Disseminated and Redundant Design of Ship Monitoring and Control Network

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Abstract:
The modern integrated monitoring system of ships plays an important role intelligent control and systematic management to the instruments and equipments are integrated both on bridge and in engine room in ship automation. The design scheme of the ship integrated monitoring and operating system based on two layers distributed and redundant computer network was presented in this paper. The distributed schemes are fully applied to both software and hardware. The composition, software distribution and redundant technology in the upper local network were described, some important sample codes was given to prove the design and can be realized. The technologies here can be applied in the other industrial fields.

Keywords: *Distribution, Redundancy, Ship Monitoring and Operating, Network*

1. Introduction

The automation level in a ship usually represents how advanced the ship is. Today ship automation comes into a new epoch; it integrates the monitoring, operating and management functions for all equipments in a ship into one system by the network technology [1]. There have been many products for this purpose. For example, Data Chief C20 of Konsberg of Norway, Sea-Net of Sperry of America, Master Bridge III of CS of Italy and Stella Net of Lyngso of Denmark. However, distributed and redundant design and the upper PC network design in the system are unavailable for all of these products.

We have developed an integrated system with an advanced field networks and a management computer network with high reliability, efficiency, intelligence and configurability. Here we present the topology structure of the whole system in figure 1. In this system, microcomputers collect running statuses or signals of navigation instruments, engine equipments and etc. [2], send to field industrial PCs mainly by CAN field bus and broadcast to the monitoring and operating computers by the programs which are made by Microsoft Visual C++6.0. The monitoring and operating computers are capable of displaying primary operation parameters clearly and graphically with characters, tables, curves and graphs in order to provide the men on duty with the real-time data for guidance of operation and maintenance. The men on duty can get the authority to operate the corresponding equipments on the monitoring and operating computers by login with a specific password. [3] The command data of the operation is sent to the field industrial PCs immediately by the monitoring and operating computers, then the field industrial PCs send the command data into the correct units by field buses.

2. The Integrated Ship Operation Monitoring Systems

The modern integrated ship monitoring system is a comprehensive system that monitoring the ship navigational states, the ship operation states, and the external environment, such as the weather, the hydrology, the sea condition, and neighboring ships. It is a complex system that involves many technologies, e.g., computer technology, information technology, network technology, sensor technology, automation technology, wireless communication technology, material technology and energy technology, et al. It plays an important role in the ship safety, reliability, economy and energy consumption level [1-5].

This review article describes the detailed characteristics of the integrated monitoring systems of four ships in different sizes and types. These four ships are a 2.7m length small-sized unmanned surface vehicle (USV) [6], a 57m length medium-sized floating crane [7, 8], a 59.5m length medium-sized geotextiles-laying vessel [9, 10] and an 112m length large-sized patrol ship [11].

The common features of these four ship monitoring systems are all having a network topology of double layer structure, where the bottom layer consists of a field bus network, and the top layer is an Ethernet network [1]. The bottom layer is generally responsible for real time ship data acquisition, and the top layer is chiefly used for ship control and management.

The following explains the integrated monitoring systems of these four ships in sequence of sizes from small to large.

3. The Integrated Ship Operation Monitoring Systems

3.1 A Small-sized Unmanned Surface Vehicle

Recently, a small autonomous USV is developed in Shanghai Maritime University. This USV has a length of 2.7m, a beam of 1.5m, a dead weight of 97kg, and a maximum speed of 6 knots [6]. It can communicate with its mother ship wirelessly, and complete the ocean observation task with its onboard instruments in the water area where its large-sized mother ship could not reach.

A notable feature of the USV topology is its double layer network structure [1]. The bottom layer consists of a field bus network and the top layer is an Ethernet network,The bottom layer is primarily responsible for real time USV data acquisition, and the top layer is with responsibility for USV control.

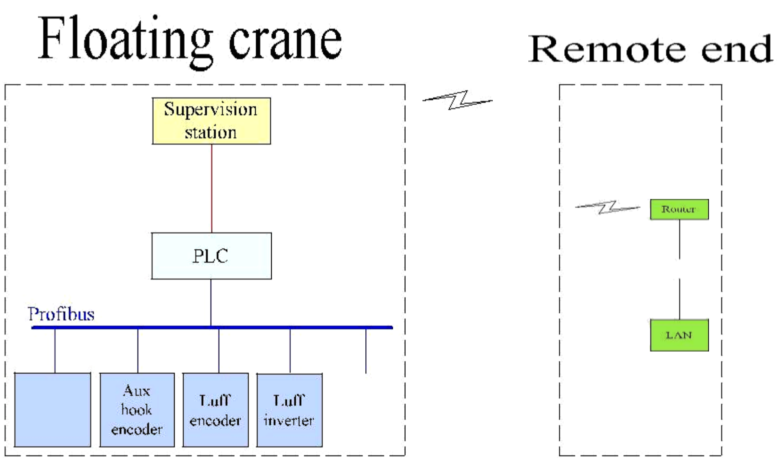

Fig. 1 The topology of the floating crane monitoring system

Ethernet is widely used for ship electrical automation system recently for its high speed, good expansibility and wide vendors support.

The field bus network in the bottom layer divides into two parts, one is the PLC module, and the other is Controller2 module. This design framework conforms to the modularization idea and the risk diversification principle. These two modules are independent, and if one is failed, the other will not be influenced and thus the reliability of the whole system is improved.

The programmable logic controller (PLC) controls the left and right propellers and acquires the state information of these two propellers by a Profibus. Controller2 gets the signals from a bathymeter and a current meter by a NMEA0183 bus, and receives the real time images from an infrared camera by a USB bus.

3.2 A Medium-sized Floating Crane

'GangGong QiZhong 1' is a non-self-propelled floating crane ship with full ac variable frequency speed regulator put into operation since 2005. Its dimensions are a 57m length, a 25m beam, a 4.5m molded depth, and a 2.8m draft. Its maximum permitted load is 500T. Its lifting control system

3.3 A Medium-sized Geotextiles-laying Vessel

A geotextiles-laying vessel is an engineering ship that lays geotextiles, such as a sand soft nappe, a sand bags and concrete interlock soft nappe, on soft foundation (seabed, riverbed, dam slope) to improve the waterway navigation capability and to protect the dam slope from damage [9, 10]. "Yu GongPai 1" is a geotextiles-laying vessel belonging to Yangtze Chongqing Waterway Engineering Bureau that is brought to use in 2003. It is a non-self-propelled ship and its geometry is a 59.5m length, an 18m beam, a 3.2m molded depth, and a 2m draft.

The integrated monitoring system of "Yu GongPai 1" has four functions, geotextiles-laying control, operation monitoring, fault alarm, and data management.

The procedure of geotextiles-laying control is, guided by the scheduled project, first to prepare the sand soft nappe, and then to compute and control the speed and direction of the drum, the deploying and retracting speed of six anchor windlasses and the laying depth of the slide taking into account the nappe length, water depth, underwater topography, current and wind, finally to lay the nappe on the riverbed according to the predefined path.

3.4 A Large-sized Patrol Ship

"Hai Xun 31" is a three thousand-tonnage patrol vessel equipped with a ship helicopter platform. It has a total length of 112m, a module width of 13.8m, and a sailing speed of 22 knots. It is belonging to Maritime Affairs Bureau of Ministry of Communication and is responsive for the patrol on South China Sea, the marine security supervision, the investigation of marine traffic accident, the monitoring of sea pollution, and the marine search and rescue. The main function of the integrated monitoring system of "Hai Xun 31" is data acquisition and display of the onboard device, office automation, optical signals transmission and display, TV monitoring, satellite communication, and routine ship management [11].

The topology of the patrol ship monitoring system. The monitoring system consists of two parts, one is the ship system and the other is the remote end system that communicates with the patrol ship by a wireless Inmarsat satellite channel.

3.5 Other marine structures

The double layer network topology of the ship monitoring system is easy to expand and widely used in other industrials, e.g., a complex monitoring system of Three Gorges ship lock [12]. Liu et al. has reported that former isolated 192 dock container cranes distributed on 1000m^2 are connected together based on the Ethernet centered double layer monitoring topology to facilitate the integrated control and supervision [13].

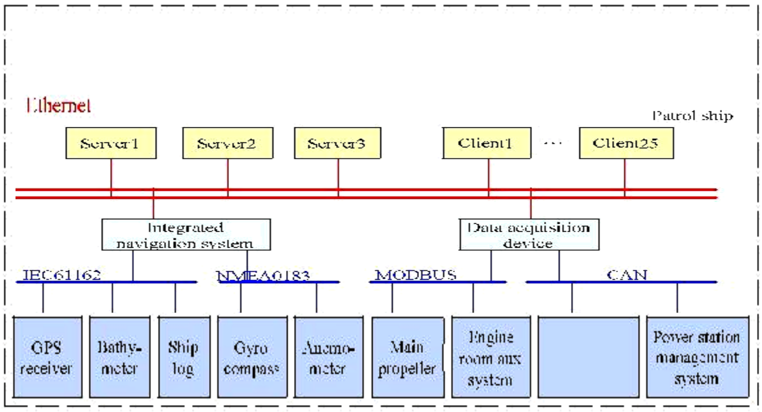

Fig. 2 The topology of the patrol ship monitoring system

3. Composition of the System and Distribution of Software

The whole monitoring and operating system is a large real-time network. It consists of 2 redundant severs, 5 field industrial PCs and more than 4 monitoring and operating computers. The whole network of system can be separated into two layers according to its structure. The lower layer called field bus network includes CAN, RS-485, RS-232, Industrial Ethernet bus and PLC specific bus and so on, which collects the data of engine instruments and bridge equipments. The upper one called PC network is made up of double-loop redundant fast Ethernet network, double redundant field industrial PCs and monitoring and operating computers. Winsock API is used for ensuring the real-time response to the system. Distributed schemes in both software and hardware are used for high maintenance and diagnosis. Distributed and redundant technologies are used for high reliability. Many measures and mechanisms are taken to enhance performance. For example, login by password to get operational authority

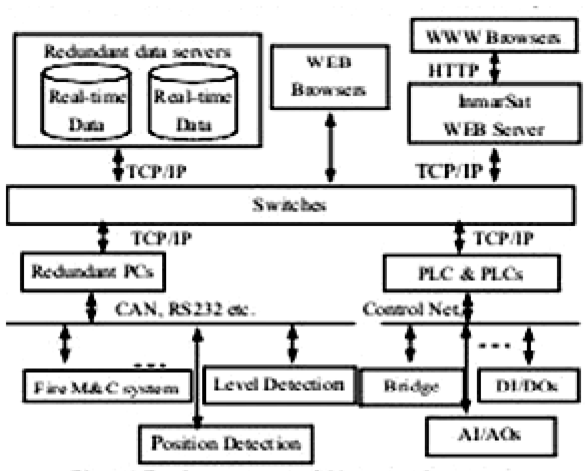

Fig. 3 Topology structure of ship automation system

automatically and separately backing up the running data by Microsoft SQL Server 2000, the integrated monitoring and operating system of UPSes, real-time display of running situations of network and statuses of the command implementation, the display and handling of failures by classification, independent design based on main function module, and data saving and backup by isolated process. The software distribution and redundant designs.

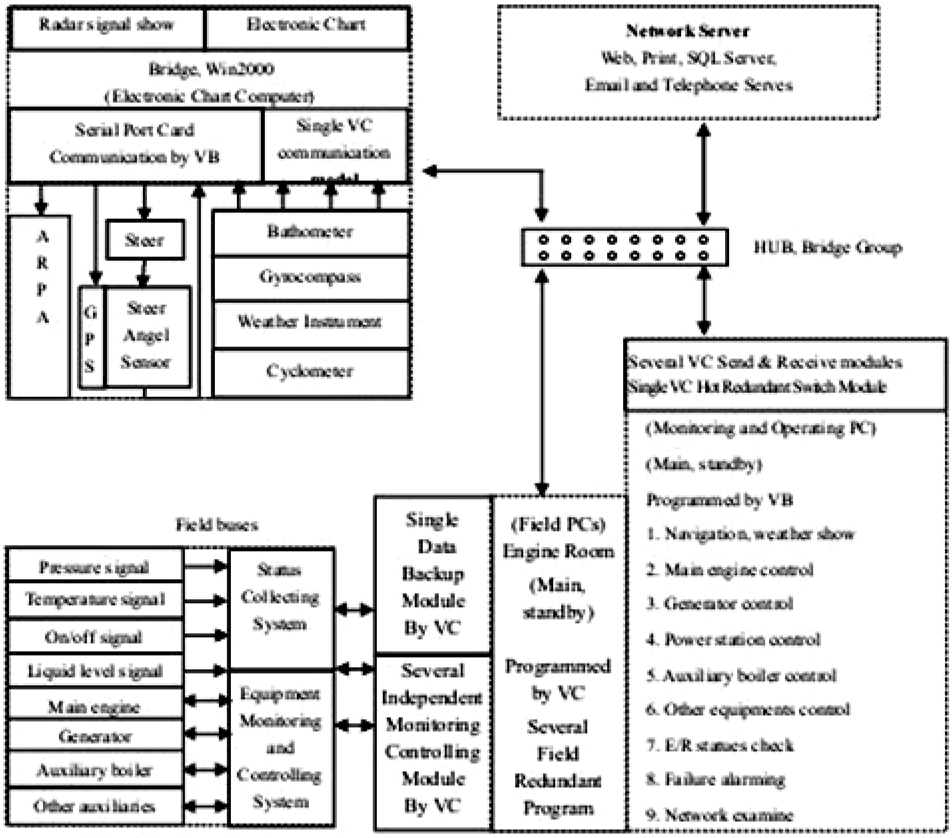

Fig. 4 Software distributed structure in the system

Two monitoring and operating PCs which locate on bridge and in engine room respectively can be redundant each other by configuring a text file manually. At the running time, the main or active PC can get control authority; the standby or inactive PC can only play a monitoring role. Once some failures occur in the active PC, the redundant program can be triggered immediately to switch the active PCs into inactive ones and the inactive PCs into the active ones. Other rooms such as engineer rooms or officer rooms are usually installed only one PC, which has no operational function until it logs in by specific password. In the whole system, there is only one PC to have control authority at a same time.

In order to interchange information with the lower field equipments such as monitoring and control units of main engine, generators, auxiliary boilers, motors and such on, to communicate with the upper network by TCP/IP protocol, judge control authority and save the data, the two redundant field industrial PCs are stationed in the engineer control room and auxiliary engineer room respectively. In more than four field industrial PCs, only one active PC can determine whether the logged user get authority to operate the system or not. All independent application programs can be redundant between the two redundant field industrial PCs, the switches between active or inactive status and vice versa can be triggered in real time.

The field industrial PC on bridge plays the role of collecting data, planning course, showing sailing trail, controlling the trail and etc. The typical navigation instruments and sensors for collecting data are shown as follows: one ARPA (raster scan) Radar providing with target-tracking and sailing route data, GPS providing with ship position, sailing speed, time mark and so on, an electronic Gyrocompass providing with the direction of the ship's head, a bathometer providing with water depth, a cyclometer providing with ship speed, a weather instrument providing with wind speed and direction, a computer with sea chart providing with electronic chart, which is used for collecting information from navigation instruments, show the electronic sea chart and broadcast the information on Ethernet. It can show the position, sailing direction and speed of the ship on the screen, design route line, show the executive situation of the sail plan in real time, plan the time of reaching the turning points and calculate all sailing geometries including the direction and position of sail line segment, voyage, tracking error, distance between the current ship position and the next turning point, and calculate the time of reaching the next point.

Every main monitored object in the system has an independent application program and communication interface which is installed in field industrial PCs in engine room. The programs for receiving and sending data by network are developed in the monitoring and operating computers and interfaced with the monitoring and operating programs in COM DLL type. A server installed with Microsoft SQL Server 2000 is stationed on bridge for saving and querying important operational data. A special program is developed to back up all data if necessary. Another special program is developed to classify, query and print data.

4. Field Control Redundancy

Five independent Visual C++6.0 programs in the field industrial PCs in engine room are developed to monitor main engine, powers, auxiliary boilers, statuses of engine room, and switch between the main and standby PCs respectively. In the same control workstation, programs running in the two redundant field industrial PCs can switch individually. Some signal detection programs can communicate with field equipments by CAN bus to monitor and control main engine, auxiliary boilers and statuses of engine room, another programs can communicate with field equipments by RS-485 to monitor and control powers and generators. Field industrial PCs with simple HMI make full use of Winsock API to transfer data to broadcast on network and provide real-time field information to the monitoring and operating PCs by point-to-point mode.

The switch programs between the main and standby field industrial PCs make full use of memory-mapping file to communicate with the other processes in the computers and control them to start, show, hide, quit and switch. This mode permits keeping a block of virtual memory where the object files are mapped, which is called many processes share the same memory. Here every process in memory block uses the same segment of program codes. The shared virtual memory for processes are started at an address of 0XFFFFFFFFF, named “My Shared Memory” with length of 256 bytes to realize status controls and information communications from the switch process between the main and standby to others. The first 128 bytes are used for saving statuses of every monitoring and operating process, every application program takes up a continuous 16 bytes, the first three bits of the first byte are used for showing statuses of start, switch between the main and standby field industrial PCs, and the switch, the second byte is used for watchdog's count; from the128th byte to the 223rd byte are used for saving control information, every continuous 8 bytes are called control information area of application programs, the first three bits of the first byte are used for saving the information about application programs' quit, hide, show. The switches to hardware equipments are decided by the bytes from the second to the fifth, CAN adapter must start working as soon as switched into main status, on the contrary, CAN adapter must stop working as soon as switched into standby status.

In this system, this procedure to create shared memory for processes is as follows. First, try to open a memory-mapping file named "My Shared Memory" with API function "OpenFileMapping". If fails, it demonstrates that the memory-mapping file is not created, we need to create a new one with the same name and the length of 256bytes by the function "CreateFileMapping". In the result, many processes in the computer can use the same segment of codes but only one shared memory is created. After the memory-mapping file is created or opened, the function, "MapViewOfFile", is used for mapping it to this process' address room to access shared data, and the usual measure is taken for reading data from this memory and writing into it, the operation result is visible to the other processes. The specific codes for creating shared memory are as follows:

```
#include "StdAfx.h"
#define HSHAREDMEM (HANDLE)0xFFFFFFFF
HANDLE hMapFile;
LPVOID g_pcDispMem;
hMapFile = OpenFileMapping(FILE_MAP_WRITE,FALSE,"My Shared Memeory");
if (hMapFile == NULL) {
    hMapFile = CreateFileMapping(HSHAREDMEM,NULL,PAGE_READWRITE,0,256, "My Shared Memeory");
    if (hMapFile == NULL) {AfxMessageBox("Could not create file-mapping object.");
        return NULL;}
}
g_pcDispMem =MapViewOfFile(hMapFile,FILE_MAP_ALL_ACCESS,0,0,0);
if (g_pcDispMem == NULL) { AfxMessageBox("Could not map view of file."); return NULL;}
```

All switch programs between main and standby PCs and other monitoring and operating processes use the codes like that to create or open the shared memory-mapping file and create mapping object view. These processes include quit, hide and show events. Reading and writing data by using this object view can control every process's operations in this computer.
Attention: At the end of process, the function, "UnmapViewOfFile", must be used for canceling the view of address room; the function, "CloseHandle", must be used for releasing the memory-mapping file as follows:

If(!UnmapViewOfFile(g_pcDispMem)) AfxMessageBox("could not unmap view of file");

CloseHandle(hMapFile);

The switch between main and standby field industrial PCs is implemented by Winsock API. The concrete information to be transmitted on the network is the status of the main and standby, start or stop, switch, watchdog count, priority and etc.

5. Monitoring and Operating Redundancy

The monitoring and operating programs are installed in the monitoring and control PCs on bridge, in engine rooms, engineer rooms and the other public occasions. All programs in the PCs are developed by VC++6.0 and VB6.0, VC++6.0 is used for implementing sending and receiving the information of main engine, generators, powers, auxiliary boilers, the statuses of engine rooms and switch between the main and standby PCs. The human-machine interfaces are programmed byVB6.0, which combines with the programs by VC++6.0 in COM DLL type based on event-driven mechanism.

The main and standby redundancy is implemented by point-to-point communicational mode. The information interchanges between the two redundant monitoring and operating PCs at period. The main PC sends the status of running or stopping, main or standby, and the time which the current statuses is started at period to the standby PC using the running status sent function. After receiving this information, the standby PC responses to the main one by call of a function with the same codes. In the event of the two redundant PCs are both in main or standby status at the same time, the start time is necessary to make the judgment of which one is set to main status, The one who starts up first will be set in the main status and the other is set in the standby status. The PC in main status can also be set to standby status manually. If does so, a request would be sent to the original standby PC to be set to main status. When some monitoring and operating programs are quitted, the quit information will be sent to the other computers. If receiver is not in main status, it will be switched into the main status.

6. Network Redundancies and Database Redundancy

The whole network redundancy includes the lower layer field network redundancy and the upper layer computer network redundancy, the two layers network are both designed in double-loop redundancy. Detect and control units of equipments are linked into the main and the standby field industrial PCs by CAN, RS-485 or RS-232, whether the PC adapter or interface work or not depends on the main or standby status of its relevant application programs. For example, in the field industrial PCs, if an application program communicate with the field units by CAN and the CAN adapter's application program in main status, the CAN adapter is opened to receive or send data, the other CAN adapter is closed to stop working. Special network hot backup software, server, switch, double-loop Ethernet and intelligent network adapter are adopted to improve network redundancy and reliability.

In this system, a local Access 7.0 database is set up in all field PCs to save system structure information and initialize the objects and data variables at the beginning of program running. Special programs are developed to ensure the local databases renovated when the server databases changed, therefore this system equals to a distribute database system with good reliability and independency.

In order to reduce data connections and network loads and to increase reliability and independency, a single process is developed to backup and save data. The operation which the other processes point to the database sever must use this model. Communication between the backup and saving data process and the other processes takes use of WM_COPYDATA message. The function SendMessage here is used to solve the question that Windows can't provide synchronic succession mode. The grammar of this function is "SendMessage(hwnd,WM_COPYDATA, wParam, lParam)", The parameter of wParam includes the handle of data windows. The parameter of lparam points to the structure of COPYDATASTRUCT.

Data backup and saving process has data connection to database in server, provides an interface to writing real-time records, which avoids breaking down of the whole system in event of errors from connection to database. The mechanism improves reliability further.

7. Conclusion

This ship monitoring and operating system presented in the paper is a large integrated computer network system. It makes full use of control[2], computer, communication and electronic technology to make any computers on the network have monitoring and operating function. A high real-time performance is achieved by communication technologies among processes and in networks, various techniques in software and hardware are used for improving the reliability. For instance, distributed structure is used in software and hardware design, which means when parts of the system are failed or stopped, the other parts can still work. In addition, failure alarming of software, network, equipment and etc. is handled in detail. While any failure occurs, the type, position, description and classification will be reported to improve the system maintenance and diagnosis. This system has been completed successfully in laboratory environment. The command executed time is less than 50 milliseconds. The data fresh period is less than 500 milliseconds. The good performances are full shown as this paper described. Many techniques of software and hardware developed here have been applied successfully in several large projects on land.

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