THE APPLICATION OF THE FUSION POSITIONING SYSTEM TO MARINE ARCHAEOLOGY

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The Sonardyne `Fusion' underwater acoustic positioning system was developed for the oil and gas industry but has recently been used on a number of marine archaeological projects. This paper describes the use of the system for accurately positioning remotely operated vehicles and divers and the results that were achieved. The paper describes recent work undertaken on two sites; the wreck of the *Mary Rose* at 10m depth in the Solent and the remains of the WWII U Boat U-166 in 1500m depth in the Gulf of Mexico.

1 Introduction

When the hull of King Henry VIII's warship *Mary Rose* was raised from the seabed off Portsmouth parts of the ship and contents were not recovered [3]. Timbers and artefacts were reburied on site while the remains of the bow castle were never investigated. Planned dredging work in the area could affect the site of the *Mary Rose* historic wreck so what remains on the site has had to be removed. A multi-phase project was put together by the Mary Rose Trust with the aim of recovering the buried artefacts and debris, excavating the spoil mounds to remove any artefacts, undertaking visual and magnetic searches and delimiting the extent of the debris field. The fieldwork for 2003 included using an excavation ROV to remove the top layer of silt that had covered the wreck leaving the delicate excavation to be done by divers with airlifts. As part of Sonardyne's long-standing involvement with the Mary Rose Trust [2], a Fusion Acoustic Positioning System (APS) was used on the 4 week project to provide high accuracy positioning for support vessel, ROV and divers.

The U-166 was a WWII type IX-C German submarine that sank 7,593 tons of Allied shipping during its first patrol before the submarine was itself sunk in the Gulf of Mexico. The wreckage of U-166 was located approximately 45 miles off the tip of the Mississippi River Delta in 1500m water depth. The submarine was found by a Hugin autonomous underwater vehicle (AUV) during an oil field survey conducted by C&C Technologies Inc. [4]. In October 2003 a joint team of researchers from C&C Technologies Inc., the PAST Foundation, the NOAA Office of Exploration, the US Minerals Management Service and Droycon Bioconcepts undertook a complete survey of the wreck.

2 The Fusion Acoustic Positioning System

The Sonardyne Fusion Long Baseline acoustic positioning system used on this project is more often found on oil and gas projects, being used to position ROVs or structures on the seabed.

The Long Baseline (LBL) or 'range-range' acoustic navigation method involves measuring distances from a transceiver mounted on a vessel, ROV or diver to four or more transponder beacons deployed at known locations on the seabed. The transceiver transmits acoustic signals into the water that can be received by the beacons. If a beacon receives a signal it recognises then it sends back a different signal to the transceiver. If the time taken for the signal to go out to the beacon and back is measured then it is possible to calculate a distance from the transceiver to the beacon. By measuring the ‘travel time’ and thus the distance to four or more beacons at known locations then it is possible to calculate the position of the transceiver.

Standard deep water equipment was used on the *Mary Rose* project despite the working depth being only 10m and the working area only 100m square. The beacons and transceivers used on this project can operate from the surface down to 2500m depth with array sizes up to 700m square. By changing to the medium frequency band maximum range increases to 2500m, by changing the housing the maximum operating depth increases to 7000m.

To assist with the position calculation both the transceivers and beacons can measure their own depth. Depth measurements from the beacons can be obtained remotely as they are sent back to the transceiver using telemetry through the water.

To be able to calculate a distance from the measured travel times it is essential that the speed of sound in water is known, however this can be calculated from salinity, temperature and depth measurements. For this reason the beacons can also carry sensors to measure temperature and salinity allowing these values to be measured remotely.

A PC computer running Sonardyne’s ‘Pharos’ navigation software controls the Fusion system. The software is developed under Microsoft Windows and contains many Wizards and Tools to assist with commissioning and tracking.

The distance and depth measurements are converted to positions by Fusion using advanced positioning techniques. As well as calculating positions the method also calculates quality figures so you can readily see the accuracy of each fix. The positions calculated for the ROV and diver are in 3 dimensions X, Y and Z. If suitable instruments are fitted to the ROV then Fusion can also calculate heading, roll and pitch. If the position of the beacons is known in real-world co-ordinates, such as from a GPS receiver, then the positions for the diver and ROV are also shown in the same co-ordinates.

Fusion can generate position reports and sentence strings for the diver and ROV including standard sentences used by GPS receivers. In this way Fusion can be used as an underwater GPS receiver feeding data to other survey programs. All measurements, positions and quality figures are time stamped and logged in a database so they can be replayed or analysed after the dive.

3 The *Mary Rose* Project

3.1 Tracked Vehicles

On the Mary Rose 2003 project there were three vehicles that were tracked by the Fusion system either singly or all together; the dive support vessel *Terschelling*, the crawler excavator ROV and a survey staff carried by a diver.

Terschelling is a 40m long vessel fitted for ROV and surface supply diving operations. A four-point mooring system was used to keep the vessel in position on the site so it could deploy the divers or ROV anywhere they needed to work. The Fusion system used the on-board differential GPS and gyro compass to position the vessel.

The Swan 2002 crawler excavator ROV was custom built by Sea Boston Ltd for excavation, burial and trenching work. The crawler is fitted with colour cameras and a scanning sonar so the ROV operator and team archaeologists can monitor the excavation. The crawler can also carry a Hyball free swimming ROV and a 5 function tool arm.

For the project the ROV was also fitted with a Sonardyne RovNav 5 transceiver connected by an umbilical to the navigation computer on board the vessel. The transceiver had two remote acoustic transducers connected to it using short cables, these were mounted at each end of the ROV's boom. Acoustic range measurements made to both of the transducers enabled the heading of the ROV to be calculated. A high-accuracy DigiQuartz depth sensor was installed inside the transceiver providing very high quality depth measurements to the Fusion system.

Divers using surface supply diving equipment did much of the work on site. The divers used helmets that allowed voice communications to the supervisor or other archaeologists. The helmets were also fitted with lights and a video camera so the underwater work could be monitored on the surface.

The divers used a lightweight 2.5m long survey staff for positioning artefacts and objects. The staff was fitted with a Lightweight Mini RovNav transceiver and 100m depth rated strain gauge depth sensor and had an acoustic transducer fitted to the top.

Acoustic range measurements were sent via a dedicated umbilical cable to the navigation computer so the position of the diver could be calculated. It was essential that the pole remain upright when position fixes were taken so the staff was fitted with a bubble gauge.

3.2 Transponder Beacons

The four Sonardyne COMPATT transponders were deployed on the seabed in a 70m x 80m array. The project required the highest position accuracy possible so Extra High Frequency (EHF) transponders were used, operating at frequencies up to 100 kHz. In addition, the beacons were deployed in rigid frames so that they would not move. Each beacon was fitted with a tilt sensor so could report if it was upright or on its side after deployment from the vessel.

Depth and temperature sensors were fitted in all transponders and these could be read remotely using either transceiver. One beacon was fitted with a high-accuracy DigiQuartz depth sensor so that it could be used to monitor changes in tide height. The tide range was 4m on spring tides so changes over time had to be monitored. The same beacon was also fitted with a salinity sensor, along with its other sensors it could be used to measure the salinity, temperature and depth required to calculate the speed of sound in water. Typical values were 34.54ppt salinity, a temperature of 19.7C at a depth of 10m giving a speed of sound of 1520.25 metres per second.

3.3 Operation

Once the beacons in their frames had been deployed the system was set up and calibrated in a matter of hours. An experienced Sonardyne offshore operator commissioned the system but it was soon handed over to an archaeologist from the Mary Rose Trust after some informal hands-on training. The system was left on board *Terschelling* in the hands of the project team after three days.

The finds handling system being used by the project team used positions from the Fusion system for each artefact recovered. Objects and artefacts located but not recovered were plotted on a live site plan generated using a geographic information system. Position and fix data logged by the Fusion system was archived and used as part of the primary archive for the project.

4 Mary Rose Results

4.1 Array Box-in Calibration

An ‘array box-in’ calibration was used to determine the positions of the beacons in the real world. The survey staff was mounted on a pole on the side of the vessel so its transducer was below keel depth. Acoustic range measurements were made from the transceiver on the vessel to all four beacons as the vessel sailed once around the array. Position measurements from the GPS receiver, headings from the gyro and the range measurements were used by the Fusion system to calculate the positions of the beacons. As the positions from the GPS receiver were in real-world co-ordinates it was possible to obtain real-world co-ordinates for each of the beacons. The latitude and longitude co-ordinates from the GPS were converted to Universal Transverse Mercator (UTM) grid co-ordinates by Fusion. Of the 1195 measurements made during the box-in calibration, only 27 (2%) were rejected as being out of tolerance. The computed position error for each beacon was 0.21m (post-computed error ellipses at 95%).

4.2 Baseline Calibration

The array box-in calibration would not provide beacon positions of high enough accuracy so a second method was used; baseline calibration. The beacons were commanded in turn to measure the distance from themselves to the other three beacons in the array and to telemeter the values back to the Fusion navigation computer. Once all the distance measurements had been collected they were used to compute better positions for the beacons. As well as the distances measured in the baseline calibration the calculation also used depth measurements from each of the beacons and position measurements generated by the previous array box-in calibration. As only one beacon was fitted with a high-accuracy depth sensor, the depth measurements were obtained by levelling from it to the other beacons using a diver's digital depth gauge. In total, 96 distance measurements were measured with only 1 rejected as being out of tolerance. All the measurements used agreed to within 30mm (RMS of the residuals was 14mm). The time taken to collect the data was only 14 minutes and the positions were calculated in minutes using Fusion's Calibration Tool.

4.3 Static Fix Tracking Test

A static fix test was carried out to prove how precisely the system could position the diver or ROV. For this test the diver took the survey staff to a point in the middle of the site and pushed it into the ground so it would not move. The staff was left in this position for some time while the Fusion system continuously calculated its position every 2 seconds. When plotted, all but 2 of the 235 position fixes were within a circle 30mm in diameter (Fig. 1).

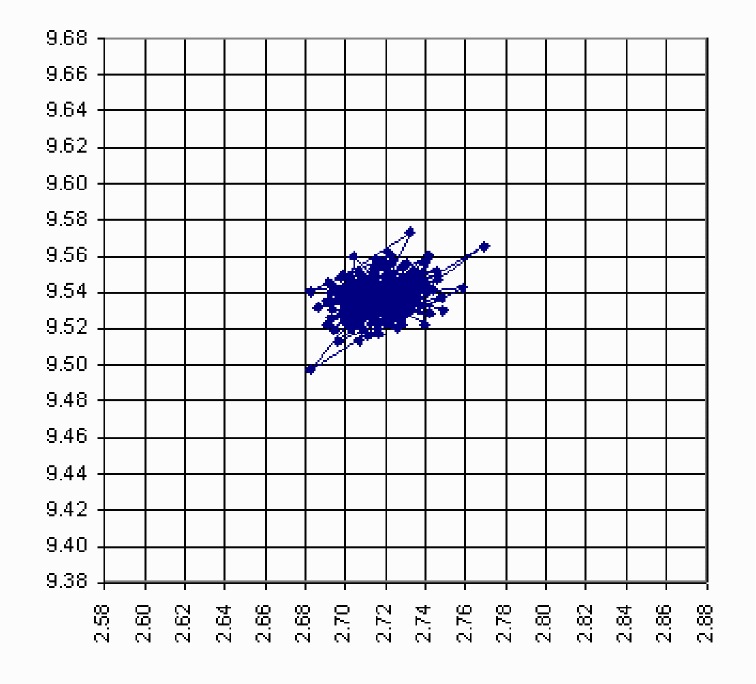

Figure 1: *Mary Rose* Static position fix test - 235 fixes, distances in metres

4.4 Dynamic Tracking Test

The results from one dive show the quality of positioning that can be achieved using the Fusion positioning system. The diver carrying the survey staff was asked to walk around the perimeter of the hole left by the original excavation work. The track of the diver is shown below. The diver leaves the dive cage on the port side of *Terschelling* and travels clockwise around the hole, occasionally stopping to look at debris and artefacts (Fig. 2).

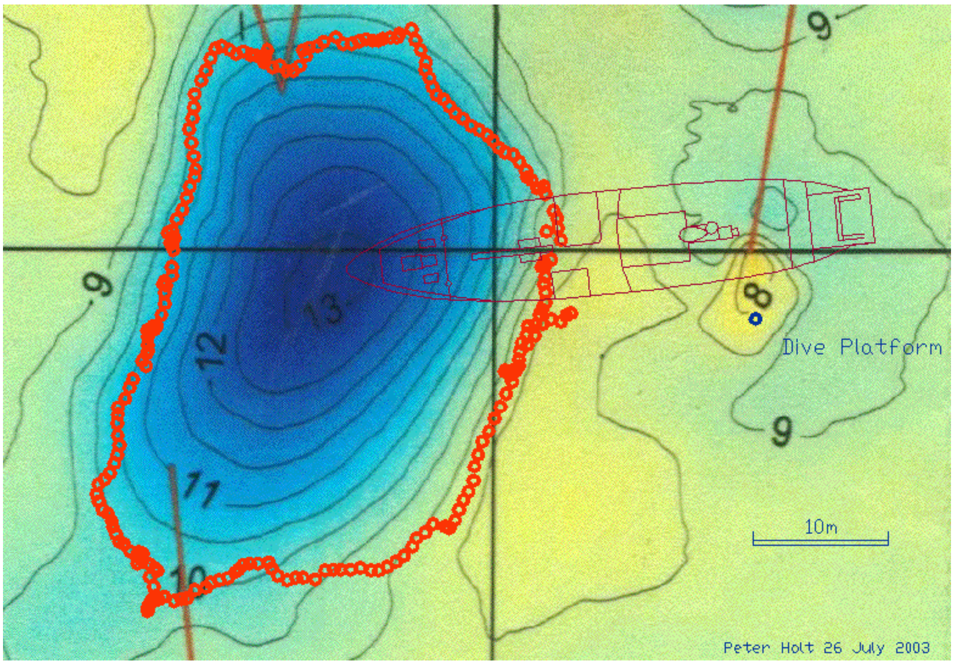

Figure 2: Dynamic tracking test diver track

5 The *U-166* Project

5.1 Tracked Vehicles

On the *U-166* project a single SonSub Innovator work-class ROV was positioned using the Fusion system. The ROV was fitted with a Sonardyne RovNav 4 transceiver connected through the ROV's umbilical to the Pharos navigation computer on board the support vessel. A high-resolution camera was mounted vertically on the ROV so it could take still images of the seabed. The Fusion system used acoustic range, depth, heading and offset measurements to compute and report the position of the camera so the images could be geo-referenced.

5.2 Transponder Beacons

The *U-166* debris field covered a wide area so an array of five COMPATT transponders was deployed in a circle 700m in diameter. Medium frequency (MF) beacons were used (18-36 kHz) for this project so they could be commanded from the vessel 1500m above. The beacons were each deployed with a short rope strop and sinker weight attached to the release hook on the bottom of the unit. A float collar wrapped around each beacon provided buoyancy. The beacons could then be commanded to drop their weights and float back to the surface. This method was used rather than fixed frames so the beacons could be recovered easily without the use of the ROV.

6 *U-166* Results

6.1 Box-in Calibration

The absolute co-ordinates of two of the five beacons were computed separately using the 'box-in' method, similar to that used on the *Mary Rose* project. A total of 617 acoustic range measurements made on beacon 101 and 349 made on beacon 608. The computed position error for the beacons was 260mm and 150mm.

6.2 Baseline Calibration

Again a baseline calibration was used to compute the relative positions of the beacons and combined with the box-in measurements to compute real-world positions for each of the beacons. After combined processing of all measurements the total RMS of the residuals was 146mm.

6.3 Static Fix Tracking Test

A static fix test was undertaken to check position quality with the ROV sat on the seabed. Of the 102 position fixes, all but one was within a circle 300mm in diameter (Fig. 3).

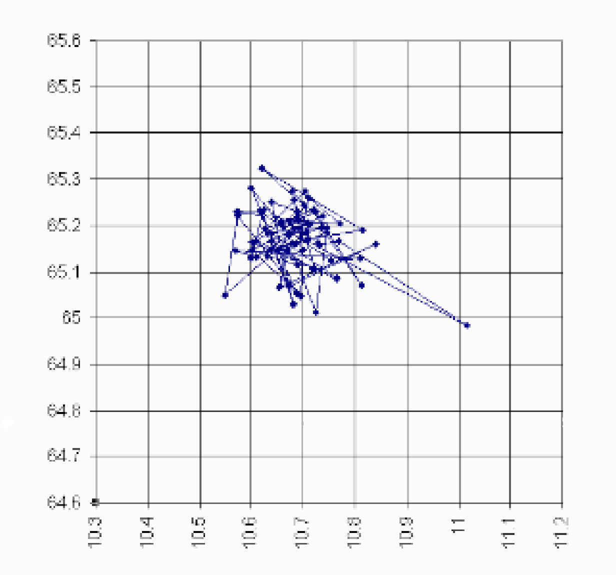

Figure 3: U-166 Static position fix test - 102 fixes, distances in metres

7 Conclusions

The results from these projects show that the Fusion Long Baseline acoustic positioning system can be used to achieve high accuracy positioning underwater on an archaeological site. The system can perform just as well tracking an ROV at 1500m or in the difficult acoustic environment found in tidal water only 10m deep.

The position accuracy achieved on the *Mary Rose* project is the highest achievable by any commercially available acoustic positioning system. The achieved accuracy is comparable to conventional survey methods over equivalent areas [1] and is sufficient for plotting finds and the extent of hull structure. The accuracy achieved on the U-166 site was less but was considered sufficient for the task; the difference was most likely to be that the beacons were not deployed in fixed frames. The Fusion system can be deployed on any marine archaeological site and has a proven track record in depths down to 7000m.

The experience of the *Mary Rose* project showed that the Fusion system is easy to use. An experienced operator set up the system however for the remaining weeks of the project it was run by a marine archaeologist after only a few hours training.

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