Design of Intelligent Security Management and Control System for a Large Nuclear Facility

MingGuo¹, FeiWu¹* and Mohan Wang²

¹ College of Nuclear Science and Technology, Naval University of Engineering, Wuhan Hubei, 430033, China
² Wuhan Shipbuilding Institute, Wuhan Hubei, 430050, China

*Corresponding author’s e-mail: theone1999@163.com

Abstract. There are many kinds of safety control sub-systems of a large nuclear facility, and their information is isolated from each other, so the overall safety control efficiency is low. To solve this problem, based on the original security control sub-system, an intelligent security management and control system is designed by using the technology of system integration and multi-sensor cooperative scheduling. Firstly, the web service interfaces of each security control sub-system are developed, and the interconnection and information sharing of each security control sub-system are realized through these interfaces. Then, based on the multi-sensor system cooperative optimization scheduling technology and the improved ant colony algorithm, the information synthesis and security cooperative optimization scheduling of heterogeneous multi-sensor messages are realized. The highly integrated intelligent security management and control system reduces the alarm omission rate and false alarm rate of the safety control and improves the efficiency of the security control.

1. Introduction
Large nuclear facilities occupy a large area and have many technical support personnel. And high environmental protection conditions and strict safety management requirements are necessary. In order to ensure their nuclear safety, many online management and control systems have been built. However, these systems are relatively independent, so that information resources cannot be shared, and the security effect from point to surface cannot be achieved. Therefore, it is difficult to realize the comprehensive management and control of the overall situation of the large nuclear facilities. On the basis of the existing hardware resources, the comprehensive use of system integration, multi-source information fusion and other technologies can realize the intelligent integration of security management and control system, so as to realize the information sharing and collaborative control among the online security management and control systems. After intelligent integration, the online safety management and control systems are integrated into a complete security system, and the integration and automation degree of the whole safety management and control system can also be significantly improved [1-2].

A large nuclear facility has stored nuclear materials and equipment. In order to ensure its safety, the nuclear facility is equipped with several independent security control sub-systems, such as video surveillance system, access control system, personnel partition control system, intrusion alarm system, command and dispatch system, fire alarm system, equipment monitoring system, etc. However, these security management and control systems, which are generally produced by different manufacturers, only aim at a certain aspect of the security control of nuclear facilities. Moreover, these systems are
relatively independent from each other, and the security control information of these systems cannot be shared with each other. Therefore, the unified and coordinated scheduling of various security management and control systems cannot be realized from the perspective of the whole, which makes the security control efficiency of large nuclear facilities low in general, and it is easy to cause missed or false alarms.

With the rapid development of computer technology and the continuous emergence of intelligent computing technology, multi-sensor system optimization scheduling technology has become an important technology to solve the multi-system coordination and linkage. The key of multi-system collaborative scheduling optimization problem is to establish the mathematical model and solve the algorithm of optimal scheduling under the premise of the unified integration of different types of systems. There are many security control sub-systems of the large nuclear facility, and the standards and specifications of each system construction are not unified. Therefore, the complexity of security control of the whole the large nuclear facility is high. These characteristics make it difficult to model and optimize the coordinated linkage of security management and control system. In recent years, security integration based on bus and network technology [3-8] and collaborative optimization based on artificial intelligence technology [9-12] have received rapid development and high attention. In order to improve the safety of the large nuclear facility and the automation degree of security control, it is necessary to integrate and synergistic optimize the intelligent security management and control system of the large nuclear facility from the perspective of the system as a whole on the basis of the functions of the original security control sub-system. And the security information of each system can be effectively integrated, the rate of missing alarm and false alarm can be reduced, and the precision and efficiency of safety control of the large nuclear facility can be improved.

2. Overall design of intelligent security management and control system
Security information sharing among security management and control sub-systems is the basis for realizing intelligent security management and control of the large nuclear facility. Therefore, first of all, it is necessary to conduct unified integration of each sub-system through software and hardware transformation of each sub-system on the basis of analysis of each security management and control sub-system, so as to realize the interconnection and security information sharing among all sub-systems. Then, on the basis of sub-system integration and multi-sensor and multi-system optimization scheduling technology, information synthesis and collaborative optimization scheduling of heterogeneous multi-sensor and multi-system are realized, and intelligent security management and control of the large nuclear facility are realized. The overall design idea of the intelligent security management and control system is shown in Figure 1.

![Figure 1](image-url)
3. Intelligent security management and control system integration

According to the linkage requirements of security prevention and the requirements of abnormal event alarm, the original security management and control sub-systems, which include video surveillance sub-system, access control management sub-system, personnel partition control sub-system, command and dispatch sub-system, equipment monitoring sub-system, fire alarm sub-system, intrusion monitoring sub-system and radiation monitoring sub-system and so on, are reformed with corresponding hardware and software. After the reformation, all the security management and control sub-systems are connected to the integrated management platform of the command and monitoring center through the network, and security information sharing of each sub-system is realized based on the ESB bus technology.

3.1. Integration of video surveillance sub-system

According to the function, the video surveillance sub-system can be divided into three parts: front end, transmission system and control equipment. In the integration of the video surveillance sub-system, the video signals of the front-end equipment are first connected to the video optical terminal through the video optical cable, and then the video optical terminal sends the signals to the hard disk video recorder for long-distance transmission. Finally, the hard disk video recorder parses the video signals and sends them to the display screen for display through the video switching matrix. The hard disk recorder is the core component of the signal transmission of the whole video system. Therefore, the integrated management platform of the intelligent security control system obtains data through calling the Web service interface of the hard disk recorder, so as to realize the functions of video monitoring, video switching, video playback, pan-head control and so on. Firstly, the camera model is built on 2D and 3D scenes. Then, the parameter matching and control interaction between the camera model and the scene camera are realized. Finally, in 2D and 3D scenes, the functions of real-time video monitoring, pan-head control and video playback can be realized by controlling the camera model.

3.2. Integration of access control monitoring sub-system

The access control monitoring sub-system is mainly composed of hardware such as management server, monitoring management terminal, access control controller, access card reader, exit button, electronic magnetic lock and personnel ID card. The access control controller is the core component of the entire access control monitoring system. All functions of the access control monitoring system can be realized through the access control controller. Therefore, the intelligent security control system can obtain data by calling the Web service interface of the access control controller, so as to realize the functions of door switch status display, remote opening, entry and exit data recording, real-time data statistics of the access control in each area under the two-three-dimensional scene, and parameter setting of the access control controller. Firstly, the access control model is established on 2D and 3D scenes. Then, the match and control interaction between the access control model and the field access control controller are realized. Finally, in 2D and 3D scenes, the access control model in controllable scenes can be used to realize real-time display of door switch state, statistical analysis of regional personnel data, remote access control and other functions.

3.3. Integration of personnel partition control sub-system

The personnel partition management and control system is mainly composed of hardware such as management server, card issuing management terminal, monitoring management terminal, access control controller, access control card reader, integrated computer and personnel ID card. The access control controller is the core component of the whole personnel partition control system. All functions of personnel partition control can be realized through the access control controller. Therefore, the intelligent security control system can obtain data by calling the Web service interface of the access control controller, so as to realize functions such as partition control data recording, real-time access control card information display, real-time access control data statistics of each region in the two-three-dimensional scene, and access control controller parameter setting. Firstly, the partition access control model is established on two - and three - dimensional scenes. Then, the matching and control interaction
between the partition access control model and the field access control controller is realized. Finally, in 2D and 3D scenes, the partitioned access control model in controllable scenes can be used to realize regional personnel data statistical analysis, on-site real-time access card information display, access control controller parameter setting and other functions.

3.4. Intrusion alarm sub-system integration

Intrusion alarm sub-system is mainly composed of monitoring and management terminal, intrusion alarm controller, double discriminator detector, acousto-optic alarm and equipment box anti-disassembly switch and other hardware. The intrusion alarm controller is the core controller of the intrusion alarm system, so the intelligent security control system can obtain data by calling the Web service interface of the intrusion alarm host, and realize the functions of real-time display of alarm signals, recording of alarm data, setting of alarm controller parameters, disarming and other functions. Firstly, alarm detector models are built on 2D and 3D scenes. Then, the matching and control interaction between the alarm detector model and the on-site alarm controller is realized. Finally, in 2D and 3D scenes, functions such as alarm signal positioning and display, alarm data recording, alarm controller parameters setting, deployment and withdrawal can be realized through the alarm detector model in controllable scenes.

3.5. Command sub-scheduling system integration

The host computer of digital program control dispatcher is the central equipment of dispatching system, which can be transferred to the superior dispatching system through the relay line, so as to complete the charging function of uploading and distributing. In order to realize the integration of command and dispatch system, the digital program-controlled scheduling host must be connected to local area network. Firstly, the digital program controlled dispatching host is connected to the local area network system of the large nuclear facility by the program controlled telephone access equipment, and the terminal telephone equipment is paged and controlled by the communication network integration module. The intelligent security control system connects with the digital program control scheduling host through the network, and calls the Web service interface provided by the digital program control scheduling host to obtain data, so as to command and schedule the whole large nuclear facility on the intelligent control platform and ensure the smooth communication of the large nuclear facility.

3.6. Fire alarm sub-system integration

The fire alarm sub-system is mainly composed of centralized fire alarm controller, regional fire alarm controller, manual fire alarm button, fire detector, graphic display terminal and other hardware equipment. The GST-GM9000 graphic display software of the sub-system provides the GSTAPI integrated application programming interface for the third party software. Therefore, the intelligent security management and control system can obtain the data of the fire alarm system by calling the Web service developed based on GSTAPI, so as to realize the function of providing fire alarm, data recording, disarming and other functions in the 2D and 3D scenes.

3.7. Device monitoring sub-system integration

The equipment monitoring sub-system includes three sub-systems: the information system of safety assurance elements of the large nuclear facility, the independent process monitoring system and the facility equipment management system. The information system of safety assurance elements of the large nuclear facility includes ventilation and air conditioning monitoring system, water supply and drainage monitoring system, power monitoring system and temperature and humidity monitoring system. The independent process monitoring system includes radiation monitoring system, special exhaust linkage system, nuclear waste water treatment system, sewage treatment system, filling fire alarm system, remote control system of protective door and air compressor station system. The facilities and equipment management system includes facilities and equipment information management system, facilities and equipment operation management system. In the system integration, the Web service
developed based on OPC communication service is called to access the PLC data and events of the
device monitoring system, so as to obtain the data of the device monitoring system and realize the real-time
monitoring of the device monitoring system.

4. Multi-sensor and multi-system collaborative optimization and scheduling

Through system integration, each independent security control sub-system has been integrated into a
whole security information sharing. However, how to more comprehensive safety monitoring sub-
system of the multi-sensor information effectively, and realize the coordination between each sub-
system and sensor scheduling is an important task of the large nuclear facility safety control system of
intelligent. Multi-sensor and multi-system cooperative scheduling is the core of intelligent management
and scientific operation of the whole intelligent security management and control system. Modeling and
scheduling algorithm optimization is the key to study the problem of multi-sensor and multi-system
cooperative control.

4.1. Establishment of multi-sensor and multi-system collaborative optimization scheduling model

Based on the comprehensive integration and data sharing of each sub-system of security control of the
large nuclear facility, the optimal strategy of security control can be mapped to the shortest sensor
response time as the goal of solution. Therefore, in view of the large nuclear facility nuclear security
multi-sensor collaborative scheduling problem, the collaborative optimization scheduling model can be
established.

Firstly, some variables are defined as follows.

\[
x_{ik} = \begin{cases} 
1 & \text{Sub-system } k \text{ responds from sub-sensor } i \text{ to sensor } j \\
0 & \text{Sub-system } k \text{ does not respond from sub-sensor } i \text{ to sensor } j 
\end{cases} 
\] 

(1)

\[
y_{ik} = \begin{cases} 
1 & \text{Sensor } i \text{ belongs to sub-system } k \\
0 & \text{Sensor } i \text{ does not belong to sub-system } k 
\end{cases} 
\] 

(2)

Then, objective function can be established as follows.

\[
\min Z = \sum_{i \in C} \sum_{j \in C} \sum_{k \in V} c_{ijk} x_{ijk} 
\] 

(3)

Where, \( \min Z \) means the shortest comprehensive reaction time. And \( c_{ijk} \) is the response time of sub-
system \( k \) from sub-sensor \( i \) to sensor \( j \).

\[
\sum_{i \in C} \sum_{j \in C} x_{ijk} \leq Q \quad k = 1, 2, ..., m 
\] 

(4)

\[
\sum_{j \in C} \sum_{k \in V} x_{ijk} = 1 \quad i \in V 
\] 

(5)

\[
\sum_{j \in C} x_{ijk} = y_{ij} \quad j \in V, \forall k \in V 
\] 

(6)

\[
\sum_{i \in C} x_{ijk} = y_{ik} \quad j \in V, \forall k \in V 
\] 

(7)

\[
\sum_{j \in C} x_{ijk} = 1 \quad \forall k \in V 
\] 

(8)

\[
\sum_{i \in C} x_{ijk} - \sum_{j \in C} x_{ijk} = 0 \quad \forall h \in C, \forall k \in V 
\] 

(9)

\[
\sum_{i \in C} y_{ik} = 1 \quad \forall k \in V 
\] 

(10)
Equation (4) indicates that the sub-system is not overloaded, which means that the sub-system has capacity limitation. Equation (5) indicates that each sensor can only be responded once for each task; Equations (6) and (7) represent the constraint relationship between variables $x_{ik}$ and $y_{ik}$. Equations (8), (9) and (10) represent the uniqueness of each sensor in each security sub-system; Equation (11) expresses the time window limit.

### 4.2. Multi-sensor Cooperative Optimization Scheduling Algorithm and Optimization

The optimal solution of the above model can be solved by ant colony algorithm [13]. The ant colony algorithm has good robustness, parallelism, cooperation and optimization, however, the traditional ant colony algorithm often has long search time, slow convergence speed and easy to fall into the local optimal solution. Therefore, it is necessary to improve the ant colony algorithm appropriately on the basis of the traditional ant colony algorithm. The improved algorithm can improve the convergence speed and global optimization ability, so that the multi-sensor and multi-system collaborative scheduling can be better.

1) Improved convergence speed

In the case of large task area, because of the volatility coefficient $\rho$ of information, the information on solutions that have never been searched will gradually decrease to close to 0, which reduces the global search ability of the algorithm. On the contrary, too large $\rho$ will affect the global search ability of the algorithm. If the $\rho$ is reduced, the convergence rate will be slower. And the adaptive control strategy for $\rho$ value should be adopted as shown in Equation (12). At the beginning of iteration, the initial value of can be larger to ensure the convergence speed. With the increase of iteration times, $\rho$ decreases gradually to ensure the global optimization of the algorithm. At the same time, the minimum volatility coefficient $\rho_{\text{min}}$ should be limited to avoid too slow convergence, which will affect the performance of the algorithm.

$$\rho(i+1) = \begin{cases} \mu \rho(i) & \rho(i+1) \geq \rho_{\text{min}} \\ \rho_{\text{min}} & \rho(i+1) < \rho_{\text{min}} \end{cases} \quad (12)$$

Where, $\mu$ is generally 0.5-0.9, $\rho_{\text{min}}$ is generally 0.1.

2) Improved global optimization capability

After obtaining a set of local minimum values $x_k$ by using this algorithm, the genetic mutation with small probability is carried out by using genetic algorithm, so that the $\alpha$, $\beta$ and $Q$ values change in the whole desirable range. Save the optimal solution $x_k$ during iteration and continue execution. After this improvement, the quality of the solution can be improved by jumping out of the local minimum region.

3) The solution of improved ant colony optimization algorithm

The specific solving steps are as follows:

1. Parameters $\alpha$ and $\beta$ are initialized. Set $\tau_0 \leftarrow 0$, and the number of iterations is $nc \leftarrow 0$, $NC_{\text{max}} > 0$;

2. Place $m$ ants at the initial point, and place the initial point in the current solution set $tabu_k(s)$;

3. For each ant $k (k=1...M)$, according to the probability $p^k_{ij}$, move to the next city $j$ and place the city $j$ in $tabu_k(s)$;

4. According to formula $\tau_{ij} = (1-\varepsilon)\tau_{ij} + \varepsilon \tau_0$, the pheromone is partially updated;

5. Calculate the objective function of each ant and record the local optimal solution;

6. For a group of local minimum $x_k$, the genetic algorithm is used to optimize the optimal solution with small probability.
(7) Calculate the adaptive volatility coefficient

(8) Global update of pheromone according to formula $\tau_{ij}(t+n) = \rho \tau_{ij}(t) + \Delta \tau_{ij}$

(9) Let $\tau_{ij} \leftarrow 0$ and $nc \leftarrow nc + 1$

(10) If $nc < NC_{max}$, move on to step (2).

5. Conclusion

Aiming at the problems of multiple types of security control systems for a large nuclear facility, isolation from each other and low efficiency of security control, an intelligent security management and control system for a large nuclear facility was designed by integrating security information of each subsystem from the perspective of the system. Firstly, the information transformation of each security control subsystem is carried out by developing the corresponding Web service interface. The information of each safety control sub-system is shared, so as to realize the integration of all safety control sub-systems of the large nuclear facility, and achieve the interconnection and intercommunication of each subsystem. Then, a multi-sensor system optimization scheduling model is constructed to realize the coordinated optimization scheduling of heterogeneous multi-sensor information synthesis and security. It has been verified by the nuclear facility that the intelligent security management and control system significantly improves the reliability, credibility and timeliness of safety control of the large nuclear facility.

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