The 2014 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM14)
Busan, Korea, August 24-28, 2014

Effectiveness analysis on SHM system using multi-agent integration

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ABSTRACT

Structural health monitoring (SHM) system has been developing not only on theories but also on applications to real world structures. However, the system integration is mostly in centralized management, which leads to accumulate huge number of sensor measurements, increase the data process time and require high-tech hardware and so on. Multi-agent system is a kind of technology to supply the distributed management for SHM system, while the traditional centralized management is expected to be distributed by using multi-agent integration in SHM system. The paper is proposed to introduce the concept of multi-agent system, which is followed by analysis on the advantages using multi-agent integration compared with which using traditional centralized management in SHM system. The stress prediction method is used as an example to illustrate the effectiveness of the proposed technology, in which the feasibility, time consumption and system reliability is proofed separately.

1. INTRODUCTION

With the rapid development construction business, SHM has also been carried out vigorously. In traditional SHM, sensors are arranged in the different region distributed on the whole structure, and all the data acquired from sensors are transmitted to computing center. For example, there are about 1000 sensors placed on the Great Belt East (Wang 1998), which are arranged everywhere on the bridge. The monitoring system of Oresund Bridge (Peeters 2003) contains sensors to monitor stress, strain, acceleration, temperature, humidity and wind velocity, and computing center to do data acquisition,

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remote access and static data processing. But method with integrated function will lead to a low efficiency of the system. Researchers have made some progress on distributed, decentralized method to structural health monitoring. For example, J. R. Lynch and K. H. Law embedded a simple information and signal processing algorithm into the sensor nodes to develop an intelligent information processing node (Lynch 2006), which is successfully applied into the structural health monitoring system of bridge acrossed New Mexico and Alamosa Canyon. However, dispersion capacity of the function by this method is limited, while the process of data processing is still concentrated.

The idea of multi-agent systems is from the discipline of artificial intelligence (Wooldridge 1995). It can decentralize the function, and assign the decentralized function to each distributed agent, then achieve the required function by the coordination and contact among the agents. The ideas of multi-agent systems are particularly suitable for the distributed problem where the function of solving problem needs decentralizing. Such as the weather forecasting, Hartvigsen took the regional observatory as an agent, and coordinated other agents to form a multi-agent system, and then distribute the entire region to solve the global storms forecast (Hartvigsen 1990). For a problem of predictive control modeling, Oliveira uses multi-agent to distribute the centralized function to different agents, while each agent solves a part of the whole problem (Oliveira 2010). The analysis algorithm and decision method would be a novel distributed one if the multi-agent system can be used into structural health monitoring system, which will reduce maintenance costs and improve operational efficiency of the system.

The theory on structural health monitoring using multi-agent systems is introduced firstly. As following, the stress identification of a single layer Schwedler reticulated dome structure is carried out to verify the feasibility of the proposed method, in which the multi-agent division method, the identification errors and the time consumptions are listed and discussed.

2. STRUCTURAL HEALTH MONITORING USING MULTI-AGENT SYSTEMS

The function structure of multi-agent system is divided as Fig.1. There are three parts, which are sensors, junior agents and senior agents. Sensors connect to junior agents, and junior agents connect to senior agents. Sensors can collect the structural response information. Junior agents can receive and process the information from the sensors preliminarily. Senior agents can receive and process the information processed by junior agent to obtain a senior monitoring results. Building a multi-agent system can solve the problem brought from the centralized data processing effectively.

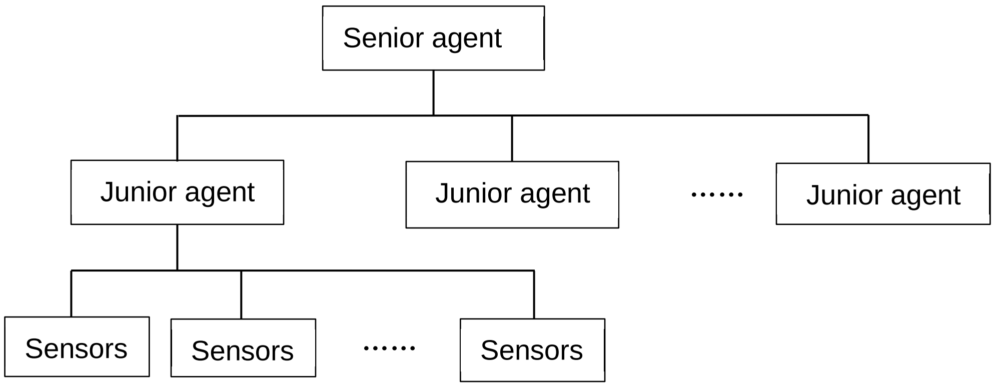


Fig. 1 Functional structure division of multi-agent system

2.1 Sensor level

Sensor level includes different types of sensors located on the structure. The main purpose of these sensors is to monitor the information of the important positions of structure in real-time. In order to reduce the costs of monitoring system and improve the recognition accuracy of the system, the distance between sensors and correlation between measurements should be considered to group sensors.

2.2 Junior agent level

Junior agent level includes all kinds of junior agents. In order to decentralize the integrated function of SHM, the junior agent is used to achieve some functions of analysis and assessment methods of SHM. It can receive and store the information collected from connected sensors, the decision information is then uploaded to the senior agents. The function blocks of junior agent are shown in Figure 2, the section circled by the dotted line represents the junior agent.

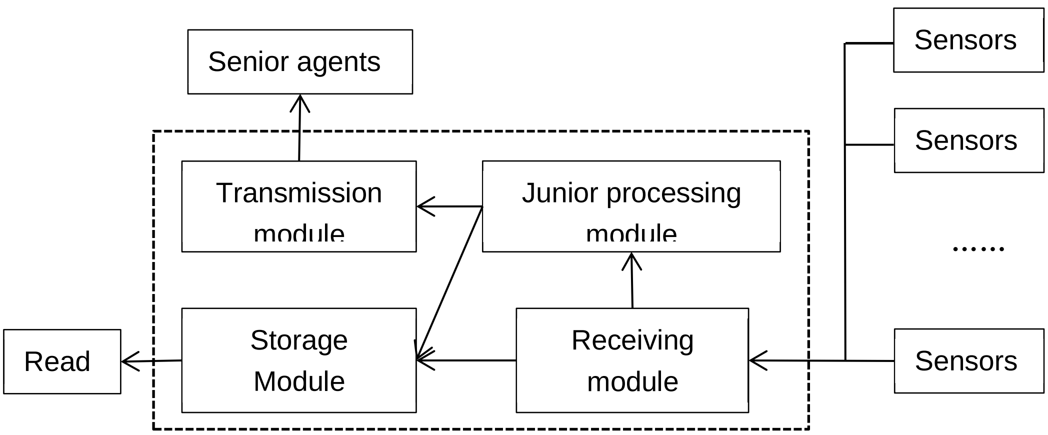


Fig. 2 Junior agent function block

In the figure, receiving module collects information, junior processing module collects and processes the information passed from receiving module. Then the information is sent to senior agent by transmission module. Junior processing module is the core module to realize the assessment or decision method using junior agents.

2.3 Senior agent level

Senior agent level includes all kinds of senior agents. Its purpose is to synthesize the analysis and evaluation results from the junior agents to complete the analysis and assessment methods of SHM. It can receive and store the information collected from connected junior agents. Then the information is used to advanced structural identify or structural health monitoring method. The function blocks of senior agent are shown in Figure 3. The section circled by the dotted line represents the senior agent.

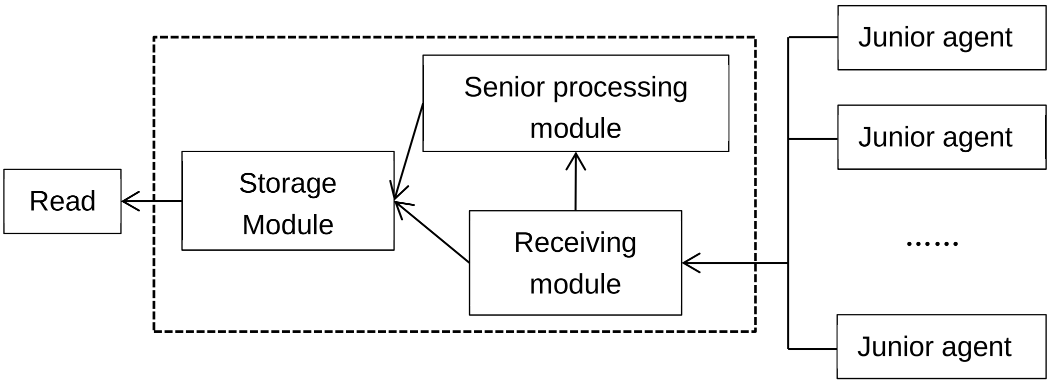


Fig. 3 Senior agent function block

In the figure, receiving module connected to junior agents collects information. Senior processing module collects and processes the information passed from receiving module. Then the information processed is transmitted to the storage module to store. Senior processing module can integrate information from each junior agent to obtain the final synthesized outcome.

3. FEASIBILITY ANALYSIS OF STRESS PREDICTION METHOD USING MULTI-AGENT SYSTEM

Stress prediction is taken as an example to illustrate the detailed processes of the proposed method. The core technique for stress prediction is pattern recognition, including finite element model establishment, pattern library extraction, decision making and so on (Teng 2010).

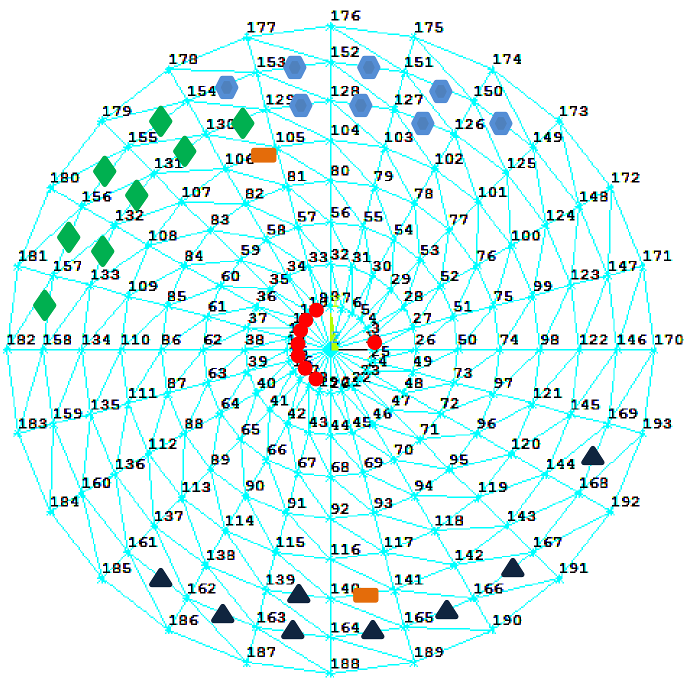
3.1 Description on stress prediction of dome-like structure

A single layer Schwedler reticulated steel dome structure(Lu in press) is used here. The placements of strain sensors, deformation monitoring points and the assumed prediction elements are determined by the responses from analysis when the structure is subjected to fluctuating wind load and dispersion equation. The equation is shown as,

$$\gamma = \frac{\sigma}{\mu} \tag{1}$$

Where γ ——the dispersion of measurement;
σ ——the standard deviation of measurement;
μ ——the mean of measurement.

The finite element model, the placements of monitoring points and predicted elements are all shown in Fig. 4. The article chose 32 placements to arrange sensors, in which strain sensors are arranged to 24 placements, displacement sensors are arranged to 8 placements. The predicted parameters are the stress values of rod 105 and rod 140.



-----displacement sensors connected to junior agent 1
----strain sensors connected to junior agent 2
----strain sensors connected to junior agent 3
----strain sensors connected to junior agent 4
--rods whose stress value are predicted

Fig. 4 The placements of the sensors and the predicted bars

3.2 Division and simulation of multi-agent system

Four junior agents are designed to distribute the stress prediction process. Each junior agent connected to different sensors precedes the information to get a preliminary result of the stress recognition. Senior Agent synthesizes the information from junior agent to obtain a further stress recognition result. The simulation models of four junior agents and one senior agent using Matlab are shown in Figs. 5-9, respectively, where d-2 represents deformation measurement at location point 2, and s-139 represents stress measurement at location element 139.

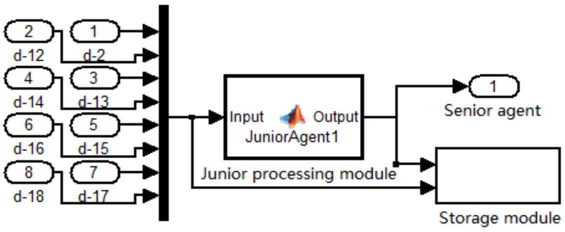


Fig. 5 Simulation of junior agent 1

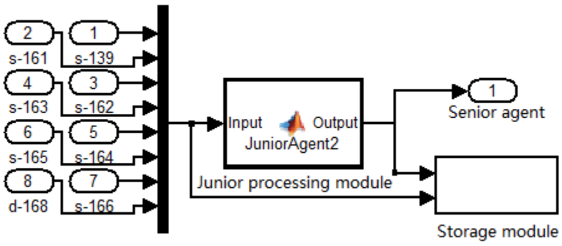


Fig. 6 Simulation of junior agent 2

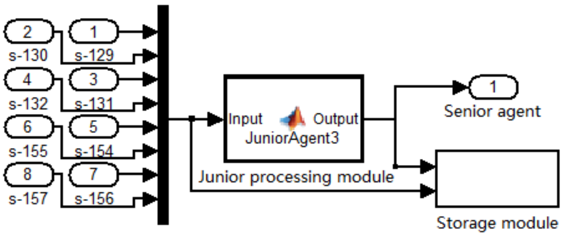


Fig. 7 Simulation of junior agent 3

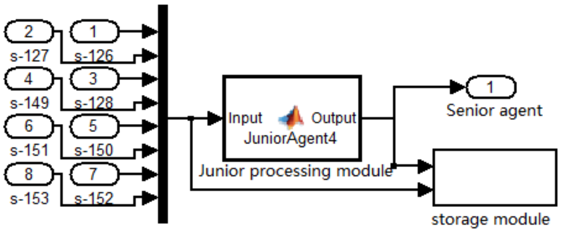


Fig. 8 Simulation of junior agent 4

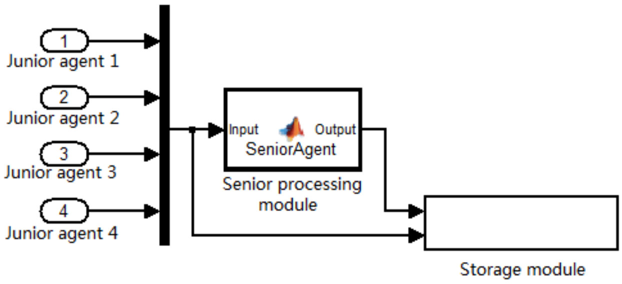


Fig. 9 Simulation of senior agent

3.3 Stress prediction and error analysis

The predicted stresses and errors are shown in Table 1, in which the errors are calculated by

$$\Delta = \left| \frac{\sigma_T - \sigma_P}{\sigma_T} \right| \times 100\% \qquad (2)$$

Where Δ represents the calculation error, σ_T represents the theoretical stress, σ_P represents the predicted stress.

Table 1 Predicted stresses and errors using each agent

Agents	Bar 105		Bar 140	
	Stress (MPa)	Error (%)	Stress (MPa)	Error (%)
Junior agent 1	12.6924	3.9	21.1750	3.3
Junior agent 2	13.4809	2.1	22.7781	4.1
Junior agent 3	15.1875	15.0	20.3656	7.0
Junior agent 4	12.1598	7.9	21.6177	1.8
Senior agent	13.3801	1.3	21.4841	1.2

It can be seen from Table 1 that different agents can all get predicted stresses and errors. The predicted results using senior agent are better than that using the junior agents. Therefore, the feasibility of stress prediction method using multi-agent system is proofed by this simulation process.

4. TIME CONSUMING ANALYSIS FOR MULTI-AGENT SYSTEM

With the different number of patterns in pattern library and different number of identified scenarios, the calculation time using multi-agent system and the calculation time using centralized one agent system are compared, which are shown in Table 2.

Table 2 Comparison on calculation time (s)

No. of patterns in pattern library	No. of identified scenarios	Multi-agent system	One agent system	Time difference
15000	125	7.27	7.56	0.29
15000	250	14.37	15.12	0.75
15000	500	28.22	30.15	1.93
7500	500	14.15	15.05	0.90
3750	500	7.11	7.53	0.29

It can be seen from Table 2 that the time can be saved by using multi-agent system, while the time consuming can be improved to stress prediction using multi-agent system.

5. CONCLUSIONS

The structural health monitoring using multi-agent system is proposed. This method can effectively solve the problem which is brought from traditional centralized health monitoring process. The Simulink components of Matlab are used to simulate the system function, while the stress identification of a single layer Schwedler reticulated dome structure is carried out to illustrate the division method of agents, the identified errors comparison and time consuming. The proposed method is verified its effectiveness and feasibility.

ACKNOWLEDGMENTS

The work is supported by the National Science Foundation of China (Grant No. 51308162), Natural Scientific Research Innovation Foundation in Harbin Institute of Technology (HIT.NSRIF.2015085), and the Supporting Project for Junior Faculties of Harbin Institute of Technology Shenzhen Graduate School.

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