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An automatic marine-organism monitoring system for the intake water of the nuclear power plant

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ABSTRACT

On a review of the nuclear power plant accidents caused by marine organism intrusion and current strategies used by the NPPs, a complete set of marine-organism monitoring system for the water-intake of the nuclear power station was designed. The system integrates sonar and high-definition camera as the detecting equipment to have wide detection range of the marine organism. Integrated with automatic inspecting instruments and data transmission networks, the system can realize the automatic inspection with different depth, different directions and different time periods.

1. Introduction

From the grid generation of the world's first commercial nuclear power generating units, the interaction between nuclear power facilities and the surrounding environment has been a hot topic of research. The process of site selection, construction, operation, maintenance and waste disposal of nuclear power plants will inevitably have an impact on the environment and be restricted by the surrounding environment.

In order to study and control the negative impact of nuclear power plants to the environment, the research institutes, power plant operators, government monitoring system and other agencies have done a lot of work. The radioactive pollutants emissions and migration observations were studied by using of automated environmental monitoring equipments (Huang et al., 2013); the impact of nuclear power plants on the marine environment and biology has been revealed by observing the changes of the surrounding ecosystem of animals and plants (Li and Cai, 2001). Detailed results disclose that the surrounding environment becomes significant for the commercial operation of nuclear power stations. The thermal discharge and chemical discharge of the power station lead to the change of the quantity and the normal growth period of the marine organism. As a result, the frequency of the red tide and other marine biology intrusion have been increased gradually (Lair et al., 1980). The marine biology explosion and its intrusion to the water surrounding the power station will seriously affect the safety of the station operation. Furthermore, the NPP accident caused by the intrusion of marine biology has been reported quite often in recent years. How to manage such intrusion to avoid the accidents becomes a hot topic in the field of nuclear power security.

The cold water intake system provides the required water for the nuclear power plant (NPP) water cycling system. The operating state of the water intake directly affects security and reliability of the power plant operation. A large number of marine organisms in the NPP surrounding waters will seriously affect the normal operation of the water intake system, and even lead to the NPP shutdown. According to the Institute of Nuclear Power Research (INPO) statistics, between 2004 and 2008, there were sixty-one clogging incidents in the nuclear power plant globally. Most of these incidents are due to the blockage of marine organisms. Nearly 80% of these events resulted in power reduction or NPP shutdown, with more than 20% of events directly impacting safety-related NPP systems. In recent years, various invaders have been reported to cause serious accidents, such as: invasive weeds (blocked filtration system and caused loss of cold water source, Unit-4 of French CRUAS NPP, 2009) , sea shells and jellyfishes (blocked cooling water intake system, Coastal NPP of California,

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United States, 2012), floating rubbish (blocked water intake system and caused light load operation, Qinshan second NPP, China, 2011), jellyfishes (blocked water filtration system and caused unit H1/2 shut down, Hongyan River NPP, China), and marine organisms (invaded into the water intake system, and caused urgently shutdown of Unit-2 reactor, Ling'ao NPP, China, 2016). Therefore, it is an urgent problem to predict the invasion tendency of marine organisms and to prevent such serious accidents.

2. Methods and system configurations

2.1. Intrusion preventing methods

In order to solve the intrusion problem of biology or foreign matters into the water intake, many strategies have been putting forward. The construction and improvement of the water intake interceptors is a passive defense scheme generally adopted by the NPPs, which can effectively prevent the intrusion of foreign objects (Ruan, 2015). Such technologies include the optimal design of multi-channel classification of interception facilities (Xu and Bao, 2016), the use of rotary screen and auto-flushing pipeline at the entrance of the water intake (Han et al., 2011) and so on.

Besides the passive defense, the active monitoring and early warning strategies are now considered by many NPPs as well. In such active methods, the living statues of the marine organism at the water-intake entrance are monitored to forecast the biology explosion and to provide early warnings. The basis of these active strategies is an real-time marine-organism monitoring system working at the water intake. The existing monitoring methods mainly include:

a. Automatic inspecting vehicles

The automatic inspecting vehicles may working underwater or on the water surface. These vehicles acquire images or information by detecting sensors (normally underwater camera) and transfer the information to the operators (Choa, 2004; Lee et al., 2010). These automatic vehicles are flexible, and easy to be used rapidly to detect specific water areas. However, the inspection using such vehicles has a high requirement for the control operation, and the support of ship.

b. Buoy-type water quality monitoring

The buoy-type monitoring system integrates multi-parameter water quality monitor on a buoy to detect sea water quality parameters that can influence the living conditions and growth of the marine organism. The water qualities to be monitored mainly include pH, temperature, conductance, turbidity, chlorophyll concentration, dissolved oxygen concentration, etc. The detected data of such key parameters are stored and used to estimate the marine organism living condition (Zhu, 2014). The efficiency of the organism estimation is an indirect method which relies on the marine biochemistry.

c. Sonar detection

Sonar detection method has been reported to be widely used in both marine-organism monitoring, such as fish schools (Brehmer et al., 2006, 2007) and underwater structure scan, including sewer (Duran et al., 2002) and harbor inspection (Jacobi, 2015). Currently, the sonar detection method is mainly used in the NPPs for the detection of underwater threat (Rothenbuh, 1987) and for the localization of inspecting robot (Burguera et al., 2009). It is also reported that in Cooper nuclear power plant in the United States, a 3D digital sonar system has been installed at the water intake to continuously monitor the bottom of the fore bay and provide the real-time sediment conditions. However, the detection of marine organism using sonar at NPP has not been reported.

Considering the advantages of the sonar detection and the requirements of the NPP water intake inspection, this work designs an automatic system for the water intake marine-organism inspection, utilizing sonar and underwater camera. The realization of this system is significant for the security assurance in the operation of NPP. The monitoring data provided by this system could be used to study the formation and movement of marine-organism or foreign substances, and consequently to generate the warning system prevention mechanism.

2.2. System configurations

The whole system consists of four function parts: monitoring equipments, an on-site control unit, a coast control station and the remote control station (cf. Fig. 1). Optical fibers and submarine cables are used for the communications and data transportation between these four functional parts.

2.2.1. Monitoring equipments

A high-precision 2D sonar detector and a high-definition waterproof camera are used in conjunction as monitoring detectors to acquire real-time information of underwater substances in the upstream direction of the NPP water intake. The sonar detector and the camera are installed on a rotational platform which is integrated in a turret.

The turret together with the rotational platform is able to move along vertical direction (z-axis) through the guideway, which is mounted on the middle platform of the cold water-intake entrance. The vertical movement of the turret is realized by an electric winch system and water-proof hoist cable. The rotational platform is driven by an AC motor to realize the horizontal rotation (in x-y plane). This combination of the platform rotation and the turret vertical movement enable the scan of 2D sonar and the underwater camera at different water depth and through different scan directions.

2.2.2. On-site control unit, costal control station and control system

The actions of the monitoring instruments is controlled by a control system. The close loop control system includes the on-site control unit, the costal control station and the actuators and sensors, shown in Fig. 2.

The on-site control unit, mounted on the platform in the water intake, receives control instructions and generates the actuator driving signals to realize the movement of the rotation platform and the turret. The orientation of the rotation platform is detected by an electronic compass. The vertical position of the turret along z-axis is detected by an ultrasonic sensor by measuring the distance between the turret and the water-intake bottom. These orientation and position signals are transferred to the slave computer of the on-site control unit to form the close loop control.

The coastal control station is the control center of the monitoring system. This station is equipped with an industrial control computer, which is serving as a master computer of the control system. This coastal control station is also equipped with an real-time monitoring data display system to display and relay the image data acquired by the sonar detector and the waterproof camera.

2.2.3. Data transmission and remote control station

The data captured by the 2D sonar and the underwater camera is transmitted to the on-site control unit though the water-proof hoist cable. Then the data will be sent to the costal control station through an individual optical fiber. After the real-time display at