Surveying shipwrecks and tracking ROVs with the High Precision Acoustic Surveying System (HPASS)

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Abstract

This paper describes the High Precision Acoustic Surveying System (HPASS), which has been developed for archaeological wreck site surveying and has also been successfully used for tracking ROVs. The system consists of a mobile unit and up to six static transponders. The system measures the time an acoustic signal takes to get from the measuring unit to a transponder and back again, thus allowing distance to be calculated. An accurate pressure sensor on the mobile unit provides an additional depth measurement. Initial field trials indicated the system was capable of locating position within a standard deviation of ±5 mm over distances of up to 50 m. The system has been used and evaluated on two wreck sites, the *City of Launceston* in Port Phillip Bay, Victoria and the *Pandora* on the Great Barrier Reef in Queensland. The two sites are physically different, presenting different operating and data processing problems. The system worked remarkably well, providing accurate and reliable positional information. A number of problems were encountered in the application of the system to a real situation, including temperature variations, tidal effects and physical interruptions to the acoustic path caused by wreck site features. These issues and the methods used to deal with them are discussed. In addition the results of tracking a ROV are described.

Introduction

In 1997 the Australian National Centre of Excellence for Maritime Archaeology and the Centre for Marine Science and Technology at Curtin University of Technology undertook a joint project to develop a diver operated High Precision Acoustic Surveying System (HPASS) for surveying shipwreck sites. The underwater acoustic surveying system was designed to be deployed in a number of different environments and provide sub-centimetre accuracy over ranges of up to 50 m. After the construction phase the system was evaluated in January and February 1998 to determine the accuracy and operating parameters. It was then deployed in November 1989 on the wreck site of the *City of Launceston*, a iron steamship lost in Port Phillip Bay, Victoria in 1865 and then in February 1999 on the *Pandora* wreck site, a vessel lost in 1791 on the northern part of the Great Barrier Reef, Queensland.

Although HPASS is intended primarily as a diver operated system, an adapter has been developed that also allows it to be used for high precision tracking of a remotely operated underwater vehicle (ROV). In this mode the system has been used to track an experimental ROV with centimetre accuracy during manoeuvring trials.

This paper briefly describes the results of the evaluation trials, wreck site surveys, ROV tracking trials and discusses the advantages and limitations of the system.

The system

When used in its normal surveying mode, the HPASS system consists of a diver unit consisting of two components, a mobile unit used by the diver to locate position and a series of static transponders. The diver operated unit contains the electronics in an underwater housing and is attached by a cable to an acoustic and hydrostatic unit, or probe. The static transponders (up to six in number) are positioned strategically around the site on support tripods. The electronics unit has a start button, together with a viewing port showing the signal status of the transducers and the fix number. Essentially the system measures the time an acoustic signal takes to get from the probe on the diver unit to a transponder and back again. If all six distances are known it is possible to calculate the three dimensional position of the diver unit with a high degree of redundancy. A vertical measurement is made with a pressure transducer to determine the depth of the probe, thus providing an additional measurement to give greater accuracy to the Z component which is usually weak because of the relative flatness of wreck sites.

Figure 1. The basic HPASS unit, six transponders, diver unit and tripods.

Figure 2. The transponder unit, the diver is unscrewing the protective cap

Figure 3. Calibrating a transponder, note the diver unit placed on top of the transponder.

Figure 4. Close-up of the probe unit, the diver unit in background.

Figure 5. Using HPASS on the calibrated protowtower.

The system was designed to operate over a range of about 50 m, with the operator concentrating on surveying fixed positions and the post-survey work conducted on the surface. It was decided that providing the position underwater would be too complex and the diver would have difficulty in interpreting the information due to a variety of physical and physiological considerations.

The transponders are mounted on tripods at fixed locations surrounding the area to be surveyed and the operator, after calibrating the system, takes the diver unit to the points that need to be surveyed. At each of these points the diver places the probe accurately on the point; levels the probe so that the tip at the base is vertically above the acoustic/hydrostatic unit; writes down the fix number displayed by the unit and describes the survey point; the diver then presses the start button on the unit to initiate the sequence. The probe transmits a series of coded ultrasonic signals to interrogate the first transponder. If the transponder detects the appropriate signal (each transponder is programmed to respond to a particular code), it then retransmits a similar coded acoustic signal. The interrogation sequence is as follows:

i. The diver unit probe transmits a coded ultrasonic signal coded for a particular transponder;
ii. It waits for a predetermined time for the appropriate transponder to respond, either starting the next step on receiving a response, or continuing the cycle after a pre-set elapsed time;
iii. At the end of each transmission period the unit records the elapsed time (zero if no response) between transmitting the burst and receiving the corresponding reply;
iv. The diver unit repeats this sequence for a pre-set number of times (usually 20)

for each transponder;

v. On completing the interrogation of the first transponder, it then repeats the same process for each of the remaining transponders;
vi. On completion of the acoustic measurements, the diver unit then measures the pressure at the probe to determine its depth;
vii. It records the time the recording was initiated;
viii. Finally in the last cycle the unit measures the water temperature which is used to determine the speed of sound in water.

Small red lights (LEDs) above the numeric display indicate the progress of the interrogation sequence. When a given transponder is being interrogated its corresponding LED is illuminated. Once the interrogation sequence is completed, LEDs corresponding to transponders that were successfully interrogated will be illuminated steadily, while those corresponding to transponders that were not successfully interrogated will flash. The diver then has the option of either repeating the interrogation sequence in an attempt to obtain a better fix or moving on to the next point to be surveyed.

At the end of the diving operation, the unit is brought to the surface, the data port on the electronics unit is accessed through a water-tight inspection plate and plugged into the serial (RS232) port of a computer. The data of up to 1200 readings is then downloaded to the computer for processing.

When used for tracking the experimental ROV, the diver electronics unit remains on the surface vessel and is connected to an interface box instead of to the probe. This interface box communicates to a pre-amp/power-amp unit in the ROV via the ROV’s umbilical. The processor in the diver electronics unit runs a different program (this is simply a matter of swapping EPROMs) which causes it to continually cycle through, sending one interrogation to each transponder and immediately outputting the result on the serial link. These data can then be logged for later post processing and/or used for real-time tracking of the ROV, although this latter capability has not yet been implemented.

Calibration of the transponder array

The usual arrangement for surveying a site is that the diver first takes the unit to each transponder in turn and makes a measurement on top of the transponder, in order to calibrate its position. In addition at various points during the survey, the positions of a reference transponder may need to be re-calibrated to allow for tidal changes.

When using the system for ROV tracking this method of calibration is often not practical and the approach taken is to exploit the high degree of redundancy in the data to compute the transponder locations as well as the ROV positions. The redundancy arises because five or six transponders are usually used for these trials whereas a minimum of two are required to compute a fix. This method gives satisfactory results provided highly redundant fixes are obtained from many widely separated points throughout the survey area.

Software processing

The data is processed to convert the measurements to distances and depths and to produce data compatible with a commercial survey reduction program. In this calculation parameters relating to the delays in the electronic initiation and also the temperature and salinity of the water, which affects the speed of sound, are taken into consideration.

Two survey reduction programs have been used to date, the Web program developed by Nick Rule and the Site Surveyor program developed by Peter Holt of 3H Consulting, both of which provide the capability to graphically edit the data to remove outliers, the latter being more sophisticated and particularly good at adjusting data. This capability has proved extremely useful as the acoustically challenging environment in which HPASS usually operates sometimes produces a small number of errors that are extremely difficult to detect automatically.

The assessment tests

In 28 January and February 1998 field tests were undertaken at Bathers Bay off the Western Australian Maritime Museum, Fremantle to assess the accuracy of the system. In the tests, a calibrated tower, normally used as a photo tower for photogrammetry, was used to test the accuracy of the system. The tower consisted of a 2 m-square base made out of 20 mm square-section tubing. From each pair of corners, two squares were mounted, which joined together at an apex about 2.5 m above the base. The tower was marked with 27 targets on the base and on the parts of the tower above the base. The targets were measured with a tape measure on land and the co-ordinates calculated using the Web program which converted the direct measurements to Cartesian co-ordinates.

The tower was lowered to the seabed in about 7 m of water and erected. Five transponders were mounted in tripod holders and deployed in an approximate circle around the tower at distances from the tower ranging between 17 m and 31 m. A total of fifteen points on the tower were surveyed. The resulting data set was down loaded and processed. The calculated direct distances were then processed using Web and the results gave co-ordinates and distance and depth. The results indicated that the average absolute residual of the acoustic range measurements was 4 mm (with a maximum residual of 14 mm and a minimum of –12 mm). Differences between repeated measurements at the same point (8 pairs of repeated measurements) was X = 12 mm, Y = 13 mm, Z = 63 mm. RMS differences between the X, Y and Z co-ordinates derived from acoustic measurements and the X,Y and Z co-ordinates derived from tape measured distances on land were: X = 23 mm, Y = 36 mm and Z = 45 mm.

The second test was more ambitious using the tower and a calibrated vertical tube to assess the vertical accuracy. The tower, tube and transponders were deployed in the same place and a total of 83 measurements were made during this test. The survey first established the transponder location, then the positions of the 200 mm scale graduations on the base of the tower, together with the fixed targets that had been previously surveyed on land and during the first test. The calibrated tube was then surveyed and the transponders re-surveyed. The objective was to obtain more detailed information of the repeatability and the vertical accuracy.

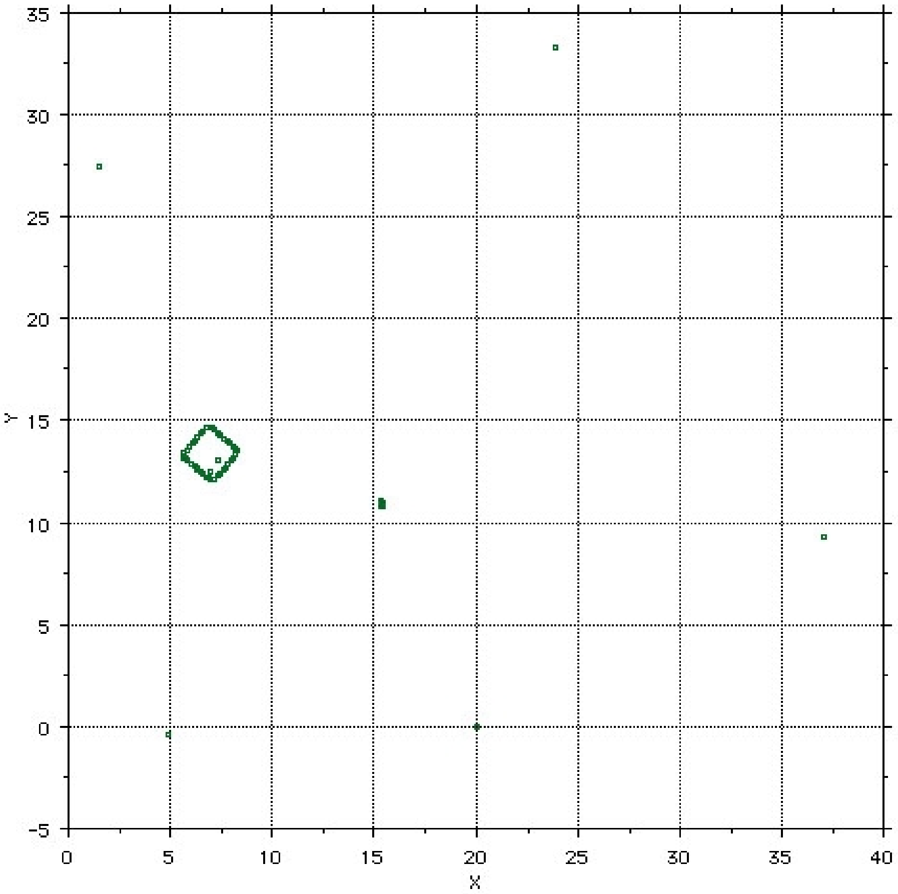

Figure 6. Basic plan of tower and tube test showing location of transponders (scale in m)

The results are divided into four separate areas:

1. Co-ordinate and distance residuals
   This assessed the accuracy of measuring small distances, in this case a number of measurements were made of the 200 mm graduations on the base of the tower. The average absolute residuals for the direct distances ranging up to 40 m was 8 mm (the maximum residual was 27 mm the minimum –49 mm).
2. The repeatability of measurements
   This attempted to assess the co-ordinate differences when the point is re-measured. The average of eight repeat measurements, where the probe was relocated on the same control point (co-ordinate X = 6.855, Y = 12.190, Z = 4.975) at different times, gave standard deviations of 5 mm in X, 9 mm in Y and 53 mm in Z.
3. Accuracy
   This assessed the measurement of medium distances (*c*. 2 m) and of small (*c*. 200 mm). In the former case the horizontal distance to corresponding targets across the base of the tower were measured in air to be 1.977 m and from the HPASS system 21 measurements were averaged to 1.980 m (SD 0.012 m). The 200 mm graduations on the on the base of the tower were averaged over 31 measurements and found to be 199.5 mm (SD 10.8 mm).
4. Vertical accuracy and the limitation of vertical measurement
   The depth measurements showed an inconsistent variation against the depth differences. The residuals for individual readings were small (max negative residual 4 mm; average absolute residual 2 mm; max positive residual 12 mm). However,

when the depths were plotted against the measured datum a regression plot indicated small positive and negative errors, of mean 11 mm (SD 50 mm) suggesting that the water surface or sea conditions were affecting the readings. The errors showed no correlation with time and thus were not related to tidal changes or with poor tower stability. It was recognised that there is some uncertainty in how the software program treats the relationship between the pressure-depth measurement and the depth calculated from the direct distances and this is being studied at present.

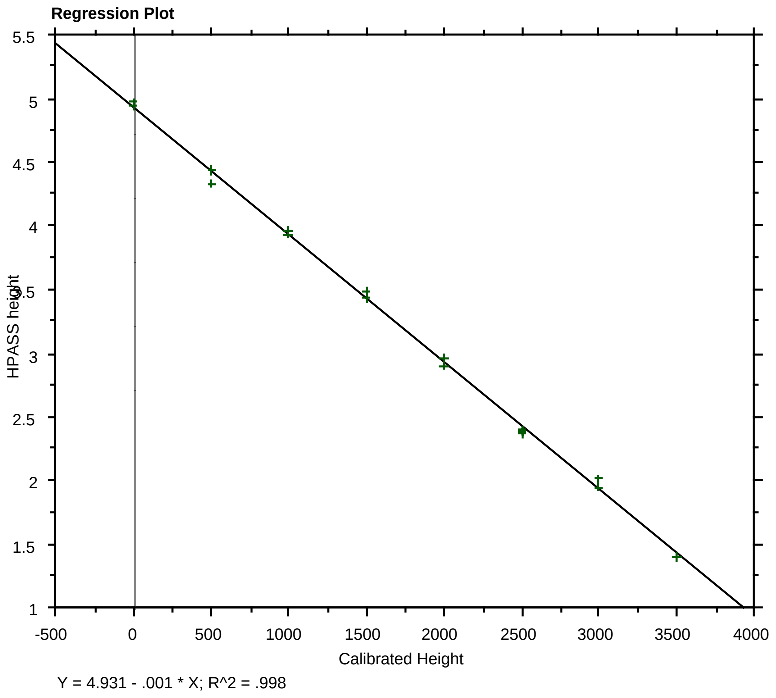

Figure7. Regression plot using calibrated tube

The *City of Launceston* operation

The first field trial was on the *City of Launceston,* a large iron wreck, intact to the upper deck, about 54 m long by about 7 m wide, lying upright in a depth of approximately 21 m. The depth to the deck is between 17 and 19 m. Considerable debris from collapsed deck structures is present on the deck forward of amidships. The vertical distance from the upper deck to the seabed varies between approximately 2 to 4 m. The sea bed bottom and the surface of the deck is soft silt mud. Visibility is generally no more than 5 metres and generally less than one metre. The objective of the HPASS survey was to assist the archaeologists in mapping the deck level features of the site including the outline of the hull, plotting the excavation areas and locating individual objects.

The immediate problem was how to locate the transponders, since generally they are located outside the area of interest, this would require them to be off the main site and thus on the sea bed considerably below the level of where the survey was to take place. One option was to mount the transponders off the site on towers, however, this was considered impractical because they would have to be mounted at least 3 m above the seabed in order to be above the level of the deck and thus would inevitably be unstable and vulnerable to damage. It was decided to deploy the transponders around the edge of the site on the deck. This had the disadvantage that the large metal objects on the deck would cause acoustic shadowing of signal from some transponders and also it would lower the accuracy around the periphery off the site. Initial trials showed that certain positions could not be recorded because of acoustic shadowing. However, these situations were rare and most positions could be measured.

Two control positions were located on the site, one at the stern post the other on the corner of an engine hatch. This was used as a method of checking the reliability of the system on a day-to-day basis and to assist in fixing the co-ordinate system. Seven dives were conducted on the site, totalling 258 measurements. A series of outlines of the deck area of the vessel and major feature on the deck were made. The outline of excavation trenches were recorded together with positions of the artefacts within the trenches. The trial showed the difficulties in surveying a real site, particularly where there is considerable vertical elevations that cause acoustic shadowing. However, it was generally considered that the system was more efficient than the traditional tape trilateration system, which itself has similar problems with large objects obstructing the tape measurement.

The *Pandora* operation

The *Pandora* lies in 32 m of water and the site is approximately 50 m by 20 m wide. As part of the 1999 Pandora Project, sponsored by the Port of Townsville as part of the Pandora Foundation, Queensland Museum, the objective of the HPASS survey was firstly to plot the position of the survey stakes used in previous expeditions and then to plot targets and artefacts. Because of the length of the site, it was decided to deploy the six transponders around the stern half of the site first, and then move the stern-most transponders to the bow, for the second stage of the work. It was also acknowledged that tides would have an unpredictable effect on the work, given that the mean tidal range at the site was about 3 m. During the expedition the system was used for a total of 540 minutes on eleven dives; each individual dive lasting for 45 minutes and a total of 245 measurements were made.

Figure 8. Plot of temperature variation over time during two dives in one day (time in mins)

Processing of data produced some unexpected results. Firstly, it was noted that on occasions the temperature varied up to 0.13°C over a 45 minute period and 0.8C over 4 hours. As this would have a small but significant effect on the velocity of sound, a redesign of the software processing (which previously had a fixed temperature applied to all results of a single data set) was made. The distances, corrected to the temperature at the time of recording, produced more consistent results. It was assumed that the temperature fluctuations were due to reasonably strong, but variable currents, which produced unpredictable eddies mixing cold deep oceanic water with warmer shallow reef water on the site at the edge of the Barrier Reef.

Report Generated : 10/06/99 12:03:26

Project
Project Name : NewProject
Project Code : SITE-
Created By : Western Australian Maritime Museum
Date Created : 9/06/99 16:17:10
Last Modified : 10/06/99 12:02:58
Project Notes :

Units : m

Statistics

RMS Residuals:	0.045 m
Avg. Residual:	0.021 m
Horiz. Geo. Error:	0.079 m
Depth Geo. Error:	0.333 m
Unit Variance:	7.050 m
Redundancy:	23
Auto Reject:	Off
Points Used:	14
Points Ignored:	0
Observations Used:	65
Observations Ignored:	8
Observations Rejected:	0
First Ref. Point:	T2
Second Ref. Point:	T1
Third Ref. Point:	T3
Depth Ref. Point:	T2

Points :

Name	X	Y	Z	Major	Minor	Theta	ZError	Comment
T1	11.816	-3.371	2.059	0.023	0.000	90	0.000	
T2	33.892	12.768	-0.000	0.000	0.000	28	0.000	
T3	25.140	-1.751	2.331	0.031	0.021	134	0.000	
T4	47.653	-6.136	-0.169	0.046	0.022	227	0.110	
T5	14.164	25.399	0.318	0.042	0.020	226	0.099	
T6	50.385	15.323	-1.258	0.059	0.028	16	0.167	
3	12.050	0.105	0.816	0.049	0.025	160	0.068	12,0
6	41.885	3.755	1.355	0.044	0.028	36	0.066	Bx11/Bx13 +1
7	42.427	3.714	1.383	0.062	0.031	234	0.067	Bx9 + 1m
8	42.043	3.502	1.325	0.062	0.030	234	0.068	Bx10 +1m
9	42.691	3.668	1.209	0.040	0.026	27	0.068	Bx8 +1m
11	43.981	-0.189	1.285	0.043	0.027	33	0.070	D44,0
13	20.840	7.786	2.131	0.055	0.034	106	0.158	S3x
14	21.145	10.323	1.139	0.033	0.025	38	0.093	S4x

Measurements :

Baselines :

Source	**Dest.**	**Obs**	**O-C**	**Error**	**w-Test**	**Comment**
T1	T2	27.409	-0.015	0.015	1.153	Std devn = 0.00122
T1	T2	27.440	0.016	0.015	1.237	Std devn = 0.00192
T1	T3	13.492	0.067	0.015	4.959	Std devn = 0.000221
T1	T3	13.477	0.052	0.015	3.842	Std devn = 0.000221
T2	T3	17.118	0.006	0.015	0.485	Std devn = 0.000555
T2	T3	17.114	0.002	0.015	0.160	Std devn = 0.000555
T1	T4	36.035	0.022	0.015	1.740	Std devn = 0.000441

T1	T4	35.985	-0.028	0.015	2.256	Std devn = 0.00132
T2	T4	23.404	0.021	0.015	1.736	Std devn = 0.00176
T2	T4	23.350	-0.033	0.015	2.738	Std devn = 0.000481
T3	T4	23.099	0.027	0.015	2.131	Std devn = 0.000221
T3	T4	23.050	-0.022	0.015	1.767	Std devn = 0.000441
T1	T5	28.887	-0.031	0.015	3.895	Std devn = 0.000453
T2	T5	23.455	0.028	0.015	2.285	Std devn = 0.000727
T2	T5	23.409	-0.018	0.015	1.504	Std devn = 0.000453
T1	T6	42.964	-0.025	0.015	1.892	Std devn = 0.00068
T1	T6	42.947	-0.042	0.015	3.175	Std devn = 0.00107
T2	T6	16.828	0.091	0.015	7.080	Std devn = 0.00043
T2	T6	16.842	0.105	0.015	0.000	I Std devn = 0.000215
T3	T6	30.703	0.016	0.015	1.211	Std devn = 0.0048
T3	T6	30.658	-0.029	0.015	2.203	Std devn = 0.000907
T4	T6	21.653	-0.007	0.015	0.591	Std devn = 0.00181
T4	T6	21.678	0.018	0.015	1.638	Std devn = 0.000215
T5	T6	37.610	-0.019	0.015	1.981	Std devn = 0.000555
T5	T6	37.553	-0.076	0.015	0.000	I Std devn = 0.000453
3	T1	3.720	0.021	0.015	4.357	Std devn = 0.000221
3	T2	25.270	0.010	0.015	0.864	Std devn = 0.000257
3	T3	13.260	-0.047	0.015	4.458	Std devn = 0.000221
3	T4	36.192	0.033	0.015	3.406	Std devn = 0.000221
3	T5	25.399	0.012	0.015	1.987	Std devn = 0.000481
3	T6	41.304	0.007	0.015	0.635	Std devn = 0.000466
6	T1	30.907	-0.004	0.015	0.452	Std devn = 0.00136
6	T2	12.128	0.005	0.015	0.624	Std devn = 0.00192
6	T4	11.554	0.003	0.015	0.476	Std devn = 0.00172
6	T6	14.588	-0.003	0.015	0.374	Std devn = 0.00136
7	T2	12.522	0.003	0.015	0.493	Std devn = 0.00136
7	T4	11.261	0.003	0.015	0.493	Std devn = 0.00172
7	T6	14.321	0.001	0.015	0.493	Std devn = 0.00043
8	T2	12.415	0.003	0.015	0.569	Std devn = 0.00129
8	T4	11.255	0.003	0.015	0.569	Std devn = 0.00043
8	T6	14.698	0.001	0.015	0.568	Std devn = 0.000882
9	T1	31.630	-0.049	0.015	4.475	Std devn = 0.00865
9	T2	12.729	0.013	0.015	1.507	Std devn = 0.00387
9	T3	18.441	0.038	0.015	3.437	Std devn = 0.00365
9	T4	11.078	0.003	0.015	0.550	Std devn = 0.00559
9	T6	14.174	-0.007	0.015	0.899	Std devn = 0.00181
11	T1	32.306	-0.026	0.015	2.388	Std devn = 0.00233
11	T2	16.454	-0.018	0.015	1.873	Std devn = 0.00024
11	T3	18.974	0.040	0.015	3.595	Std devn = 0.00024
11	T4	7.136	-0.003	0.015	0.645	Std devn = 0.00043
11	T6	16.986	0.013	0.015	1.543	Std devn = 0.000215
13	T1	14.350	0.000	0.015	0.001	Std devn = 0.00172
13	T2	14.132	0.000	0.015	0.000	Std devn = 0.00272
13	T3	10.463	-0.000	0.015	0.000	Std devn = 0.00612
14	T1	16.643	0.047	0.015	4.694	Std devn = 0.0014
14	T2	13.098	0.068	0.015	5.972	Std devn = 0.000363
14	T3	12.782	0.008	0.015	0.904	Std devn = 0.000453
14	T4	31.200	-0.030	0.015	2.684	Std devn = 0.00128
14	T5	16.655	0.021	0.015	2.112	Std devn = 0.000993
14	T6	29.753	-0.008	0.015	0.729	Std devn = 0.0029

Depths :

Source		**Obs**	**O-C**	**Error**	**w-Test**	**Comment**
T3		2.198	-0.133	0.100	0.000	I Computed
T1		2.198	0.139	0.100	0.000	I Std devn = 0
3		1.488	0.672	0.100	0.000	I Std devn = 0
T5		0.322	0.004	0.100	0.238	Computed
6		1.331	-0.024	0.100	0.324	Std devn = 0

7		1.346	-0.037	0.100	0.493	Std devn = 0
8		1.283	-0.042	0.100	0.569	Std devn = 0
9		1.236	0.027	0.100	0.371	Std devn = 0
T4		0.590	0.759	0.100	0.000	I Computed
11		1.362	0.077	0.100	1.080	Std devn = 0
T6		-0.766	0.492	0.100	0.000	I Computed
13		1.772	-0.359	0.100	0.000	I Std devn = 0
14		1.063	-0.076	0.100	2.130	Std devn = 0

Figure 9. Report generated from a typical survey day on Pandora site

The practical application of the system also had logistical problems. Firstly, due to the limited life of the transponder batteries (14 days continual use), it was considered prudent to turn the transponders off at the end of each diving day and turn them on again at the beginning of a new diving day. This required a diver to swim around the site turning each unit on or off, a swim of about 120 m, together with a minute or so at each transponder switching it off. This usually took about 15 minutes, a considerable part of a 45 minute working dive. Additionally, the HPASS operators had to swim around the site at the beginning of the survey, calibrating each of the transponder positions, again a considerable part of a working survey dive. In retrospect, there was also a need to return to a reference transponder to keep a check on the tidal variation during the dive, and this did not become obvious until the data started to be processed in detail at the end of the expedition.

As had been previously noted on the *City of Launceston* site, acoustic shadowing became a problem because some recording positions were in excavation holes lower than the level of the seabed. As a result the method of recording was modified; the recording unit was placed on the top of a one metre tube which had a small, survey-staff, bubble level attached to it. The end of the tube was placed on the point to be recorded and the operator then levelled the tube so that it was vertical. This proved to be easy to do and was quite stable, resulting in a less obscured acoustic path to the transponders.

The results of the HPASS survey were processed on a daily basis and data files were initially processed using Web but later the Site Surveyor program was used. In the latter program, it was very easy to rotate or set the co-ordinate system. This was necessary since each survey tended to produce a slightly different co-ordinate system at the end of the adjustment. Site Surveyor was able to set a particular point to a fixed X, Y and Z co-ordinate (translation of the co-ordinate system) and to nominate another point with a fixed Y value (rotation of the co-ordinate system). The X, Y and Z co-ordinates were then exported and used in a GIS (Geographical Information System) package, Arc View. This enabled the results to be plotted on a site plan and incorporated with previous survey data and site plans.

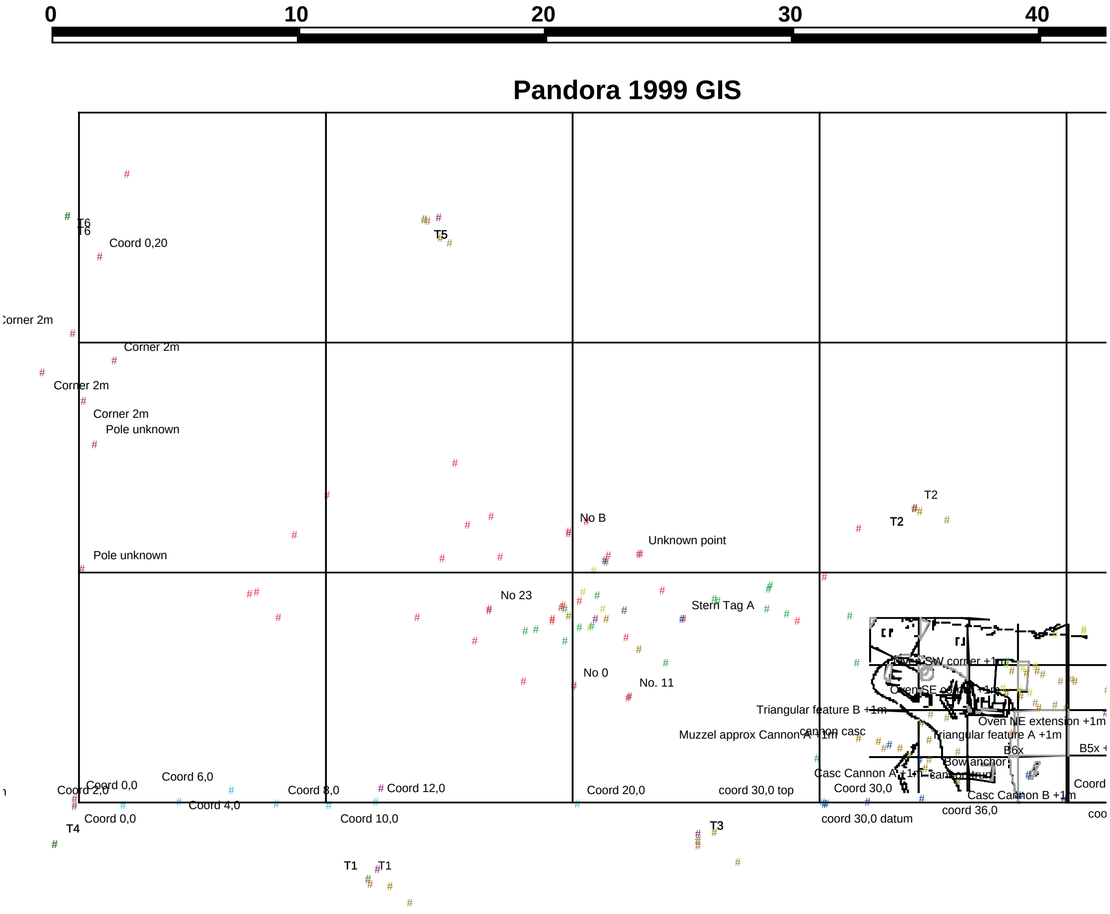

Figure 10. GIS of Pandora

ROV tracking results

In July 1998 the HPASS system was used to track a half-scale model of the PAP104 mine countermeasures ROV during manoeuvring trials. Figure A shows the range data measured by the HPASS system during one of the thirty manoeuvres carried out. Some obvious outliers have been removed from this data set but no other filtering has been carried out.

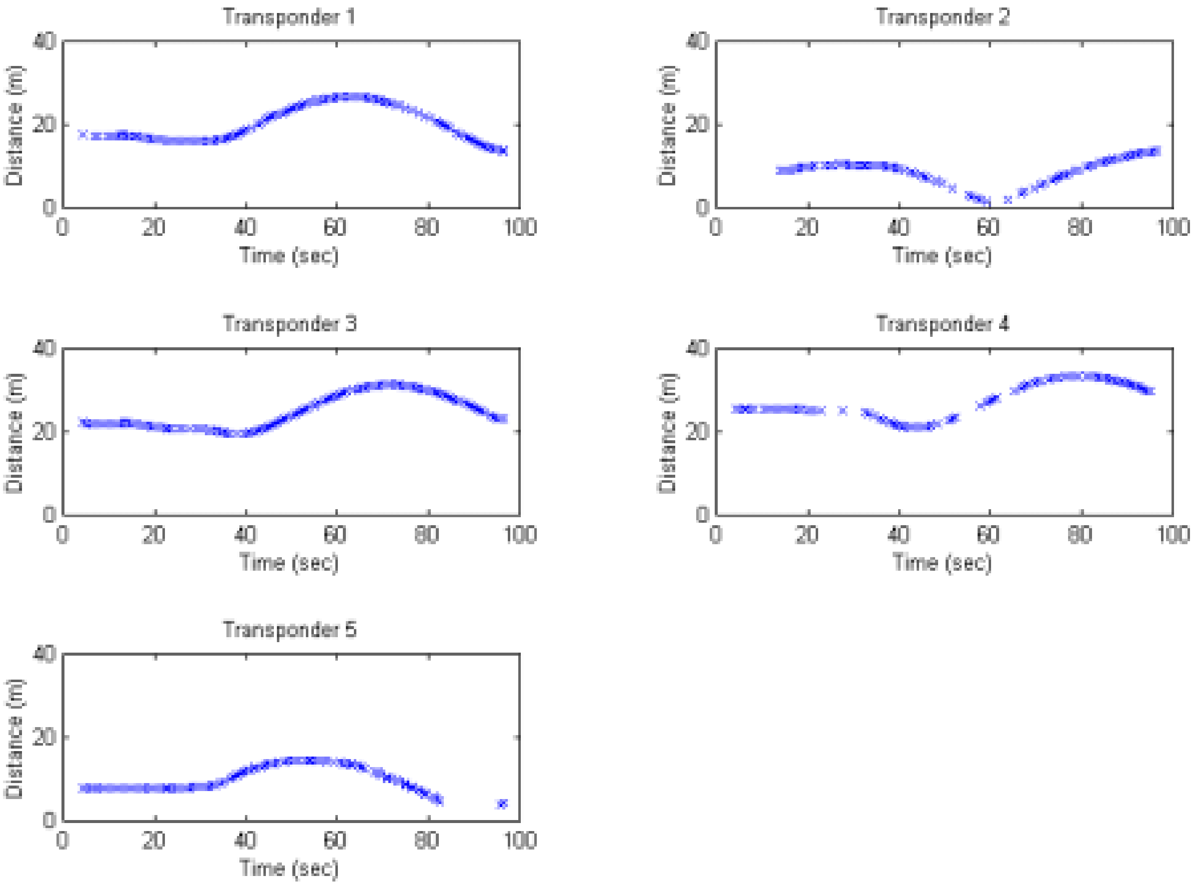

Figure 11. *Range measurement data for ROV manoeuvre 5 (circle to starboard). Each cross corresponds to an acoustic range measurement.*

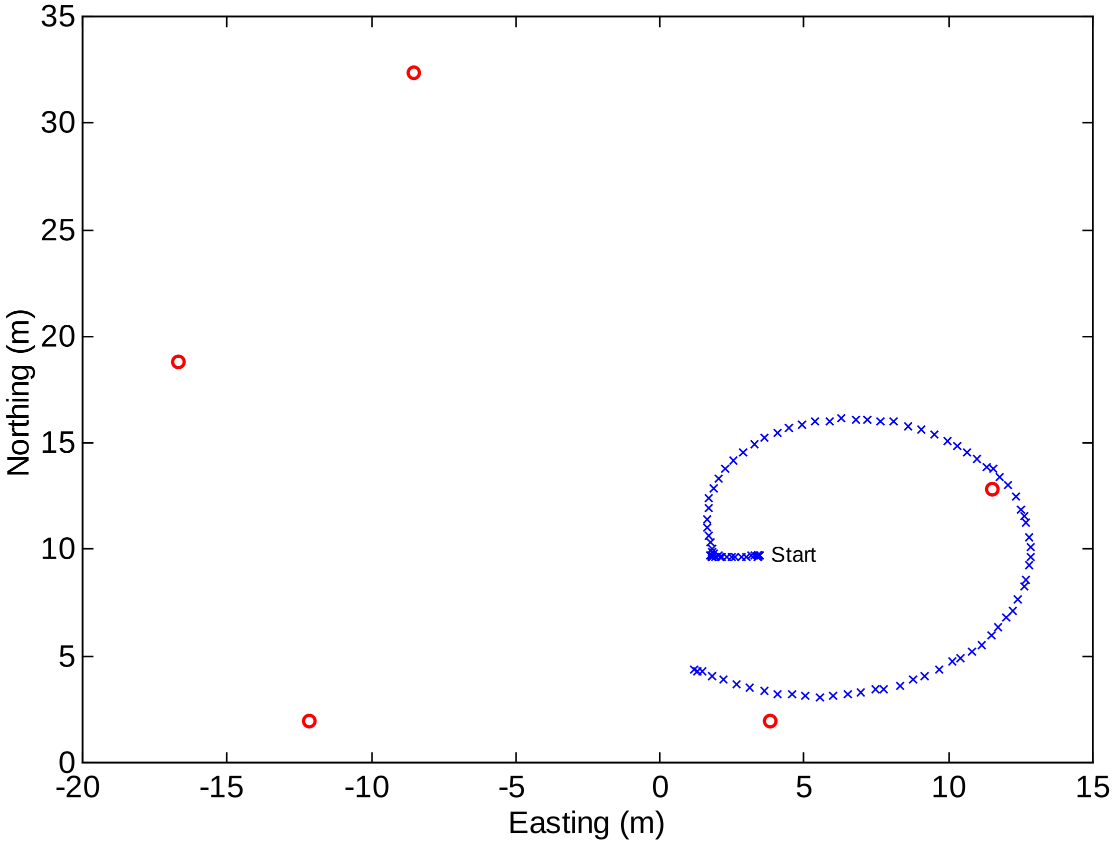

Figure 12. ***Plan view of ROV manoeuvre 5 (circle to starboard) showing all transponder locations. Circles are transponder locations, crosses are vehicle locations.***

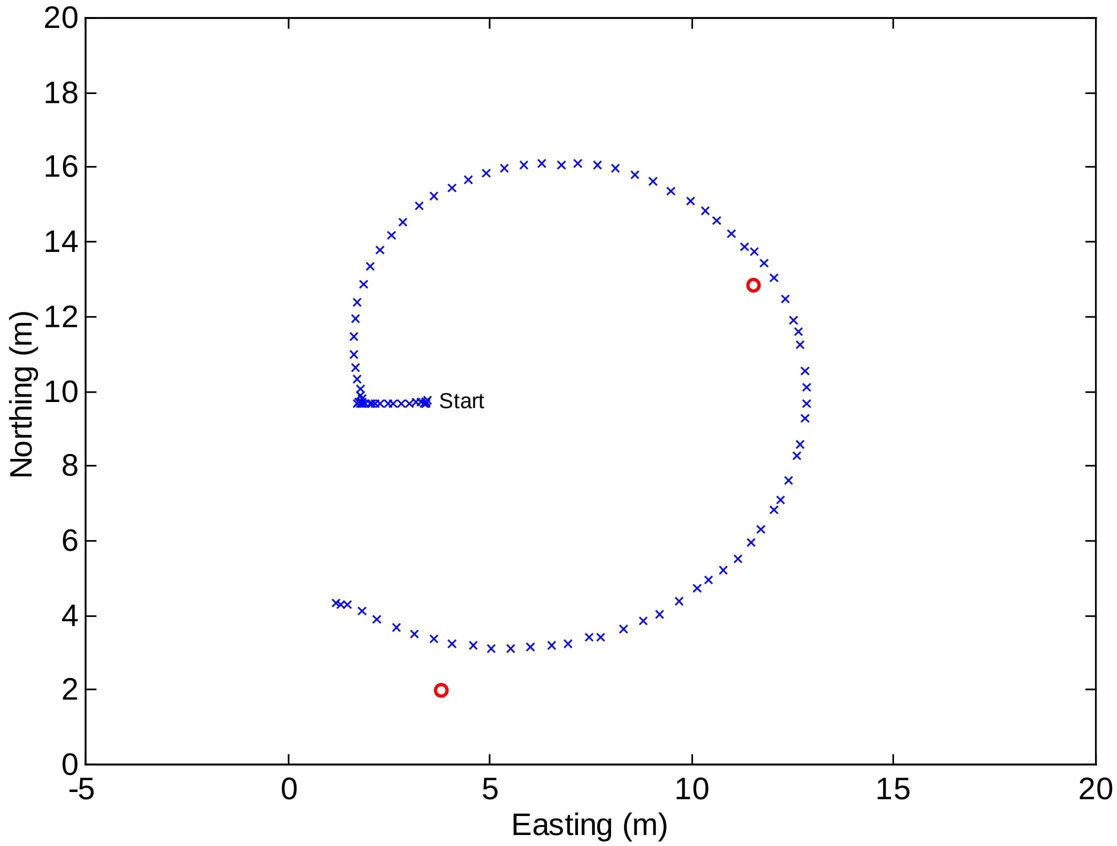

Figure 13. ***Plan view of ROV manoeuvre 5 (circle to starboard) showing close-up of vehicle track. Circles are transponder locations, crosses are vehicle locations.***

Five transponders were used in these trials and the high degree of redundancy provided by this arrangement enabled the relative transponder positions to be calculated by selecting a set of fixes that were distributed throughout the survey area and using Web to compute the best-fit transponder locations.

Figure B shows the transponder locations and a plot of the computed vehicle track and Figure C shows a closer view of the vehicle track. The vehicle locations were calculated one fix at a time using a least-squares adjustment routine and have not been filtered in any way. Time slew between the measurements to the different transponders and drop-outs in the transponder ranges have been taken into account by linearly interpolating onto a constant time interval and assigning a variance to each measurement that increased as the time between the interpolation time and the nearest measurement time increased. The vehicle took just under 100 seconds to traverse the track shown.

The use of a variable range measurement variance makes the comparison of measurement residuals used for the static survey data inappropriate for the ROV tracking data. Instead, the unit variance, σ_0^2, has been computed for each fix according to the formula:

$$\sigma_0^2 = \frac{v^T W v}{n - m}$$

where v is a column vector of measurement residuals, W is a diagonal weight matrix which has the inverses of the range measurement variances on its main diagonal, n is the number of measured ranges (5), m is the number of parameters being estimated (2), and the superscript T represents the transpose operator. The range measurement variances were then scaled so that the mean of σ_0^2 over all fixes was 1.0.

This resulted in a range measurement variance of 0.025 m^2, corresponding to a rms range measurement error of 0.16 m. The covariance matrix output by the least squares algorithm then provided estimates of the mean squared uncertainties in the estimated co-ordinates for each fix. When these were averaged over all fixes they produced rms uncertainties of 0.12 m in Easting and 0.15 m in Northing. These uncertainties are substantially larger than those discussed above for the static surveying mode of the system in which averaging of a number of range measurements was used to enhance the accuracy. Better results would be expected if a Kalman filter were used to process the data, but this has not been done here in order to highlight the fundamental accuracy of the HPASS system itself.

Conclusions

Results of the surveys were extremely encouraging and while the data is still being worked on, preliminary results indicate that the average residual is about 20 mm over distances of up to 50 m. The system has been tested so far in two different wreck site environments. In both cases the system performed well and modifications to the method of operation were made on both occasions. At present, there remains an unresolved issue relating to the depth measurements, both on the *City of Launceston* and *Pandora* sites. Given that the test work carried out initially indicated that the depth measurements were very accurate, it is possible that a software bug may be causing the discrepancies.

One unexpected issue, not directly related to the HPASS system is the difficulty in adjusting the co-ordinate systems for the different days of survey. Thus on day 1, the adjustment program produces the co-ordinates of the transponders and the survey points in an arbitrary co-ordinate system; on day 2 the co-ordinate system is not necessarily the same. This is due to two factors: firstly slight variations in the measurements causes the positions to be slightly different; and, the program, in its present form, does not allow the co-ordinate system to be pre-determined. At present this issue is being addressed in the Site Surveyor program by Pete Holt from 3H Consulting. It is also anticipated that modification of the Site Surveyor program to enable the data to be downloaded directly will enable a better understanding of the errors and a more suitable method of adjusting the co-ordinate system. It is also unclear, at present, what is the best process in evaluating data in cases where the transponders are fixed for a period of time. Either the inter-transponder distances could be averaged over the whole period of the survey, the co-ordinates of the transponders determined and the data then processed using fixed transponder co-ordinates; or, if the inter-transponder distances should be used on a day-by-day basis. While the incorporation of the temperature at the time of measurement has improved the repeatability within a single day, there does still seem to be a scaling factor, or something that is affecting the measurements when they are compared over a number of days. Given that there is a certain error in the placement of the diver probe unit, it is not possible at present to determine the origin of these slight errors.

Acknowledgements

The authors would like to thank Pete Holt from 3H Consulting for advice and help with the Site Surveyor program. Peter Gesner, Bill Jeffery and the team from the 1999 Pandora Expedition sponsored by the Port of Townsville and the Queensland Museum, for help and assistance with implementing the project. Shirley Strachan and the Heritage Victoria team from the City of Launceston project. The Australian National Centre of Excellence under a federal grant made the development and implementation of this project possible. In particular we would like to acknowledge the help and assistance of Corioli Souter who assisted with the field operation of the HPASS system. We would also like to thank Professor John Penrose and Malcolm Perry from the Centre for Marine Science and Technology and Australian Maritime Engineering CRC for their advice and assistance. The assistance of the Maritime Operations Division of the Defence Science and Technology Organisation in many aspects or the ROV program is gratefully acknowledged.

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