Development of ship structure health monitoring system based on IOT technology

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Abstract. It is very important to monitor the ship structure, because ships are affected by all kinds of wind wave and current environment factor. At the same time, internet of things (IOT) technology plays more and more important role of in the development of industrial process. In the paper, real-time online monitoring of the ship can be realized by means of IOT technology. Ship stress, vibration and dynamic parameters are measured. Meanwhile, data is transmitted to remote monitoring system through intelligent data gateway. Timely remote support can be realized for dangerous stage of ship. Safe navigation of ships is guaranteed through application of the system.

1 Introduction
In the process of the voyage, the structure will not only suffer from a variety of external load, wind, wave, current, ice, and other environmental conditions, but also suffered from corrosion of the marine organism when the ship is at zero speed. Once some key parts stress value exceed the permitted value of during the normal sailing, ship structure will be affected seriously, which even can lead to the damage of the ship.

Under the long-term effects of the harsh environment load, coupled with the design or improper use, easy to produce various forms of hull damage, make the structure bearing capacity drops, catastrophic accident, cause huge casualties and economic losses.

It is become very difficult to assess of hull damage through the load to the hull by means of the experience of the crew and captain, as the ship structure becomes more and more complex, sailing speed are faster and faster.

Ship structure health monitoring system based on IOT technology can be used for timely discovering failure hidden danger and irrational ballast condition of the ship during navigation. Ship stress condition and movement condition are monitored in real time. Necessary early-warning information is provided for the safety of ship structure.

Therefore, the crew can adopt proper operation under poor sea condition and in the process of ship loading and unloading. Meanwhile, the system is provided with positioning function. When the ship suffers from severe failure, alarm information and ship position can be automatically sent, thereby guaranteeing safe navigation of the ship [1].

2 Design principle of system
System constitutes and structure is shown in figure 1. Monitoring equipment mainly includes fiber Bragg grating strain sensor and interrogator, tri-axial vibration acceleration sensor and data processing
gateway. Finally, the sensor data is transmitted to data collection computer through reticule. The stress change condition of the hull monitoring part during navigation, hull curving and twisting transformation condition, influence of vibration impact on hull structure and acceleration information of ship movement are displayed on the computer in real time.

At same time, maritime satellite network or GPRS wireless network can be adopted for transmitting ship safety state alarm information and ship position to remote monitoring system. Remote monitoring system can provide technical guidance or the rescue work according to alarm information and ship position.

In this system, fiber strain sensor with corrosion resistance and high precision is used for collecting data on the monitoring part during hull deformation monitoring and local stress monitoring. Many monitoring points can be connected in series through transmission cable. Data is preprocessed through optical fiber grating interrogator, which can be transmitted to the database for storage and analysis; Tri-axial vibration acceleration sensor with low cost and high precision can be adopted for realizing response collection of vibration features during monitoring of hull dynamic features and external load. Many vibration monitoring points are connected through CAN bus, and data is pretreated through data processing gateway, which can be transmitted to database for storage and analysis [2].

![Figure 1 System overall structure](image)

### 3 Subsystem design

#### 3.1 Fibre Bragg grating sensing detection system

In the part, to-be-measured physical quantities are converted into fibre Bragg grating wavelength change mainly through fibre Bragg grating strain sensors [3][4]. Mainly monitored physical quantities include bending moment, torsion deformation on key parts of the ship. Functions of hull deformation monitoring and hull local feature monitoring are completed.

Optical fibre has many excellent properties, such as: performance of resisting electromagnetism and atomic radiation interference, mechanical performance with thin diameter, soft texture and light weight; electrical performance with insulation and no induction; chemical performance of resisting water, high temperature and corrosion, etc.

It can act as eyes and ears of human beings in the places which can not be reached by people (such as high temperature area), or areas harmful to human beings (such as radiation area). In addition, it also can exceed physical boundaries of human beings, thereby receiving external information which can not be felt by human organs.

The basic working principle of optical fibre sensor is that light from light source is transmitted into the modulator through optical fibre, therefore light optical properties (such as light intensity, wavelength, frequency, phase, polarization, etc.) are changed after interaction between to-be-measured
parameters and light entering into the modulation area. It is called modulated signal light. The measurement can be completed through utilizing the measured influence on light transmission properties.

At present, the optical fibre sensor is comparatively mature. Major brands include Everlight, OSRAM, YL, TAIYO, USHIO, Tenglong and other brands. If one monitoring point only suffers from unidirectional compressive stress, one strain sensor can be arranged along the stress direction. If the stress is complex on the monitoring point, three-way strain sensors should be arranged, and the measuring points are mainly arranged in the following positions (see figure 2), which is described as follow.

The sensor is installed on cross section girder or end portion 1/4L, 1/2L and 3/4L (L refers to ship length) to the stem, which is mainly used for measuring total longitudinal strength bending moment of the hull;
The sensor is installed on broadside reinforcement plate, which is used for measuring the stress role of seawater pressure on broadside;
The sensor is installed on transverse bulkhead, which is used for internal stress of bulkhead;
The sensor is installed on local open part, which is used for measuring the damage due to local stress concentration;
The sensor is installed on the bottom plate of the ship, which is used for measuring total longitudinal bending moment thereof.

3.2 Vibration sensing detection system
In the vibration sensing detection [5,6] subsystem, vibration frequency of the ship on transverse, horizontal and vertical directions is mainly monitored through acceleration sensor. Mainly monitored physical quantities include slamming load, vibration, etc. on the key parts of the ship. Functions of 'hull dynamic feature monitoring' and 'hull external load monitoring' are completed.

Bus sensors are adopted in the system for collecting nodes. Distributed data collection system can be formed. The node is provided with high precision tri-axial acceleration sensor based on CAN communication bus. It is composed of collection and processing module and CAN transceiver module, which are wrapped in metal waterproof shell. The sensor nodes can form a huge distributed data acquisition system, and large-scale structure test can be carried out during support for multiple measuring points simultaneously.

Data collected by the sensor can be transmitted to the computer in real time. The product is characterized by simple structure, low cost, high transmission speed and remote communication distance. Vibration sensing detection system measuring point is mainly arranged on the following key positions, which is also shown in figure 2:
It is installed on the bow deck, which is used for measuring the wave slamming load during the sailing of the ship;
It is installed in the mid-ship position, which is used for measuring centre vibration acceleration and bending moment of the hull;
It is installed on the bottom plate of the ship, which is used for measuring impact load due to the wave and current.

4 Monitoring system software

4.1 Database system software
Database system is mainly used for uniform management on various data in ship structure health monitoring system, which mainly includes data and information storage, query, calling and other functions. The database structure is divided into real-time database, historical database and information database.

Real-time database is mainly used for managing measured hull structure stress and vibration data; history database is used for managing previous hull structure stress and vibration data; information database is used for managing hull structure information, software system parameter information and system operation information, wherein hull structure information includes ship name, loading condition, structure materials, component size, etc.

Software system parameters include storage settings, hull material settings, sensor initial value setting, monitoring point settings, etc. System operation information refers to record information of all operation and automatic calculation process after software system is started.

4.2 Monitoring analysis software
Ship structure health monitoring system platform is mainly used for measuring signal processing and hull structure data analysis. State data of monitoring module can be displayed in real time. Intuitive and simple interpersonal interaction interface is provided. Ship structure stress and vibration characteristics can be monitored in real time through the system platform. Crews can preliminarily evaluate according to current status of the ship. The hull strength and vibration state can be improved through changing ship speed and direction or adjusting ballast and other measures, which are mainly based on data display and curve display respectively. States of all monitoring points on the hull are reflected in real time.

5 Main functions of the system
Ship structure health monitoring system is mainly used for measuring, recording and assessing dynamic performance state of the hull. Involved measuring parameters include stress and strain and vibration acceleration, wherein stress and strain parameters are measured through adopting fiber Bragg grating sensor.

Vibration characteristics are measured through adopting tri-axial acceleration sensor. The system is mainly used for monitoring contents in the following aspects:

5.1 Hull deformation monitoring
Main contents of deformation monitoring include the follows: hull components are deformed due to hull strain, the deformation is serious and component curving, cracking or damage can be caused, thereby affecting the service life thereof.

It mainly includes monitoring of structure stress deformation of ship deck, broadside reinforcement plate and bottom plate under static load (mainly referring to water pressure and cargo pressure) and total vertical strength bending effect, the law of hull fatigue and internal crack expansion under alternating load effect.
5.2 Hull local stress monitoring
Local component or node fatigue damage and bearing capacity drop can easily lead to instability and safety hidden danger of ship structure as a whole. Therefore, the internal force status, bearing capacity, durability of the components should be monitored, by means of obtaining local characteristic parameters, and it is also one of the goals for hull health monitoring.

The monitored contents mainly include monitoring of influence of stress concentration and welding effect loss on hull longitudinal stiffeners and bulkhead, frame joint, deck opening position, hatch corner, bottom side tank and internal bottom side joint. And the curve of strain gauge of the mid ship is shown in figure 3, and the horizontal and vertical axial unit of the figure is hour and micro strain respectively. From this figure the scope of the micro strain is -88.12 and -87.60 during the past 72 hours.

![Figure 3 micro strain curve of the mid ship position](image)

5.3 Ship motion parameter monitoring
During the sailing, hull damage, corrosion or aging will cause changes in structure parameters at different levels. Therefore, hull dynamic characteristics are monitored aiming at obtaining dynamic response parameters of hull structure through the monitoring system. And three axial (X, Y, Z axial) acceleration curve of the mid ship is shown in figure 4, and the horizontal and vertical axial unit of the figure is minute and m/s/s respectively.

![Figure 4 three axial acceleration curve of the mid ship position](image)

Hull vibration parameters are recognized. If the wave is higher than the freeboard and surged on the deck, the deck and equipment on the deck can be damaged. In addition, when the ship is moved at
larger extent, the hull bottom is exposed from water surface, which is fed into water again, and it also can produce strong shock with wave.

Damage of impact vibration response and hull bottom slamming response of the deck layer on the local and overall ship structure should be monitored, including steady-state response under cyclical effect and transient response under short time load effect.

5.4 Hull external load monitoring
Hull external load is monitored aiming at recording various variable loads and the process thereof on the hull, and providing data for structure diagnosis analysis. Main external loads on the hull include wave load, impact or explosion impact load and wind load. When the wave impacts bow flare area, the ship acceleration can be mutated. Vibration monitoring of the impact loads is beneficial for providing theory basis for hull structure response analysis and safety reliability assessment.

5.5 System remote alarm
Intelligent data processing gateway not only has data acquisition and transmission functions, also has the functions of ship safety status information threshold setting and remote alarm functions. Intelligent data processing algorithms are embedded in the gateway. The monitored ship stress and vibration value are judged.

When the value is higher than certain value, the alarm information and ship position information can be sent through maritime satellite network or GPRS wireless network, thereby requesting support.

6 Summaries
In this paper, design ideas, system composition and functions, monitoring point layout plan and other aspects of ship health monitoring system based on IOT technology are discussed. It has certain guidance significance for developing the ship health monitoring system. Meanwhile, it also provides certain reference basis for safe navigation of the ship.

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