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Study of Mountainous Long Span Prestressed Concrete Box-Girder Bridge Cantilever Construction Safety Monitoring System Based on Multi-Agent System

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Abstract. Mountainous long span prestressed concrete box-girder bridge cantilever construction has too many risk factors, and it is difficult to control the construction safety. To ensure the construction safety of Xi-jun bridge, a mountainous long span prestressed concrete box-girder bridge cantilever construction safety monitoring system based on Multi-Agent System is built in this paper. To make full use of cooperativity and interaction of Agent, there are six kinds of Agent in MAS construction safety monitoring system model framework. The monitoring system is built based on .NET Framework. The communication mechanisms of Agent are built based on WinSocket. Then the automatic updating of finite element analysis model is achieved, and the analysis and forecast of box-girder bridge cantilever construction safety state can be done in the system. The safe state of Xi-jun bridge construction is always be in controlled by use of the system.

Keywords: Multi-Agent System; construction safety monitoring system; mountainous long span prestressed concrete box-girder bridge; cantilever construction

1. Introduction

The total length of Xijun Bridge in Danjiangkou City is 678m, the main span of which is 75m+4×130m+75m, and the width of bridge deck is 11m. The structure of Xijun Bridge is six-span prestressed concrete continuous box girder bridge structure. The bridge is designed to connect Xijiadian Town and Junxian Town. It is one of the supporting facilities in the central line of South to North Water Diversion Project. It is a typical high-pier and long-span continuous beam bridge in mountain area.

The main beams of Xijun Bridge are of single box and single chamber sections. The height of the beam root is 8.0m. The height of mid-span beam is 3.2m. The variation curve of beam height is just like a 1.6-th power parabola. The construction method of main beams is cantilever hanging basket cast-in-place construction method.

MAS is a multi-agent system, which is a system composed of multiple agents. These agents can complete their own tasks and cooperate with each other to achieve more complex system functions in an artificial environment. The single agent capability is limited, and the completed tasks are relatively simple. To make full use of the autonomy, interactivity, responsiveness, reasoning and planning ability of agent, MAS organizes the agents to complete multiple task requirements of a complex system through interaction and collaboration. At present, the main research and application of MAS is in the fields of power system, traffic control, robot control, manufacturing control and so on [1, 2].

Xijun Bridge is a large-span PC box girder bridge in mountain area. The terrain is complex, the



climate environment is changeable, there are many high-altitude cross operations, the flow of personnel is large, the construction progress is slow, the construction risk factors are many, so the construction safety management is difficult [3, 4]. To ensure the safety of the construction of the bridge, it is necessary to do real-time monitoring of the design parameters of the beam bridge structure, temperature, internal force of the control section and geometric line type, timely feedback of data analysis results, correction of mechanical analysis models, to make the construction status of bridge be within the controllable range. This is a complex system with multi-objective control. This paper attempts to apply MAS to implement Xijun Bridge construction safety controlling on line.

2. Agent and MAS

Agent, which first appeared in economics in the sense of "agent", was widely studied and applied in artificial intelligence and related fields. Agent was understood as the subject of behavior that can interact with its environment [2]. This subject can be a human, a robot, or an intelligent program or an embedded device. Agent can have specific attributes and behavior rules by using certain programming methods. After the agent adapts to the environment, interacts with the environment and constantly adjusts the self-behavior, the agent can achieve specific behavioral goals.

The basic structure of the agent includes environment awareness module, information processing module, communication module, intelligent control and decision module, execution module, knowledge base, and task table. As shown in the figure 1. The information processing module collects the environmental perception information of the agent and the interaction information between the agent with the other agents. The information can also be processed and treated by information processing module. The intelligent control and decision-making module works according to the knowledge base and the task table. After receiving the data from the information processing module, the task is reasonably planned, and the decision result is transmitted to the execution module.

MAS is an intelligent interactive system that is integrated by multiple agents using a specific architecture. Each agent in the system interacts in a loosely coupled manner on the basis of completing its own tasks. MAS can complete multi-objective task of complex systems that cannot be completed by a single agent. MAS is more powerful, more efficient, more adaptable, robust and scalable than a single agent. The modeling steps of MAS are as shown in the figure.1. Firstly, the tasks of complex systems are clarified. Secondly, according to the task, the complex system model is divided into multiple functional modules, and agents with specific attributes and behavior rules are designed to implement these functions. Thirdly, after the organization of MAS is defined, the agents in the model communicate, interact and collaborate with each other. Then the MAS simulation model is obtained, and the model is continuously iterated, tested and corrected.

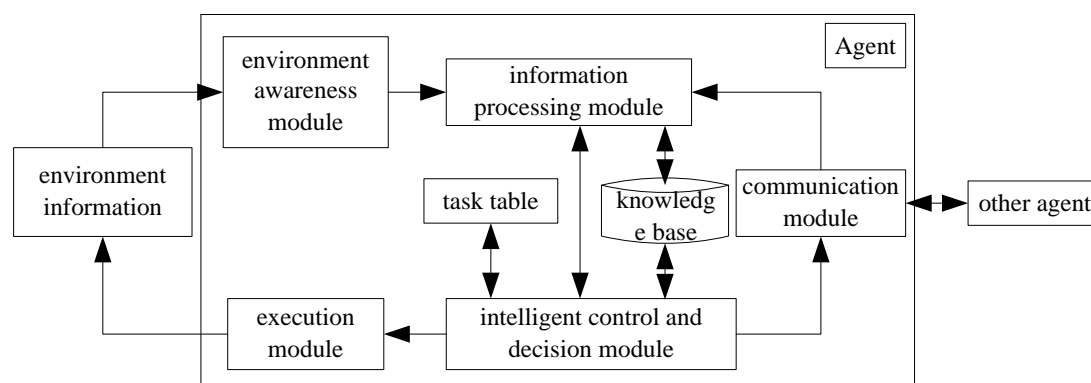


Figure 1. Schematic diagram of the basic structure of the Agent

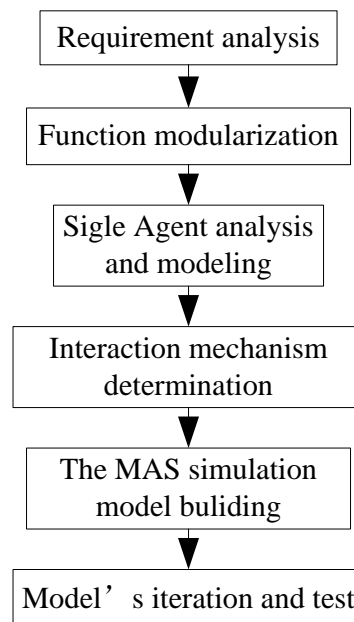


Figure 2. MAS-based system modeling steps

3. Design of safety MAS Monitoring System for Cantilever Construction

3.1. Analysis of Safety Risk Factors of Cantilever Construction

For large-span PC box girder bridges, the risk factor affecting the safety of cantilever construction lies in the deviation of the construction state. There is a large difference between the actual line type and the theoretical value, and there is also a large difference between the stress state of the bridge and the theoretical value. When the difference is within the safe range, it is easy to be ignored and not controlled in time. The cumulative effect of these differences will quickly make the construction state of the box girder bridge out of the safe range, resulting in an irreparable situation.

Therefore, establish a real-time monitoring and proper rectification safety monitoring system is necessary. The factors causing the deviation of the cantilever construction state of the large-span PC box girder bridge mainly include the deviation between the actual structural parameters and the design parameters, the deviation between the structural analysis model and the actual construction process, the construction positioning and manufacturing error, the construction monitoring measurement error, and the deformation of the hanging basket.

3.2. Cantilever Construction Safety MAS Monitoring System Workflow

The main work contents and process of the safety MAS monitoring system for PC box girder cantilever construction are as follows:

First step, according to the drawing and construction organization design of the PC box girder bridge, the bridge analysis software is used to establish the girder bridge construction simulation analysis model and the corresponding Agent. The pre-camber and control section stress value of each stage of the girder bridge under the ideal construction state are calculated. The master agent can access the calculation result as needed.

Second step, the monitor of the status parameters of the beam bridge construction can be done along with construction. The status parameters are the main beam axis, the main beam deflection, the construction environment temperature, the control section stress, the abutment settlement, and deformation of the basket monitoring. The important structural parameters which need to be monitored are geometric parameters of beam bridge sections, bulk density and elastic modulus of concrete, shrinkage and creep parameters of concrete, elastic modulus of steel strands, parameters of prestressed

friction loss, temporary loads for construction. Then the collection monitoring data should be collated and processed.

Third step, through the communication agent, according to the monitoring data, the beam bridge construction simulation analysis model is automatically updated. The calculation results of the updated model are compared with the measured beam bridge construction state parameters. Then the safety of the PC beam bridge cantilever construction state is determined according to the result of comparison. The system will carry out construction warning or next construction decision.

Fourth step, the MAS go to the second step to carry out the next construction safety monitoring cycle. If the construction is completed, the cycle ends.

3.3. Cantilever Construction Safety MAS Monitoring System Model Framework

According to PC box girder cantilever construction safety monitoring task and agent function division, the system is divided into six categories: construction monitoring data collection agent, construction monitoring data processing agent, construction safety state analysis agent, construction simulation calculation agent, communication agent and main control agent. [5-6].

Construction monitoring data collection agent, construction monitoring data processing agent, construction safety state analysis agent and construction simulation calculation agent cooperate and interact with communication agent. Then the construction simulation analysis model updates automatically, and complete beam bridge construction safety state analysis. On the basis of beam bridge safety judgment, the parameter error of the simulation model is identified. The intelligent algorithm such as generalized neural network is used to predict the stress and deformation of the beam bridge [7], and preventive measures are taken in advance.

The main control agent accesses the security monitoring data and the security analysis data interact with the communication agent. Then the main control agent feeds back the result to the client agent, and maintains the normal operation of each agent. Based on the results of construction safety analysis, the client agent makes the final construction decision based on certain engineering experience and issues the next construction instruction. If the construction is completed, the safety monitoring cycle ends.

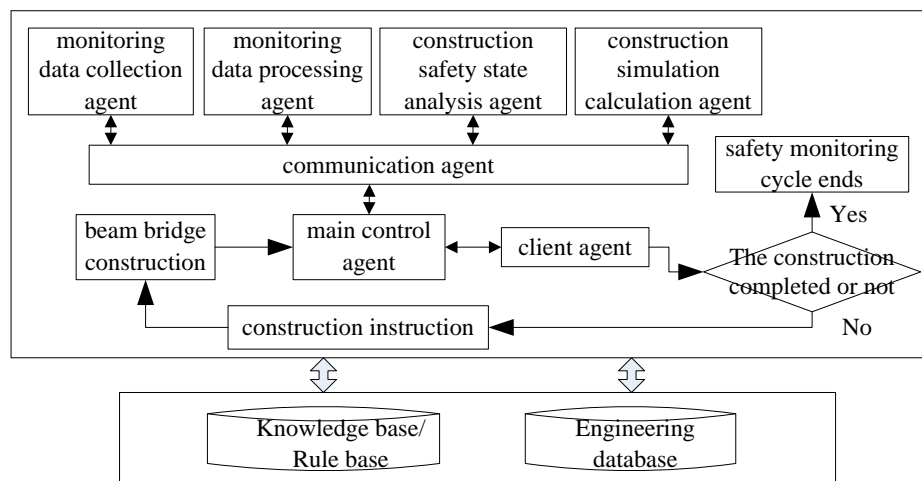
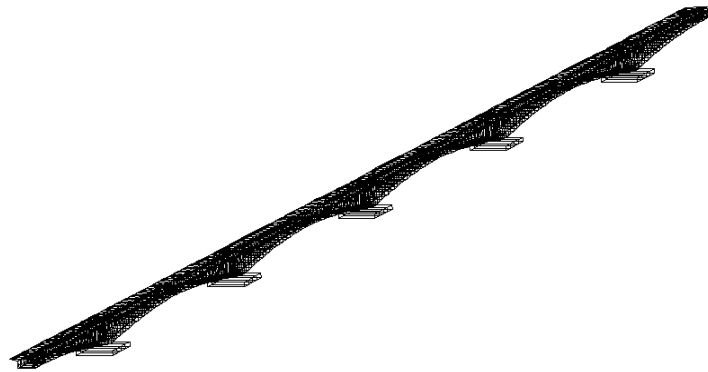


Figure 3. Cantilever construction safety MAS monitoring system model framework

4. Implementation and Application of Safety MAS Monitoring System for Cantilever Construction

Dr. Bridge software was used to establish the finite element dynamic simulation analysis model of Xijun Bridge construction (Fig. 4). The model nodes were divided by the support, boundary and construction boundary points. A total of 219 nodes and 68 construction stages were established. The finite element simulation analysis of the beam bridge cantilever construction can obtain the

pre-camber of the beam bridge construction, which is an important reference for the construction of the beam bridge.



全部选定单元立体模型图

Figure 4. Dr. Bridge finite element analysis model

4.1. NET-based MAS Monitoring System Construction Platform

The MAS-based mountaineering large-span PC box girder bridge cantilever construction safety monitoring system is built on the basis of .NET Framework [8]. The system construction principle is shown in Figure 5.

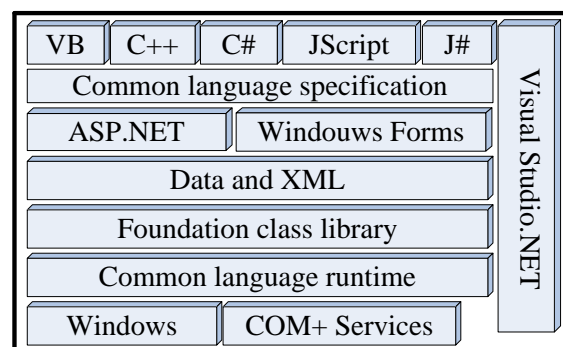


Figure 5. TECH-based agent construction technology diagram based on NET platform

The application layer such as VB, C++, etc. provides development language support for the development of various intelligent bodies such as the main control agent and the construction safety state analysis agent in the beam bridge construction safety monitoring system. Data and XML provides technical support for agents to access database and data across platforms. The base class library provides basic underlying operation functions such as input and output functions and thread support functions for the Agent. The Common Language Runtime (CLR) provides services such as memory management and thread management, and hosts the Agent development code, which makes the agent have good cross-platformity.

4.2. Communication Mechanism Based on WinSocket

Agents communicate in the form of Sockets. Each Agent contains server functions for listening to data and client functions for sending requests. The Socket-based communication mechanism is shown in Figure 6. On the server side, the following tasks are completed in sequence: 1) Establishing a socket; 2) Binding the socket to the local IP address and port; 3) Adjusting the state of the socket to the listening mode, waiting to receive the message; 4) Establishing the connection request to establish Communication with the client; 5) Data transmission with the client; 6) Processing of the data

according to the received information; 7) Closing the socket. On the client side, it mainly completes socket establishment, connection with server, and data transmission.

Based on MAS, KQML is used as the communication language between Agents in the mountain large-span PC box girder bridge cantilever construction safety monitoring system. This language has the characteristics of independent of content entity and independent of network transmission mechanism [9]. The composition of the communication message edited with KQML is: message header + primitive + content + this message number (+ response message number). Such as:

Tell

```
::content(COrder<<01<< Construction Monitoring Data Collection <<<Message
Content<<2010/2/01<<100<<)
```

```
::receiver Construction Monitoring Data Collection Agent
```

```
::language order
```

After receiving the instruction to collect data, the construction monitoring data collection agent collects the construction data, performs preliminary processing, and uploads the collected data.

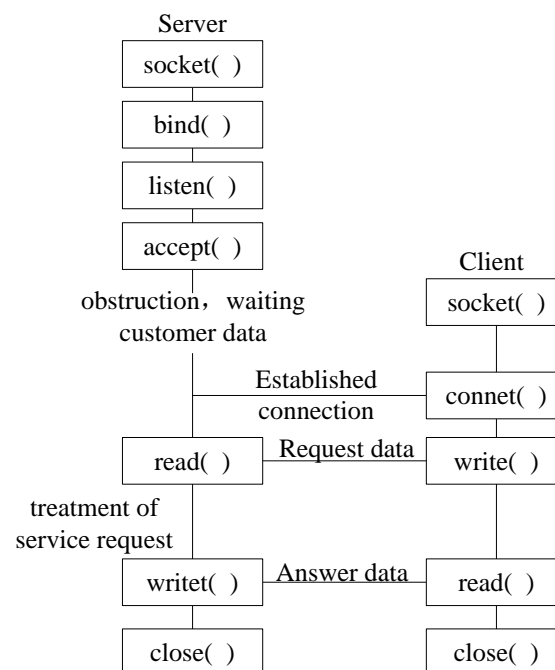


Figure 6. Winsock-based communication process

4.3. Application of Cantilever Construction Safety MAS Monitoring System

After the user logs in the mountainous long span prestressed concrete box-girder bridge cantilever construction safety monitoring system based on Multi-Agent System, and enters the main control agent interface (Fig. 7), the interface shows the status of the five completed conditions.



Figure 7. Cantilever construction safety MAS monitoring system master control agent interface

The construction simulation analysis agent performs the automatic update of the beam bridge cantilever construction simulation analysis model after interacting with other agents (Fig. 8). After the measured beam bridge construction state parameters are entered into the system, it is accessed by the construction safety state analysis agent (Fig. 9). And the results of the beam bridge safety state analysis are obtained, as shown in Figure 10. The client gives the next construction instruction based on the calculation results and engineering experience.



Figure 8. Construction simulation calculation agent interface



Figure 9. Construction Security Status Analysis Agent Interface



Figure 10. Construction safety state analysis calculation results

With the assistance of the MAS beam bridge construction safety monitoring system, the construction safety status of Xijun Bridge has been in a controllable state. The deflection deviation of the bridge is controlled within $\pm 15\text{mm}$, and the beam bridge can be successfully closed after cantilever construction.

5. Conclusion

The mountainous long span prestressed concrete box-girder bridge cantilever construction safety monitoring system based on Multi-Agent System ensures the safety of the entire construction process of Xijun Bridge. The following conclusions can be drawn through the research and application of the system:

- (1) Establishing a construction safety monitoring system based on MAS, which can meet the multi-target requirements such as deformation control and stress control of cantilever construction of large-span PC box girder bridges in mountainous areas;
- (2) Agent's interaction and cooperation realizes the timely update of the beam-bridge finite element analysis model, and simultaneously uses a variety of intelligent algorithms to predict the deformation and stress of the beam bridge, and take precautionary measures in advance.

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