Underwater Structure Inspections Using Unmanned Underwater Vehicle

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As oceans cover two-thirds of the Earth's surface, they have a huge implication on the future of all human beings. Maritime accidents caused by structural failures are significant sources of lost revenue, so periodic preventative inspections of underwater structures are very important to detect typical defective situations such as corrosion, cracks and growth of marine organisms.

Figure 1 shows typical corrosion on a jetty and Figure 2 shows two years of marine organism growth on the starboard bow of a boat. These defects are critical factors which will affect the service lifetime of underwater structures, therefore, any inspection data obtained will be useful in helping to detect such defects in order to schedule maintenance jobs.

Figure 1: Corrosion on a jetty [1]

Figure 2: Marine growth on a boat [2]

Underwater inspection technique is also important in maritime archaeology surveys. For example, it can help locate, identify and investigate an unknown shipwreck. Studying shipwrecks such as that in Figure 3, can help us understand the past, connect us to our heritage and teach us lessons on damage caused by environment and human error.

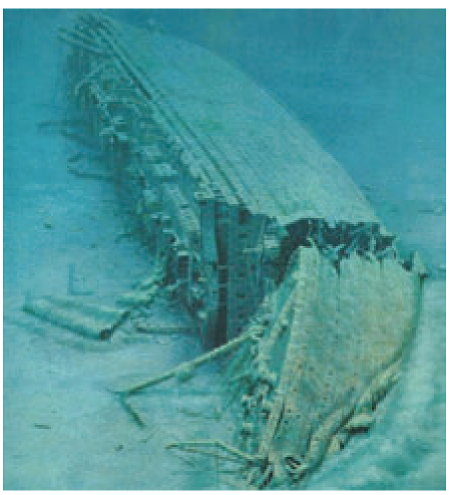

Figure 3: Picture of The Britannic, which sank in the Aegean Sea [3]

LEVELS OF INSPECTION

The levels of inspection are defined according to the effort and intensity required. There are three levels: Level 1, 2, and 3 (4,5), based on the American Society of Civil Engineers (ASCE) Waterfront Facilities Inspection and Assessment Manual.

Level 1: Visual & Acoustic Inspection

This includes acoustic and visual examination of the underwater structure. Level 1 inspection normally covers the entire exterior surface of the structure, whether it is a jacket leg, retaining wall or a ship's hull.

A visual inspection is often used to detect obvious damage or deterioration of the submerged structure. In bathymetric survey, acoustic sounding equipment, such as single-beam echo sounder, multi-beam echo sounder and side scan sonar, is used. This provides information about variations in depth to the seabed or structures on it.

Figure 4 shows a map of the seabed generated by using side scan sonar, the most likely method of finding unknown wrecks due to its large coverage and high surveying speed.

Furthermore, level 1 inspection also indicates the location or the portion of underwater structure which requires more detail inspections.

Level 2: Detailed Inspection with Partial Cleaning

Level 2 inspection is more detailed and requires the underwater structure to be cleaned of marine growth. This level is intended to detect and identify damaged and deteriorated areas which may be hidden by marine growth or corrosion, so partial removal of the biofouling growth or corrosion products is required. Surface cleaning tools like brushes, hydraulic grinder with barnacle buster attachment or a high-pressure water jet gun may be used. During the cleaning process, care should be exercised to prevent damage to the surface of the underwater structure. As Level 2 inspection is expensive and time consuming, it is done on critical location of the underwater structure. Figure 5 shows a Level 2 inspection of a steel pile. The marine growth on the surface of the pile is removed before measuring its length.

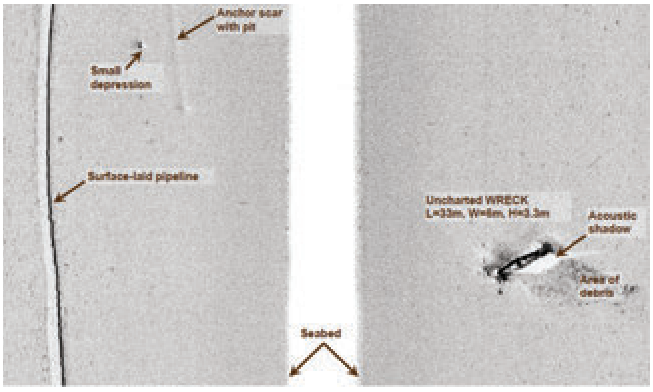

Figure 4: Mapping of seabed by using side scan sonar [6]

Level 3: Highly Detailed Inspection

Level 3 inspection is a highly detailed inspection used to detect hidden or interior damage and to evaluate material homogeneity. It includes extensive cleaning and detailed measurements using non-destructive and partially destructive testing techniques, such as thickness measurement and hardness testing. Figure 6 shows a diver measuring the remaining thickness of a steel pile using an underwater ultrasonic thickness measuring device.

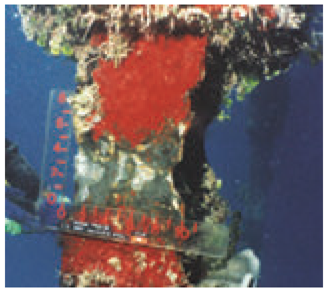

Figure 5: Level 2 inspection on a steel pile [7]

Figure 6: Level 3 inspection on a steel pile using ultrasonic devices [7]

Table 1 summarises the detectable defects and inspection tools for the three levels of inspection. The level of inspection is usually decided early in the planning phase.

There are many international standards available for underwater inspection. This article mentions a few of them. The National Bridge Inspection Standards (NBIS) establishes criteria to determine the level and frequency to which the bridge must be inspected. The periodic inspection of

Table 1: Detectable defects and inspection tools for the three levels of inspection

LEVEL	PURPOSE	DETECTABLE DEFECTS	INSPECTION TOOLS
1.	General visual or acoustic inspection to confirm as-built condition, detect severe damage, and locate position.	Extensive corrosion, major spalling and cracking, broken piles and bracings, and severe mechanical damage.	• Acoustic imaging tools: Single-beam echo sounder, multi-beam echo sounder and side scan sonar. • Visual recording tools: Underwater camera and clear-water box. • Ground penetrating radar for detecting scour holes.
2.	To detect surface defects normally obscured by marine growth.	Corrosion staining, surface cracking and crumbling, loss of bolts and fasteners, coating loss and moderate mechanical damage.	• Dimension measuring instruments: Tape measures, calipers, rule, and graduated scales. • Visual recording tools: Underwater camera and clear-water box.
3.	To detect hidden and imminent damage or to collect more detailed information.	Thickness of material, electrical potential for cathodic protection, thickness of coating, internal voids and cracks and material strength.	• Ultrasonic measuring devices for measuring thickness of steel. • Magnetic particle testing using electromagnetic yoke with magnetic field indicator for detecting surface discontinuities in magnetic structures. • Ultrasonic pulse velocity meter for estimating the strength of concrete structures and locating cracks and voids. • Schmidt test hammer for estimating the compressive strength of concrete structures. • Rebar locator for locating reinforcing steel in concrete structures. • Underwater voltmeter for determining the level of cathodic protection on steel structures.

submerged components of a bridge is vital to determine damage that may have occurred since the previous inspection.

On the other hand, the International Association of Class Societies (IACS) shipbuilding and repair quality standard, IACS REC 47, provides knowledge on the different types of defects and damages that occur on ships or hull structures. This standard provides guidelines and requirements for hull structural and welding preparation and workmanship quality. Besides, NACE International Standard Practice for In-Line Inspection of Pipelines, SP0102-2010 provides requirements for qualification of onshore and offshore pipeline inspection. It is applicable to carbon steel pipeline systems used to transport natural gas or hazardous liquids. It is a performance-based standard, which includes tethered or free-flowing systems for detecting cracks, metal loss, mechanical damage and pipeline mapping. However, this standard does not define how to meet qualification requirements.

CURRENT AVAILABLE UUVS FOR INSPECTION MISSION

As conventional underwater inspection operations using human divers and manned underwater vehicles, are high risk, high cost and require dedicated surface support, Unmanned Underwater Vehicles (UUV) are now often used for the job. UUVs are able to accomplish underwater inspection missions in a cost-effective manner when the underwater conditions prove too dangerous for divers. Today, many UUVs related to underwater structure inspection applications have been developed such as:

1. **Walking Robot:** A walking robot moves on the seabed with crawlers or legs, without making the water muddy. Figure 7 shows the schematic view of a six-legged walking robot inspecting rubble foundation with an underwater camera. Figure 8 shows CR200, a sprawling type underwater walking robot which was used to survey underwater structures and shipwrecks off the coast of the Korean peninsula. A walking robot can maintain a stationary direction and position, thus giving high quality visual inspection data and accurate measurements. However, it is only able to inspect underwater structures which are near the seabed.
2. **Climbing Robot:** A climbing robot climbs along the underwater structure while inspecting it. Normally a climbing robot will make physical contact with the submerged structure to be scrutinised. A pole climbing robot is designed (10) for bridge pier inspections. As shown in Figure 9, this consists of two identical mobile robots moving along opposite surfaces of the pole. Figure 10 shows AIRIS 21, a wall climbing robot which performs inspections on the nuclear reactor pressure vessel shell from the inside. Using two propellers, AIRIS 21 sticks onto the vessel walls and moves along the wall, using one caster wheel. This wall climbing robot can inspect structures at a very close distance, thus providing high resolution data.

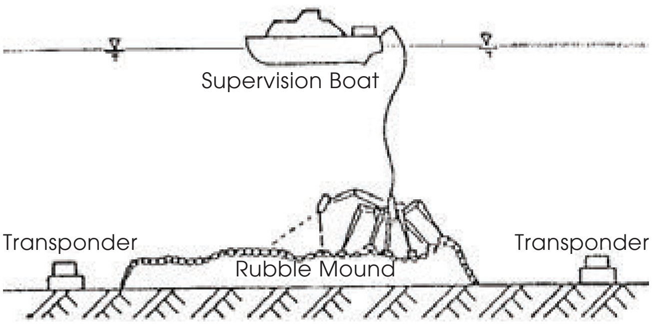

Figure 7: Schematic view of a walking robot inspecting rubble foundation [8]

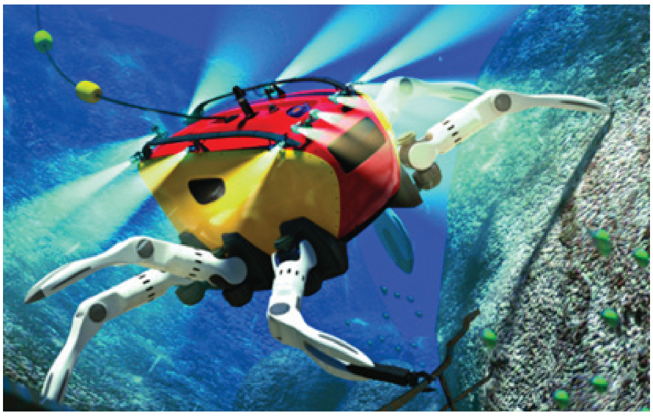
Figure 8: CR200 [9]

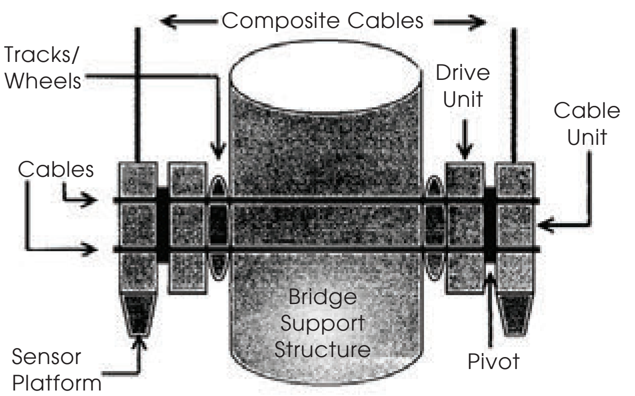

Figure 9: The system concept of pole climbing robot [10]

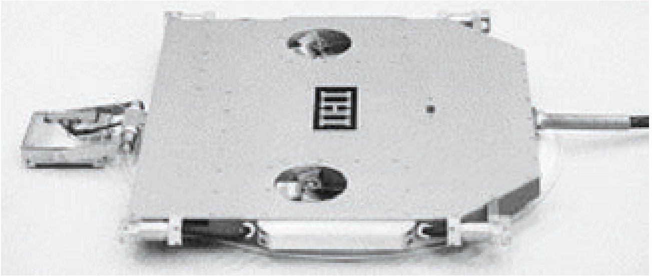
Figure 10: AIRIS 21 [11]

3. **Remotely Operated Vehicle (ROV):** Many ROV prototypes have been developed to inspect various underwater structures like ship hulls, shipwrecks and wall of port dock. An ROV can inspect an underwater structure without physical contact. Most employed a passive stabilisation system to retain its original vertical axis as vertical without control input needed. Figure 11

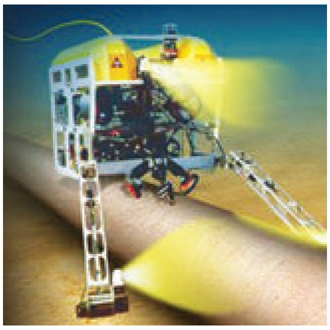

Figure 11: Seaeye Panther inspecting an underwater pipe [12]

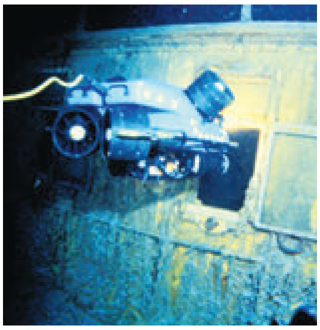

Figure 12: Jason Jr. exploring Titanic in 1986 [13]

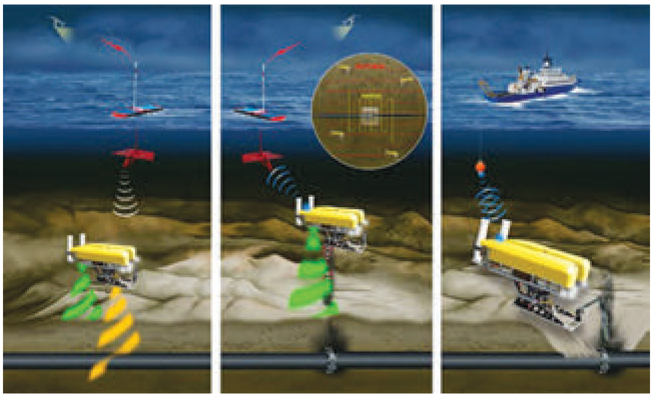

Figure 13: From left: An AUV performing pipeline localisation, leak detection and intervention [14]

shows ROV Seaeye Panther inspecting an underwater pipe using an underwater camera and profiling sonar while Figure 12 shows Jason Jr., an undersea robotic vehicle exploring the sunken Titanic in 1986. An ROV faces serious limitations because of the tether cable which links it to the control station. It cannot go far from the control station without a long tether cable and a long tether cable can easily get stuck.

4. **Autonomous Underwater Vehicle:** This robotic vehicle can travel through the ocean deep without requiring the real time control of an operator. It provides a flexible and economical solution to many underwater inspection tasks such as underwater pipeline inspection and submerged ship hull inspection. Figure 13 shows an AUV performing pipeline localisation, leak detection and intervention.
5. **Towed Vehicle:** A towed vehicle is connected, via an umbilical cable, to a mother ship which provides towing forces and electric signals. Figure 14 shows a two-stage towing arrangement that includes a long primary cable, a gravity depressor and a secondary cable. This arrangement achieves excellent performance in terms of rejection of the disturbances transmitted to the towing system. A towed vehicle can maintain its efficiency even if the current is fast, complex and in the opposite direction. However, this inspection technique is costly because it involves both the submerged vehicle and surface vessel. Figure 15 shows an AUV employed as a towed vehicle for underwater observations in the Tokyo Bay port area (16).

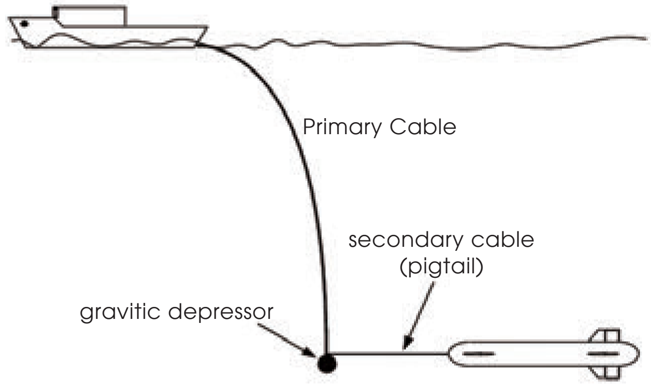

Figure 14: Two-part towing arrangement [15]

Figure 15: AUV that was used as a towed vehicle [16]

CONCLUSION

We have discussed the general overview of inspection levels and UUV platforms used in inspection operations. UUV is an important technology for underwater operations. The advancement of the technology is closely related to the triggered event for the system improvement and development.

The Underwater, Control & Robotic Group (UCRG), Universiti Sains Malaysia (USM), is exploring the realisation of the underwater inspection system using both AUV and ROV platforms.

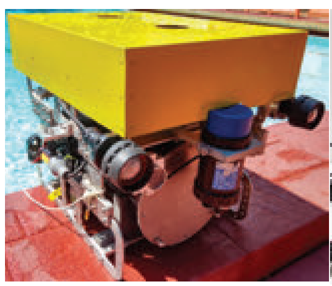

Figure 16. AUV developed by UCRG

Figure 17: ROV developed by UCRG

First, an AUV will visually inspect the entire surface of the underwater structure to find the location of potential damage for more detailed inspection. Then an ROV will be sent to the selected location for cleaning and detailed inspection. Figure 16 shows a box-shaped AUV and Figure 17 shows an ROV developed by UCRG. These have been developed for underwater pole and submerged ship hull inspection application. ■

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