Title:
Modeling of the Bridge Spaces in the Bridge Maintenance Information Model for Displaying Inspection Results in Virtual Reality

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Introduction:
In recent years, there has been a growing trend toward using Information and Communication Technology (ICT) to maintain and manage civil engineering structures such as buildings and bridges to improve work efficiency. Much research has been performed on bridge maintenance as part of this trend. In one such research, we proposed a bridge maintenance management information model [5] by extending Industry Foundation Classes (IFC) [4], an international standard for Building Information Modeling (BIM).

Virtual Reality (VR) is one of these ICT technologies; however, when displaying bridges in VR, it was difficult to understand which elements were being inspected due to the characteristics of VR. Additionally, because bridges are enormous compared to people, it takes time to move to specific locations and check for defects. Since workers can recognize the inspection range by the span number, we propose defining the space above and below the bridge as a VR work area for each span and incorporating it into the information model in this study. Furthermore, when creating an Unmanned Aerial Vehicle (UAV) inspection plan, it is necessary to represent the surrounding area fully [1, 3], so we propose modeling the bridge's upper and lower spaces and its site information and incorporating them into the information model. Although this information has been discussed concerning Geographic Information Systems (GIS) [2], there is not enough discussion regarding the detailed structure. In addition, based on the proposed information model, we construct a system that supports viewpoint movement and obtaining viewpoint position in a VR environment.

Immersive VR display and the challenges of this study:
In this research, workers collect the information necessary for inspection by automatically measuring bridges using UAVs and then evaluate defects by observing bridges in an immersive VR environment. The immersive VR display allows the viewpoint to change as the user's head moves, making it easy to check the situation around the defects and to freely check the defects in a situation closer to the site. On the other hand, as shown in Figure 1, there are the following problems regarding movement and recognition of the viewpoint position:

- It takes time to move the VR viewpoint significantly between different spans to check for any defects;
- Communicating the viewpoint and UAV position to VR workers and other engineers in the VR space is difficult.

The bridge is enormous compared to the workers, so moving the viewpoint and understanding the position become serious problems. In order to solve the above problems, this paper proposes the following items:

- Defining the bridge space, which is the place where the VR viewpoint and UAV exist in the bridge structure;
- Implementing the function to move the viewpoint position to the specified bridge space and the function to display the bridge space where the viewpoint exists.

While there has been significant focus on the structural elements of bridges, there is a lack of representation for non-structural elements, such as space.

The advantage of representing the bridge space is that it allows workers to specify viewpoints easily, making it easier to inspect each span and communicate inspection areas. Bridge space provides helpful information when planning UAV flight plans. In this study, the bridge site and space are referred to as the surrounding area of the bridge. However, detailed modeling of the bridge site is a topic for future research.

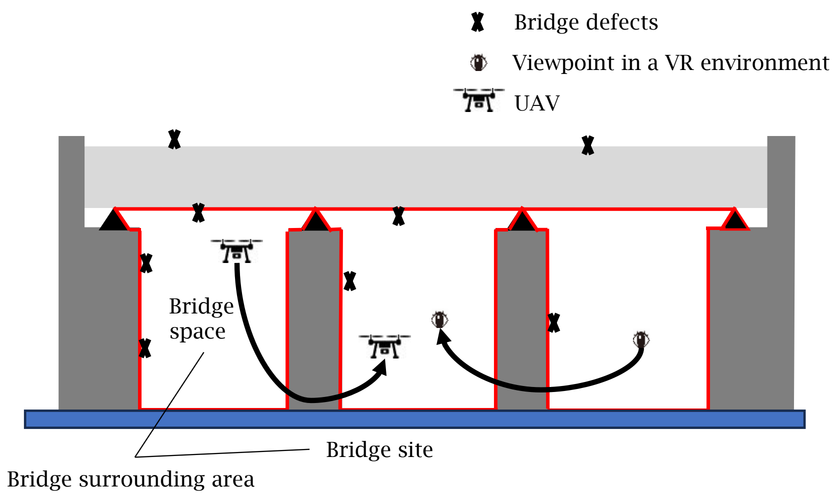

Fig. 1: Immersive VR display problems.

<u>Definition and representation of the bridge space</u>

Definition of bridge space and information requirements

In this paper, bridge space is defined as the spatial area occupied by the bridge other than the physical elements of the bridge. Figure 2 shows a schematic diagram of the bridge space. The bridge space has an upper and lower area corresponding to the superstructure and substructure of the bridge, respectively. The bridge space is divided into regions corresponding to span numbers. The information requirements for applying bridge space to VR are as follows:

- It is necessary to represent it as part of the bridge structure since the bridge space is a bridge component;
- It is necessary to represent information regarding its relationship with the connected bridge structure (such as the relationship between lower space 2 and Piers 1 and 2);
- It is necessary to represent the shape (boundary surface) to determine where the viewpoint is in the bridge space in the VR environment and implement the movement of the viewpoint, specifying the space.

We propose using IfcSpace, defined in IFC as a bridge space, to meet the above requirements.

In this study, the bridge space is used for VR displays, but future applications include representation of the operable area when using UMV.

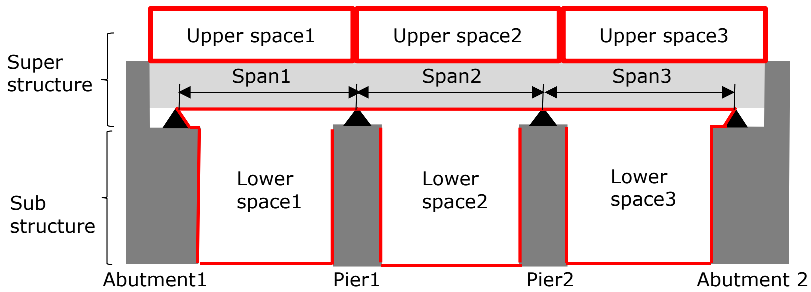

Fig. 2: Schematic diagram of the bridge space.

Spatial structure representation of bridge space using IFC

IfcSpace is an entity that represents the space itself in a building in IFC. Figure 3 shows a spatial structure representation of the bridge space using IFC. In this representation, the whole-part relationship (IfcRelAggregates) represents the bridge space as a part of the structure. The space boundary element relationship (IfcRelSpaceBoundary) is also used to represent the relationship information with the connected bridge structure. For example, the IfcSpace, which represents the upper space 1, is represented as a part of the superstructure by the whole-part relationship. The spatial boundary element relationship of that IfcSpace represents the relationship with IfcBridgePart, which is the superstructure contained in span 1.

The IfcSite is a defined area of land on which the construction is to be completed. The IfcSite is at the top of the spatial structure. The detailed model structure of the IfcSite is under development.

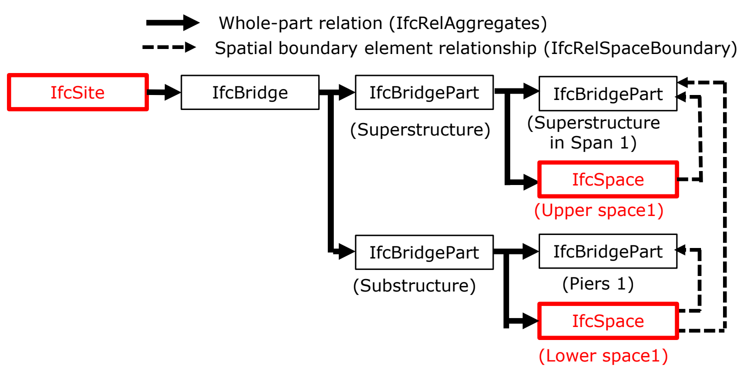

Fig. 3: Spatial structure representation of the bridge space using IFC.

Physical Structure representation of bridge space using IFC

Next, we explain the physical elements of the space element (IfcSpace). Figure 4 shows a physical structure representation of the bridge space using IFC. This figure is described using the EXPRESS-G diagram, a graphical notation of EXPRESS. Square boxes represent entities. The thin lines extending from the entity indicate the entity's attributes, and the thick lines indicate the inheritance relationship between supertypes and subtypes.

IfcProduct, representing the physical structure, and IfcSpace, representing the bridge space, are linked by IfcRelContainedInSpatialStructure. The IfcProduct is an abstract representation of any object related to a geometric or spatial context. IfcProduct has a subtype, IfcElement, which is a generalization of all components that make up a facility. IfcVirtualElement, IfcFeatureElement, and IfcGeographicElement are subtypes of IfcElement. IfcVirtualElement represents an element that provides imaginary, placeholder, or provisional areas, volumes, and boundaries. Typically, a physical element of IfcSpace corresponds to this entity. IfcFeatureElement represents a generalization of all existence-dependent elements that modify the shape and appearance of the associated master element. This entity represents the physical elements of an IfcSpace using a bridge element associated with the IfcSpace. IfcGeographicElement is a generalization of all elements within a geographical landscape. This entity can be used to represent the physical elements of the surrounding area, IfcSite.

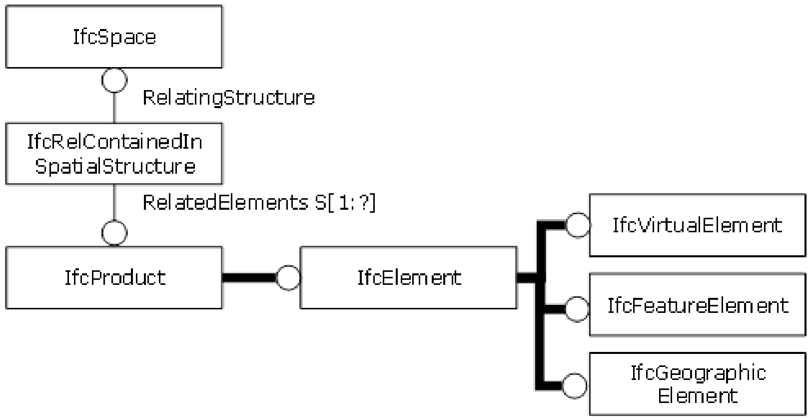

Fig. 4: Physical structure representation of the bridge space using IFC.

<u>VR system using the bridge space</u>

Overview of the VR system

The structure of a proposed VR system is shown in Figure 5. The bridge maintenance information model is created from an as-is bridge model obtained from measuring technologies such as Structure From Motion (SFM) and measured data such as photo images of the defects. The as-is model is segmented into bridge components. For simple bridge structures, the surrounding area, especially the bridge space, is automatically created based on the algorithm defined in the next section.

The VR display results of the bridge SfM data with a texture photographic image can be obtained from a web server using webXR technology and a VR device. The function for moving the viewpoint by specifying the bridge space is also implemented in this system. In this function, the viewpoint moves to the center of gravity of the spatial shape as a representative point where the entire bridge structure surrounding the bridge space is visible.

The function that shows the viewpoint position by text is also implemented. This function displays the name of the bridge space where the current viewpoint exists by calculating the viewpoint and geometric representation of bridge spaces.

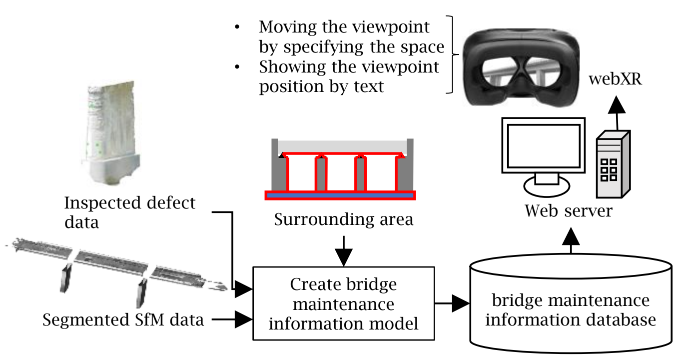

Fig. 5: Structure of a developed VR system.

In this study, the essential functions of moving the viewpoint and displaying the position of the viewpoint were implemented in the VR display system.

First, the viewpoint movement function is explained. The program sets up a selection menu in response to the number of spans contained in the bridge. Pressing the trigger button moves the viewpoint to the center of gravity of the space while the beam from Controller 1 is in contact with the menu representing the space to be moved. In this case, the center of gravity can be derived from the shape representation of the IfcSpace. The program can move to the viewpoint in the initial position at any time by pressing the trigger button on Controller 2.

Second, a function for displaying the position is implemented. Using a shape representation of the IfcSpace, this function evaluates which IfcSpace the current viewpoint is in and displays the name of the IfcSpace containing the viewpoint.

Shape representation of bridge space

It is necessary to represent the shape of the bridge space to satisfy the information requirements. If the bridge is a simple structure, the space of the bridge can be represented using a rectangular box placed parallel to the axes. In the IFC, such a box (axis-aligned bounding box) can be represented using the entity IfcBoundingBox.

The shape of the bridge space is derived from a detailed and precise bridge model. Figure 6 shows the derivation method for the space of the bridge. The maximum and minimum values of X and Y coordinates are extracted from the vertex coordinates of the superstructure included in each interval to create a rectangle surrounding the superstructure. The rectangle is then extended to the Z minimum of the substructure in the minus Z-axis direction, and a rectangular shape is created as the spatial shape of the bridge.

In this paper, the target of the bridge is a concrete girder bridge with a simple and limited geometry. Complex bridge shapes, such as curved bridges, can be represented by a representation_item other than IfcBoundingBox, but the modeling details are for future work.

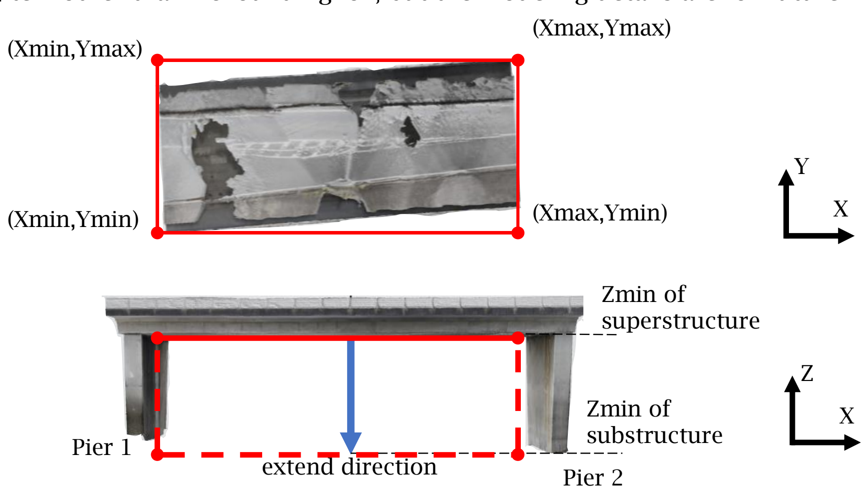

Fig. 6: Derivation of bridge space.

<u>Conclusions:</u>

In this paper, a bridge maintenance and management information model that can represent the space of a bridge is proposed to solve the problem of the immersive VR display for bridge inspection and maintenance.

In addition, we implemented a function to move the viewpoint using the bridge space and a function to display the viewpoint by the bridge space name, and we confirmed that it is effective for the problem of immersive VR display for bridge inspection and maintenance.

Future challenges include more accurately representing the shape of the bridge space and modeling the surrounding area of the bridge to represent the operable area of the UAV.

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