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Proposal of the Use of Differential Render in Rebar Inspections

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Abstract

In Japan, the number of people working in construction has been decreasing yearly since peaking in 1997 because of the declining birthrate and aging population. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is promoting i-Construction, which aims to increase productivity by using ICT (Information Communication Technology) across the entire construction industry. In particular, the use of ICT is expected to be applied to the inspection of reinforcement rebars, which form the basis of all concrete structures, as the inspection of reinforcement bars has become stricter due to the influence of the structural calculation falsification problem that occurred in 2005. The existing methods use image triangulation to obtain a 3D point cloud of the rebar surface, so depending on the lighting conditions and the arrangement and shape of the rebars, there are some sites where it is not possible to obtain enough point clouds, and thus the range of application is limited. This paper proposes a method for using rapidly developing differentiable rendering technology for rebar inspection. Since differential rendering makes it possible to reproduce free viewpoint images, the rebar can be inspected even if the distance to the rebar surface cannot be directly measured, as long as the appearance of the rebar can be reproduced in 3D space. Image inspection can be expected to become more versatile than before. This paper reports on the evaluation of accuracy and systematization schemes.

1 Introduction

The influences of the declining birthrate and an aging population have been enormous in the Japanese construction industry in recent years. As shown in Figure 1, by 2023, the number of people aged 55 and over will be around 36%, and those aged 29 and under will be around 12%. Compared to all industries, the number of young people in the construction industry is decreasing, and the population is aging. The aging of the working population is inevitable, and the number of young people entering the workforce is also expected to decline, so there are further concerns about the weakening of the construction workforce. For this reason, it is necessary to promote the recruitment

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of young people and ensure a smooth generational shift through their retention, as well as to effectively pass on the skills, know-how, and tacit knowledge backed by the experience of skilled workers, which is an issue on construction sites, and to ensure quality. In addition, further use of ICT (information and communication technology) is attracting attention to maintain and improve productivity through improving construction technology among the limited number of workers.

The Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) is promoting i-Construction, which aims to improve productivity at construction sites by using ICT and other technologies in all processes, from surveying and measurement to design, construction, and maintenance management. By consistently using 3D data, it is possible to automate the calculation of construction volumes and to understand and inspect the situation on-site using the data. Since many manual tasks, document creation, and checking are not required, labor savings and shorter construction periods can be expected. In this context, one of the items that MLIT and related companies focus on in this context is the inspection of the reinforcement of steel rebars at construction sites.

At existing construction sites, inspections of reinforcement rebars are carried out as shown in Fig. 2 (left), based on the items listed in the guidelines and other documents set out by MLIT. However, visual and manual inspections are still the norm despite the large number of inspection items. Including the time spent preparing inspection reports, the issue of a significant amount of time and effort required by many workers is raised. As a response to these issues, there are some cases where full-scale operation has been carried out since July 2023 (MLIT, 2023) to reduce the labor required for checking the reinforcement bar layout using digital data by measuring the spacing, number, diameter, and cover of the reinforcement rebars, etc., through analysis of images taken with a digital camera, and confirming the layout of the reinforcement rebars in the structure.

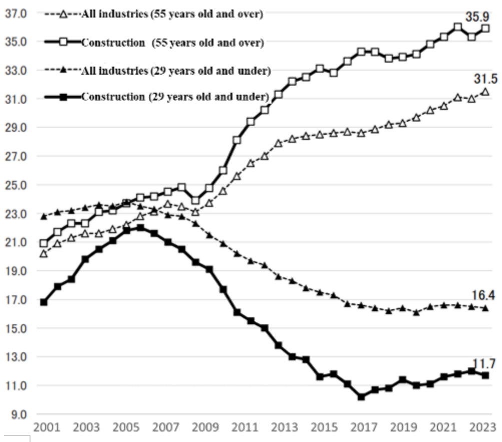

Figure 1: The aging of the construction workforce
(Japan Federation of Construction Contractors (2023))

2 Related Work

Morimoto et al. (Morimoto, 2023) developed an AI rebar placement system using images taken by a stereo camera and advanced image processing technology. They achieved implementation in the field after conducting basic measurement accuracy experiments and experiments on its application in construction sites. The service is now being provided; as of 2022, 58 units have been installed. In a technology competition held by MLIT in 2020, it received an A grade evaluation. The AI rebar inspection system can automatically measure and determine the rebar's diameter, number, and spacing simply by photographing the rebar with a stereo camera. It also has a function to display and record the automatic measurement results on the screen as shown in Fig. 2 (right).

BAIAS (Bar Arrangement Inspection AR System) is an AR rebar inspection system developed jointly by GRIFFY Corporation and Muramoto Construction Co., Ltd. It allows us to inspect the rebar in reinforced concrete structures easily. It takes photographs of the reinforcement, acquires point cloud data, and measures and identifies the steel rebars' diameter, number, and spacing. The basic principle of measuring the intervals between the reinforcement rebars is to use the LiDAR (Light Detection And Ranging) scanner function built into the iPad Pro to project laser light onto the target steel bars and then use the reflected light information to acquire the distance to the steel bars and 3D point cloud data. Like the stereo camera described above, the ranging function enables measuring the rebars' quantities and spaces. It is also possible to measure the diameter of each rebar, and it is compatible with the measurement items in MILT's guidelines.

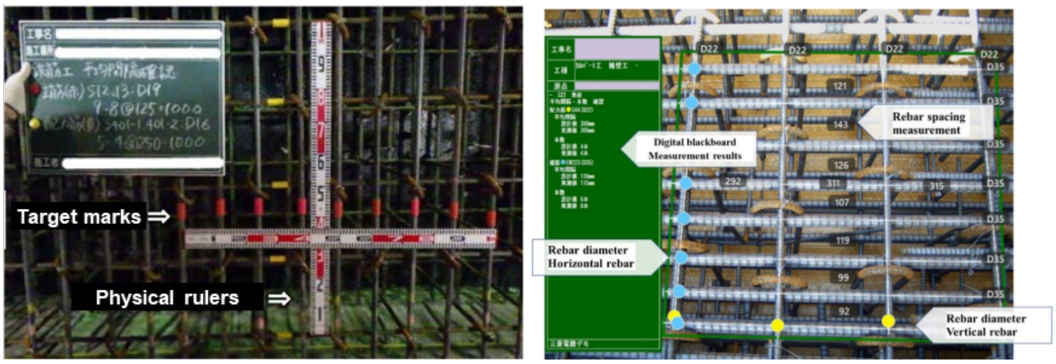

Figure 2: Conventional inspection (left) and Stereo-camera based system (right) (edited from Morimoto, 2023)

3 Method

3.1 Objective

As mentioned in the previous section, the construction industry, both public and private, shares the need to use ICT to reduce the labor required for rebar inspections due to the aging workforce and stricter regulations. Preceding research is being carried out into automatic rebar inspection using stereo cameras and LiDAR. However, due to the principles of these 3D data acquisition technologies, it is difficult to obtain sufficient 3D point clouds in cases where it is impossible to secure a complex structure of rebar or a shooting viewpoint, and it is challenging to meet the required data accuracy for inspection.

In this study, we will utilize a free-viewpoint image generation technology based on differential rendering called Neural Radiance Fields (NeRF) (Mildenhall, B., 2020) to enable the reproduction of the same appearance as the real thing through deep learning within NeRF, even in cases where it is challenging to acquire 3D point cloud data, such as complex structures with poor visibility or reinforcement sites where the shooting viewpoint cannot be secured. The aim is to propose an inspection method for a reproduction space that accurately reflects the actual size of the rebar and to clarify the potential of reproduction and inspection performance

3.2 Basic Idea

In this study, we propose introducing a completely different 3D reconstruction technology using NeRF to improve the limitations of the 3D measurement based on the principle of capturing the shape of the object surface by 3D measurement of the feature points using image triangulation. Image triangulation is not intrinsically suited to obtaining dense 3D point clouds for objects with long, thin shapes and inconspicuous colors, such as rebars. On the other hand, neural rendering, as typified by NeRF, is a technology that can reproduce the appearance of detailed scenes from arbitrary viewpoints by acquiring radiance distribution in 3D space through deep learning.

Therefore, even in cases where the scaffolding and viewpoints that can be observed on-site are limited, the shapes and arrangements of the target rebar are complex, or it is impossible to see through, it is possible to observe the rebar from a viewpoint that is virtually close, around, or inside, it is desired that the limitations of physical inspection work will be eased. The 3D volume space reconstructed using NeRF is accurate in geometry, but an unknown scale is set during the 3D reconstruction process, which does not necessarily reflect physical dimensions. Therefore, even if images are generated from a viewpoint clearly showing the target rebars, they are not directly linked to measurement inspections such as rebar diameter and intervals. In this study, we enable dimensional inspection from any viewpoint by displaying and moving the necessary measuring tape as a surface model in the space output by NeRF.

3.3 System and Process Configuration

NeRF is a technology that generates images from a 3D model from a relatively small number of images and camera positions and poses using deep learning. It generates images that allow you to view the 3D model from any viewpoint. NeRF takes as input the 5-dimensional coordinate position (x, y, z) and direction (θ, Φ) of the viewpoint in the scene, and outputs the 4-dimensional color (RGB) and transparency emitted from the viewpoint. By passing through a multilayered neural network, it learns to predict accurate output values from the input values, improving the accuracy of generating images from new viewpoints.

Hanada et al. (Hanada et al., 2023) applied NeRF to museum exhibition contents. They proposed a digital archive method and exhibition content that takes advantage of simultaneously displaying additional annotations that explain the exhibits to reflect the intentions of the museum curators within the photorealistic space rendered by NeRF. This paper proposes a method for rebar visualization by employing Nerfstudio (Tancik, M. et al., 2023), a software that can display the results of NeRF using deep learning, based on the method of Hanada et al. as shown in Figure 3. Nerfstudio uses a proprietary algorithm called nerfacto to execute NeRF, which allows NeRF to run faster than in the original paper. NeRF is executed on the backend, and the results are displayed as streaming video on the frontend web app. It is also possible to manipulate the viewpoint of the video on the web app. NeRF requires multiple images with known shooting viewpoints, prepared with the SfM (Structure from Motion) process of 3D reconstruction. Displaying a ruler model that matches the SfM's 3D coordinates' scale as additional annotation information allows a real-scale inspection of the rebars displayed by NeRF.

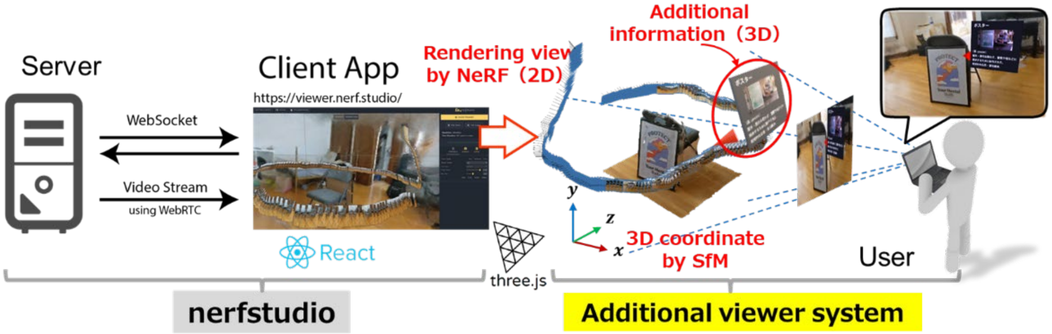

Figure 3: Process Chain of the System based on Hanada's method (edited from Hanada et al., 2023)

3.4 Data Acquisition

The steel rebar mesh cage (800mm x 800mm x 1000mm) used in the experiment is made up of vertical and horizontal main bars and the horizontal cross rebars that support them, and the back and sides overlap the front, making it difficult to obtain a 3D point cloud from some viewpoints. A ruler was placed before the steel cage as shown in Figure 4, and footage was taken using an iPhone. Repeatedly moving closer to the steel cage to capture the details and moving away to recognize the whole structure, the videos were taken slowly from the previous week to obtain overlap. The image frames were exported as 4K (2160 × 3840) resolution using Adobe Premiere Pro.

Figure 4: Target sample of the rebar cage)

4 Result and Discussion

As shown in Figure 5, comparing the output of NeRF with the production of photogrammetry using SfM, the NeRF output could express the primary vertical rebars and horizontal rebars without any loss. In contrast, the photogrammetry output had many gaps in the horizontal thin rebars. Next, in the production results using 48 images, the NeRF output could express both vertical and horizontal rebar, as in the previous example, and the photogrammetry had a much higher number of breaks in the banded rebar than the model using 102 images shown in Figure 6.

Next, we checked the inspection accuracy of NeRF, using a set of 102 images for NeRF. The ruler model imported into the viewer was adjusted to match the actual ruler placed on the site based on the surface model output using the marching cube method (Figure 7 (left)). In addition to the 5mm grid of the actual ruler, we prepared a finer 2mm grid as a high-resolution texture to match the ruler's image generated from NeRF. The texture is automatically mapped to the surface model using UV mapping and appropriate scaling to be used universally for NeRF output. This virtual ruler made it possible to display the measurement resolution required for inspection, and by simply superimposing it on the free viewpoint in the NeRF image, it became easy to read the rebar diameter and laying interval. In the same way, the scale was moved (Figure 7 (right)) as in the image where the scale was placed.

Figure 6: 3D reconstruction results from 102 images: SfM (left) and NeRF image (right)

Figure 5: 3D reconstruction results from 47 images: SfM (left) and NeRF image (right)

Figure 8: 3 Virtual ruler setup: scale adjustment (left) and inspection setup (right)

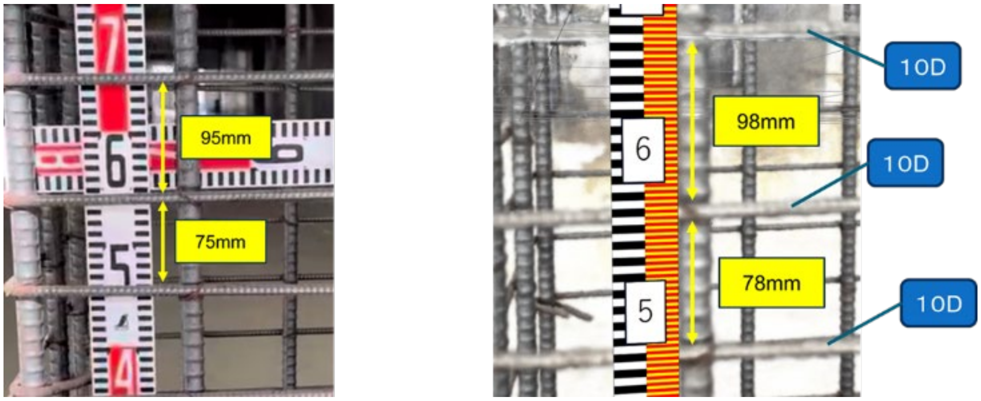

Figure 7: 3 Virtual ruler setup: scale adjustment (left) and inspection setup (right)

In the photo of the actual object in Figure 8 (left), the upper row was 95mm, and the lower row was 75mm, but in the viewer image, the upper row was 95mm, and the lower row was 75mm, with an error of +3mm as shown in in Figure 8 (right). The diameter of the deformed bar was also measured from the viewer image, and was 10mm, so it can be determined that it is a 10D rebar.

Since the construction site's structure often limits the areas that can be photographed, we applied the method of this study to a group of images photographed from only one direction, as shown in Figure 9 (left). In this case, photogrammetry added noise that was not there because the back surface was assimilated with the ground or wallpaper. In addition, the side surface needed to be sufficiently expressed and was interrupted. On the other hand, the output of NeRF can be adequately expressed not only on the front but also on the back and side surfaces. As in the previous section, the position and size of the scale were adjusted (Figure 36). This effect allows the scale to be adjusted to a position that cannot be physically placed and allows inspection to be performed from a viewpoint that cannot be photographed for structural reasons.

5 Conclusion

In this paper, the output of photogrammetry and NeRF was compared by changing the number of images input for a steel-reinforced cage, and the accuracy of the rebar inspection was confirmed by adjusting the scale for the output of NeRF. In addition, assuming a limited shooting space at an actual construction site, this study was also applied to images taken from only one direction. Firstly, while NeRF could produce photorealistic representations even with a limited number of images and shooting angles, photogrammetry showed some deficiencies. From this, it is a visualization method that is relatively easy to use for on-site construction workers. In addition, in the accuracy check for the rebar inspection, the reproduction error in the rebar spacing from the actual object was within +3mm, and it was also possible to determine that the rebar diameter was the same type as the actual object. From this, it was possible to generate inspection images with the same level of accuracy as previous research that measured point clouds. In future work, the authors plan to develop a system that allows intuitive alignment of the ruler model and to reduce the time required for deep learning, which currently takes several tens of minutes.

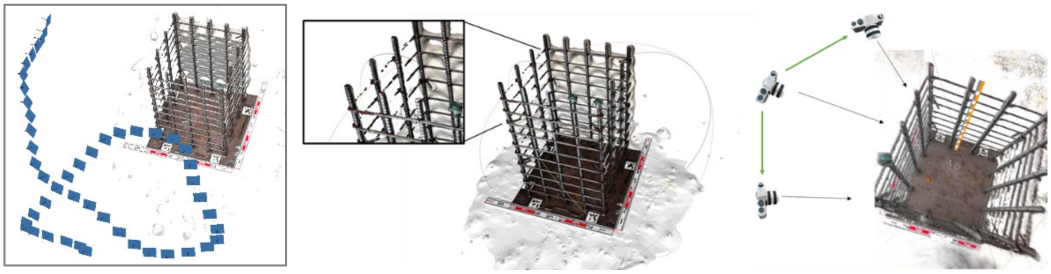

Figure 9: Limited angle of view for the input photos from 50 viewpoints (left), the result of SfM (middle) and NeRF (right)

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