

## [Invited Paper]

Active inspection supporting system based on mixed reality after design and manufacture in an offshore structure<sup>†</sup>Jung-Min Lee<sup>2</sup>, Kyung-Ho Lee<sup>1,\*</sup>, Dea-Seok Kim<sup>2</sup> and Chung-Hyun Kim<sup>2</sup><sup>1</sup>Associate Professor, Department of Naval Architecture, Inha University, Incheon, 402-751, Korea<sup>2</sup>Graduate Student, Department of Naval Architecture, Inha University, Incheon, 402-751, Korea

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**Abstract**

When inspection is conducted in the fields of design and manufacturing, how well that inspection is carried out is as important as how well the design and manufacturing are done. It is important that we consider how well a product is inspected in the offshore industry because offshore structures are operated far from center of operations. This paper presents a fast and effective inspection system to guarantee product performance after the design and manufacturing process by using Mixed Reality (MR) and Ubiquitous Sensor Network (USN).

*Keywords:* Augmented reality; Inspection; Mixed reality; Offshore structure

**1. Introduction**

Offshore structures, especially floating production storage and offloading (FPSO), have a very dense and complex structural character [1] because the limited space inside the structure is filled with all the equipment required to drill crude oil. Once these structures start to operate in the ocean, all functions should be maintained in the right condition during the working period. Once any function stops, it may cause great loss to the ship owners and critical damage to the ship builder. The structural character of offshore structures makes it difficult to inspect the product and the operation together with the engineers, and this may be a critical problem that can hinder good operations in offshore structures. [2]

As the core technology that displays information overlapping with the real world (especially, the system we call Augmented Reality (AR), Mixed Reality (MR)) provides the possibility of a novel technology that makes presenting technical information to the user easy, such as 3D graphic computer-aided design (CAD) data. The Ubiquitous Sensor Network (USN), which is a current focus in the industry, can facilitate easier site operation. Therefore, we tried to bring these technologies to the inspection field of offshore structure to improve safety. In this paper, we studied these technologies and

suggested a system that could support prompt inspection by providing design information and current information to the workers on site. We also suggested the possibility of its implementation through a simple prototype.

**2. Related works**

Over the years, a variety of MR-based applications has been developed, and many industries have tried to build MR-based environments for their facilities and products. The automotive industry has been investigating driver/maintenance assistance system [3], user manual for user maintenance [4], and the idea of factory layout [5, 6] using interfering edge analysis [7] to improve manufacturing efficiency. However, nothing has been developed for the offshore industry, which this paper aims to rectify.



Fig. 1. Kinds of offshore structures: tension leg platform (TLP) and FPSO.

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\*Corresponding author. Tel.: +82 32 860 7343, Fax.: +82 32 864 5850

E-mail address: kyungho@inha.ac.kr

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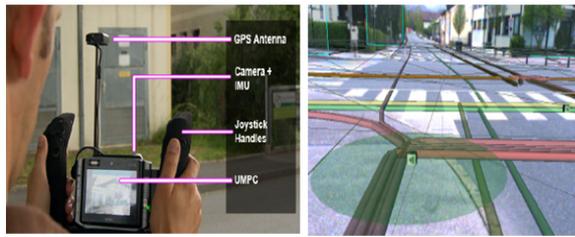


Fig. 2. Virtual redlining for civil engineering: ultra-mobile personal computer (UMPC) (left) and system demonstration (right).

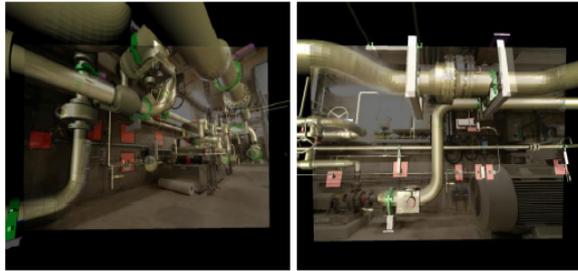


Fig. 3. AR-based application for discrepancy check.

### 2.1 Virtual redlining for civil engineering in real environments [8]

The term “redlining” is used for manually annotating either printed paper maps or a 2D geographic information system on a notebook computer taken to the field. When field workers of a utility company conduct outdoor tasks related to redlining, this system provides underground infrastructure information to workers, such as information related to electricity or telecommunication lines. From the results of this system’s evaluation, field workers clearly prefer 3D visualization to 2D. The depth perception of pipes is especially beneficial. Therefore conventional 2D information does not fully address workers’ needs compared with 3D information.

### 2.2 “Discrepancy check” procedure [9]

Construction companies employ CAD software during the planning phase, but the final product often does not match the original plan. The procedure of validating models is called “discrepancy check”. This system was designed in close collaboration with industrial partners for fast inspection of inconsistencies. As a complete software system, it guides the user every step of the way and allows someone with no knowledge related to Computer Vision or AR techniques to use this tool because expert knowledge is not required as shown in Fig. 3. In this system, the inspector can select the room to inspect and download the pictures from a database in the office instead of going to the site to measure and document a room. Based on the software, the user registers the image to the CAD coordinate system. When this is done, the inspector can start the inspection and select the 3D components (retrieved from the database) to be superimposed.

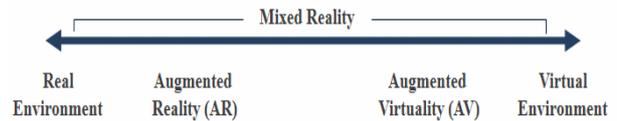


Fig. 4. Virtuality continuum [10].

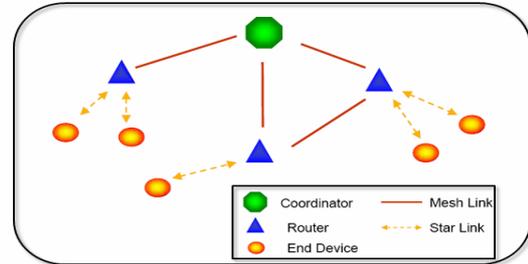


Fig. 5. Zigbee network.

## 3. Related technology

As shown from the related works, 3D model information and rapid remote support makes it easy for workers to work on site, especially in cases of high work complexity. MR can improve workers’ recognition when displaying 3D model data, in which reality and data overlap in the real environment depending on the user’s position. USN technology makes it possible for this information to be displayed on-site promptly.

### 3.1 Mixed reality and augmented reality

“MR” first appeared in the literature in 1994 when Milgram and Kishino published taxonomy and continuum to identify an emerging subclass of virtual reality technology called AR [10]. In MR, the “real world and virtual world objects are displayed together within a single display,” and when it is based on a real environment it is called “AR” as shown in Fig. 2 (right). Fig. 4 shows that AR is a subclass of MR and is entirely different from virtual reality. Virtual reality is the created virtual world that copying the real world while AR is the real world overlapped and displayed with virtual objects. At the point when information can be displayed in the real world, AR is very suitable for supporting engineers working in offshore structures. The benefits of AR have already been reported [11].

### 3.2 Ubiquitous sensor network

Recently, Zigbee-based USN has been spotlighted in industries. Zigbee is widely studied as a sensor network because of its low price, low power consumption, and the advantage that it can be organized as mesh topology. Mesh topology is beneficial because connections are stable even through obstacles such as walls or other instruments. If one route is blocked, the Zigbee sensor tries to find another route to the goal. Fig. 5 presents the conceptual Zigbee network configuration.

Therefore, the offshore industry has been trying to adapt these products because it is necessary to inspect for product

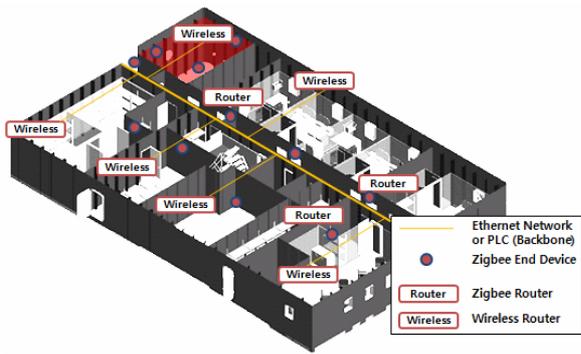


Fig. 6. Zigbee based wire backbone network.

safety regularly. Offshore structures work far from the center of operation and such structures are stressed periodically by wave force. Thus, frequent inspection is needed for the structure’s safety. The rising problem of building a wireless communication network on an offshore structure hinders data communication. Therefore, we adapted a “wire backbone network” based on an example partially tested in a real environment [12].

### 3.3 CAD data handling

For effective and accurate product inspection, workers need CAD information, such as drawings, 3D models, part’s information, and so on, especially to verify the design and manufacturing. However, there are several problems in using CAD information on-site.

First, the big model’s geometry data should be simplified to they can be sent to the site directly because it takes too long to transfer model information to the site if the size is big.

Second, we should be able to extract and manage geometry information, including 3D mockup and bill of material (BOM) information, for effective materials management.

Therefore, we also intend to determine how to simplify and manage CAD effectively. In this paper, we first introduce piping information retrieval from Smart Plant 3D (SP3D).

#### 3.3.1 Piping information retrieval from SP3D

SP3D is a full-3D CAD solution used in plant and ship building industries. Generally, models designed in 3D are useful in providing support for workers on site because 2D drawings cannot represent much information on paper. However, a 3D model can represent all feature information as they are. Therefore, an efficient handling of CAD information in our system can be effective in supporting workers.

To acquire freely the information we want, it is necessary that we be able to handle the database in our system. Fig.7 shows that an SP3D database consist of several few database sets: report, site, catalog, and model.

#### 3.3.2 Augmenting pipe information

Fig. 8 shows how this system is implemented. To display the augmented 3D model in a real environment, a marker is needed

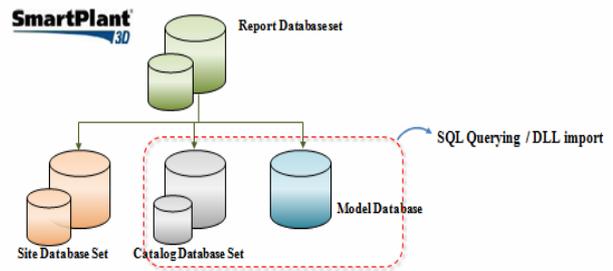


Fig. 7. SM3D database sets.

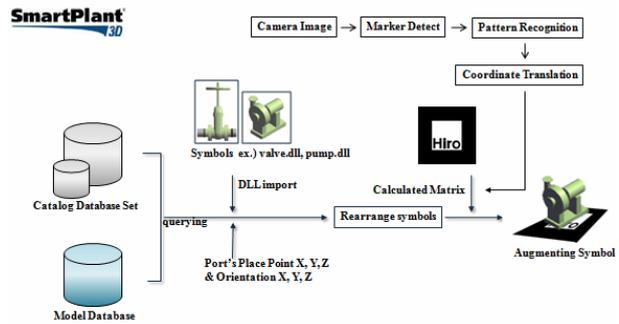


Fig. 8. Augmenting a 3D CAD model.

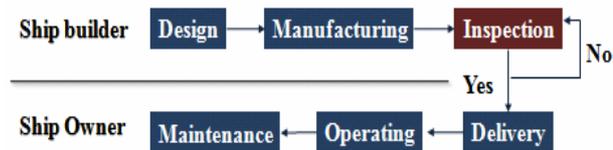


Fig. 9. Purpose of our system.

to decide how it will be displayed according to the user’s position.

Once the camera receives a real-world image, this system will try to find a marker and recognize a pattern that represents the unique model number. This system then operates certain matrix calculations to determine the model coordinate information depending on the user’s position. With the calculation result, this system can display the 3D CAD model and information.

## 4. Active inspection supporting system

Correct and efficient inspection is important after design and manufacturing when the system is in operation. As the product becomes more complex and has a higher value, how well we inspect the product determines its reliability in the same way we design and manufacture the initial system does. Fig. 9 shows a simplified representation of the purpose of the active inspection supporting system.

This system plays a role in helping with the inspection, in which all products are manufactured according to the design rules. For example, when an inspector checks the pipe if it has satisfied the design rules and matches the CAD information, this system displays the 3D CAD model information, promptly overlapping the real environment.

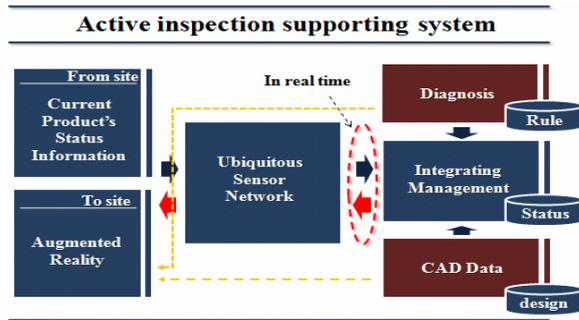


Fig. 10. Active inspection system.

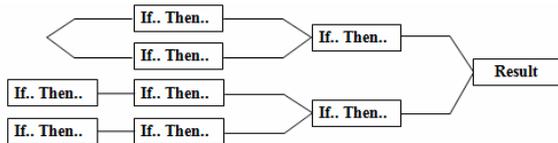


Fig. 11. Rule based decision making.

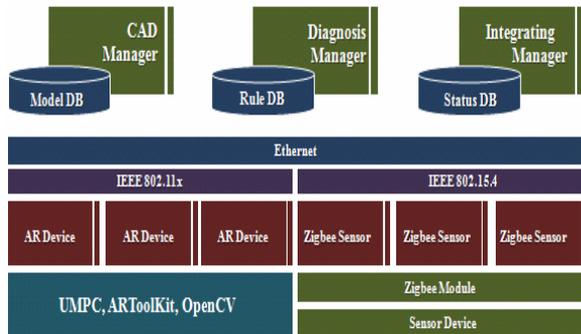


Fig. 12. system architecture.

**4.1 Active inspection based on rules**

As stated, an offshore structure has a complicated system of structural features. Therefore, if the system only provides a product’s status such as temperature or pressure, then it may not be helpful for the workers because if a problem arises, the solution should come quickly, and the problem should be corrected with proper handling. In the case of a pipeline, one problematic line could affect the entire system as every pipe line is connected to the others. Therefore, if we could provide design information specifically to the workers, for example 3D pipe modeling information or a pipe distribution diagram, then the system would be both attractive and beneficial. Active inspection could include a performance that could show the results of the diagnosis and the ways of dealing with the problem in real time. Fig. 10 shows the concept of an active inspection supporting system.

A diagnosis module consists of many rules such as “if... then...” It involves safety guidance or machinery operating manuals.

**4.2 System architecture**

We studied AR and USN to introduce them to our field. Fig.

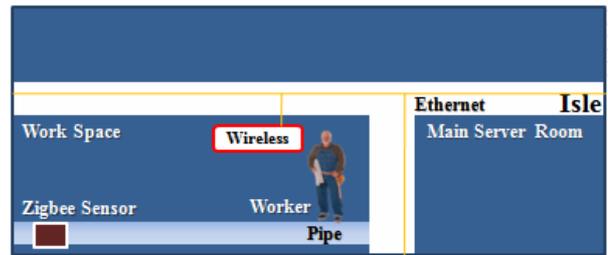


Fig. 13. Our test bed configuration.

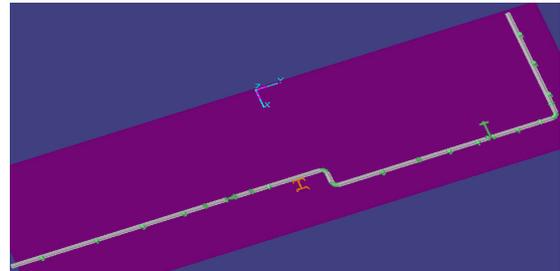


Fig. 14. SM3D Pipe line modeling.

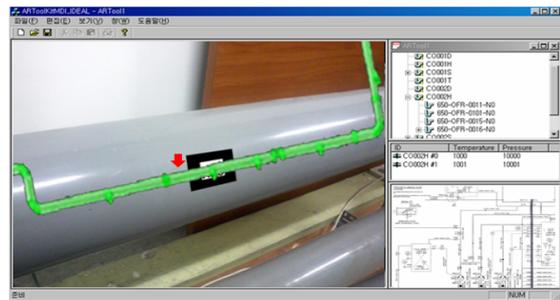


Fig. 15. Pipe inspection supporting prototype.

12 shows the system architecture for the active inspection on-site. We intend to use UMPC, because it is lightweight and easy to use.

The Zigbee sensor plays the role of periodically checking the pipe’s pressure and temperature and sending data to the integrating manager, which manages all products’ status data using the Zigbee protocol. These data are diagnosed by the diagnosis manager on whether the product is in the right condition or not. The result is sent to the workers on-site. If they request for 3D model information for inspection, then the CAD manager promptly sends the 3D geometry information to the workers on-site.

**5. Pipe inspection supporting prototype**

We have developed a pipe inspection supporting prototype, and we intend to investigate the potential of our application. The items to be displayed by this prototype are as follows.

1. Pipe’ temperature
2. Pipe’ pressure
3. 3D model to determine the pipe’ distribution
4. Diagnosis results

### 5.1 Prototype's scenario

We limited our work scope to pipe inspection. The scenario for the prototype is shown as follows.

1. Worker arrive holding a UMPC in front of the pipe to perform the inspection
2. The workers do not know the pipe's identification (ID) or status. If they want this information, they have to go to the location where the nameplate and gauges are located.
3. Instead of going there, they pull out the UMPC and point it towards the pipeline.
4. According to the pipe's ID, the system requests the status, 3D model data, and diagnosis results depending on the status.
5. Finally, the workers acquire the pipe information and begin working by following the instructions.

### 5.2 Test bed configuration and modeling

We could not test a real offshore structure; therefore, we built a test bed that simulated a real environment to evaluate this prototype.

One main server room and the work-space are surrounded by thick wall and steel doors. A wired backbone based USN network is installed between the server room and the work space; a wireless router that covers the work space is installed at the entrance of the work space. A pipe is installed in the work-space with a Zigbee sensor on it. We modeled a simple pipe-line using SM3D, as shown in Fig. 14. The system displays the 3D model and hierarchy information.

### 5.3 Prototype implementation

Fig. 15 shows the prototype implementation. This system is divided into four areas. As shown in the figure, the AR screen is placed on the left side and the pipe's structural hierarchy information and status information are placed on the right side.

A trial and interview was performed with three experienced field workers who confirmed the high potential of this system to save time and avoid error during inspection. According to the results of the interview, the significant advantage of this system is its capability in spatial display and in acquiring the status information of the product promptly anywhere on site. Therefore, the workers were able to inspect the pipeline easily and correctly by comparing the results with the CAD information, without any change in position.

## 6. Conclusions

It is important for any inspection be accurate and effective in guaranteeing product performance after the design and manufacturing process as well as during operation. This system could promptly provide 3D information and diagnosis results to workers depending on the current product's status on site based on AR/USN. Evaluation has proven that augmenting the 3D information about the product can help workers

understand a part's information for correct inspection. Further, the USN can help inspect products efficiently because all the required information is available, and it is possible to support this information anywhere in the structure. Although we have limited the work scope and omitted other variables, we believe this system can be extended fully to a real environment and can become novel technology helpful in increasing a product's reliability. In the future, we intend to study the methodology necessary to simplify the CAD design data for its use on site.

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**Kyung-Ho Lee** received his B.S. degree in Naval Architecture and Ocean Engineering from Seoul National University, South-Korea, in 1988, where he also obtained his M.S. and Ph.D. degree in 1990 and 1998, respectively. Dr. Lee is currently a Professor at the School of Naval Architecture Engineering in Inha

University in Incheon, Korea. Dr. Lee's research interests include Artificial Intelligence in Design, Simulation-Based Design, Data Mining, Evolutionary Computation, Ubiquitous, Augmented Reality, and product lifecycle management (PLM) in ship design.