Manta-ray-inspired robot for detecting damages in underwater concrete structures

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https://doi.org/10.1016/j.device.2024.100368

In a recent paper published in *iScience*, Zhang and co-workers present a manta-ray-inspired robot designed for detecting structural damage in underwater concrete structures. These robots are equipped with a self-adjusting balance function and have transient driving functionality for navigating around challenging obstacles underwater.

Various robotic systems have been developed for automatic assessment and damage detection in large-scale underwater concrete structures in recent years.1,2 The development of underwater robots for maintaining the safety of critical infrastructure is in demand due to the limitations of manual inspection methods; these limitations include costs, safety, and the inability to reach certain areas using human divers.

In a recent paper from *iScience*, Chenjie Zhang and co-workers present a robotic detection system inspired by the manta ray for complex underwater concrete structures. The presented manta-ray-inspired robot can adjust its posture in underwater environments and has a self-adjusting balance function to minimize the influence of ocean waves on its stability. Moreover, the robot is designed with a transient driving function that enables sudden high acceleration to navigate through or avoid surrounding water plants and sediments. The hardware of the manta-ray-inspired robot comprises an ejection actuator, a steel chamber for housing the control module and onboard processors, and a 3D-printed biomimetic body shell. The soft membrane in the ejection actuator is made of silicone rubber. The steel chamber is manufactured using selective laser melting. The body shell is printed using resin materials with a density close to that of water.

The robot’s movements can be controlled wirelessly. The explosion module activates the ejection system to propel the robot for obstacle avoidance. The manta-ray-inspired robot can adjust its orientation and position using a combination of its wings, balance sensors, and propellers. The camera on the robot’s head sends video signals to the controller unit for analysis. The robot is equipped with two fill lights to address dim underwater lighting and murky conditions.

Datasets play a key role in training deep-learning-based computer vision models for detecting and analyzing a diverse array of damage types.3 The authors created high-quality concrete target detection datasets, which are categorized into four damage types: cracks, spalling, exposed reinforcement, and corrosion (see Figure 1). The annotation of 3,917 sample images has been performed manually. Four types of data augmentation techniques are used in the training pipeline: photometric distortion, geometric distortion, mixup, and mosaic. The YOLOX algorithm5 is expanded to YOLOX-DG by enhancing data augmentation techniques and modifying the loss function to improve damage detection performance in underwater concrete structures. YOLOX is an advanced version of the YOLO (You Only Look Once) family of algorithms designed for real-time object detection in digital images with enhanced accuracy, especially in challenging environmental conditions. Three sets of comparison experiments are conducted: the plain YOLOX model, the YOLOX model using the data augmentation strategy (YOLOX-D), and the YOLOX-DG model. Although the YOLOX-D model converges more slowly, it achieves better convergence results compared to the plain YOLOX model. The results indicate that the YOLOX-DG model outperforms the YOLOX-D model and is the preferable model for the detection of concrete damages. The YOLOX-DG model’s confusion matrix indicates clear differentiation among the four damage types. Contrarily, the model confuses spalling, exposed reinforcement, and corrosion with unlabeled backgrounds. This includes instances where damaged areas are misidentified as background and vice versa.

Besides identifying damages by marking the area in the video feed, the model includes a comprehensive damage assessment algorithm for evaluating the extent of the concrete damage. A multi-attribute decision model is designed to automatically calculate the image damage scores. Corrosion is assigned the highest weight due to its severity and danger to concrete structures. Cracks, being a common but mild damage type, receive the lowest weight. The damage score is intended to be a part of the robotic systems to provide the auxiliary judgment basis.

Ocean testing conducted at the underwater marine harbor near Gouqi Island in the East China Sea yielded satisfactory performance for the detection of concrete cracks. Visible structural damage resulting from ocean waves and tides, particularly in the pile array structures below the waterline, is evident in this marine harbor. Conventional structural monitoring equipment is unable to approach the harbor pile arrays. All four types of concrete damage have been identified within the harbor’s pile array structures. Damage scores are obtained and reported accordingly. Although mussels and water plants are
clearly visible in the monitoring images, they are not classified as concrete defects. The authors also admit that the proposed robotic system needs to be further optimized. Despite the self-balancing module enhancing stability, waves and currents still affect the robot’s movement. Furthermore, the robotic system is not fully autonomous, relying on a cable for energy supply and underwater communication. Lastly, enhancing the dataset with additional high-quality underwater concrete images could further improve it.

**DECLARATION OF INTERESTS**

The author declares no competing interests.

**REFERENCES**


