Kalpa Publications in Computing
Volume 22, 2025, Pages 1009–1017
Proceedings of The Sixth International Conference on Civil and Building Engineering Informatics

Proposal for a Simple Inspection Tool using HoloLens2

Tomohiro Mizoguchi[1]
[1] Sanyo-Onoda City University
mizoguchi@rs.socu.ac.jp

Abstract

The importance of maintenance is growing as civil engineering structures age in Japan. For proper maintenance, it is important to carry out regular inspections at high frequencies and to accumulate the data in a way that makes it easy to use later. In recent years, with the spread of 3D scanning technology, it has become an effective method to use 3D models obtained by 3D scanning of the target structure as a base, and to associate electronic inspection information such as photos with the relevant locations and manage them for a long term. By providing location information on the 3D model to the inspection information in this way, it has the advantage that it becomes easier to grasp the spatial location of deterioration and damage, and later searches can be made intuitive and easy. In this paper, we propose a simple inspection tool using the head-mounted device HoloLens 2. The developed tool can perform 3D scanning while moving around the structure based on SLAM. And when deterioration or damage is found, images can be captured with the device's camera. In addition, the corresponding location on the 3D scanned model can be specified by simply pointing to the relevant location in the real structure with a hand gesture, and inspection information such as images and documents acquired can be registered here. Experiments are conducted on an actual bridge with this tool to demonstrate that entire inspection process, including 3D scanning, taking photos, and registering the photos on a 3D model, can be performed with very simple and intuitive operations at the inspection site. In addition, the accuracy of the constructed 3D model was evaluated by local plane fitting and comparing it with the TLS point cloud using ICP alignment. Due to the nature of the device, the scanning distance of the developed tool is short, so it is limited to relatively small structures, but it is suitable for simple inspections.

1 Introduction

The importance of maintaining civil engineering structures that were built during the period of high economic growth is increasing as they deteriorate in Japan. For example, there are about 730,000

I. Hkust, J. Cheng and Y. Yantao (eds.), ICCBEI 2025 (Kalpa Publications in Computing, vol. 22), pp. 1009–1017

road bridges, of which about 65% are managed by relatively small local government. Although the number of structures is huge, unfortunately there is a shortage of engineers involved in management, and the budget is limited, so regular and daily inspections are sometimes not carried out sufficiently. For maintenance, it is important to carry out regular inspections at high frequency, record information such as images that capture damage and deterioration, and store this information for the long term in a way that is easy to use later. However, photos that record deterioration and damage generally only show a small part of the structure and do not include location information. Therefore, in recent years, it is becoming common to associate related image and other information with the corresponding parts of 3D models such as point clouds and BIM/CIM, and manage them centrally (Sacks et al., 2018; Shim et al., 2019). By providing location information on the 3D model to inspection information, it is possible to easily grasp deterioration and damage visually and spatially. However, since there are almost no 3D models for old infrastructures, it is necessary to scan the actual infrastructures in 3D and directly use the obtained point cloud data, or to use BIM/CIM created from the point cloud as the base for management. Many previous studies have been reported on the use of 3D models for the maintenance management of infrastructures, but most of them have targeted large structures (Mizoguchi et al., 2023). As a result, there are few examples of the development of inexpensive and efficient inspection tools for relatively small structures.

1.1 3D Scanning for Infrastructure Maintenance

With the rapid spread of 3D scanning technology, it has also become widely used for infrastructure maintenance and management. The well-known terrestrial laser scanner (TLS) has the advantage of being able to obtain high-precision, high-quality point clouds. However, since it is not possible to scan the entire object from a single location, scans are usually taken from multiple locations and then processed to combine the data. This requires movement and the installation of a tripod for each scanning, which has the disadvantages of being inefficient in scanning and not being able to scan in inaccessible places (Rashidi et al., 2020). On the other hand, with the spread of SLAM-based 3D mobile laser scanning (MLS) technology, it has become possible to efficiently obtain 3D point clouds for civil infrastructures of tens to hundreds of meters in size (Yan and Hajjar, 2021; Blaskow and Maas, 2024). Although SLAM-based methods are inferior to TLS in terms of accuracy, they have the advantage of being highly efficient in scanning and being able to obtain point clouds with few deficiencies. In addition, if they are installed on a UAV, scanning can be made even in inaccessible places. However, MLS is expensive, and UAV flights require the cooperation of experts, making it difficult to use for maintenance. In addition, in both TLS and MLS, the user must interactively indicate the corresponding location on the 3D model for each inspection image of deterioration and damages to register them on it. This is inefficient and there are cases where the correct position cannot be accurately specified. In contrast, 3D reconstruction processing from images using structure from motion (SfM) can obtain high-quality point clouds or 3D mesh with rich texture with only a relatively inexpensive camera and commercial software (Mohammadi et al., 2021; Tang et al., 2024). In addition, it has the advantage that information on the relative position and orientation on the reconstructed 3D model can be obtained for each captured image, making it easy to register the inspection results using images on the 3D model. However, the disadvantages are that it takes time to capture images and the reconstruction processing.

(a) Bridge abutment (b) Hololens2 (c) 3D scanned mesh

(d) Superimposing of mesh (e) Example of deterioration or damages (rust) (f) Image registration on 3D model

Figure 1. Overview of our developed tool

In particular, in recent years, in addition to mobile devices such as iPads and iPhones, head-mounted 3D scanning devices have also appeared, and 3D scanning is becoming increasingly popular. With such devices, even general users without specialized knowledge can easily perform 3D scanning. Among them, HoloLens 2 is equipped with a wide range of functions, including not only 3D scanning and camera photography, but also augmented reality (AR), internet communication, and gesture recognition (Ungureanu et al., 2018). Therefore, it is expected that a new inspection tool can be developed by making full use of these functions.

1.2 Research Purpose and Overview of Proposed Tool

In this paper, we propose a simple inspection tool using the head-mounted device HoloLens 2. In this report, we implemented core functions essential for maintenance management, such as 1) constructing a 3D model using a depth sensor, 2) photographing deterioration and damage using a camera, and 3) registering the images to a 3D model using hand gestures. We also evaluated its effectiveness through experiments simulating inspections of actual bridges. Furthermore, to evaluate the accuracy of 3D measurement using HoloLens 2, we performed plane fitting and distance evaluation to point cloud for local accuracy evaluation, and point-to-point distance evaluation based on global ICP alignment with the TLS point cloud. Due to the characteristics of the device, this tool is not suitable for large-scale structures, but it can be used to perform simple inspections efficiently and at low cost for relatively small structures such as ditch bridges. And this can be also used for narrow areas where TLS scanning and UAV flight are difficult. The developed tool is a combined implementation of existing 3D scanning and hand-gesture functions, but we believe it demonstrates its potential as a future human-machine collaborative maintenance which contribute to efficient and low-cost inspection. The features and advantages of this tool are summarized as follows.

<u>1) Creating 3D models and registering inspection information at the inspection site</u>

Conventionally, the creation of 3D models and the registration of inspection images to the 3D models were carried out separately in the office after the on-site inspection. In contrast, with this tool, the entire process of creating 3D models using SLAM, camera imaging of deteriorated or damaged areas and registering the images to the 3D model can be carried out at the inspection site. This reduces the amount of work required in the office and makes inspections more efficient.

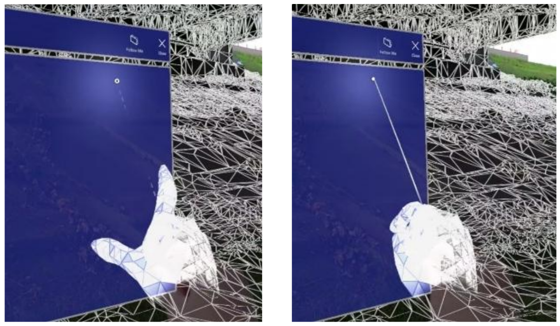

(a) An instruction of registration location
(b) Registration by pinching fingers

Figure 2. Image registration by hand gesture

2) Obtaining location information using hand gestures

Even in places where GPS does not reach or where it is difficult to install QR codes or RFID, the corresponding location information on the 3D model can be easily obtained by simply indicating the relevant location on the actual structure using hand gestures.

3) Hands-free inspection

By using a head-mounted device, inspections can be carried out in a hands-free state. And this makes it easier to access areas with poor footing or narrow areas and to inspect areas that were difficult to do using conventional methods.

2 Overview of Our Proposed Tool

An overview of the developed tool is shown in Figure 1. With this tool, for example, the narrow section of a bridge (Figure 1(a)) is targeted. When an inspector moves around the area while wearing the device (Figure 1(b)), 3D scanning of the surrounding environment, including the target object, are taken at any time as the inspector moves (Figure 1(c)). The acquired 3D model and the real environment are superimposed so that their positions match and are displayed on a see-through display (Figure 1(d)). If the inspector finds deterioration or damage in the structure while moving, a photo is taken with the camera mounted on the device (Figure 1(e)). Furthermore, immediately after taking the photo, the inspector can register it at the corresponding position on the 3D model by indicating the damaged area in the real environment with a hand gesture (Figure 1(f)). In the following, we will provide an overview of the SLAM-based 3D scanning and hand gesture-based photo position acquisition functions that are mainly used in this tool.

2.1 3D scanning by SLAM

HoloLens 2 is equipped with a variety of sensors. In particular, the Time-of-Flight (ToF) depth camera can measure depth in the form of distance images. Four grayscale cameras also provide robust self-localization (Weinmann, 2020). During inspections, users can simply wear HoloLens 2 on their head and move around the surroundings to perform 3D scanning of the area within the camera's field of view and obtain a 3D mesh of the target in real time. Compared to conventional TLS and MLS, the scanning distance is a maximum of 3.5 m, so the target is limited to small structures. However, the operation is simple, so it can be used by general users as well.

(a) Bearing(1) (b) Bearing(2) (c) Bearing(3)

(d) Plumbing(1) (e) Plumbing(2) (f) Slab

Figure 3. Experimental locations for image capture and registration

2.2 Specification of image registration position using hand gestures

When an inspector finds deterioration or damage, a picture is taken with the camera mounted on the HoloLens. Since the image is taken of a local area, it does not have global position information, and the location of the image cannot be identified later. Therefore, immediately after taking the image, the image is registered at the corresponding location on the 3D mesh being constructed. For this registration process, when the location of the structure to be photographed is specified with a finger as shown in Figure 2(a), the hand tracking function draws the point and the curve leading to it, called a hand ray, on the transparent display. The user can specify the registration location of the image while checking them. Once the position is determined, registration is completed by pinching the tips of the thumb and index finger together as shown in Figure 2(b). In the development tool, a marker is displayed at the registration location as shown in Figure 4(a). In addition, as shown in Figure 4(b), when the marker is clicked after registration, a form is opened on which the registered image can be viewed. It is also implemented so that a simple memo can be written in the form later. Thanks to the graphical guide, even general users can specify the position intuitively and easily.

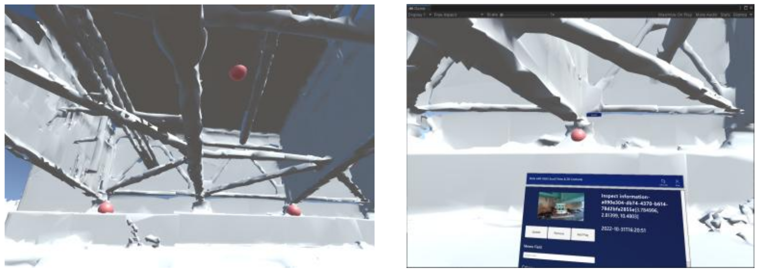
3 Results

3.1 Test site and overview of experiment

The experiment was conducted at the abutment of a steel girder bridge shown in Figure 1(a). The area around this abutment is sloped, making it difficult to move around with your hands occupied. And GPS is also difficult to reach, making it suitable for performance verification of the developed tool. In the experiment, 3D scanning were taken while moving around the area, and multiple images were taken of areas showing deterioration or damage, and location information for each was given using hand gestures, which were then registered on the measured 3D model.

3.2 Performance evaluation of our developed tool

While scanning the target site, photos of the six locations were taken as shown in Figure 3 and they were registered on the 3D model. The total time required was about 10 minutes, and the obtained 3D mesh was 14.1 MB in size with 84,078 polygons. We confirmed that the operations of scanning,



(a) Markers specifying registered information (b) Registered image and information

Figure 4. Display of inspection information on PC

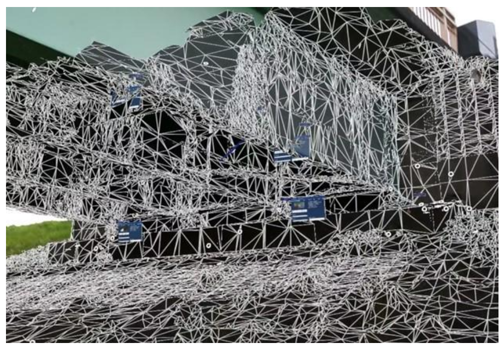


Figure 5. Display of 3D model and inspection information on HoloLens 2

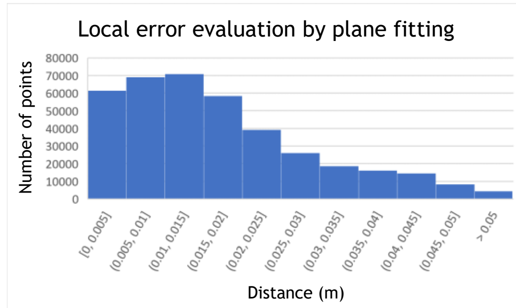
photographing, and position specification were all very simple and could be accurately registered at the location intended by the user on the 3D model. The resolution of the captured images was 3,904 x 2,196 pixels. Figure 5 shows the results of overlaying the entire scanning mesh and structures, as well as the registration results, displayed on HoloLens 2.

3.3 Accuracy evaluation of 3D scanning by HoloLens2

We evaluated the accuracy of 3D scanning using HoloLens2. For the evaluation, we obtained a dense point cloud shown in Figure 6(a) according to the procedure described in (Ungureanu et al., 2018). The number of points was 50,646,562. In the evaluation, we performed two evaluations: local accuracy evaluation based on plane fitting and global evaluation by comparing with TLS point cloud.

First, to evaluate the local accuracy, we cut out a partial point cloud in the planar area of the point cloud shown in red in Figure 6(a), fitted a plane using the least squares method, and calculated the distance to each point as the scanning error. Figure 6(b) shows the error distribution of the point cloud. The mean absolute error was 1.71 cm, and about 90% of the points were within an error of 3 cm, so sufficient accuracy was obtained for simple scanning.

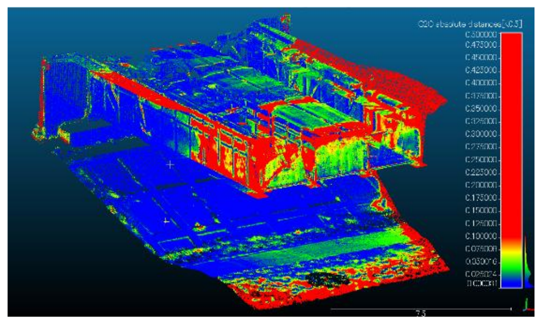
Next, to evaluate the global accuracy, we scanned the same area of the bridge using a terrestrial laser scanner. Figure 7(a) shows the point cloud data. The laser scanner used was a FARO Focus 3D Scanner. Its maximum range is 150m and scanning accuracy is ±1mm when scanning is between 10m and 25m. The overlapping parts are cut out from this point cloud, and the closest point distance between the point clouds is calculated after alignment using ICP (Iterative Closest Point) method. The number of points is 16,923,998. For global accuracy evaluation, the point clouds were sampled at 1cm intervals, and the closest point distance was calculated. The color-coded results are shown in Figure



(a) Planar region for evaluation (in red)

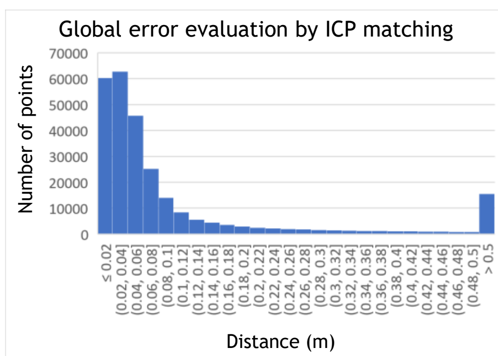
(b) Evaluation result

Figure 6. Local error evaluation by plane fitting



(a) TLS point cloud for comparison

(b) Error distribution



(c) Evaluation result

Figure 7. Global error evaluation by ICP matching with TLS point cloud

7(b), and the histogram is shown in Figure 7(c). In Figure 7(b), points over 5cm are shown in red. Here, the average point distance is 4.69cm, and approximately 90% of the points are within 10cm, which is sufficient accuracy. The graph also shows points over 50cm, but this is because the scanning distance of HoloLens 2 was insufficient and corresponding points between the data could not be found.

4 Conclusions and Future Works

In this study, we developed a simple inspection tool using the head-mounted device HoloLens 2 and verified its performance. Through various experiments, we confirmed that the developed tool can perform a series of inspection processes, such as 3D scanning, photographing deterioration and damage, and registering the photographs on a 3D model with simple hand gestures. In addition, an evaluation of the accuracy of 3D scanning confirmed that scanning with sufficient accuracy is possible for simple inspection.

Future works include a quantitative comparison of the accuracy of position specification by hand gestures and linking with remote locations using communication functions. We also consider using it to supplement areas where 3D measurement by UAV is difficult. In addition, the developed tool can be used widely, not only for infrastructure inspection, but also for maintenance and management of buildings and park trees, and on-site investigations immediately after the disasters. It is also thought that multiple workers can use the tool in parallel and share the obtained information such as 3D models and images on a server in real time via high-speed communication. It is also possible for an expert to analyze this aggregated information and give appropriate instructions to each worker on site based on the analysis results. Such two-way communication between the office and the field via a 3D model is expected to improve the sophistication of inspections and investigations.

Acknowledgements

We thank Kumonos Corporation for providing the terrestrial laser scanning point cloud used in this study.

References

Blaskow, R. and Maas, H. G. (2024). Structural health monitoring of bridge with personal laser scanning: segment-based analysis of systematic point cloud deformations, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, X-2-2024, 9-16.

Khoshelham, K., Tran, H. and Acharya, D. (2019). Indoor Mapping Eyewear: Geometric Evaluation of Spatial Mapping Capability of Hololens, ISPRS Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, Volume- XLII-2/W13, 805-810.

Mizoguchi, T., Mizuno, K. and Taniguchi, O. (2023). Automatic Creation of 3D Textured Simplified Model for Supporting Piled Pier Maintenance, Proceedings of The Fifth International Conference on Civil and Building Engineering Informatics, 289-295.

Mohammadi, M., Rashidi, M., Mousavi, V., Karami, A., Yu, Y. and Samali, B. (2021). Quality evaluation of digital twins generated based on UAV photogrammetry and TLS: bridge case study, Remote Sensing, 13, 3499.

Rashidi, M., Mohammadi, M., Sadeghlou Kivi, S., Abdolvand, M. M., Truong, H. L., and Samali, B. (2020). A Decade of Modern Bridge Monitoring Using Terrestrial Laser Scanning: Review and Future Directions, *Remote Sensing*, *12*(22), 3796.

Sacks, R., Kedar, A., Borrmann, A., Ma, L., Brilakis, I., Hüthwohl, P., Daum, S., Kattel, U., Yosef, R., Liebich, T., Barutcu, B. E. and Muhic, S. (2018). SeeBridges as next generation bridge inspection: overview, information delivery manual and model view definition, Automation in Construction, 90, 134-145.

Shim, C. S., Dang, N. S., Lon, S., and Jeon, C. H. (2019). Development of a bridge maintenance system for prestressed concrete bridges using 3D digital twin model, *Structure and Infrastructure Engineering*, *15*(10), 1319–1332.

Tang, Z., Peng, Y., Li, J. and Li, Z. (2024). UAV 3D modeling and application based on railroad bridge inspection, Buildings, 14, 26.

Ungureanu, D., Bogo, F., Galliani, S., Sama, P., Duan, X., Meekhof, C., Stühmer, J., Cashman, T. J., Tekin, B., Schönberger, J. L., Olszta, P. and Pollefeys, M. (2020). HoloLens 2 Research Mode as a Tool for Computer Vision Research, arXiv:2008.11239.

Weinmann, M., Jäger, M. A., Wursthorn, S., Jutzi, B., Weinmann, M. and Hübner, P. (2020). 3D Indoor Mapping with the Microsoft Hololens: Qualitative and Quantitative Evaluation by Means of Geometric Features, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Science, Volume-1-2020, 165–172.

Yan, Y. and Hajjar, J. F. (2021). Automated extraction of structural elements in steel girder bridges from laser point clouds, Automation in Construction, 125, 103582.