A Steel Bridge Design System Architecture using VR-CAD and Web Service-based Multi-Agents

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Summary
This paper presents a new design environment based on Multi-Agents and Virtual Reality (VR). In this research, a design system with a virtual reality function was developed. The virtual world was realized by using GL4Java, liquid crystal shutter glasses, sensor systems, etc. And the Multi-Agent CAD system with product models, which had been developed before, was integrated with the VR design system. A prototype system was developed for highway steel plate girder bridges, and was applied to a design problem. The application verified the effectiveness of the developed system.

1 Introduction

1.1 Structural Detailed Design and Product Models
In structural detailed design, engineers determine the section dimensions of each member and check all the members for compliance with applicable design codes. If a member is found to violate any code, engineers have to re-design the member and perform code checking repeatedly until the member satisfies the code. If the design change is significant, they have to analyze the total structural system again and repeat the code checking process. The whole process tends to be time-consuming and error-prone.

A number of research efforts have been made in order to develop efficient design environments by using 3D CAD systems and product models. These design environments can provide capability of fairly smooth data transfer among 3D CAD systems and non-CAD application systems by the interoperability of the product model. Although they improve the efficiency of the design process, engineers have to spend time and consciousness for data transfer among systems yet. This problem may be solved by putting all related systems together and by making a single package. However, this solution would lose a number of other advantages such as free competition among software developers and vendors, and it would let users abandon their legacy systems.

1.2 Multi-Agent CAD
We believe that intelligent agents, which can support engineers and designers autonomously in various ways, operating in the background and without users' consciousness, play a significant role in solving the problem. Thus, we previously developed multiple agents, and developed Multi-Agent CAD (Yabuki and Kotani 2002) by integrating them with a 3D CAD system while using an IFC-based product model for sustaining the interoperability. In this system, one agent autonomously checks the compliance of the user's design with a design code when the engineer designs steel members in the 3D CAD system. The other agent checks external constraints such as constructability and economy, and gives the user comments and advices while the engineer is designing.

Then, we divided each agent into an agent interface and the main functional content. The agent interface is in each user's computer and the main functional content is in the developer's server.

The communication between the agent interface and the main functional content is done over the Internet by adopting the new technology called Web Services, which is based on standardized and open technologies such as Simple Object Access Protocol (SOAP). By using this system, the user does not have to install the agent programs every time they are updated because the systems can be upgraded automatically at the developers' servers (Yabuki and Kotani 2003).

Although the developed Multi-Agent CAD worked well, the user interface of 3D CAD of the Multi-Agent CAD environment has many aspects to be improved. One of the main deficiencies is that the 3D CAD shows the three-dimensional objects and space on a two-dimensional display so that the user often wonders which member is close to the user and which is far. This is particularly seen in the situation of three-dimensionally complicated structures such as steel girder bridges.

1.3 A New System with Virtual Reality

Therefore, we incorporated a virtual reality function into the Multi-Agent CAD environment in this research. Unlike the pseudo virtual reality, where only 3D CAD images are displayed on a computer monitor, the virtual reality we utilized is based on the two different images shown alternately with a great speed; one is to be seen by the right eye and the other by left. We used a high-speed shutter glasses to view the 3D virtual world.

In this system, the user not only can view the 3D CAD models more three dimensionally but also can edit the members in the 3D CAD. For example, the user can change the dimension of a member by selecting it appropriately, which was an irritating task in the conventional 3D CAD system. Once the user modifies the dimension, the agent autonomously converts the data into a product model data, and the modified dimension is checked for compliance with applicable design codes by the agents. If the design violates a design code, the agent tells the user so by popping up a small window on the computer display.

This paper presents the architecture of the system, describes its prototype system, and shows an illustrative example of application of the system to a steel girder bridge.

2 The Previous Multi-Agent CAD Environment

The previously developed Multi-Agent CAD environment (Yabuki and Kotani 2002) is shown in Fig. 1. In this model, the result data of structural analysis is transferred to the 3D CAD system via the product model and converters. Although load and basic dimensional data of each member are contained in the data, the detailed section dimensions are not included yet. Thus, the user determines section dimensions by using 3D CAD system. In this process, the Multi-Agents support the user's design.

The Multi-Agent CAD system consists of a 3D CAD system, a system interface, a user interface, and Multi-Agents. Three agents were developed: (1) a simple code checking agent, (2) a design situation checking system, and (3) a database agent. These agents can check the user's design autonomously and inform any violation and improper design to the users while they are using the Multi-Agent CAD system.

All the data designed in the Multi-Agent CAD system is transferred to the Code Checking System via the product model and converters. However, almost all members should already conform to the design codes because the simple code checking agent has already checks the design in the detailed design process.

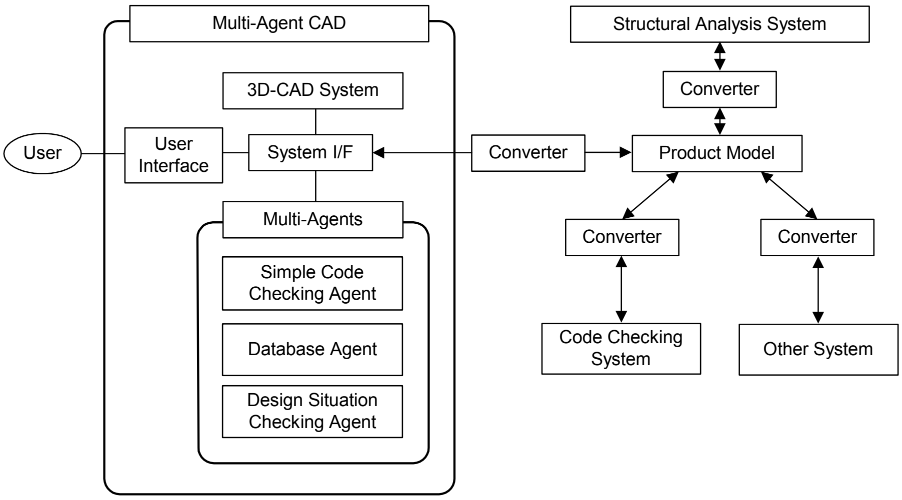

Fig. 1 The previously developed Multi-Agent CAD environment

3 An IFC-Based Product Model for Steel Girder Bridges

3.1 IFC of IAI

In this research, we used Industry Foundation Classes (IFC) Release 2x, i.e., IFC2x, (International Alliance for Interoperability 2000) of International Alliance for Interoperability (IAI) as a base of the product model for steel girder bridges. IFC is an object-oriented data model for representing buildings and other construction related information. IFC contains not only physical properties of structures such as its parts and members, their dimensions, materials, shapes, locations, etc., but also spatial concepts such as floors, rooms, and abstract concepts including projects, organizations, etc. IFC has been developed to enable the interoperability among CAD and non-CAD application systems by IAI.

In IFC2x, there are four main classes, i.e., IfcObject, IfcPropertyDefinition, IfcRe-lationship, and IfcRepresentationItem. IfcObject class and its sub classes define physically existing objects such as beams and columns. IfcPropertyDefinition class and its sub classes can contain supplementary information, which is not included in IfcObject classes. IfcRelationship class and its sub classes define the relationship among objects and property sets. IfcRepresentationItem class does not share the root with other three groups of the classes and is defined separately. This class provides resources on geometric information of members.

3.2 Modification of IFC2x for Steel Girder Bridges

Although IFC2x provides the IfcBeam class for representing beams, it is not possible to divide IfcBeam into flanges and webs. Thus, we defined a new class for plate girders, which is a sub class of a newly defined CivilStructureElement class, a sub class of IfcElement class. Since IFC2x has no classes for representing loads, we defined a new class “load” and attached it to IfcObject class as its sub class. The “load” class can contain the load data of objects such as beams and columns. A part of the product model is shown in Fig. 2. To implement the product model schema and instances, ifcXML (Extensible Markup Language) (International Alliance for Interoperability 2001) was used.

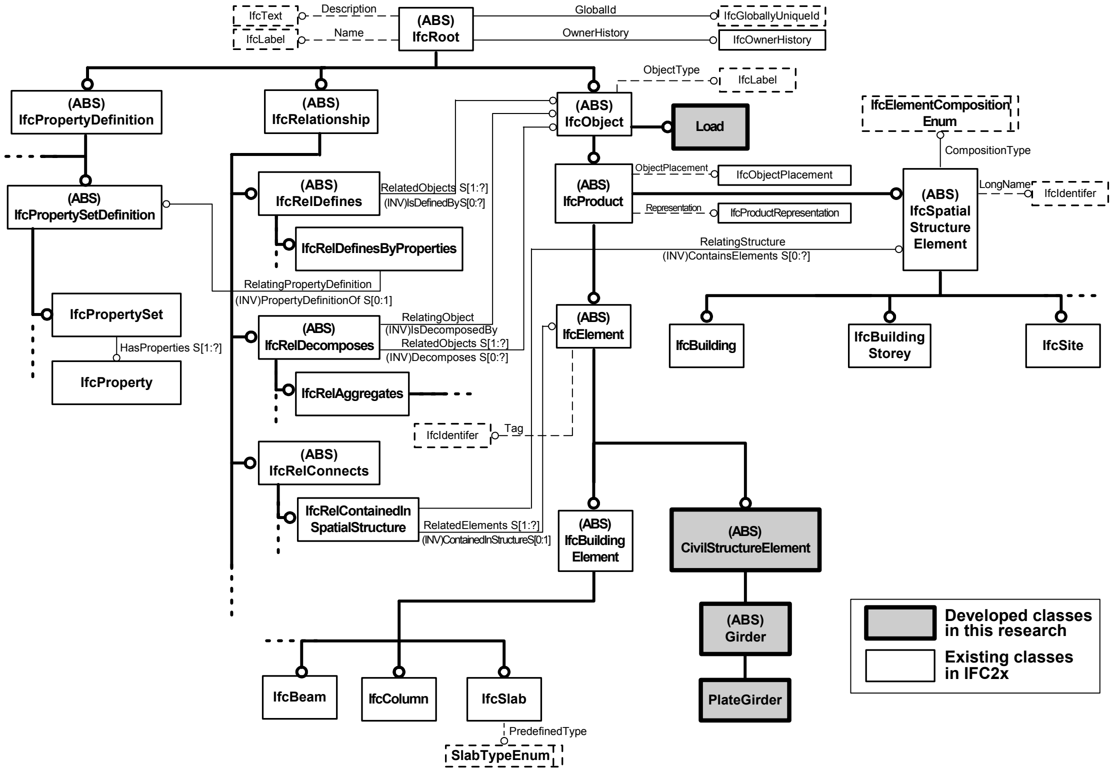

Fig. 2 Outline of the developed product model for steel girder bridges

4 Multi-Agents for Supporting Design of Steel Girder Bridges

The multi-agents developed in this research consist of a strength checking agent and a design situation checking agent.

The strength checking agent checks whether the section designed by the user is appropriate or not for the given loads by checking the conformance with the design code. As a design code, Japanese Highway Bridge Specification (Japan Highway Association 2002) is used.

The design situation checking agent checks whether the design satisfies situational constraints such as: whether the selected section of the girder has the same height as the adjacent girder and whether the designed section is economical or not. This agent retrieves the location and section data of the related given by the product model data and checks the situation based on the knowledge given by design engineers.

5 A Design System with Virtual Reality

Virtual reality is a realistic simulation by a computer system using interactive software and hardware. The requirements for virtual reality include (1) virtual world, (2) immersion, (3) sensory feedback, and (4) interactivity. The virtual world can be realized as a three-dimensional space by using computer graphics. The user can feel immersed in the virtual world by using a special display system. Feedback and interaction can be realized by using a sensor system connected with the virtual world and the user.

5.1 Virtual World

3D computer graphics is a computing technique for rendering images of objects in the three-dimensional space. Most typical 3D computer graphics include OpenGL (2004) and DirectX

(2004). DirectX is an application program interface (API) for Windows, and was developed by Microsoft. On the other hand, OpenGL does not depend on particular hardware or operating systems. Thus, we considered choosing OpenGL for implementation. However, OpenGL is a library of the C language. Since we used Java as a system development language, we decided to use GL4Java (2001), which is one of the OpenGL Java bindings and which Java programs can call OpenGL libraries.

5.2 Immersion in Virtual Reality

Although a perspective view image on a 2D display, generated from a 3D model, can be viewed as a three-dimensional image, true cubic effect lacks and most viewers cannot feel immersed in the virtual world. It is necessary to generate two different images: one is for right eye and the other for left in order to enable true three-dimensional viewing. Such images can be generated by using GL4Java. Further, liquid crystal shutter glasses can allow the user to see the images for right eyes by his right eye and the left for left. We used CrystalEYES3 of StereoGraphics as liquid crystal shutter glasses. The shutters of these glasses synchronize with the computer display showing right and left images alternately at more than 120 Hz by using the infrared emitter unit. More than one viewer can see the images three dimensionally if they wear the glasses.

5.3 Sensory Feedback and Interactivity

Sensor systems such as transmitters and receivers can realize sensory feedback and interactivity. Within the boundary of such sensor system, the user can change the viewing direction and location by just moving his or her head or fingers without typing commands from a keyboard. We used FASTRAK of Polhemus as a sensor system. Since the radius of the boundary of FASTRAK is about 1 m, viewing location is limited to 2 m, which is too small considering the size of typical bridges. Thus, we magnified the distance in the sensor area with some factor so that the user can view bridges from any point in the virtual world.

We developed a detailed design system using virtual reality. The system architecture is shown in Fig. 3 and Fig. 4. Fig. 5 shows computer graphics images of a steel girder bridge for right and left eyes respectively.

6 An Example of Application

In this section, an example of application of the developed prototype system to highway bridge design is described. The bridge is a highway simple supported non-composite steel plate girder bridge. The design follows the Specifications for Highway Bridges (Japan Highway Association 2002).

First, the preliminary structural analysis of the given bridge has already been performed, and the output data of member forces (bending moments, shear forces, etc.) of plate girders and coordinate data are converted to product model data. The data has been input to the developed detailed design system.

Next, the user designs the plate girders, viewing the images for right and left eyes by the liquid crystal shutter glasses, so that the user can feel immersed in the virtual world as shown in Fig. 6. While the user is in the process of determining the dimensions of the plate girders, Multi-Agents check the design and warn the user, e.g., “The thickness of the upper flange must be larger under the given load condition,” if the design needs modification. And the violating element of the design member is highlighted by changing its color from yellow to orange in the display. The user can modify the dimensions by using the window under the 3D virtual world. Other agent, which checks the situation and warns the user, works like this way.

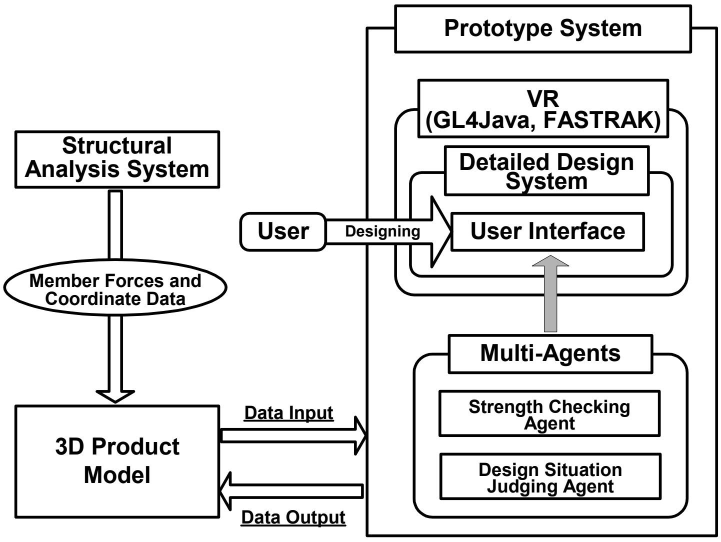

Fig. 3 The developed design environment

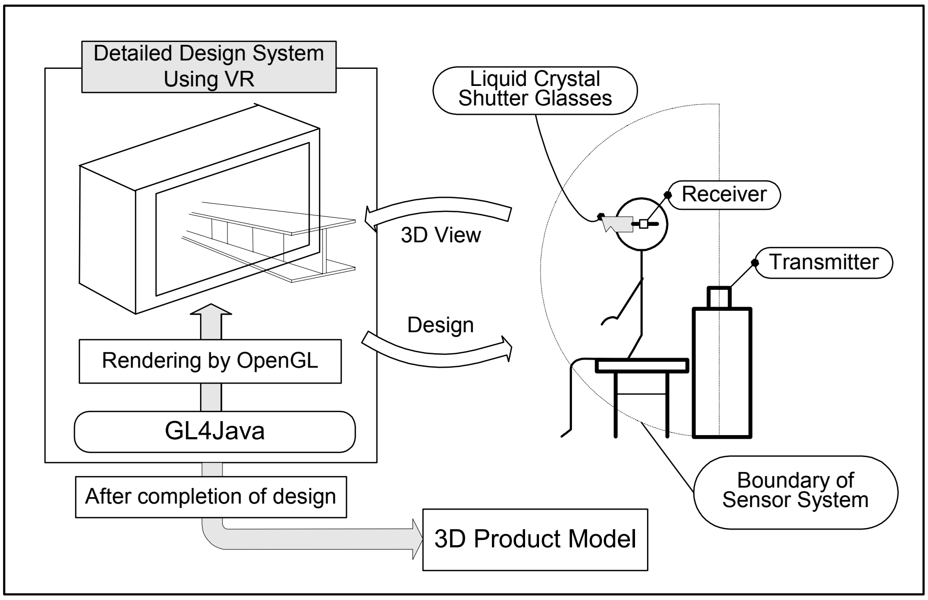

Fig. 4 Detailed design system using virtual reality

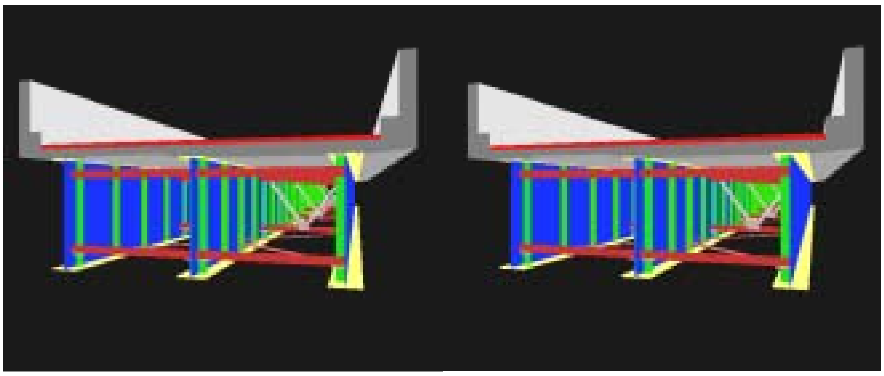

Fig. 5 Computer graphics images representing a steel girder bridge for left and right eyes

Fig. 6 A selected element of the design member is highlighted by changing its color from yellow to orange

Several students and engineers used this system for designing a steel bridge and they gave good comments on the system performance.

7 Conclusion

In this research, a design system using virtual reality was developed, and the previously developed Multi-Agent CAD system connected with product models was integrated with the new VR design system. The design environment using VR and Multi-Agents found to be effective by applying the prototype system to a design problem. Future issues include the improvement of the VR system and application of the system to other bridge design.

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