Applying Augmented Reality Technique to Support On-site Rebar Inspection

H.W. Hsu[a], S.H. Hsieh[a]

[a]Department of Civil Engineering, National Taiwan University, Taipei, Taiwan
E-mail: r05521605@ntu.edu.tw, shhsieh@ntu.edu.tw

Abstract –

Rebar inspection plays an essential role during construction phases to assure the safety of the construction. Usually, inspectors use 2D drawings and tape measures to inspect rebars. However, the effectiveness of the inspection is greatly hindered by indirect three-dimensional information in 2D drawings and visual obstruction of measuring by rebars, especially when the structural elements become more complicated. To address these issues, this paper proposes an Augmented Reality (AR) approach to assist rebar inspection, which includes a framework of inspecting rebars with AR models. An experiment on stirrup inspection is conducted to evaluate the benefits of the AR approach by comparing with the traditional method. The result of the experiment indicates that the AR approach takes shorter time for inspection but with less precision.

Keywords –

Augmented Reality; Rebar inspection; On-site inspection

1 Introduction

The inspection work is one of the most important parts during construction phases. This process assures the quality of construction. In most construction projects, rebars account for a great part of the construction inspection among all the inspected elements. The efficiency of rebar inspection works is influenced by two main factors. The first one is indirect 3D information retrieval from 2D drawings. 2D drawings are still commonly used in most construction projects but do not present 3D information clearly, often leading to information missing. The other one is the measuring tool used for length measurement. Mostly, inspectors use tape measures to check whether the rebar is in accordance with the 2D drawings. However, the tape measures need to be aligned to the specific rebar, which is probably obstructed by other rebars.

Augmented Reality (AR), a technique which allows the user to superimpose virtual information on the real environment, has showed its potential to be applied in the field of architecture, engineering and construction industry [1]. Webster et al. pointed out that AR could be used to provide an inspection guide for inspectors without the use of drawings [2]. Therefore, AR becomes a promising solution to address the aforementioned issues and an AR-based rebar inspection approach was developed in this research to improve the efficiency of rebar inspection. A case study was conducted to evaluate the feasibility of the approach.

2 Literature Review

Many attempts have been made with the purpose of inspection based on AR. Chung et al. [3] conducted an experiment on thickness inspection of manufactured parts, using the instruction and sequences in forms of manual, computer-aided and AR-aided methods. The experiment was taken at fixed location to ensure the superimposition of AR information. The results showed that different forms of information did not affect the accuracy apparently; however, the completion time of AR-aided method was faster than others. Moreover, the augmented information was unaffected by the part shape complexity, proving the benefits of conveying information to inspectors. Shin and Dunston [4] developed an AR prototype system for steel column inspection, including the deviation of position and plumbness. For tracking the deviation of position, the users had to manually move and rotate the virtual model to match the real one and the system would report the value of deviation. Compared to the use of total stations, the AR approach showed time-saving advantage but lost a little precision. However, the system was said to be lab-based and not yet developed for on-site inspection applications. In 2017, Zhou et al. [5] applied marker-based AR techniques for the inspection of tunneling construction. Markers were used as the coordination of the virtual segment models during the inspection of the segment displacement. Similarly, the AR-based method took less time than the conventional measuring method and met the precision requirements. However, the number of the attached markers would be a problem in practice.

Learning from some design of AR inspection methods in previous research [4-5], this research proposes a marker-less AR-based approach that uses model-based superimposition of the virtual and real objects for rebar inspection.

3 AR-based Rebar Inspection Framework

3.1 The Framework

This research proposes an AR-based rebar inspection framework for solving current on-site rebar inspection issues. It consists of three main modules: motion tracking module, inspection module, and interaction module, as illustrated in Figure 1.

First, we need to have the Building Information Modeling (BIM) models of the on-site structural elements constructed during the design phase. Then, these BIM models are transformed into AR models which retain necessary geometry and non-geometric information for specific inspection items of rebars. Second, inspectors use devices like a mobile phone equipped with video camera to capture the on-site scene and target rebar. To fix the virtual coordinates of rebars while the camera is moving, the motion tracking module, which uses the feature descriptor technique from Google ARCore, increases the precision of position and rotation calculated by the Inertial Measurement Unit (IMU) in devices [6]. This process includes the transformation of global coordinates, camera coordinates, screen coordinates, virtual coordinates, and virtual camera coordinates, which are mainly derived from the pose estimation technique [7]. Besides, ARCore offers the function of detecting real horizontal planes from the photo images. This function is used for anchoring the virtual rebar objects on the real ground plane and minimizing the inaccuracy caused by the IMU.

After that, the user is able to retrieve information from the models, adjusts its position, switches layers of objects, and annotates problems through the interaction module. Last, the inspection module allows the user to transform the target rebar model into a simplified form used for inspection. The forms are based on the type of rebar and the items that are going to be inspected. This process prevents the inspector from the visual obstacle of the whole virtual model, which supports the inspector to focus on one item to be checked. Because of the length limitation of this paper, only the inspection module will be discussed in detail with the case of stirrups in the next section.

3.2 Inspection Module

For proper use of the AR models in the inspection work, the inspection module transforms the rebar model into different forms based on the types of the structural elements and rebars. In this research, we consider four main types of structural elements in the inspection module: columns, beams, slabs, and walls. Columns and beams have columnar rebar combination in their structure; in contrast, walls and slabs have planar rebar combination. This research concludes the BIM model parameters for general rebar inspection of these four elements, as illustrated in Figure 2. Columns and beams consist of main bars, stirrups and tie bars. The parameters of the main bar are size, length, hook length, and splice length. Stirrups and tie bars have the same parameters that are size, spacing, and total number. As for walls and slabs, the rows of rebars have two directions, and each row has its parameters which are size, spacing, and total number.

Considering the complexity and size of the rebar model, this research adopted only some of these parameters for prototyping, as showed in Figure 2. This

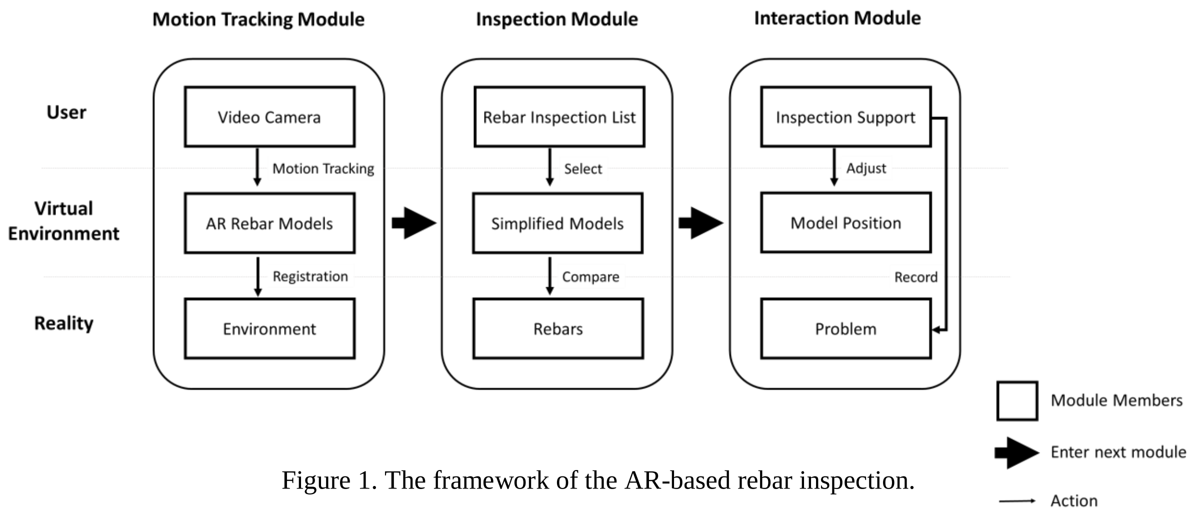

Figure 1. The framework of the AR-based rebar inspection.

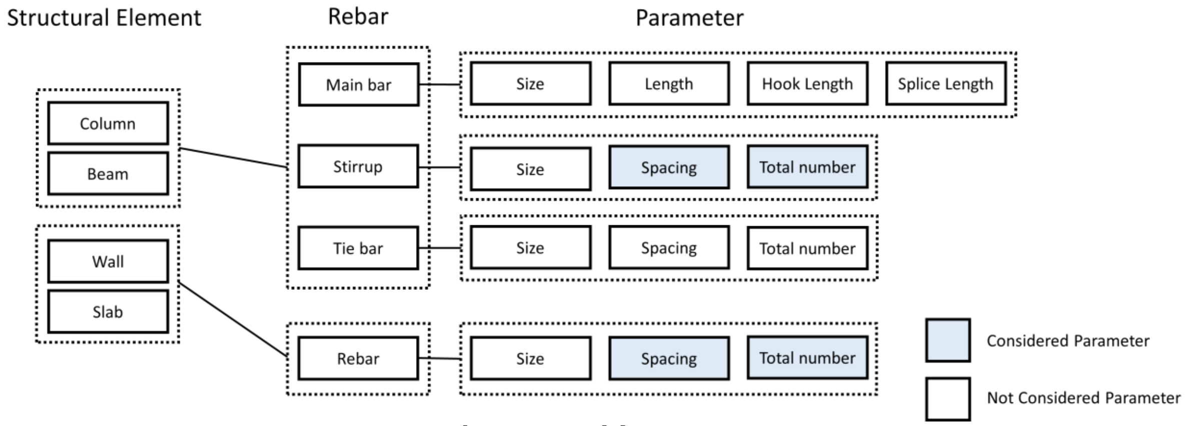

Figure 2. Rebar BIM model parameters.

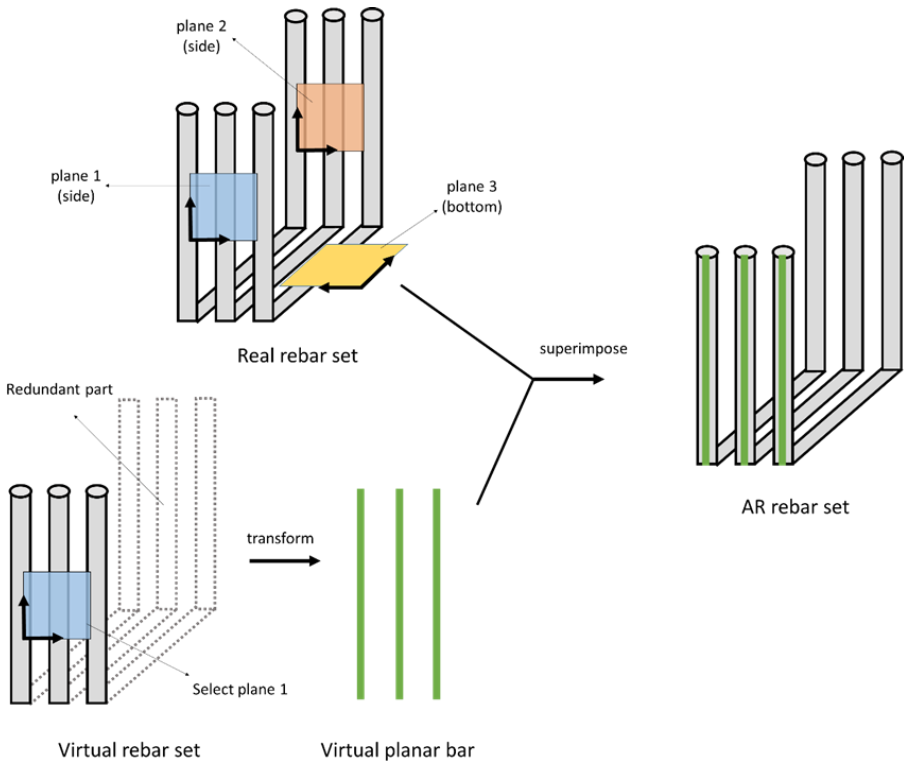

Figure 3. Spacing inspection for rebar sets.

form of AR model is called spacing check which is used for checking the spacing between the stirrups, rebars of walls and rebars of slabs. The size parameter was not used in the inspection on amount and spacing. Besides, this inspection can be implemented on each of the planes on rebar set as shown in Figure 3. Thus, this research transforms the original rebar into a planar bar on the plane facing the inspector. By doing this, the redundant part of the rebar model can be removed, remaining the planar bar representing the center line of the rebar.

When inspectors determine to check the spacing and amount of a specific rebar set, the first rebar in the rebar set will be used for duplication of the rest rebars in the form of planar bar objects. Each of the clones shifts a spacing distance along the same side plane of the rebar set. Through comparing the augmented planar bar with the real rebar, the inspector can check whether the real rebar is far from the correct position where the corresponding planar bar aligns or the rebar set has the wrong total number of rebars.

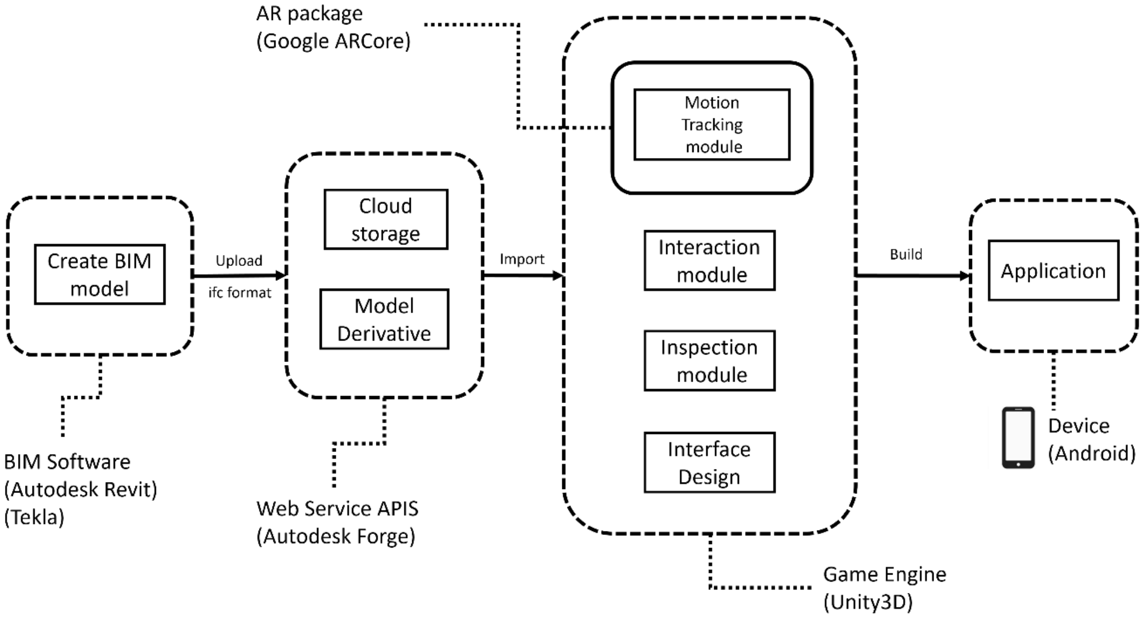

Figure 4. Application setup of the AR-based rebar inspection workflow.

4 Case Study

A case study was conducted to investigate the benefits of the proposed AR approach on stirrup inspection. The implementation of a prototype application system, the setup of experiments in the case study, and the results are discussed in this section.

4.1 Application Setup

To implement the AR rebar inspection framework, different software and packages have been adopted in this research. The process from input to output can be divided into four parts as illustrated in Figure 4. First, Autodesk Revit and Tekla are used as BIM model authoring software to create BIM models. Then, the models are exported to the format of Industry Foundation Classes (IFC) files because of the format's high interoperability. Second, the IFC files are uploaded to the cloud storage of Forge, which is a cloud-based developer tool from Autodesk Inc. Next, to import the model to the Unity 3D game engine, this research uses Forge AR/VR Toolkit to transform the BIM models into Unity 3D game objects that retain both the geometry and information from the original models. Third, this research uses C #, which is an object-oriented language based on the .NET framework, to program AR rebar inspection modules in Unity 3D. To build the AR environment, the Unity package from Google ARCore is adopted. Finally, the application is built on the device powered by the Android operating system.

4.2 Experiment Setup

To test the usability of the application prototype, this research adopted a precast beam as the target. The rebar model was created with Autodesk Revit according to its 2D drawings from the precast factory. In that process, the detail of the rebar model was simplified in order to decrease the data size. The finished model is showed in Figure 5.

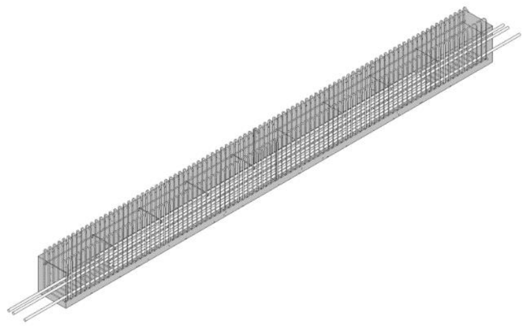

Figure 5. Test BIM model of a precast beam.

The total length of the precast beam is 9,190 mm, and the width by depth is 600 mm x 674 mm. The parts of the rebar tested with the inspection module are stirrups. The total number of the stirrups is 92, and its spacing is 100mm. The center-to-center distance can be expressed as (45 x 100 + 1 x 30 + 45 x 100). To match the model effectively, the origin point in the game engine is set to be in front of the beam section.

After the model was built, an experiment was conducted to evaluate the benefits of the AR approach. The subject was a civil engineer working in a precast factory and having good experiences in inspecting the rebars of precast structural elements. The task for the engineer was to inspect the total number and spacing of the stirrups using both the traditional manual method and the AR method with an Android phone. The inspection standards of both methods were judged by the inspector. The manual method for measuring stirrup spacing is to count the number within a section of one meter. Normally, inspectors sample two sections for inspection; on the contrary, the AR method inspects stirrups one by one. The picture of the stirrup is shown in Figure 6.

Figure 6. Stirrups of the precast beam.

4.3 Results and Discussions

The results of the experiment are shown in Figure 7, where t0 is the duration for the setup, t1 is the duration for the stirrup inspection, and sum is the total duration, which is the summation of t0 and t1.

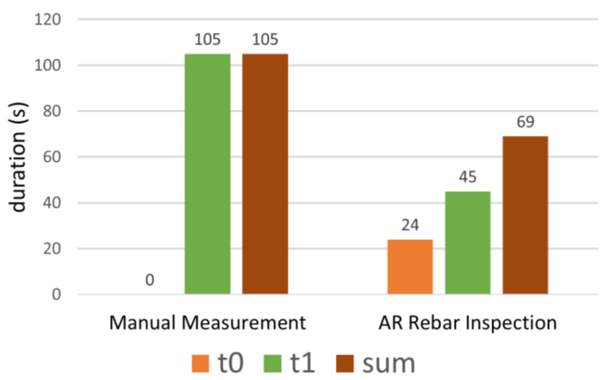

Figure 7. The duration of the manual measurement and AR rebar inspection in the experiment

At first, this research assumes that the setup time for manual measurement is zero because the tape measure and 2D drawings are handy for the inspectors. Thee setup duration for the AR approach is the time for matching the virtual model and the real rebar set. The snapshots of this process are shown in Figure 8. In this case, the inspector adjusts the model from each of the x, y, and z axis one by one to complete the matching task, which takes most of the time in this duration.

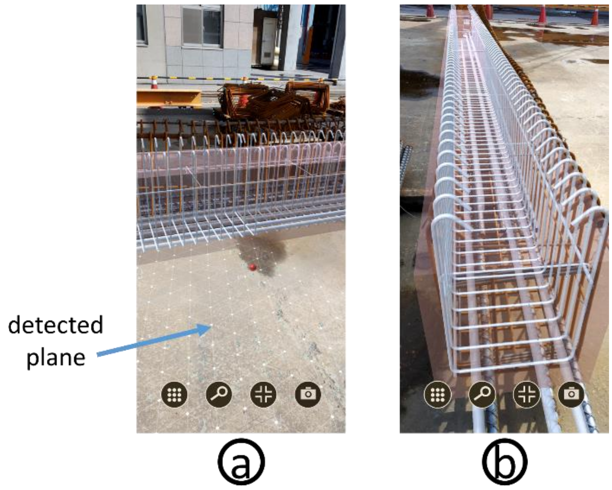

Figure 8. Snapshots of the AR-supported rebar inspection application in the setup duration. (a) Virtual rebar registration. (b) Position adjustment

As for t1, Figure 7 shows that the AR-supported spacing inspection for the stirrup takes much less time than the manual method. In the manual measurement method, the inspector counted the total number of stirrups, and then took two sections to inspect spacing, taking 65 seconds and 40 seconds, respectively. On the other hand, the AR method took almost half of the time to finish the inspection task because inspection on the number and spacing were carried out concurrently as showed in Figure 9. The correct amount of the stirrups can be easily checked. If the deviation between the real stirrups and the virtual planar bars becomes too big during the inspection, inspectors can easily infer that the total number of stirrups is not correct.

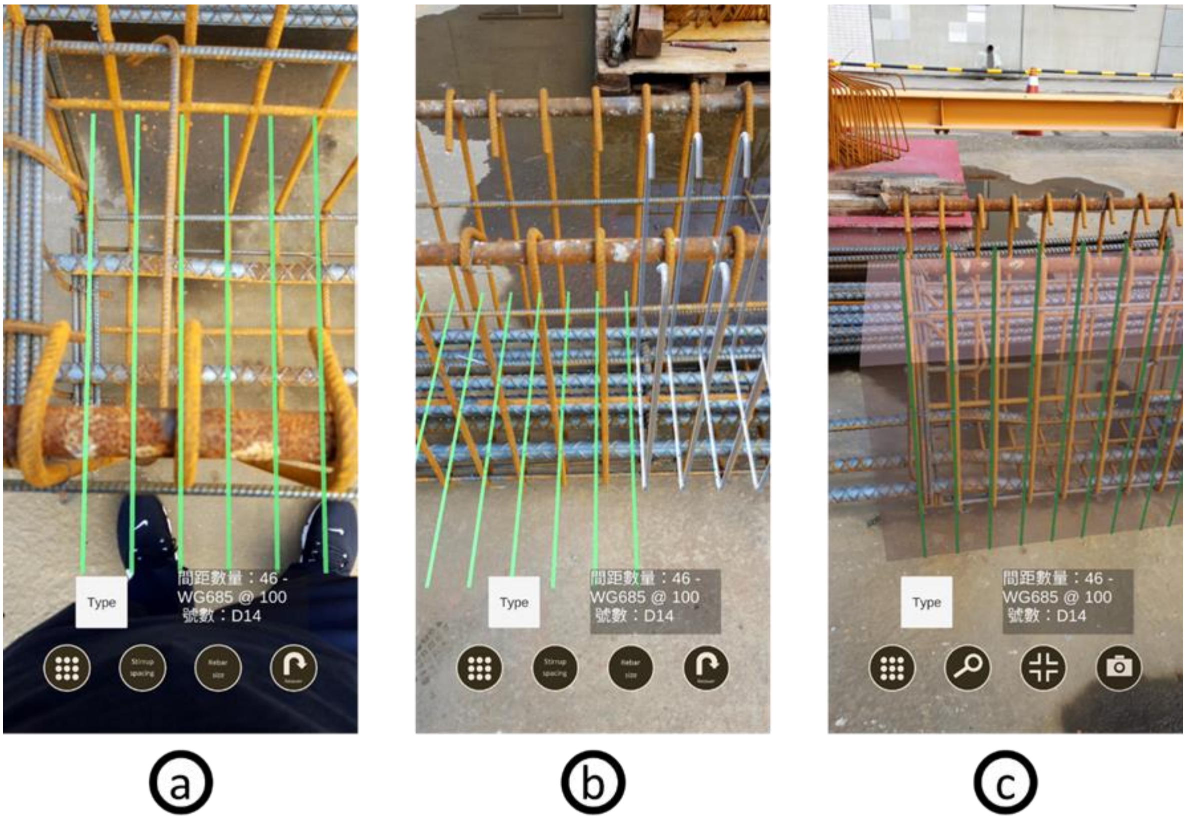

Figure 9. Snapshots of the AR-supported rebar inspection application in spacing inspection task. (a) On the left side of the stirrups, planar virtual bars are superimposed well on the bottom part of the stirrups. (b) In the middle of the stirrups, stirrups have a little deviation from the planar virtual bars. (c). The orientation of the planar virtual bars is changed to superimpose vertically on the front side of the stirrups

5 Conclusion

This research investigated an AR approach for assisting rebar inspection. The approach devised a framework that includes three main modules to facilitate the inspection task. A proof-of-concept experiment was conducted to validate the framework, especially the inspection module. The experimental results showed that the AR approach was 50% faster than the traditional approach in spacing inspection and with sufficient accuracy, proving the potential of using AR for rebar inspection.

However, it should be noted that some conditions have been controlled in the inspection test. For the tracking module, the quality of images captured from different environments may affect the accuracy of the tracking. In the experiment of stirrup inspection, the spacing is a constant, which cannot sufficiently prove the practicability of the inspection module in the AR approach. The user better faces right toward the side plane of the target stirrup so that the AR inspection would not be affected by viewing angles. Also, a proper distance from the target stirrup for the AR approach should be defined but needs further investigation.

There are still rooms for improvement on the proposed AR approach for rebar inspection. The experiment was conducted on a precast beam in a precast factory and the design of the inspection module has not considered all possible real circumstances in rebar inspection. For example, the structural elements in construction sites may be different from the tested one. Also, more inspection items like hooks can be considered in the future work.

References

[1] H. L. Chi, S. C. Kang, and X. Wang. Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. *Automation in Construction*, 33:116–122, 2013.

[2] A. Webster, S. Feiner, B. Macintyre, W. Massie,

and T. Krueger. Augmented Reality in Architectural Construction, Inspection, and Renovation. *Proceedings of the Third ASCE Congress on Computing in Civil Engineering*, Anaheim, CA, USA, 1996

[3] K. H. Chung, J.P. Shewchuk, and R. C. Williges. An Application of Augmented Reality to Thickness Inspection. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 9(4):331–342, 1999.

[4] D. H. Shin and P. S. Dunston. Evaluation of Augmented Reality in Steel Column Inspection. *Automation in Construction*, 18(2):118–129, 2009.

[5] Y. Zhou, H. B. Luo, Y. H. Yang. Implementation of Augmented Reality for Segment Displacement Inspection during Tunneling Construction. *Automation in Construction*, 82:112–121, 2017.

[6] Google ARCore Fundamental Concepts, https://developers.google.com/ ar/discover/concepts, Accessed: 12/12/2018

[7] H. Kato and M. Billinghurst. Marker Tracking and HMD Calibration for a Video-Based Augmented Reality Conferencing System. *Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99)*, pages 85–94, San Francisco, CA, USA, 1999.