INSPECTION OF DAM INFRASTRUCTURES USING ROVS - AN INNOVATIVE APPROACH

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ABSTRACT

Periodical maintenance of underwater infrastructures such as dams are very crucial for their sustenance. Conventionally divers were deployed in order to access the dam structures through visual means and videography.

As the depth and span of a dam increases, it is more convenient to employ robotic systems like underwater drones/ ROV's to do the dam inspection works as they can produce better quality videos in a systematic manner and generate user intuitive software reports.

The paper presents means of how ROV's are employed for better structural assessment of dams. Further, the paper explores latest technologies employed for ROV based dam inspection.

1. INTRODUCTION

"Dams have played a key role in fostering rapid and sustained agricultural and rural growth and development in India. Over the last fifty years, India has invested substantially in dams and related infrastructure. 5254 large dams have been completed and another 447 under construction (NRLD 2017). Storage capacity created by these large infrastructures is 253 BCM. Another 51 BCM storage under construction stages.

As per an ICOLD publication – Lessons from Dam Incidents (1973) – there have been about 200 notable failures of large dams in the world up to 1965. Globally about 2.2% of dams build before 1950 have failed, while the failure rate of dams built since 1951 has been less than 0.5%. India too has had its share of dam failures. However, the performance of Indian dams mirrors the International trends. The first such failure was recorded in Madhya Pradesh during 1917 when the Tigra Dam failed due to overtopping. The worst dam disaster was the failure of Machu dam (Gujarat) in 1979 in which about 2000 people have died. There are 36 reported failures cases so far. (Kumar, 2017)."

In earlier days, conducting inspection and surveillance of hydroelectric dams was a difficult and costly operation. The dam operations had to be shut down or reduce water flow significantly to allow divers accessible to the area. The conditions of work was often a dark overhead environment with piles of debris around the dam structure, making it a particularly hazardous and risky job. For many organisations, ROVs have become a popular choice for these inspections whenever possible.

2. ROV SYSTEM

An ROV (Remotely Operated Vehicle) is a tethered underwater vehicle or robot that is used to explore deep oceans as well as inland water bodies. It is an unmanned vehicle which will be controlled by a pilot from the control station at the surface and will be equipped with payloads such as sensors, cameras, lights, robotic arms etc. to perform various underwater operations.

It is either powered by on board batteries or externally powered through the tether. The primary driving component are thrusters which will be used to control the speed and direction.

The manoeuvrability, ability to work under very deep depths or pressure, and additional payload capabilities make an ROV the perfect choice for underwater inspections and is primarily used by the Oil & Gas industries, Shipping industries, Navy, Research institutions etc. for Underwater Critical Infrastructure Inspection, Aquaculture, Marine Survey, Recreation and for Salvage operations.

The ROV used for the following inspections methods and research studies is of the model - TUNA ROV (Fig. 1.) made by EyeROV (IROV Technologies Pvt. Ltd.), an Indian company specialised in marine robotics. The TUNA ROV system is a custom modular ROV (Remotely Operated Vehicle) designed with a high performance on board computers and an intuitive control console for critical infrastructure inspection and surveillance operations. It is designed for carrying custom payloads as per the requirement of the operation having a range of attachments and sensors.

Figure 1 : EyeROV TUNA ROV

Features are as follows:

- Depth Rating of 100 m
- Optimised Thruster Configuration
- High Manoeuvrability
- External Sensor Interface – Serial and Ethernet
- Power Options : External/On-board batteries
- Live HD Video
- High Intensity Lights
- Payload: 2 kg to 5 kg
- Payload Options: SONAR, CP Sensor etc.

3. DAM ASSESSMENT

"The overall dam safety inspection program is a continuing process of evaluating a dam's performance based on review and analysis of performance records and field observations. A dam safety inspection performed on a regular basis is one of the most economical means a dam owner can use to assure a long life of a dam and its immediate environment. The visual inspection, a component of all types of inspections, is a straightforward procedure that can be performed by any properly trained person to make a reasonably accurate assessment of a dam's condition. The visual inspection component involves careful examination of the surface and all parts of the structure, including its adjacent environment. The equipment required is not expensive, and the visual inspection component can usually be completed in less than one day. However, in some cases, the entire inspection process will usually take longer to complete, depending on the type of inspection and the complexity of the dam.

A dam, even though previously found safe by analysis and demonstrated performance, cannot be considered safe forever. Continued vigilance, visually and analytically, is essential. The integrity of the dam must be re-evaluated whenever the embankment or discharge structures are damaged, and when upstream or downstream watershed conditions are significantly altered" ("Guidelines for Safety Inspection of Dams", 2017).

Periodical assessment and maintenance of dams is a necessity to maintain the structural integrity of the infrastructure. Conventionally divers were employed for dam inspection but as ROV's have proved to be a safer, economical and much effective method of inspection, it is being highly used in present day scenario. But the methods and devices used for ROV inspection cannot be entirely unified as it is depended on a lot of factors such as area span of the dam, operational window, water current, structural differences and accessibility.

Based on the dam structure it may be necessary to attach site specific customisations on to the ROV to effectively hold it in position (Fig. 2).

Figure 2 : Customisation for Dam Inspection

4. SURFICIAL STRUCTURE ASSESSMENT

Surficial structure assessment consider the structure as a whole to get a visual realisation of the objects beneath. It is necessary to understand the structural contour of the dam or marine infrastructure in context, to identify objects lying on the water bed and for navigation of the ROV without obstruction.

4.1 Structural Deterioration

Structural Deterioration refers to the damages that occur to the dam infrastructure over a period of time due to many external and internal factors. The internal factors is usually because of the absence of formal design, poor design and poor construction. The external factors include embankment slide, meteorological or seismic activities. The damages are usually in the form of cracks, slides, depressions, weathering, erosion, debris etc.

Deterioration in concrete means corrosion of reinforcing steel and other embedded metals which can eventually cause cracks. Regular inspection is required to ensure the strength and durability of concrete structures. It would be a difficult and time consuming process if the concrete structure is underwater. Human risk is also involved in this case; expert divers are required to do the task. Here is where underwater ROVs or drones are effective. ROV's are generally equipped with cameras, sonar systems and other payloads suitable for underwater structure inspection. The scientific and technologically advanced processes incorporated in an ROV is what makes it a popular choice for underwater inspections.

The two methods for surficial structural inspection is performed using Visual Imaging and Sonar's depending on site & water conditions.

4.2 Visual Imaging

Visual imaging is one of the main technique that is being used to assess concrete deterioration. With the help of High Definition cameras, ROV can capture the details of underwater concrete structure and transmit the video data to ground station where the ROV pilot/operator is seated. The pilot can then easily find out concrete structure defects. Visual imaging is suitable only for clear water conditions (Fig. 3).

Figure 3 : Anomaly found using EyeROV TUNA during a Dam Inspection

Cameras are the most commonly used inspection devices for image capturing. Cameras made specifically for underwater applications make it easy to implement them in ROV's and the low light capabilities of the camera produces high quality images of the underwater structures provided the water turbidity is of or below acceptable levels.

As we move down from water surface, the amount of sunlight get reduced and it affects the video quality. i.e. proper lighting is also required for good video feed as well as quality inspection output. TUNA ROV is having underwater lights whose brightness can be easily adjusted by the operator according to the requirement. An optimum level of lighting will give satisfactory inspection result even when the water is not clear.

Choosing the right vision system is really important for underwater visualization applications. The camera selected for doing underwater inspection should be able to produce video stream with little to no illumination. Low light colour and monochrome cameras are popular for doing this task. Monochrome cameras are more preferred due to its high quantum efficiency.

Video quality of low light cameras are greatly depending on its sensor technology. The most common types are CCD, CMOS and SIT.

CCD (Charged Coupled Device): It is one of the oldest digital image-capture technology which offers superior image quality with noise control compared to other camera technologies.

CMOS (Complementary Metal Oxide Semiconductor): CMOS camera sensors are suitable for high-speed burst modes. They consume less power compared to CCD and more built in functionalities makes it perfect for modern cameras.

SIT (Silicon Intensified Target): This is an electron multiplication technology in which photons are allowed to strike on a silicon screen where more electron-hole pairs are created. This is then read by an electron beam to produce video signals (“Low Light Cameras Information”, 2020).

4.3 Sonar

In places where turbidity and murkiness is very high, backscattering of sunlight occurs causing visual noise and usage of cameras is practically ineffective. In such conditions of high turbidity, the practical approach is to implement Sonar devices which uses high frequency sound waves to capture the contour of the underwater objects. Two types of SONAR’s are implemented in TUNA:

4.3.1 *Side Scan Sonar*

“Side Scan Sonar is a marine geophysical technique that is used to image or “see” the ocean floor (or lake or river bottoms). The method uses pulses of sound (sonar) shot sub-horizontally across the sea bottom from a transducer attached horizontally on the ROV. The sound pulses reflect off of relief or objects that project above the bottom. The strength and travel time of reflected pulses are recorded and processed into an image or picture of the bottom (Table 1. & Fig. 4) (“Side Scan Sonar”, 2020)”.

Table 1 : Side Scan Sonar Specifications

Technology	Chirp Digital
Supply Voltage	11V to 48V
Power Consumption	200 mA @ 12V
Frequency	680 kHz
Maximum range	50 m
Horizontal & Vertical Beam Width	0.7° & 60°
Resolution	Down to 1 cm

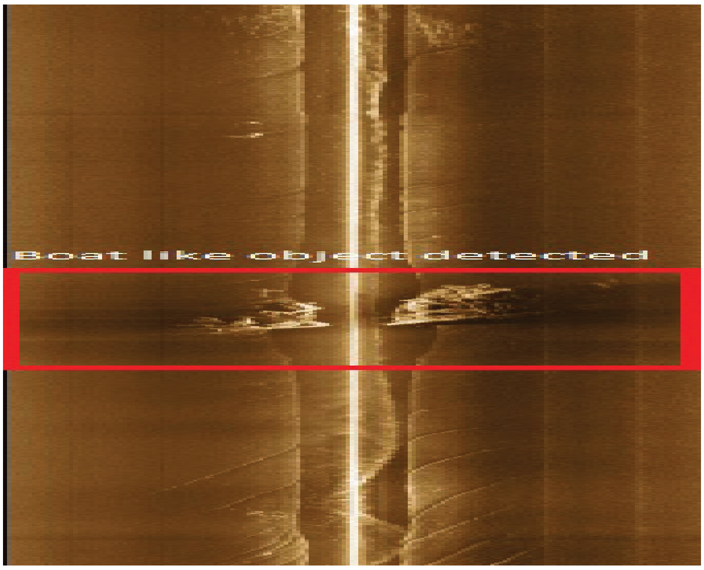

Figure 4 : Output image of a ship wreck inspection obtained using EyeROV TUNA at Mumbai port.

4.3.2 *Imaging Sonar*

“The imaging sonar is a useful addition to a positioning system on an ROV. Imaging sonar is a high-frequency, narrow field of view, underwater sonar that produces video-like acoustic imagery that can detect and identify submerged objects of interest, even in low-to-no visibility conditions. Imaging sonar systems are used by responders to inspect ship hulls and pier and bridge pilings, direct divers to objects of interest, track divers underwater, and search for underwater obstructions ahead of vessels. Scanning a large area takes only a short time. The vehicle pilot can quickly assess the nature of the surrounding area, thereby eliminating objects that are not of interest. The ability to “see” a long distance underwater allows the pilot to use natural (or man-made) features and targets as position references (Table 2. & Fig. 5) (“Imaging Sonar Systems”, 2016)”

Table 2 : Imaging Sonar Specifications

Supply Voltage	25 V
Power Consumption	200 mA @ 12V
Frequency	750 kHz
Maximum range	50 m
Horizontal & Vertical Beam Width	2° & 25°
Resolution	0.08% of range

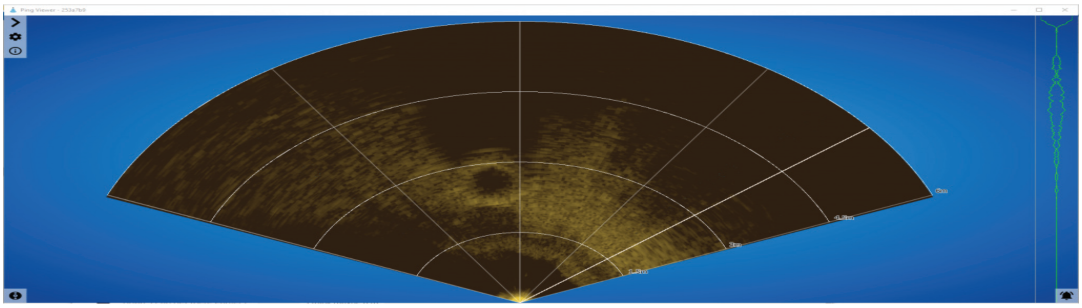

Figure 5 : Imaging Sonar Output image (Ping360 Scanning Imaging Sonar, 2020)

4.4 Size Assessment using Laser Scalar

Size assessment is of primary concern for underwater inspections as there is no reference to measure the area & dimensions of anomalies, cracks, erosion and underwater infrastructures with respect to the ROV. Also, the apparent position and size of the object may differ from the actual size due to medium refractions and angular shape of the camera dome.

An innovative yet practically simple approach to this problem is by incorporating a laser module which will be attached in front of the ROV. The two laser points of the module is fixed at a predetermined distance between them (60 mm). The laser will then be projected onto the anomaly or structure to be measured (Fig. 6).

Since, the distance between the laser points is already known, it can be used as a reference and the dimensions of the entire object can be calculated by analysing the pixel size of the visuals obtained.

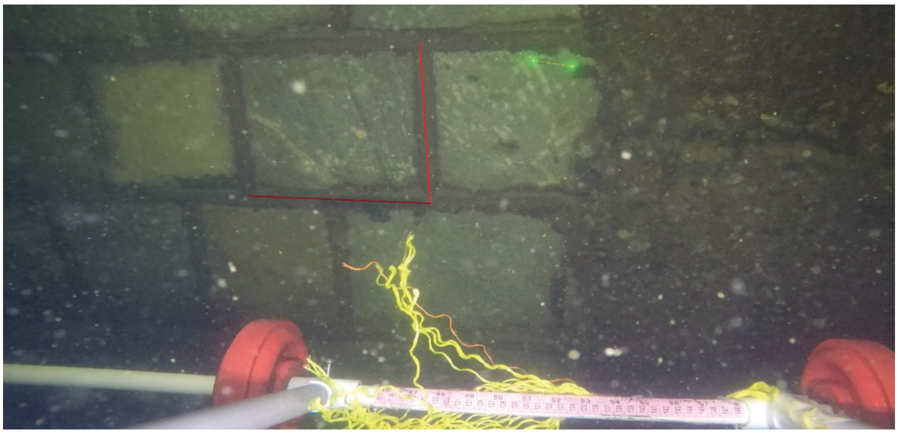

Figure 6 : Laser Scalar being used at a dam site with EyeROV TUNA

Distance between green points of Laser Pointer

Pixel Distance

In x = 83 px

In y = 14 px

Yellow line length (C) = (83*83+14*14) ^0.5 = 84.1724 px

As already known,

C = 60 mm ≡ 84.1724 px

Area of a single stone:

Height of the joint (H) = 403.6558 px ≡ 287.735 mm

Length of the joint (L) = 392.5098 px ≡ 279.677 mm

Area = H*L = 80472. 86 mm^2 = 804.7286 cm^2

5. LEAKAGE DETECTION

Leaks can develop through poorly sealed joints in pipes and concrete dam structures. It is also a major safety issue if left unchecked. Proper leakage investigation and monitoring is required for repairing the underwater structures. A lack of appropriate inspection can result in unsuccessful controlling of leakage. ROVs are perfect solution for finding leakage of underwater concrete structures.

5.1 Dye Injection Mechanism

TUNA ROV has a Fluorescent dye injection mechanism to perform leakage detection. A chamber is filled with green fluorescent dye which is injected to water by using an electronic system. An Ultraviolet Torch light is then used to trace the path of dye.

Dye could be injected from a location very close to the crack. This can ensure that the dye moved into the crack rather than elsewhere on the dam. By tracing the path of dye using UV light and camera, the exact leakage point can be located (Fig. 7.).

Figure 7 : Dye Injection testing using EyeROV Tuna

5.2 Feeler Method

Feelers are low weight hair like materials and they can be used for leakage detection of underwater structures using ROVs. They are attached to the frame of the ROV and the pilot can then observe the movement of them when ROVs are in close vicinity to the wall structure. If a leakage is there on the wall, the feeler will get directed to the points where high water velocity is observed due to leak and hence it is easy to find out the location of leakage (Fig. 8.).

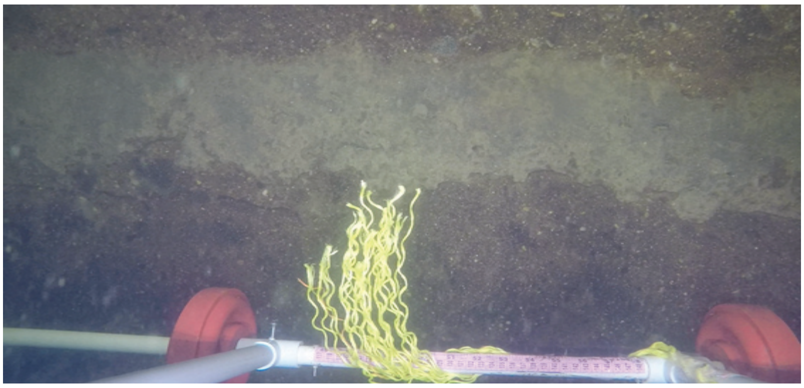

Figure 8 : Hair like Feelers attached on EyeROV Tuna

6. POST PROCESSING TECHNIQUES

The technological advancements in the area of computer image processing and enhancement has made it possible to obtain and extract crucial information from raw image data which was thought to be ineffective otherwise due to turbidity of water, haziness, back scattering etc. Apart from enhancing bad images we are able to identify cracks and anomalies automatically by software assistance which makes the identification process and post inspection report generation much easier than it was before.

6.1 Image Enhancement

Turbid waters drastically reduces the quality of video footage. Hence, the person who assesses the video fails to accurately estimate the deterioration level of concrete structures. Here we can use image processing to enhance the quality of videos. Different post processing techniques are developed by EyeROV Visualisation and Analytics platform to improve the quality of inspection videos (Fig. 9.).

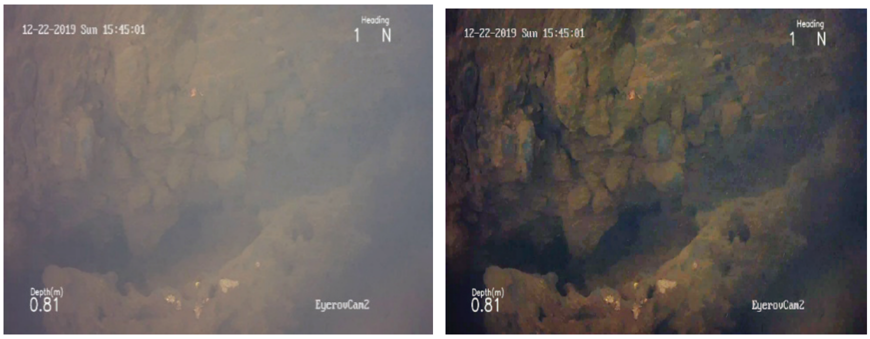

Figure 9 : Raw v/s Post Processed & Enhanced Image of an anomaly respectively.

6.2 3D Reconstruction

Due to significant attenuation of light in underwater, a single image covers only a few square meters. To assess the entire underwater structure surface, hundreds or thousands of such images are required. Here we use an image processing technique called '3D Reconstruction' to produce the exact three dimensional view of inspected underwater structure (Prabhakar & Kumar, 2012). Multiple frames of the underwater structure is taken from different angles and directions. These images are then stitched together to form a 3D construction of the entire underwater structure and the local environment. The user can then navigate through the 3D visuals similar to a 360° image and closely inspect the data in the post inspection assessment (Fig. 10.).

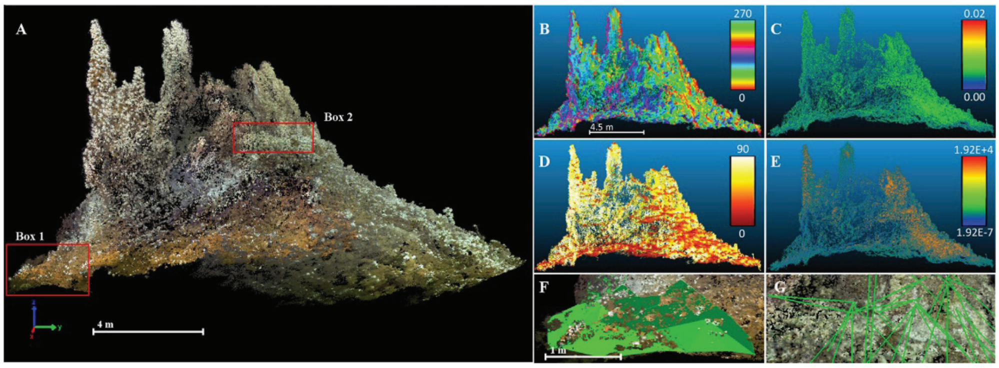

Figure 10 : A 3D reconstrcuted image of a Coral Reef (Mapping the seabed with underwater videogrammetry, 2020)

7. CONCLUSION

Visual Inspection of dams is becoming more and more practical with the advent of ROVs. Obtaining a visual record of underwater structural damage along the dam face inlet structures and outlet structures and sediment deposition around the inlets of low-level sluices using Visual or Acoustic tools mounted on ROV is some of the key use cases with ROV for dam safety inspections. Although ROV technology cannot replace all the services offered by commercial divers, it can help reduce inspection-related risks for deep-water inspections and overheads. ROVs configured with high-definition (HD) video cameras, high intensity LED illumination, sonar mapping system, and other tools can navigate and collect valuable information in conditions unsafe for diver entry. As underwater communication and positioning capabilities grow, ROV's can further operate autonomously and execute a planned dam inspections job.

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