Underwater Localisation Techniques for Marine Applications

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The disappearance of Flight MH370 has significantly increased awareness of the importance of underwater technology to our country. From the global perspective, the incident shows how far underwater technology has evolved and the extent of its capability.

Locating the black box of the plane in the deep ocean requires very advanced and sophisticated underwater technology. This process is known as underwater localisation or positioning. The basic principle of underwater localisation is very similar to the concept of Global Positioning System (GPS) but, instead of using GPS signals (radio waves), underwater localisation relies on acoustic signals as the medium of operation.

GPS radio waves are unable to penetrate water, unlike acoustic signals. The speed of sound in water (about 1450 m/s) is about four times faster than in air (about 334 m/s) though this can be changed subject to water temperature, salinity and pressure. Applications of underwater localisation include, but not limited to (1):

- Subsea vehicle positioning, such remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV)
- Diver tracking
- Towed fish tracking
- Underwater pipe and cable laying operations
- Pinger localisation

Oceans can be divided into several zones according depth, temperature and level of sunlight penetration. The details of the ocean zones classification are shown in Figure 1.

As we go deeper under the water surface, the temperature will decrease and pressure will increase. These physical characteristics will significantly affect the accuracy of underwater localisation. In the ocean, the speed of acoustic signals varies according to temperature and pressure. The accuracy of underwater localisation depends on our ability to predict and estimate the speed of acoustic signals travelling in the water as a function of depth. This changing speed of acoustic signals has created challenges in designing an underwater localisation system. Figure 2 illustrates the profiles of sound speed, temperature and pressure as a function of depth. These profiles are very important for developing an accurate underwater localisation system.

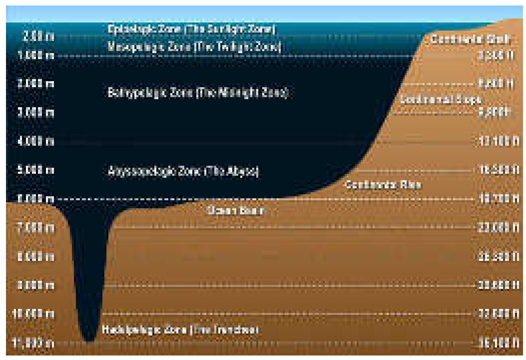

Figure 1: Division of ocean zones [2]

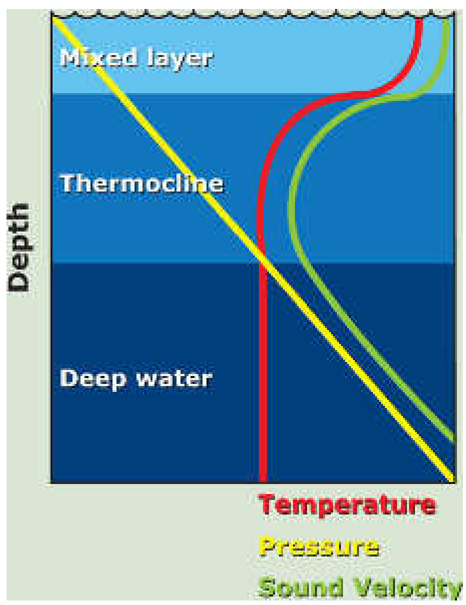

Figure 2: Temperature, pressure and sound speed variation with ocean depth [3]

Underwater sound can also be easily affected by the noisy environment in the ocean. In shallow water, sound experiences a reverberation effect. These problems can be solved through extensive signal processing and filtering and reliable underwater positioning can be developed with high positioning accuracy. Because of these problems, underwater localisation technology is slightly different for shallow water and deep water.

Apart from being able to overcome wobbly conditions of the ocean environment, underwater localisation schemes should fulfill the following desirable qualities:

1. Accuracy: The location of the sensor for which sensed data is derived should be accurate and unambiguous for meaningful data interpretation.
2. Fast: Since sensor nodes may drift with water currents, the localisation procedure should be fast so that it can report actual location when data is sensed as otherwise, the device to be located or tracked will drift away with the underwater current.
3. Wide Coverage: The localisation scheme should ensure that all sensor nodes can be localised. However, the extent of the area to be covered will depend on the method of localisation being used.
4. Low Communication Costs: If the nodes are battery-powered and may need to be deployed for a long duration, it should not waste energy for unnecessary transmissions during the procedure.

LOCALISATION METHOD

In general, there are two types of underwater localisation: Passive localisation and active localisation. Passive localisation involves listening for an emitted acoustic signal, such as that from a plane's black box. The ping signal emitted by the black box is picked up by sensors for further position estimation process and only involves unidirectional acoustic signal transmission.

Active localisation, on the other hand, involves both transmitting and listening for acoustic signals such as when tracking the location of underwater vehicles. In active localisation, when a beacon attached to the underwater vehicle receives a signal from a surface vessel, it will respond by emitting its own signal at a certain frequency. When it receives the responding signal, the surface vessel then processes it and calculates the position and direction of the target. These two concepts of localisation are illustrated in Figure 3. Passive localisation consists of a receiver only while active localisation requires both receivers and transmitters (or transceivers).

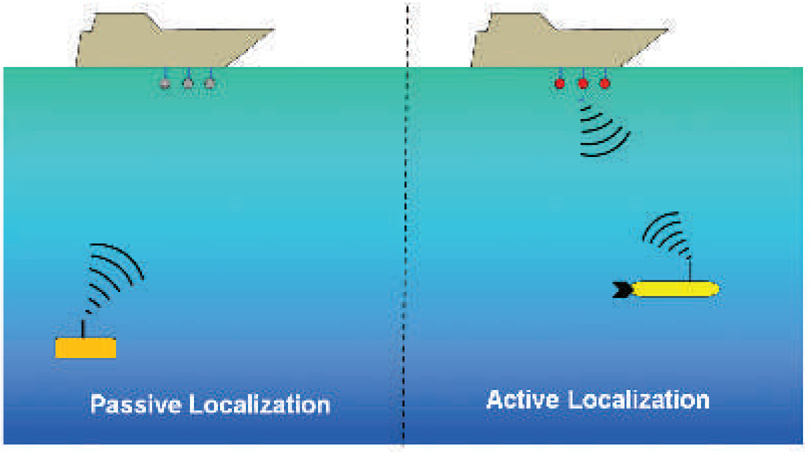

Figure 3: Passive (left) and active underwater localisation

There are three famous generalised approaches used widely in underwater localisation: Ultra-Short Baseline Length (USBL), Short Baseline Length (SBL) and Long Baseline Length (LBL) as illustrated in Figure 4. The baseline length refers to the separation distance between the receivers used to capture the acoustic signal. Each receiver consists of multiple transducers. These methods are generally based on range measurement which is directly related to sound-speed propagation in underwater. Working principles of the above localisation methods are summarised in Table 1.

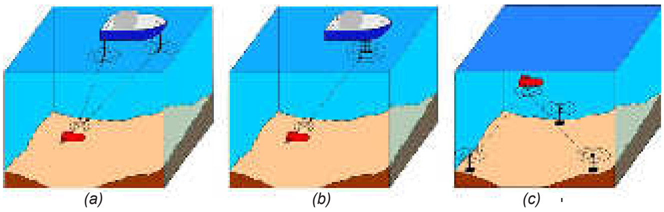

Figure 4: Stationary beacons (a) USBL/SSBL (b) SBL (c) LBL [4]

Table 1. Working principles of USBL/SSBL, SBL and LBL

Method	Description
USBL/SSBL	Positioning calculation is based on range, horizontal and vertical angle measurement from a single multi-elements transducer or very close range transducers (measuring centimetres in length). It provides three-dimensional transponder positions relative to the surface vessel.
SBL	Positioning calculation is based on range, horizontal and vertical angle measurement from a minimum of three transducers mounted on the vessel hull (metres in length). Accuracy is about < 0.5% of the slant range. It provides a three-dimensional transponder position relative to the surface vessel.
LBL	Positioning calculation is based on range measurement alone. The underwater vehicle or module and the vessel are positioned relative to a calibrated array of transponders install on the seabed (kilometres in range). Very accurate positioning of 1m to 0.1m.

Apart from the above three basic localisation methods, buoys are also widely used for underwater localisation. Unlike conventional buoys, this is known as GPS Intelligent Buoy (GIB) and possesses a special characteristic. It can calculate the signal's times of arrival (TOA) to determine the range before a geometrical solution calculates the position of the transponder.

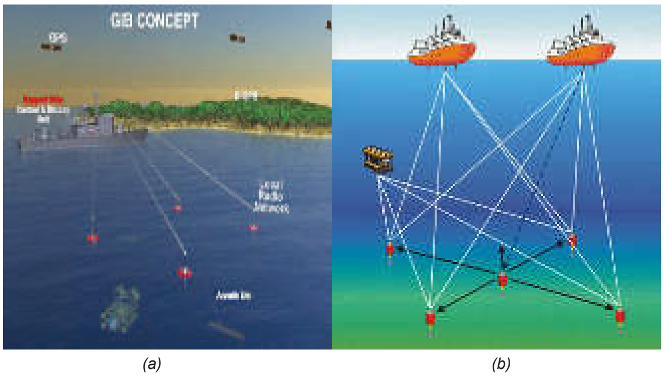

Figure 5: (a) Illustration of GIB Concept [5] (b) MULBL Localisation [6]

Multi-User Long Base Line (MULBL) is another method of underwater localisation where several underwater vehicles can position themselves using a few similar transponders installed on the seabed. This method can be viewed as enhancing LBL because the localisation concept is similar to LBL positioning, except that it is configured to locate multiple targets at the same time. Figure 5 illustrates GIB working principles and MULB in localising underwater vehicle.

CURRENT UNDERWATER LOCALISATION TECHNOLOGY

1. Shallow Water

Through the years, technology related to underwater localisation has evolved to include that for shallow water and deep water localisation and led to an innovative acoustics-based system. An acoustics modem (Figure 6) has simplified conventional localisation techniques where a transducer array is not necessary.

It also eliminates the need for the installation of on-site beacons as commonly found in a conventional method of localisation. The acoustics modem not only serves as a localisation device but it also provides direct communication between two underwater devices. It consists of a receiver and a transmitter. The principle of operation is still based on acoustics as in the conventional positioning system. See Figure 7.

Figure 6: Mobile beacons (acoustic modem) [7]

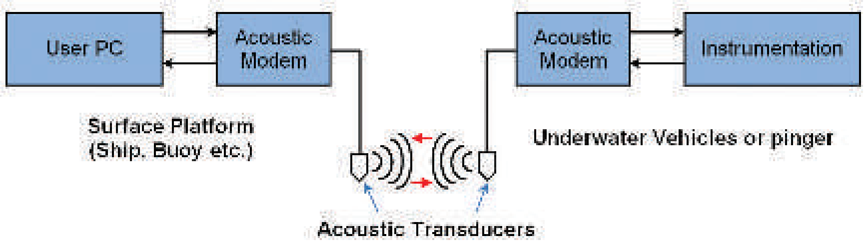

Figure 7: Basic acoustics modem working principle

Open water Remotely Operated Vehicle (ROV) positioning using USBL is one of the underwater localisation technologies that use the acoustics modem. It is useful for pipeline and tunnel inspections. The communication network consists of data transmission interchanging between multiple components: Satellite, surface vessel, ROV garage and ROV.

Figure 8 shows a satellite used to provide GPS data to the vessel. Apart from the GPS device, the vessel contains a gyroscope to measure heading, pitch and roll which will be a reference to the ROV location. The ship is also used to deploy a transceiver, a device which can transmit as well as receive sounds underwater. The transceiver is submerged underwater and positioned just below the ship.

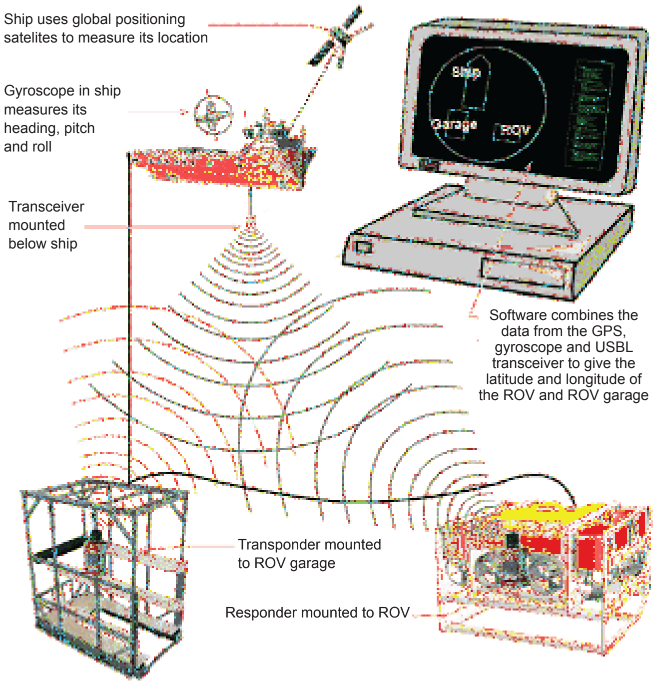

Figure 8: ROV positioning using USBL [8]

There is a cable linking the ship and an underwater ROV garage which is used to launch and recover the ROV. Most importantly, it has a mounted transponder to receive and send an acoustics signal to the transceiver.

Using a transponder has the advantage of simple deployment but this is at the cost of calculation inaccuracies due to sounds travelling twice and being affected by thermoclines. A responder installed on the ROV is similar to a transponder but it receives the trigger signal from the cable instead of sound and gives a more accurate position of the ROV since the sound signal only travels once through the water.

A computer equipped with underwater positioning software is included in the system to locate the ROV and ROV garage based from the fetched GPS, gyroscope and USBL transceiver data. The transponder capability determines the operation depth of the system but usually it is designed for shallow water application.

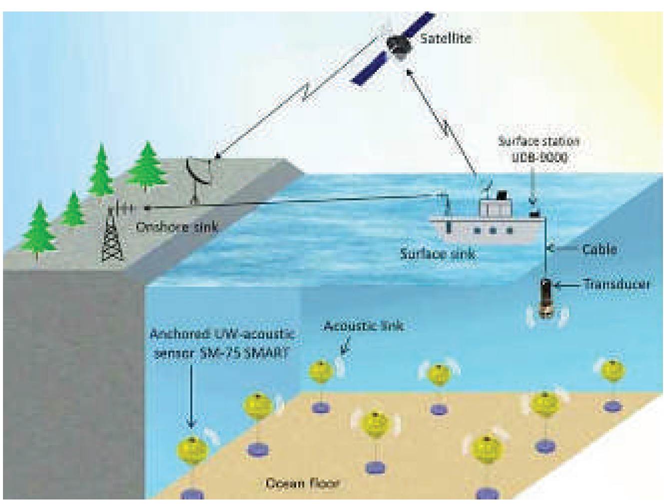

Figure 9: Underwater acoustic networking testbed [9]

An underwater acoustics networking test bed is another interesting underwater localisation technology which uses numerous acoustic sensors on the ocean floor. It is a wireless networking application used primarily to monitor and inform operators about an incoming tsunami. The system comprises a satellite, onshore sink, surface sink, surface station, transducer and acoustic sensors (Figure 9).

An onshore sink is positioned on the beach to receive data from a surface sink (ship). The surface sink conveys data from a surface station. The surface station is a wireless control unit for acoustics modems and acoustics releases. A transducer is placed just below a ship to monitor underwater communications. It converts the sound it receives to an electrical signal which is then processed and displayed on the surface station. This system is different from other localisation techniques in the sense that there are multiple anchored acoustic sensors installed on ocean floor. These sensors combine an underwater acoustics release with an acoustics modem for easy management and deployment.

An even more advanced shallow water AUV positioning technology is a cooperative type of localisation system (Figure 10). In this system, the ship is not fixed in a single position as it acts as a mobile surface vehicle.

The mobile surface vehicle acquires its absolute position in real-time and conveys the data to multiple AUVs which measure the difference in range between their positions and the mobile surface vehicle to bind the localisation errors accumulated by dead-reckoning. The advantage here is it has a larger operating area than a static beacon.

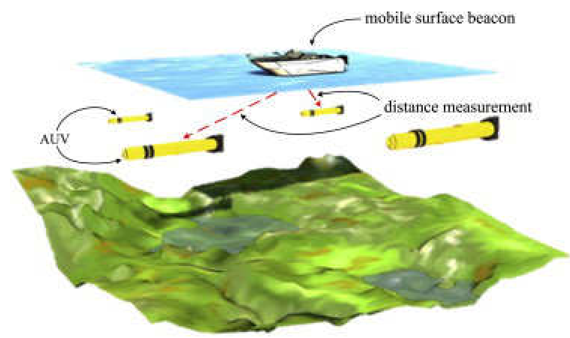

Figure 10: AUV cooperative localisation using mobile surface vehicle [10]

DEEP WATER

Discovering and tracking an underwater target of interest is a challenging task, especially in deep oceans. There is limited technology for performing deep water localisation. Towed ping locator is a technology used to locate an underwater pinger position. Figure 11 shows its working principle.

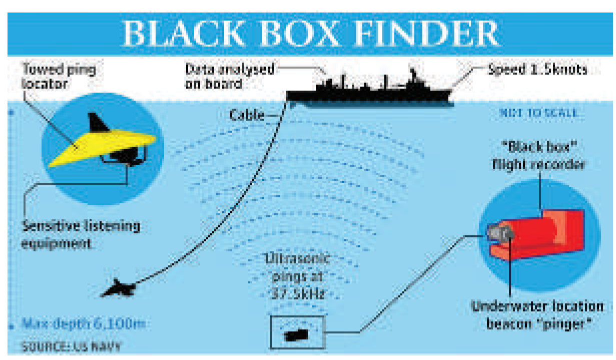

Figure 11: Towed ping locator (Source: US Navy)

This technology became well known to the public when the search for Flight MH370 began. Towed ping locators are used to locate emitted signals which cannot be detected by a surface transponder as signal strength weakens as depth increases. Using a towed pinger locator will increase the chances of detecting the emitted pinger. This technology allows us to localise the source of the pinger to thousand of metres in depth.

FUTURE DEVELOPMENT

Current technology of underwater localisation is limited in term of area of coverage and localisation time span. Thus, if we can introduce an autonomous, flexible, robust and scaleable receiver or transponder platforms, we will be able to solve these problems.

By using the swarm robot concept as part of the underwater localisation system, we can improve the search for and efficiently track underwater targets. See Figure 12 for an illustration of this concept.

Theoretically, by implementing a swarming concept, more simultaneous readings can take place, thus reducing any positioning error. In addition, large number of swarming platforms can cover large areas, reducing the time taken to locate a target.

A simple, smaller yet effective autonomous platform can replace the large surface vessel currently used for underwater localisation. Last but not least, this system can locate and track multiple targets at the same time without losing localisation sensitivity and accuracy.

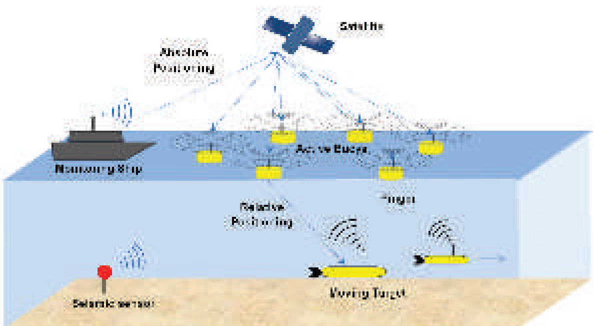

Figure 12: Proposed method of underwater acoustic postioning

CONCLUSION

We have discussed the general overview of underwater localisation for both shallow and deep water. From this, we can conclude that underwater localisation is a very important technology. There is plenty of opportunity for research and development in underwater localisation by local and international research institutions.

At Underwater, Control and Robotic Group (UCRG), Universiti Sains Malaysia, we are exploring the realisation of the underwater localisation, developed from beginning concepts and ideas towards real world implementation. ■

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