Automated On-Site Quality Inspection and Reporting Technology for Off-Site Construction(OSC)-based Precast Concrete Members

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Abstract

Recently, Off-Site Construction (OSC) is being actively applied to improve productivity by efficient factory-based production method rather than on-site production.

In OSC-based construction process, problem is the accurate quality inspection for the members produced in the factory is carried out but the quality inspection for the members shipped from the factory and brought to the site is not performed properly. The existing problem in OSC-based Precast Concrete member site detection is on-site workers have to check the members directly, which is very time-consuming and expensive, and the detection accuracy is low. In addition, quality inspection is performed only in the unit of sample, not all members

This study classifies the major detection items of PC members by analyzing the importance of all the detection items of PC members based on the PC member quality checklist that workers have used for on-site detection of PC members.

The items that can automatically detect the damage of PC members are derived, and the types of damage necessary for the detection of each member such as deformation, crack, and wear are classified.

Then, in order to apply the automatic detection technique, the data according to the damage type is collected respectively, and the damaged part is automatically detected through the machine learning. The detected damaged area is reclassified according to the degree of damage. Finally, based on the degree of damage, the status of the member is automatically identified and automatically reported to the checklist.

Keywords –

Off-Site Construction(OSC); Precast Concrete member; Artificial Intelligence; Automated Quality Inspection

1 Introduction

1.1 Background and objectives of the research

Recently, the construction industry has introduced “Off-Site Construction (OSC)”, which is a factory-based production method, rather than an existing site-oriented production method, to increase productivity and efficiency of work and to enhance the competitiveness of the construction industry. OSC is a method in which members, parts, and pre-assembled parts are produced in advance in a factory, and then transported to a site where such construction materials will be assembled and building will be constructed. In the process of OSC-based construction, accurate quality inspection is performed on parts produced in factories. However, the exact quality test has not been performed on the members that have been transported from the factory and brought into the field. The existing problem in OSC-based PC member field test is that it takes a lot of time and money and the test accuracy is poor because workers have to test the members brought into the field after being checked with the naked eye. In addition, due to the lack of manpower in the field, only the sample units are being tested. Members shipped from the factory may be damaged or get defected during transportation to the site. Therefore, it is essential to test the quality of the imported material in the field. In order to detect the breakage or defect of the member, recently, studies on image-based defect detection, such as concrete cracking and surface defect detection of electronic components, have been actively conducted using one of deep learning technologies, the Convolutional Neural Network (CNN). In addition, several researches have been conducted on quality inspection automation support systems using mobile devices such as Smart phones and tablet PC to support efficient quality inspection and management of construction and buildings by field workers. Therefore, in this paper, research was conducted to support more efficient and accurate test of field workers on PC members brought into the site. The main concepts of the automatic quality test & reporting system presented in this study are as follows. First, it prevents errors that may occur due to the manual writing of the PC member test checklist that workers are using during the existing inspection. Second, it prevents the loss of the test checklist and the detection by the subjective judgment of the worker. Third, the test results are automatically recorded and saved in a quality checklist through a mobile device-based quality test system. Finally, it assists field workers to figure out the quality status of PC members according to damage criteria.

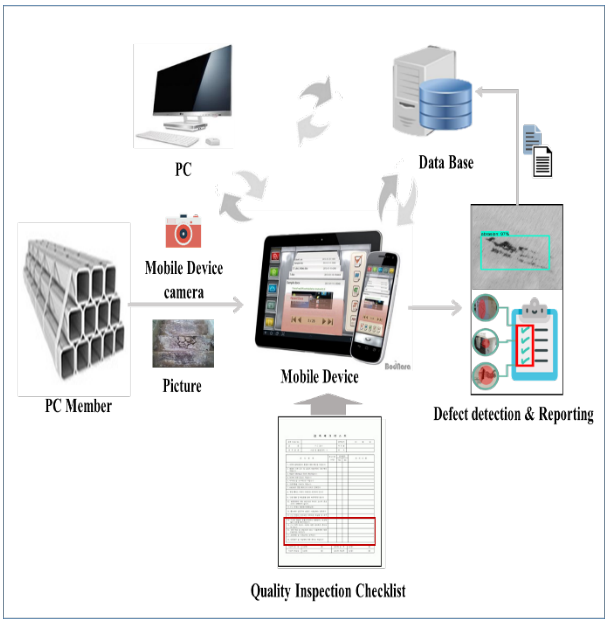

Figure 1. Conceptual diagram of automatic quality inspection reporting system

1.2 Study method and procedure

This study was conducted by the following procedures. First, the quality test automation support system using mobile devices such as Smart phones and tablet PC to support defect detection through AI technology-based image learning and efficient quality inspection and management of construction and buildings by field workers. Second, all test items in the collected PC member test checklist were analyzed to classify the main test items to be tested in the field. Third, when A.I technology is applied based on the main test items classified above, items that can be tested for member damage are automatically reclassified. In addition, the member's damage types such as breakage and cracks were classified to enable automatic defect testing of the member. Fourth, in order to apply AI-based automatic test technology, data according to the type of damage was collected and the member's damaged area was automatically detected through deep learning. In order to classify the detected damage sites in more detail, damage criteria according to the degree of damage were established. Lastly, the quality of the member is found according to the damage criteria, and a configuration diagram of an automatic quality test system based on a mobile device capable of automatic reporting is presented.

2 Analysis of previous studies

2.1 Automatic quality defect detection using A.I technology

In the past, quality test of structures or members has been performed by the operator's eyes. The quality test by the operator's naked eye takes a lot of work time and manpower, and the subjective judgment of the worker can be involved, so there is a problem of objectivity and reliability. Recently, to solve this problem, deep learning technology has been applied to perform more efficient and accurate quality tests on various objects such as concrete structures such as buildings, roads, bridges, tunnels, and electronic products. In order to perform such an automatic quality defect test, research on image-based defect detection using a convolutional neural network (CNN), one of deep learning technologies, has been actively conducted.

Kim[1] carried out a study to detect cracks in concrete ground structures by applying deep learning and image processing techniques.

Lee[3] re-learned Inception-v3, one of the deep learning neural network models, using concrete crack photography, and carried out a study to recognize and visualize cracks in concrete photography using the retrained model.

Jung[5] applied deep learning and image processing technologies to recognize cracks in concrete and conducted research on algorithms that testers can check for crack width and length information.

In Kim's research[2], deep learning models that are actively used in recent image analysis fields for image-based concrete crack detection are classified into four types (image classification model, object detection model, shape refinement model, and instance refinement model). This study compared and analyzed the performance of crack detection of representative models of ResNet-101, Faster R-CNN, DeepLab, and Mask R-CNN.

Choi[4] carried out a study on the detection of defects on the surface of electronic components by using a convolutional neural network (CNN) for the inspection of surface defects of electronic components with high detection difficulty and insufficient learning data.

As a result of analyzing the previous studies, most of the studies that automatically recognize or detect the presence or absence of a concrete surface defect on the existing structure or member have been actively carried out, but researches on automatic quality defect detection for quality testing of members are still insufficient.

Table 1. A.I-based automatic quality defect detection related research

Research area	Research subjects
CNN- based crack detection	Crack detection of concrete ground structures using deep learning and image processing techniques
	Visualization of information on the width and length of cracks in concrete using deep learning and image processing technology
CNN-based crack detection	Comparison and analysis of crack detection performance of deep learning models (ResNet-101, Faster R-CNN, DeepLab, Mask R-CNN)
CNN-based damage detection and classification	Detection of surface defects in electronic components using a convolutional neural network (CNN)
	Damage detection and classification of damage in sewer pipes using a convolutional neural network (CNN)

2.2 Automated quality inspection using IT technology

During test activities such as quality inspection, safety inspection, etc. for construction work or buildings, field workers should be familiar with various test information such as design drawings, specifications, and inspection items. They write the completed items directly on the checklist, and write a report after the test activity. In order to solve the inefficiency and inconvenience caused by the repetitive work of these workers, in recent years, workers in the field use a mobile device such as a Smartphone or a tablet PC during the test activity. For more efficient and accurate test quality test automation, several studies have been conducted.

Yoon[7] has established and prototyped a quality inspection system for the temporary construction, which is the basis for the development of an electronic work support system based on the construction test information, so that the quality of the construction work can be improved by accessibility of necessary information and the systematic inspection is performed through automation of inspection work. Research was conducted to develop the type.

In order to improve the efficiency of quality inspection, Choi[10] carried out a study on the development of a quality inspection system for a temporary construction in connection with BIM that can automate related tasks and systematically store and manage various quality inspection information.

In order to enable mobile devices to be used for safety during building safety inspection, Ko[6] carried out a research to develop a prototype for regular inspection of buildings by deriving the existing safety inspection practical problems and core required functions.

Oh[8] carried out a study to collect information on the quality inspection and defect management of apartments in real time using PDA and the web, and through this, it is an apartment quality inspection and defect management system that enables efficient business processing among related actors and support for generational history management.

Seo[9] carried out a study on the 'automated levitation railroad facility automatic inspection system'. to improve the maintenance efficiency and advancement of the magnetic levitation railway using the vision system, check the main inspection items of the track facilities, and automatically analyze the data to detect abnormal points and provide the user with location information of abnormal points.

As a result of analyzing the previous studies, the researcher found that several studies have been conducted on the quality inspection automation for the ongoing construction or completed facilities, but studies on the automation of the quality test to check the quality of the member to be assembled before construction starts, such as OSC-based PC construction are still insufficient.

Table 2. Automated quality detection using IT technology

Research area	Research subjects
Automated construction information management	Prototype research for development of electronic work support system based on construction inspection information
	Development of quality inspection system based on rule-based temporary construction in connection with BIM
Automated defect inspection	Development of prototype for periodic inspection application using mobile devices
	Development of PDA and web-based apartment housing quality inspection and defect management system
Automated Safety inspection	Development of Vision-based magnetic levitation railroad facility automatic inspection system

3 Analysis of PC Member Quality Checklist

3.1 Derivation of main inspection items for PC Member

In this study, a PC member test checklist was collected from a PC member specialist to develop automatic PC member quality test reporting technology.

The quality test of the PC member produced in the factory is based on the test checklist items as shown below. After the test is over, members with no abnormalities are brought to the construction site by a transport vehicle by attaching a test checklist. As the members brought into the site are likely to have been damaged or damaged during loading or transportation, so the field workers perform a quality test on the members one again. Workers carry check construction name, member code, manufacturing year, month, date, product inspection mark, crack,

Product Inspection Checklist

Checklist			Result: Girder	Result: Pillar	Result: Slab
Before Pouring	Mold	Horizontal x vertical x diagonal height x of the mold			
Before Pouring	Mold	Mold surface condition			
Before Pouring	Mold	Mold connection			
Before Pouring	Mold	Mold cleaning and de-oiling condition			
Before Pouring	Rebar	Rebar standard check			
Before Pouring	Rebar	Rebar spacing and quantity			
Before Pouring	Rebar	Check the end anchorage gap			
Before Pouring	Rebar	Checking the sheath after installing			
Before Pouring	Rebar	Checking the status of rebar bond (80% or higher)			
Before Pouring	Rebar	Check net spacing of main reinforcement			
Before Pouring	PL	Confirmation of the location and quantity of the purchase			
Before Pouring	CON'C	Concrete specification check	40Mpa	40Mpa	40Mpa
After demolding		Horizontal x vertical x length of the member			
After demolding		Check the location and quantity of Purchase			
After demolding		Checking deformation of members			
After demolding		Surface condition of the member			
After demolding		Displacement status of members			
After demolding		Purchase cleaning status			

Main inspection items

Figure 2. PC member quality inspection checklist

breakage, deformation, etc. in accordance with the PC Construction Standard Specification. Therefore, the main items to be tested in the field according to the specifications of the PC construction standard specification were classified as shown in the following figure2.

3.2 Deriving inspection items that can be measured using A.I technology

In order to support more efficient and accurate quality testing by on-site quality test workers, items that can be automatically tested for quality among the main items of the quality checklist derived above were classified as the following table3.

Table 3. Inspection items by A.I

Checklist	Check items
After demolding	Horizontal x vertical x length of the member
	Surface condition of the member
	Displacement status of members

4 Automatic quality inspection based on A.I

4.1 Classification of damage types and establishment of damage criteria

In this study, in order to check the surface condition of a member among testable items by applying deep learning technology, the member's damage type was classified into cracking and breaking. Later, in order to train the CNN model, which is one of the deep learning techniques, each image data of cracks and fractures was collected. The image data was secured through photographs of Google images and concrete cracks existing on the inside and outside walls, floors, and road surfaces of buildings. In addition, in the case of damage criteria for the quality condition of PC members, if the crack width exceeds 0.3mm based on the contents specified in the PC construction standard specification, it was classified as Class 1 crack, if 0.2~0.3mm, classified as Class 2 crack, and if 0.2mm or less, such fine cracks, it was classified as Class 3 crack. In the case of damage, the damage criteria was established by classifying the damage to the 1st class damage if the joint part was damaged by 200mm or more, the second class damage if the edge of the base plate was damaged, and the third class damages for other damages.

Table 4. Damage types and criteria

Damage Type	Rating	Rating criteria
Crack	Class 1	Crack width exceeds 0.3mm
	Class 2	Crack width 0.2~0.3mm
	Class 3	Crack width 0.2mm or less
Breakage	Class 1	Damage to joints over 200mm
	Class 2	Breakage of the edge of the bottom plate
	Class 3	Damage other than Class 1 and 2

4.2 CNN-based image learning and defect detection

After collecting the image data for each type of damage, the image was modified by resizing and labeling each image to enable image learning through CNN. Afterwards, image learning was performed using Faster R-CNN model, which has high test accuracy and high detection speed, among several CNN models. 500 images were used for training image data and 100 images were used for test image data. As a result of learning and testing of Faster R-CNN, it was identified that cracking and fracture recognition and detection are possible as follows. In addition, a study was carried out to enable detailed visualization of defects by applying an algorithm to visualize numerical values for the width and length of the crack.

The deep learning algorithm for automatic member defect test is largely divided into a stage of learning the damage image, a stage of extracting the damage feature (length and width of the crack), and a stage of visualizing the damage information. Defect detection is visualized through the calculation of the pixel for the damaged part and the damage type detection through the Canny Edge Detector in the damage feature extraction step. Based on this, member quality test results are output along with the check of the test checklist items.

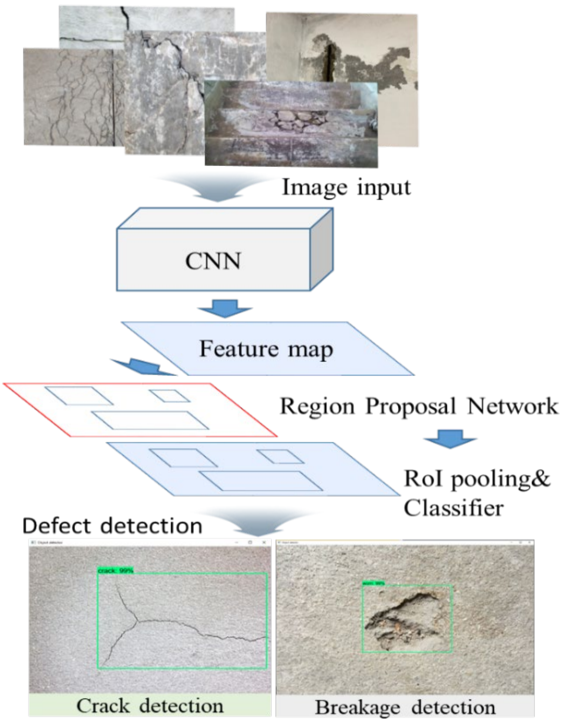

Figure 3. Automatic crack and breakage detection

5 Automatic quality inspection reporting system

The configuration of the automatic quality test reporting system is as follows. First, set the member to be tested. Second, run the camera App mounted on the tester's mobile device to take an image of the target member. Third, defects are detected and visualized through image analysis. Fourth, after a

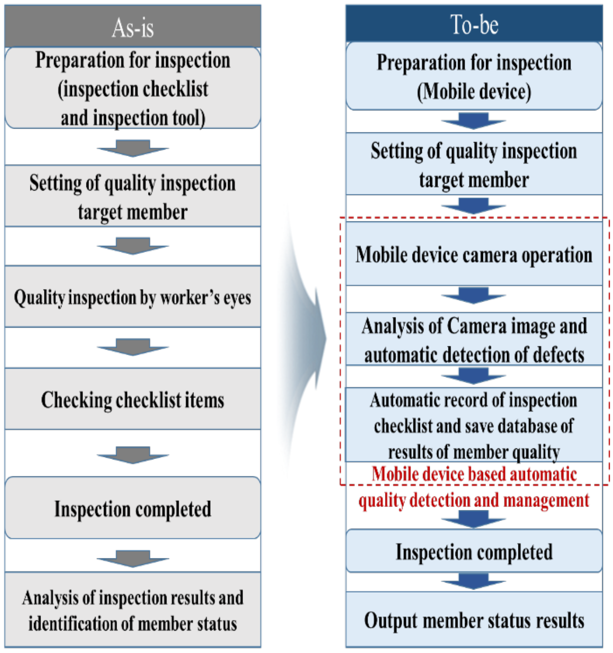

Figure 5. As is – To be Process of Quality Inspection Work

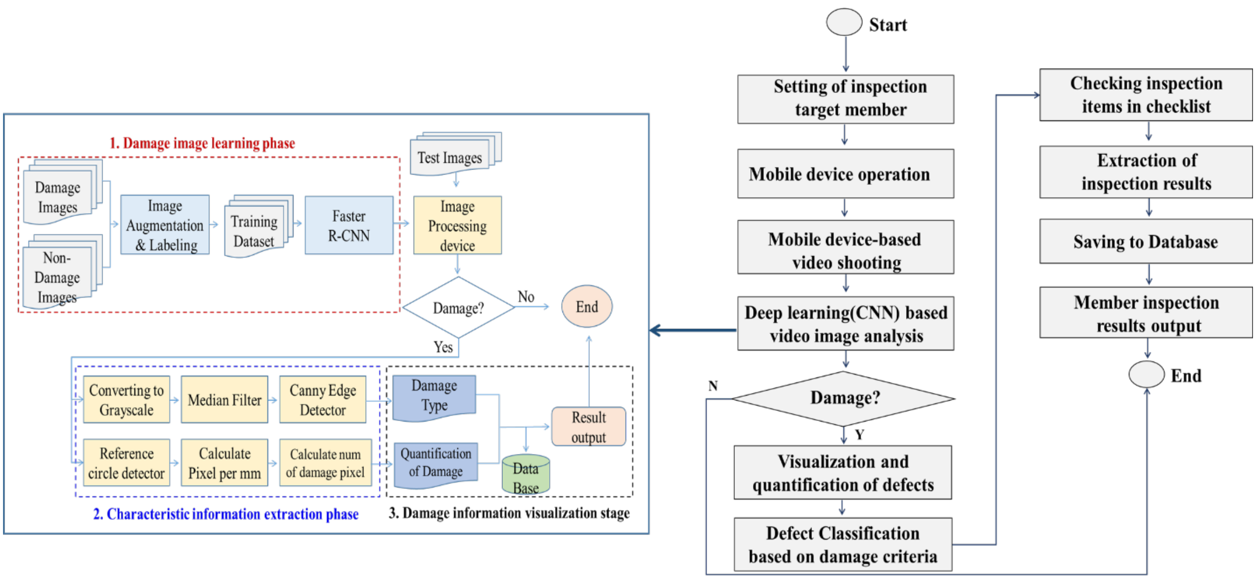

Figure 4. Member defect automatic detection algorithm

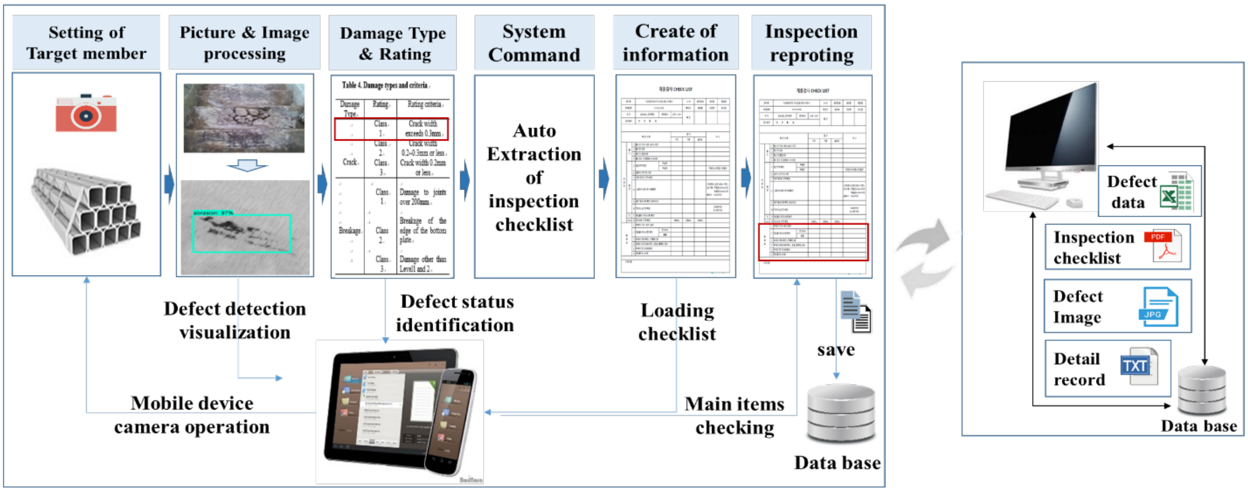

Figure 6. Automatic quality inspection reporting system

defect is detected, a test checklist is automatically loaded in the mobile device system. Finally, the main items in the checklist are checked. After the check is completed, the test checklist file is saved in the database. Test related data can be converted into file formats such as xls, pdf, jpg, txt, etc., and shared and stored in the worker PC.

Therefore, it is possible to automate member damage detection and test checklist inspection through a mobile device-based automatic quality test reporting system.

6 Conclusions

In this study, the researchers proposed an automatic quality test reporting technology to increase the test efficiency and accuracy of field quality testers for OSC-based PC members. In order to implement the automatic quality test technology, the damage type of the PC member was classified into cracks and breaks, and image learning was conducted using the deep learning model Faster R-CNN. In addition, damage criteria were established based on the PC construction standard specifications to figure out the quality status of PC members. Through the automatic quality test reporting technology of this study, on-site testers can more easily detect damages such as cracks and breakages of PC members, and finally identify the member status according to the damage criteria.

In the future, in order to complete the automatic quality test reporting technology suggested in this study, it is necessary to add a process of technology verification and feedback with workers through practical system development and field application. In addition, since this study only discovered cracks and breaks on the member surface when applying A.I technology, it is expected that the quality test method for the deformation of the member itself, such as bending or warping of the member, can be completed through further study.

Acknowledgment

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