system which will be used consists of a surface station (STM-1), a bare electronics module (EM-2), three sonar transducers (DT1-R-TDCR-40) for operation as a baseline, one sonar transducer(DT1-D-TDCR-40) for operation on the vehicle with the EM- 2. To complete the list of hardware, a PC must be used with the STM-1. Both hardware units contain the same electronics board which is the heart of the system. It includes 25 Kbytes of Flash Memory to store DiveCode, 258.5 Kbytes of RAM for data storage, and 24 Kbytes EPROM for Firmware storage for the DiveTracker™ Operating System (DTOS). It is all processed using a MC68HC11. The unit provides communications to a host computer via RS-232. The unit is powered by 9-12VDC and draws 1.2Amps peak during transmit and 100mA during receive.

The surface station, STM-1, is designed to be used topside to operate one to three sonar transducers. The electronics are mounted inside a rectangular metal case which measures approximately 9 inches by 6 inches by 1.5 inches. It has two ports for power, one is for external power, the other for power supplied from a PC cage. Three sonar ports are on the face along with a reset button and indicator LED. A DB-9 port provides the RS-232 communication to a host PC. This unit is designed to be run in conjunction with a PC running the DiveBase utility program.

The EM-2 is simply the bare electronics module. This module controls the transducer located on the vehicle and calculates the position based on ping return times. This module does not need a PC to run, as the STM-1 does, however, the position information is used ultimately by sending it to the AUV main computer, via the RS-232 communications port. This module must be mounted in a water tight housing or pressure vessel, which will be discussed further in the implementation section.

The sonar transducers used in the system are all identical, which the exceptions of their length and termination. They operate at 40 KHz and have a "near omni-directional pattern in the horizontal plane (perpendicular to the cable mounting axis) and a horizontal'8' shaped pattern in the vertical plane (about 6 db down in the vertical axis." The assumptions made are: spherical spreading loss, ambient noise level 46 db(sea state 4), attenuation 9 db/km, 100W RMS transmit power, and 1000 Hz bandwidth receive filter [2]. For the transducers attached to the STM-1 station, the connectors used are 4 pin AMP circular splash- proof connectors. For the transducer used on the AUV, the cable is terminated with an Ocean Explorer standard SeaCon FAWM-8P-MP connector.

The DiveTracker™ system is set up to use a Sen-Sym SCC300AI pressure transducer. The EM-2 is designed with bridge circuitry specifically tweaked to accommodate the sensor that comes with the unit. The signal goes through an 8-bit ADC and is converted to depth within SmartDive.

The DiveCode is the program which runs under the DTOS on all DiveTracker™ stations in use in a network. The DiveCode is written in'C', and can be modified for specific needs. The version of DiveCode in use in this system is Desert Star's SmartDiveV1.34. This program contains the coding for controlling the pinging protocol, calculating return times, and communications.

DiveTerm is a utility program which is used on a PC to configure the mobile station. It connects to the station via RS-232 and serves as the link to the DTOS. DiveTerm also allows the user to select certain DiveCode programs, download new DiveCode, etc.

DiveBase is another utility program which runs on a PC using MS DOS, Windows 3.1, or Windows'95. It is required to operate the STM-1. The DiveBase program configures the STM-1 as a surface station and begins the interrogation. It provides a radar-like display which is used to track the operation of the system. The screen displays the baseline transducers and the vehicle transducer. There are several parameters which are required to be set in order to properly configure the units for their specific usage. The DiveTerm utility is used to download this file, called DiveBase.par to the EM-2. The DiveBase program automatically downloads this file to the STM-1 when initially started or reset. The DiveBase.par file contains parameters such as baseline distance, number of mobile stations, quiet times, etc. The specific DiveBase parameters and the file are given in appendix A.

(b) Pinging Protocol

The DiveTracker™ system uses a "round-robin" type pinging protocol to determine position information. The range is calculated based on the time it takes send and receive pings divided by the speed of sound. The advantage of this type of protocol is that both the AUV and base station can determine the position of the AUV. The disadvantage is that extra time is needed to compute position which makes the accuracy sensitive to vehicle motion. The ranges determined by the DiveTracker™ are Range 1, Range 2, and Range 3. This protocol also only requires one transmitter/receiver and two receivers on the baseline instead of 3 transmitter/receivers. This is less expensive. A description of the protocol is given in Table 1. and Figure 4. Once the 3 ranges are determined, intersection of spheres is used to fix the relative position of the AUV and the baseline

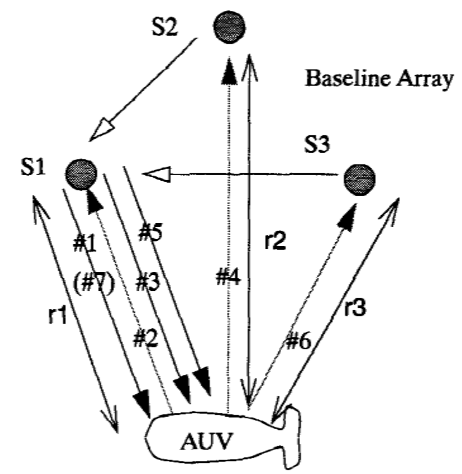

Figure 4: SBL pinging protocol.

Table 1: Pinging Protocol

Ping #	Range Calculated
1 (S1->AUV)	
2 (AUV->S1)	r1 at Base
3 (S1->AUV)	r1 at AUV
4 (AUV->S2)	S1->AUV->S2 - S1->AUV = r2 at Base
5 (S1->AUV)	AUV->S2,S1->AUV - AUV->S1 = r2 at AUV
6 (AUV->S3)	S1->AUV->S3 - S1->AUV = r3 at Base
1 (7) (S1-AUV)	AUV->S3,S1->AUV - AUV->S1 = r3 at AUV

(c) Characteristics of the System

Work was done by a graduate student at Naval Post Graduate School concerning navigating an AUV using the DiveTracker™ system [5]. That research determined the arrangement of baseline and vehicle which yields the most accurate and repeatable SBL results. Each range value from the baseline transducers describes a circle with radius equal to that range value. The angle that the tangents of these circles form at their intersection determines the results of the system. The research at NPS found that the system yielded the best results when this angle was 90°. This means that an equilateral triangle with the baseline transducers as two points and the vehicle as the third will provide the best results. If a thirty foot baseline is used, then the docking station can be place about 26 to 30 feet perpendicular to the baseline to complete the approximate equilateral triangle. This range was chosen so that docking would occur at a distance far enough from the baseline to make an abort safely possible given the vehicle turning radius.

For the docking project, the goal will be to dock at some fixed range with respect to the baseline It is at this range that the repeatability of the system is desired to be extremely high, on the specified order of six inches. Another error which is inherit in the system comes with the pinging protocol. Any error in Range 1, is also added to the error in Range 2 and Range 3 since Ranges 2 and 3 are calculated by subtracting out Range 1.

IV. Stationary Positioning Results

Once the SBL bottom array fixture was constructed and the SBL electronics integrated into the vehicle and the baseline a series of at sea tests were conducted. These early tests gave inconsistent results. It was later discovered that the Divetracker unit had a design flaw that created cross talk in the base unit channels. Some manufacturing problems also resulted in failed components on the board. Once these were fixed a new series of tests were conducted. A sample of these tests are shown below. The AUV was placed in 3 separate locations relative to the baseline. The vehicle remained in position for several minutes in each location. A plot of the calculated positions is shown in Figure 5. Histograms of the X and Y components of the AUV position fixes are shown in Figure 6. As can be seen from the figures the Dive Tracker consistently fixed the position of the vehicle to within 6" or better (at 1 standard deviation).

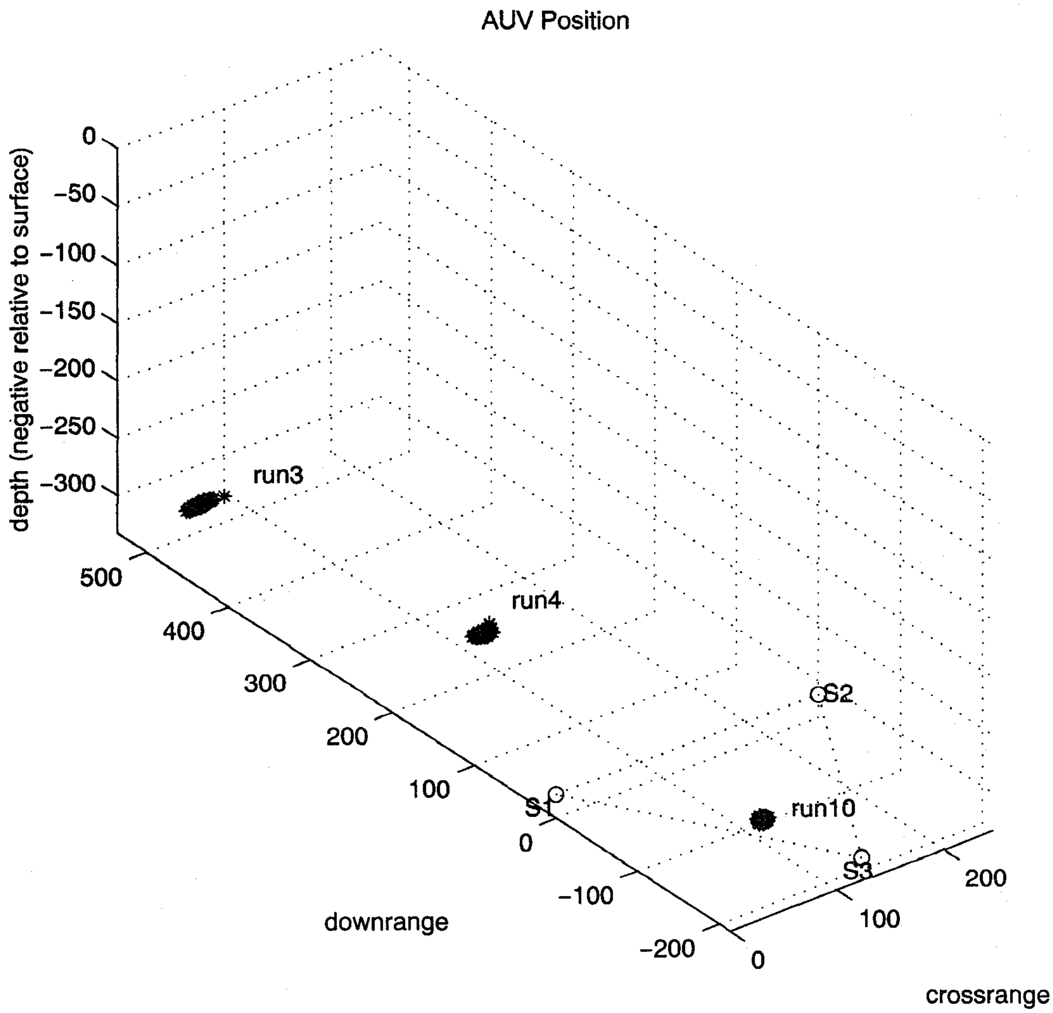

Figure 5: Stationary positioning fixes.

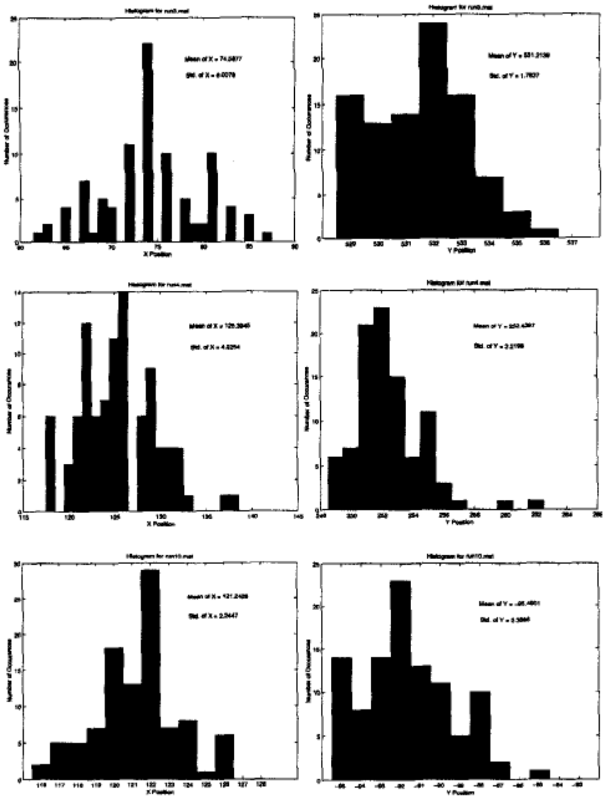

Figure 6: Histograms of stationary positioning errors. (all measurements in inches)

V. Tracking Results

To test the ability of the SBL to track the vehicle a series of short missions were performed where the AUV was programmed to follow a set of waypoints near the baseline. The AUV did not use the SBL data for navigation but merely logged the SBL fixes. A DVL and compass were used to dead reckon the AUV. A DGPS unit was used fix the geodetic position of the AUV relative to the baseline. The results of two of these runs are shown in Figures 7. As can be seen the SBL does a very poor job of tracking the AUVs position with errors one or two magnitudes greater than the stationary case.

This error is a result of the motion of the AUV. The pinging protocol takes between 0.6 to 2 seconds to complete depending on range. At 3 knots (1.54 m/s) the AUV moves between 0.8 meters and 3 meters in the time between when range 1 and range 3 are calculated. The subtraction in calculating r1 and r2 induces a doubling of this error so that the position fixes are off by meters instead of inches. Figure 8 shows the effect of this error in ranges. An exact calculation is plotted in Figure XX for the AUV moving at 36 inches/sec with a 1 second pinging protocol completion time. At very slow speeds (< 0.3 knots) the SBL will maintain high accuracy. This is appropriate for hovering vehicles. At the speeds (> 2 knots) a non-hovering AUV needs to maintain for directional stability the SBL provides relatively poor accuracy.

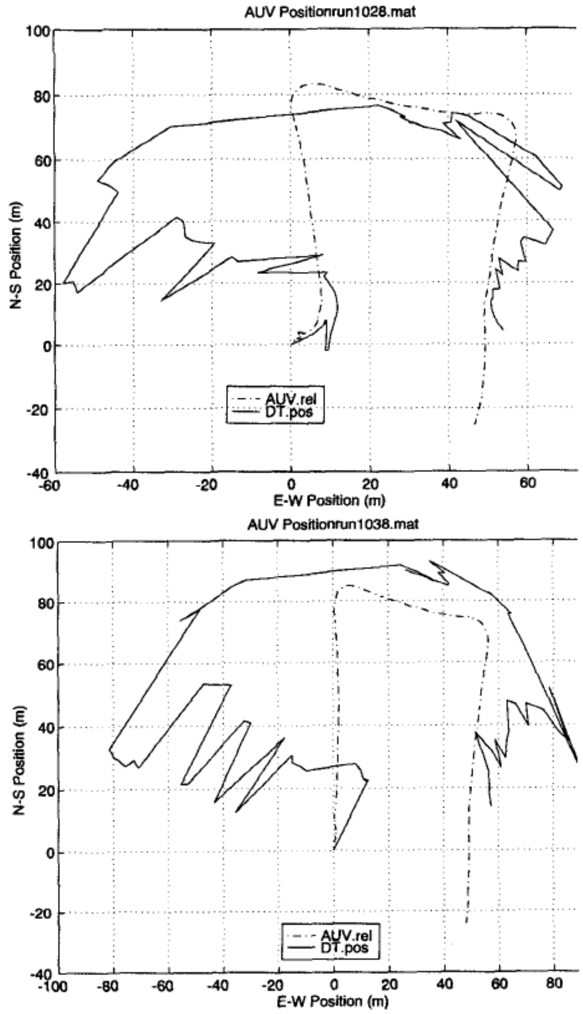

Figure 7: Results of SBL tracking of AUV

A better protocol for tracking purposes is shown in Figure 10. This is used in long baseline (LBL) systems. This requires 3 transmitter/receivers on the base station instead of 1 transmitter/receiver and 2 receivers. This is more expensive but much less sensitive to motion. The pinging protocol is as follows: The AUV sends out ping #1 to all three base station transducers. The 3 transducers each respond in turn after a small preset delays between each. Although the AUV may move a significant distance during the propagation delay between ping #1 and the return of ping #2 this delay is common to returns #3 and #4. If the AUV can measure its groundspeed relatively accurately, its motion during this initial

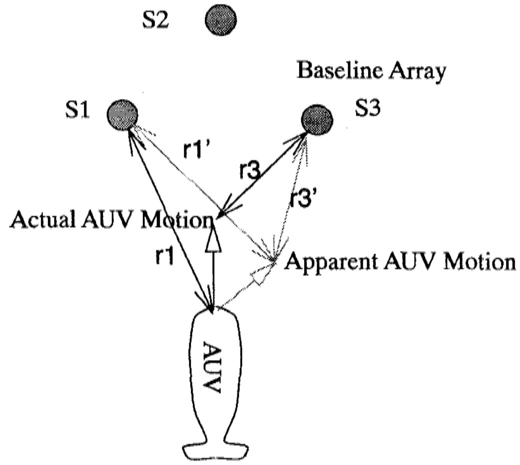

Figure 8: Apparent positional error due to AUV motion and SBL protocol.

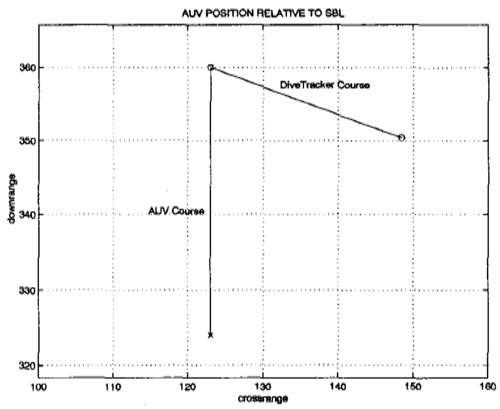

Figure 9: Calculated error due to AUV motion.

propagation delay might be subtracted out to some extent. The error that cannot be accounted for is the motion of the AUV during the fixed delay between returns #2,#3, and #4. But this is very short.

A variant of the dive tracker can be configured for LBL type operation. Currently we are proceeding to modify the navigation system to support an LBL type protocol. Once modifications are finished the tests will be repeated and a comparison of t he systems will be made.

VI. Conclusion

The designed SBL system satisfies the requirements of an inexpensive, portable, easily deployed system with high positioning accuracy. This system is appropriate for tracking hovering AUVs with very slow speeds relative to the baseline. Consistent accuracies of under 6" (1 standard deviation) were attained for static AUVs.These at-sea results confirm earlier work done by NPS with the

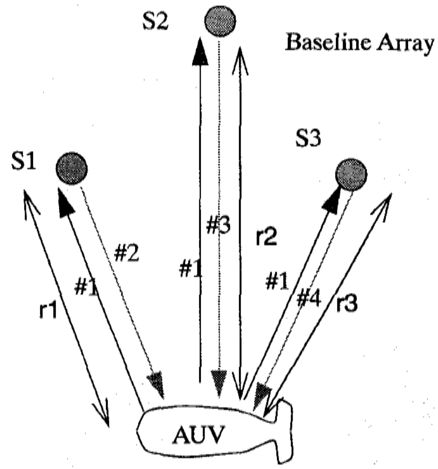

Figure 10: LBL pinging protocol

Phoenix AUV. Thus this system would be appropriate for the new hovering vehicle under development at FAU. What was not seen in previous applications of this SBL systems is experimental determination the motion sensitivity of the protocol. Based on the tests results presented here, one can conclude that the SBL system is inappropriate for the docking navigation for non-hovering AUVS that must sustain 2+ knots to maintain directional control.

VII. References

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