Distributed Ship Navigation Control System Based on Dual Network

Ying Yao and Wu Lv
Systems Engineering Research Institute, China State Shipbuilding Corporation, Beijing, China
Email: baeng@163.com, lw_all@126.com

Abstract. Navigation system is very important for ship’s normal running. There are a lot of devices and sensors in the navigation system to guarantee ship’s regular work. In the past, these devices and sensors were usually connected via CAN bus for high performance and reliability. However, as the development of related devices and sensors, the navigation system also needs the ability of high information throughput and remote data sharing. To meet these new requirements, we propose the communication method based on dual network which contains CAN bus and industrial Ethernet. Also, we import multiple distributed control terminals with cooperative strategy based on the idea of synchronizing the status by multicasting UDP message contained operation timestamp to make the system more efficient and reliable.

1 Introduction
In ship navigation system, there are many different devices and sensors responsible for collecting information, computing data, sending, receiving and executing the command. These sensors and devices are usually connected via CAN bus. This scheme is related to the system demand and the development of early technique at that time. As the development of communication technology, it is possible to network the sensors and devices via Ethernet. Under this background, we propose the dual communication network as the data transmission channel in navigation system. CAN bus and Ethernet coexist in the dual communication network. All devices and sensors will be connected via Ethernet. At the same time, some of them will also be connected to CAN bus. In dual communication network, the CAN bus is used as the redundant backups to ensure the data integrity and reliability [1]. The reliability of the system is guaranteed while bringing in the new technology to promote the development of the ship navigation system.

To make full use of the dual communication network, provide comprehensive navigation information for the system devices and make the users know the status of the system in real time, we import the integrated management device to collect the navigation information from CAN bus and Ethernet. After processing the raw information, data will be sent to the certain device to confirm that these devices can obtain all needed information. Also, administrators can use the integrated management devices to send the control command via dual communication network to the devices and sensors. The devices and sensors receive the control command, adjust the working status and report the related information to the integrated management devices.

The control commands can be divided into ordinary commands and important commands. The important commands should be sent by the integrated management device with authority. Deploying more than one integrated management device can make the system more flexible and reliable. To make the control operation correct and effective, especially for the important commands, the navigation
system needs some kind of status synchronization strategy. The strategy must guarantee that no more than one integrated management device can send the important commands at any time.

In common situation, any integrated management device can send the ordinary command. For the important command, one integrated management device must lock the control authority. The locked control authority can be canceled by any other integrated management device in the system after verifying operation permission. The integrated management device that cancels the locked authority can also get the authority at the same time. When the control authority is locked, any other integrated management device can emit the ordinary command, but only the authorized one can emit the important command.

To achieve the basic scheme mentioned above, all integrated management devices must exchange some message based on TCP or UDP protocol to synchronize the working status. The synchronization message should be sent at a high frequency to confirm the effectiveness and real-time property. And the message from one terminal should be received by all the other terminals in the communication group. According to the above reasons, UDP protocol is more suitable for the status synchronization of multiple integrated management devices [2].

However, each integrated management device simply multicasts the UDP message with status information may lead to some mistakes in the synchronization process. There may be some problems in the situation of exchanging the operation authority among two integrated management devices. To solve this problem, we add the operation timestamp that represents the execution time of each operation into the synchronization UDP message. The integrated management devices receive two UDP messages with mutually-exclusive operation message can compare the operation timestamp in the messages to determine which one is valid.

In this paper, we introduce the dual communication network in Section II. Then in Section III, we introduce the conflicted problem in the process of synchronization while simply multicasting the UDP message. Also, the cooperative strategy of multiple integrated management devices based on operation timestamp is introduced in this section. Furthermore, the evaluation is shown in Section IV, and a conclusion is followed in Section V.

2 Dual Communication Network
In this section, there is a simple description and comparison of CAN bus and Ethernet to explicit the advantages and disadvantages of each other and describe the characteristics of dual communication network.

CAN bus is a kind of serial communication network which can efficiently support the distributed or real-time control [3]. It is a kind of multiple master bus which is widely used in industrial automation, ship, medical device and industrial device for its features of high performance and reliability in communication. CAN bus has a lot of advantages [4]. First, the coding scheme of CAN bus is data encoding. Multiple kinds of transmission method can be realized based on packet filtering. Second, CAN bus has the functionality of priority and arbitration, multiple control terminals can connect to the CAN bus and realize the functionality of multi-host in local network. Third, the CAN message adopts a short frame structure. The disturbed probability is very low as the transmission time of a message is short. In this way, the error ratio of CAN message is very small. Finally, when the communication node has something terribly wrong, it can disconnect from the CAN bus by itself. Except the advantages mentioned above, CAN bus also has some disadvantages. First, CAN bus cannot connect to the Internet. It is impossible to realize the remote information sharing. Second, it is difficult to connect with the normal computer directly. The related device is much more expensive than the ordinary NIC (Network Interface Card). Third, comparing to the industrial Ethernet, the communication distance and information throughput rate of CAN bus is lower.

The Ethernet based on TCP/IP is a kind of standard open network. The compatibility and interoperability of the information system based on Ethernet is much better [5]. Also, the information sharing ability is better [6]. And it is easy to realize the sharing of control data and resources in the system. Furthermore, the transmission distance of industrial Ethernet is long. The transmission rate is high [7]. Adopting the industrial Ethernet can networking the devices in the system at a low cost. The computers and servers can be connected via the original interface. And the industrial Ethernet has
received extensive technical support in recent years. Certainly, the industrial Ethernet also has some disadvantage. It is a kind of non-deterministic network system. There is certain reduction in the reliability of Ethernet [8], especially in the extreme environment.

Based on the above analysis, either CAN bus or industrial Ethernet respectively has its own advantages, disadvantages and applied range. Each one has its own application field of comparative advantage. They will coexist for a long time. However, the development of CAN bus has entered a bottleneck. There are some limitations in the interconnect among each bus. After years of practical application, the developers have gained rich experience about the designation and application of the Ethernet. The cost of developing and application is relatively low. Importing both CAN bus and Ethernet into ship navigation system is consistent with the development trend of technology and the new demand of the system. Utilizing the advantages of real-time and stability of CAN bus can ensure the functionality with high demand of instantaneity and certainty work correctly and effectively. For the application scenario with large data and relatively low demand of instantaneity, the industrial Ethernet is much more suitable. Utilizing the CAN bus and Ethernet simultaneously can ensure the system meet multiple functional and performance requirements.

Connecting the functional devices and sensors via CAN bus and Ethernet simultaneously partly increases the deployment difficulty and complexity. Also, the redundancy of data transmission is raised. However, using two ways to do the system connection can make the data reliability further improved. Data transmitted via different channels can be used for cross validation. In this way, the abnormalities of devices or sensors in the system could be discovered timely. Extending the system data transmission by importing the Ethernet can improve the data richness in the system. Each functional device can obtain more information. The functionality of the navigation system will also be enriched. In addition, as the continuous development of storage technology and the improvement of the computer hardware, the navigation system can store the redundant data for a long period of time. Analyzing these data is useful for adjusting the overall system situation in the future and improving the reliability and usability.

In general, adding the Ethernet to connect the devices and sensors is in line with the technology development trend [9][10]. Reserving the CAN bus connection of some devices and sensors is helpful to make the system more reliable. Coexisting of CAN bus and Ethernet can help to build the reliable ship navigation system with the functionality of network connection. The example scenario of dual communication network is shown in Figure. 1.

![Figure 1. Example scenario of dual communication network](image)

3 The Cooperative Strategy

The dual communication network can make the system more flexible and effective. Multiple integrated management devices can further enhance the reliability and flexibility. To ensure that multiple integrated management devices work correctly, some kind of authority synchronization method is needed. However, some synchronization strategy may lead to the conflicted problem in the system.

3.1 The Conflicted Problem

The simplest way to exchange authority among multiple integrated management devices is to let the one with authority to transfer the operation permission to another one. This way is easy to realize without complicated scheme to synchronize the authority status among the integrated management
devices. However, this scheme is not flexible enough as the authority unlock operation must be done at specific integrated management device during some period of time. Allowing the other integrated management devices to unlock the authority by some kind of authentication is much more convenient as it is possible for someone who is far away from the integrated management device with authority to directly finish the operation without leaving current using one.

To achieve the functionality of authority remote unlocking, we add some authentication information in the synchronization UDP message multicast by the integrated management device with authority. Other integrated management devices receive this UDP message and record the authentication information in local storage. The operator must enter the correct information to match the authentication information before changing the authority status.

![Failed scenario of simplest strategy](image1)

**Figure 2** Failed scenario of simplest strategy

![Failed scenario of strategy with ordinary timestamp](image2)

**Figure 3** Failed scenario of strategy with ordinary timestamp.

The designation above seems like to make the system work flexibly and correctly. However, there may be some mistakes caused by the tiny time delay in the transmission and processing of the UDP message [11]. After the operator passes the authentication and transfers the authority from original integrated management device to a new one, the later one will multicast the UDP message with authentication and authority information. However, there may be something wrong in the synchronization procession. The example scenario is shown in Figure 2. The later one might receive the UDP message with authority information from the original one just after emitting its own UDP message with authority information. Then the later one would unlock the authority and believe that the authority is locked by another one. The same situation might happen on the former one again. The status synchronization of two integrated management devices is wrong. Each one would think the authority is locked by the other one. Then they will send the UDP message without authority information. The authority is unlocked. None of the integrated management devices owns the authority. No one can emit the important command. And anyone can lock the authority.
For the problem mentioned above, someone might argue that adding the timestamp information into the UDP message would be helpful to solve the problem. The UDP message with authority whose timestamp is newer will be seen as valid. However, the simple message generated timestamp may not always be useful for the tiny delay between generating and arriving of the UDP message. And the synchronization may not be successful. The example situation is shown in Figure. 3. In the example, the timestamp information in the UDP message with authority information from the integrated management device without authority is smaller than that in the UDP message with authority form one with authority. The authority status would not change.

Someone might think that collecting the delay information and introducing it into the process of synchronization might be helpful. However, the delay consists of transmission delay and propagation delay. The transmission delay is not easy to calculate as the practical situation may always change. The delay is not very specific. Also, the processing of the UDP message is not completely real-time. The synchronization based on delay information will be very complicated.

3.2 The Cooperative Strategy
The insufficiency of ordinary timestamp is that it increases as time goes on. To make the status synchronization among multiple integrated management devices correct and efficient, we propose the cooperative strategy based on the operation timestamp. Different with the ordinary timestamp which is dynamic refreshing, the operation timestamp represents the execution time of each operation recorded in each UDP message. It is stable without refreshing as time goes on. And the operation in the UDP message whose operation timestamp is larger will be seen as valid.

Importing the operation timestamp is very helpful to solve the problem in the process of synchronization mentioned in last subsection. When the integrated management device locks the authority, it records the operation timestamp. Then the UDP message with authority information from this integrated management device will carry the operation timestamp information. When another integrated management device wants to get the authority, it records the operation timestamp after passing the authentication and sends out the UDP message with authority information and operation timestamp. The former integrated management device receives the UDP message from another one. The operation timestamp in newly received UDP message is larger. Then the former one will multicast the UDP message without authority information. Even if the later one received the UDP message with authority information from the former one, the authority synchronization would not be failed as the operation timestamp in the UDP message from the former one is smaller than that recorded locally.

Besides solving the conflicted problem, importing the operation timestamp into the UDP message has some other benefits in some special situations. In the navigation system, if the message from one device or sensor was not heard for a period of time, the device could be seen as disconnected from the communication network. And if one device did not hear any message from any device or sensor, it would see itself as disconnected. When the integrated management device with authority is disconnected, the authority will be unlocked and any other integrated management device can lock the authority. In the special situation, the disconnected integrated management device might be reconnected. The authority might be locked by another one during the time when the original authorized integrated management device was disconnected. The reconnected one would multicast its own UDP message. If it received the UDP message with authority information before multicasting its own, then it would multicast the UDP message without the authority information. If not, it would multicast the UDP message with authority information until receiving the UDP message from another one with authority information. Even if it multicast the UDP message with authority information, there would be nothing wrong in the status synchronization as the operation timestamp from the original one is smaller comparing with the operation timestamp in the later one.

4 Evaluation
We carry out some simulating experiments to demonstrate the effectiveness of the cooperative strategy that solves the problem in the process of synchronization by importing operation timestamp into the UDP message. In the simulated experiments, there are some integrated management devices. One integrated management device is chosen to have the control authority. Then another one is chosen to get
the authority from the former one. The simulated experiments mainly calculate the ratio of successful authority transmission in the scenario with different strategy, including strategy without timestamp, strategy with ordinary dynamically refreshing timestamp and strategy with stable operation strategy.

Based on the content in last section, both strategy without timestamp and with ordinary timestamp cannot solve the conflicted problem. The probability of successful authority transmission is mainly related to the sending time of UDP message and the communication delay. The failed scenario of strategy without timestamp and strategy with ordinary timestamp is shown in the grey zone in Figure. 4 and Figure. 5.

![Figure 4. Failed situation in strategy without timestamp.](image1)

![Figure 5. Failed situation in strategy with ordinary timestamp.](image2)

We use $T_f$, $T_t$ and $T_d$ to respectively represent the sending time of UDP message on the integrated management device with authority, the sending time of UDP message on the integrated management device requesting authority and the communication delay between these two devices. It is shown in Figure. 4, in the strategy without timestamp, if these three variables meet the conditions in Eq. (1), the authority synchronization will be failed.

$$T_f - T_d < T_t < T_f + T_d$$

(1)

It is shown in Figure 5, in the strategy with ordinary timestamp, if these three variables meet the conditions in Eq. (2), the authority synchronization will be failed.

$$T_f - T_d < T_t < T_f$$

(2)

Based on Eq. (1) and Eq. (2), the result of synchronization operation could be judged from the sending time of UDP message on the integrated management devices with authority and requesting authority, and the communication delay between these two devices.

In each group of experiments, the number of integrated management device is different. The synchronization cycle is 1 second. And the sending time of UDP message is set randomly between 0
and 1000 milliseconds. And the delay between two integrated management devices is set randomly in a certain scope. The scope is related to the number of integrated management device. The bigger the number is, the larger the scope is. The experiment with certain number of integrated management device is repeated for many times to calculate the average ratio of successful authority transmission. The random seed is different in each experiment.

The experiment result is shown in Figure 6. It is shown in the picture that the operation successful rate of strategy with operation timestamp is the highest. And the operation successful rate of strategy without timestamp is the lowest. Also, as the random scope of delay between two integrated management devices increases, the operation successful rate gets lower in the experiment with ordinary timestamp and without timestamp.

The navigation system is vital to the normal sailing of a ship. There should not be anything wrong in the authority management of navigation system. From such a perspective, the cooperative strategy with operation timestamp is very suitable for the authority management among multiple integrated management devices in the navigation system.

5 Conclusion
This paper describes the distributed ship navigation control system based on dual communication network which contains the CAN bus and Ethernet. The distributed multiple integrated management devices are introduced to make the system efficient. However, the authority management among these devices faces a conflicted problem which might lead the authority synchronization failed. To solve the conflicted problem and make the authority management among distributed multiple integrated management devices correct and effective, we introduce a kind of cooperative strategy by importing the operation timestamp information into the UDP message. The proposed strategy is easy to realize and effective enough.

6 References
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