Quantitative Visualization of Secular Changes based on 3D Viewpoint Estimation for archaeological heritage maintenance

A Case Study at Barber Temple Ruins in Bahrain

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Abstract: The historical structures, which have cultural heritage value, must be continuously maintained and passed down to the next generation. Excavated archaeological sites are backfilled for conservation; however, many of them are not systematically maintained and are often found to have been destroyed or weathered. Moreover, many archaeological sites do not have detailed records of their preservation and restoration after the excavation finished. The purpose of this study is to grasp the change of the appearance of the structure from the excavation to the present time with high accuracy in the Barbar Temple in Kingdom of Bahrain. Since estimating the viewpoint of a photograph taken in the past enables overlaying the current situation from the same viewpoint, it is possible to visualize the changes by aging accurately. This paper also shows a method for quantitatively examining the changes over time by putting a virtual gridded surface with actual size into the same 3D data of the reconstructed archaeological site. The authors verified the accuracy of the method by experiments performed in prepared setup, where the known grand truth values are available in advance. This paper reports the effectiveness of the proposed method based on the case of applying this method to archaeological sites in Bahrain as well as the expected accuracy based on the quantitative evaluation.

Keywords: *H-BIM—4D—PnP Problem—3D measurement*

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Introduction

In recent years, aerial photography by UAV (Unmanned Aerial Vehicle) and laser scanning technology allows to obtain detailed 3D geometry information of outdoor structures easily. In the field of cultural heritage preservation and restoration, many projects use these techniques to maintain accurate records and to promote documentation with rich information. However, cultural heritage, especially archaeological sites, are allocated human resources and budget for excavation, but often are not systematically maintained after the excavation is completed. This study focuses on one such archaeological site, the Barbar Temple site in the Kingdom of Bahrain.

The Barbar Temple was excavated and backfilled repeatedly in the 1950s by Danish investigators (Andersen and Hojlund, 2003) and was partially restored and repaired from time to time. In Fig. 1, the upper photos show the state at the time of the excavation, and the lower photos show the current state. The red circles indicate the same spot in the upper and lower photos, but the current appearances have changed so much through the decades that it is difficult to identify. Besides, the history of damages and repairs since the excavation is rarely recorded. And thus, many maintenance items have not been communicated even among the officials in the Ministry of Culture. Therefore, it is desirable to accurately grasp the changes over time in order to accurately grasp the situation since the excavation and to promote the preservation and utilization of archaeological sites in the future.

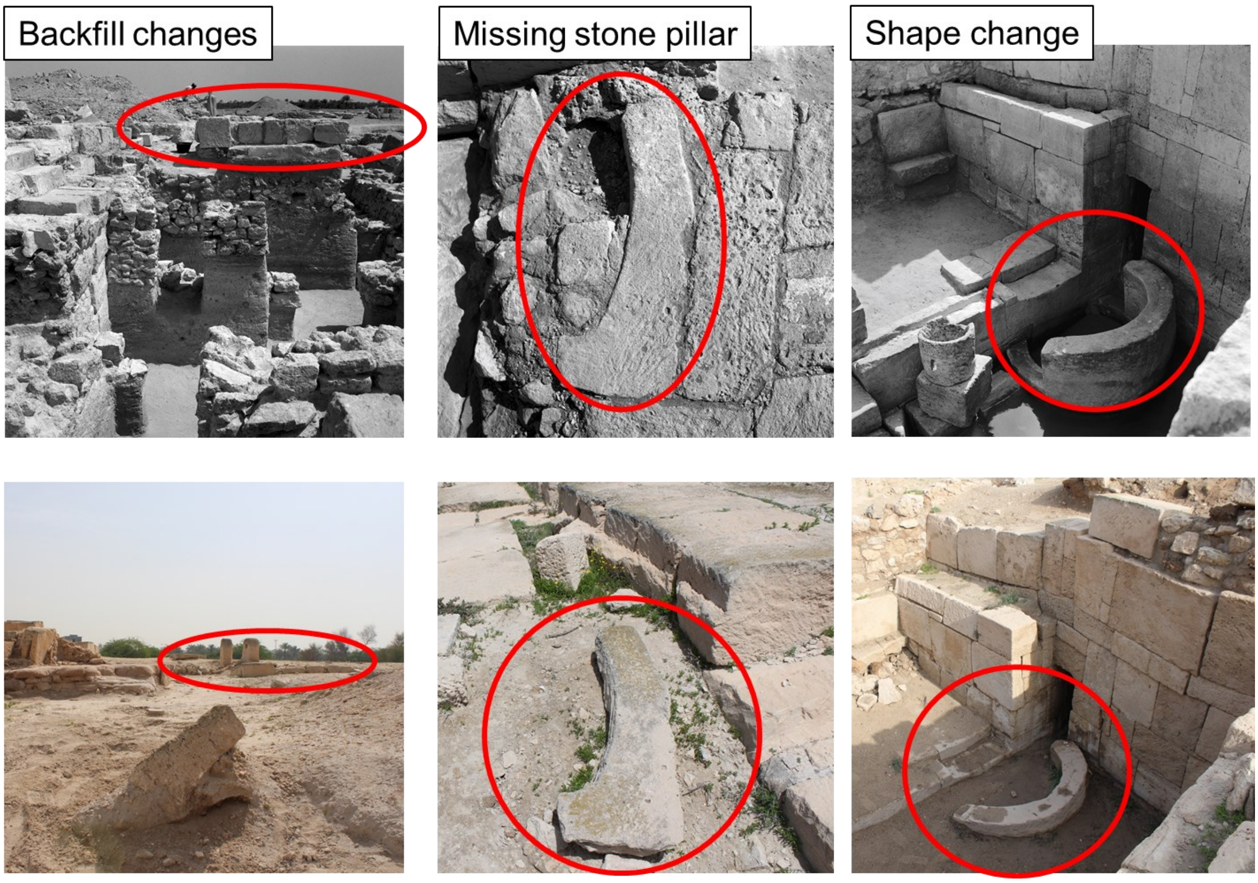


Fig. 1. Example of changes over time in appearance (© N. Mori et al.).

In this research, the authors propose a system to visualize the past and present aging of cultural heritage, and to observe the differences with high accuracy, using limited photographs at the time of the excavation as clues. The purpose of this research is to enable maintenance workers to more accurately grasp the actual situation by quantitative observation of aging structures and use it as a clue for future repair and restoration.

RELATED WORK

Information Modelling in Cultural Heritage

In promotion of digital technology for managing and maintenance of cultural heritage, a concept of Heritage-BIM (H-BIM) (Murphy et al., 2009, Volk et al., 2014), which applies BIM (Building Information Modelling) used in modern construction, is attracting attention as a method to systematically accumulate information related to maintenance, such as maintenance and repair of cultural properties. H-BIM applies a 3D model of a historical structure created based on actual measurements to objects such as building materials defined by IFC (Industry Foundation Classes) to assign attributes to contain a variety of items, including deterioration status and maintenance records. Then, various information related to historical structures can be centrally managed on a database. H-BIM is expected to be a framework that not only visualizes recorded information in an easy-to-understand manner but also realizes the regular maintenance and management of cultural heritage, as with current buildings. Although there are cases where H-BIM is applied to modern buildings that match the IFC object definition, there are few cases that target archaeological sites that do not always match the IFC object definition.

Yasumuro created a digital archive that allows registration and accumulation of various types of information by assigning attribute information to objects such as murals and damaged areas as objects, targeting a Mastaba tomb in Egypt. (Yasumuro et al., 2016). This paper also approaches to establish an information model that organizes and accumulates past incomplete records and newly recorded information by linking them to each associated spot at the site of the Barbar Temple, where maintenance history since the excavation has not been recorded.

4D Modeling for Cultural Heritage

As a method of grasping the current state of archaeological sites, 4D modeling that adds the dimension of the time axis to the 3D model has attracted attention (Glowienka et al., 2017). Rodriguez and his colleagues (2018) used “Structure from Motion” (SfM) (Tomasi and Kanabe; 1992), which is a method of restoring the 3D shape from stored aerial photographs and photographs in order to analyze past natural disasters and landscapes changed in urban development. By comparing the restored 3D models, the secular changes in the photographs were confirmed three-dimensionally, and a more detailed analysis was performed.

At the Barbar Temple site, 3D reconstruction at the time of the excavation was attempted using photographs of the remains of the excavation. However, many of the photographs recorded at the excavation were taken close-up from the front of the archaeological site, the overlap between the photographs was small, and 3D reconstruction by SfM did not work. Furthermore, performing SfM by mixing current and past photos of the same place failed as no correspondence between feature points between images could be established. There is an alternative means for grasping a change over time, even for the case where 3D reconstruction is not applicable for available photo records. The authors proposed a visualization method to overlay the past photos onto the current scene and characterize the appearance differences over time (Mori et al. 2018). This approach showed in principle that the temporal difference in appearance could be me,asured as the actual displacement by virtually arranging and reading the scale of the actual scale for the transformation to be observed (see Fig. 2). However, it has only qualitatively visualized the change over time so that human eyes easily discriminate them, and the evaluation in terms of accuracy remains an issue. This paper shows a quantitative strategy to acquire a reasonable metric for secular changes in an archaeological site.

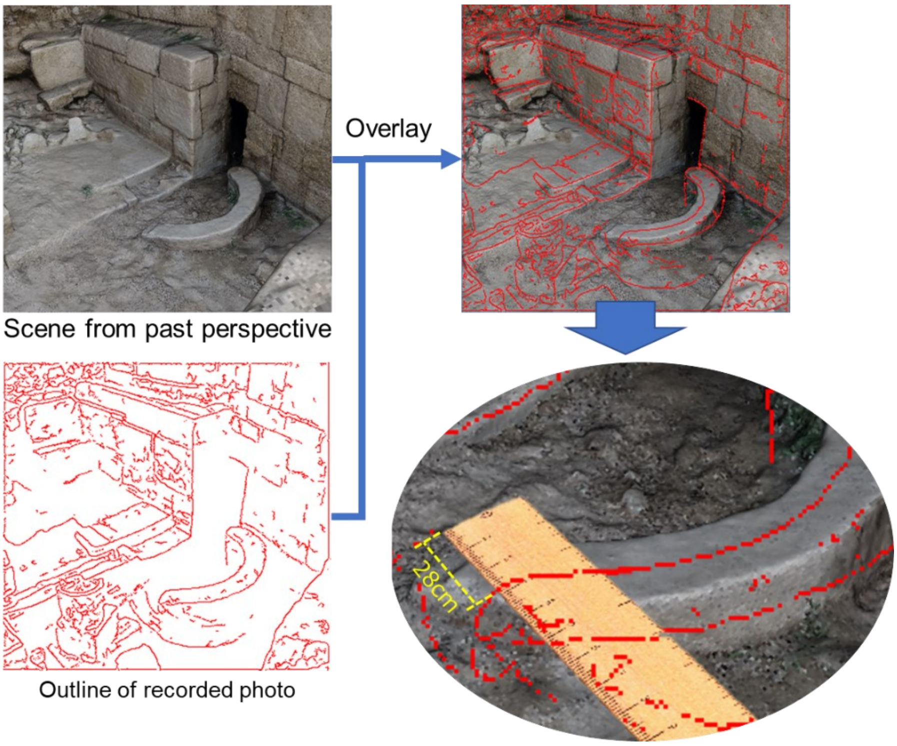


Fig. 2. Previous Method (© N. Mori et al. [2018]).

METHOD

Overview

In this study, to make the most of limited past recorded photographs and to grasp the difference from the present situation, the past recorded photographs were precisely superimposed on the current 3D shape data based on measurement. The displacement is measured by placing a virtual scale at the part where it is seen. This method quantitatively observes temporal changes that cannot be measured physically.

Fig. 3 shows the system configuration of the proposed method. First, a 3D model of the actual size is generated by 3D measurement of the existing archaeological site to superimpose the past recorded photographs. In the coordinate system of this 3D model, the shooting position and orientation of the recorded photograph are estimated. The secular changes, such as the displacement of a stone position in a wall, can be easily observed at the comparison with an old photograph (Mori et al., 2018).

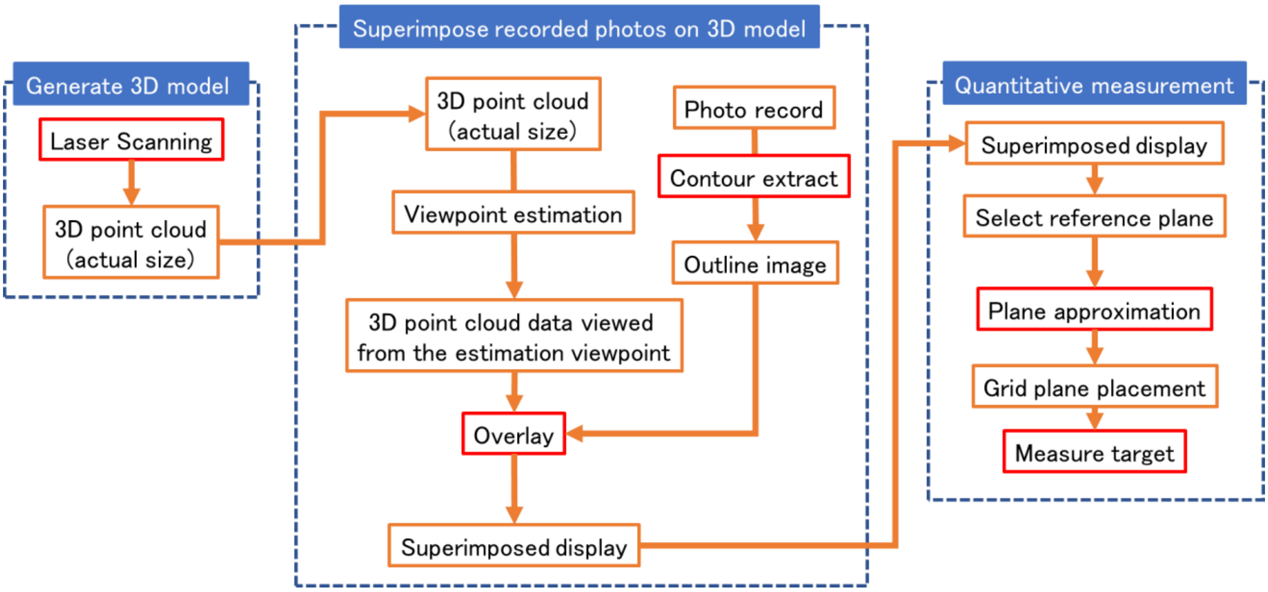


Fig. 3. Process chain of the proposed method (© N. Mori et al.).

To quantitatively observe the secular change in the real world, it is desirable to obtain three-dimensional information of the measurement target. An actual scale grid is used as a medium for giving 3D coordinates to the shape information of a photograph, which is 2D information. The secular changes, including crack sizes and stone displacements, can be investigated by arranging a gridded surface of actual size along the face of the stone. Our method uses a gridded surface that can measure the size of crack's progress and displacement of the target stone on the screen where the recorded photograph is superimposed on the current scene. By selecting two points, which are identified both ends of the size to be measured in the past and the present on the gridded surface, its displacement can be measured as a three-dimensional two-points distance.

Implementation

For estimating the shooting position and orientation of past recorded photographs, well-known Perspective-n-Point (PnP) problem (Hartley, 2003) is formulated and implemented and solver software libraries are available as well. To use this technique, it is necessary to prepare several pairs of 2D coordinates of the image and 3D coordinates of the photo image, and the internal parameters of the camera that captured the photo. In the recorded photographs of the Barbar Temple, information about the camera at the time of shooting is unknown. In this study, the pairs of the 2D coordinates of the recorded photo and the 3D coordinates of the current 3D model are manually associated in advance, and the initial values of the internal parameters such as focal length and image centre are given. The strategy of the proposed method is to change the internal parameters slightly so that the rendered 3D model overlaps the contour of the recorded photo while iteratively solving the PnP problem. The specific process for the refining of the solution of the PnP problem is shown in *Fig. 4*. Assuming the image center of the camera coincides with the optical axis, the lens distortion is assumed to be minimal, and the solution and rendering of the PnP problem are repeated while the focal length is slightly changed to obtain the best overlap display.

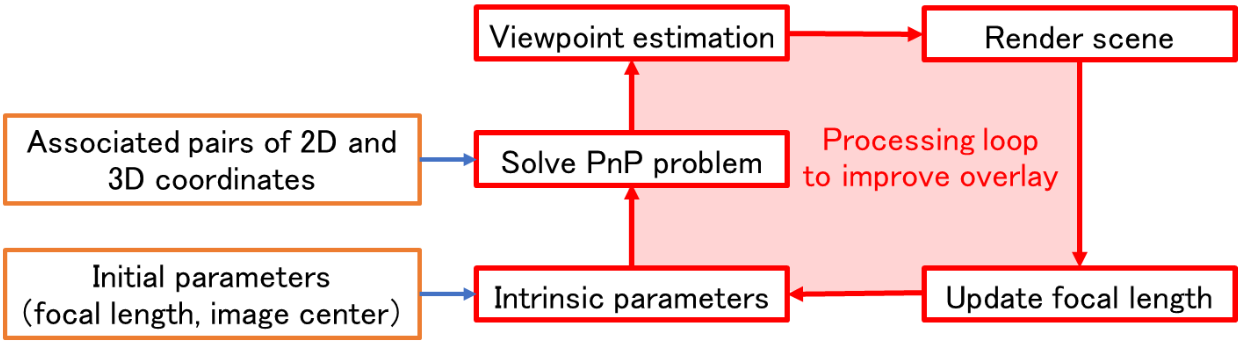


Fig. 4. Iterative estimation flow (© N. Mori et al.).

For the gridded surface placement, plane fitting by the least-squares method is performed. The plane used as the reference for gridded surface placement is a 3D point cloud included on the faces of the stones or part of the floor or wall of the structure. By solving the least-squares method for the point cloud in the sampled area, the normal of the approximated plane can be calculated. However, the least-squares method may suffer from a large error due to the influence of outliers in the sampled points. A robust way is to introduce Random Sample Consensus (RANSAC) (Fischler and Bolles, 1981), which removes outliers that have an adverse effect when using the least-squares method. The gridded surface is then arranged along with the reference point cloud by controlling the posture so that the normal of the grid matches the normal calculated by applying RANSAC. By selecting the point on the 3D model corresponding to the point on the contour line on the arranged grid by mouse picking, the displacement of the survey target can be measured in 3D space.

Case study

Barbar Temple

The proposed method is implemented on MS Visual Studio 2015 platform, and OpenCV was used in image processing for contour extraction and camera parameter estimation. As for graphical processing, OpenGL is used to display 3D data as well as 2D to 3D projection for mouse picking. This paper shows a case study to apply the method to the altar at the center of the Barbar Temple site. *Fig. 5* shows the processing flow up to the superimposed display. Comparing the past and the present state of the altar, some stones in the center of the altar pedestal cannot be confirmed in the present. Also, some stones surrounding the altar are moving or missing from their original position. In this case, the size of the missing stone on the right was measured. The 3D point cloud was acquired by measuring the surroundings of the pedestal from multiple positions using a laser scanner FARO Focus 3D X330, and aligning the scanned data by using the point cloud processing software, SCENE.

The Canny Edge Detector, which detects robust contours with few omissions in contour detection and false detection, was used to generate a contour image that was a key to confirm the difference between the past and the present. By giving transparency to the contours in the generated image, only the contours are superimposed on the scene that projected the 3D model by alpha blending during rendering. In terms of viewpoint estimation, seven identical feature points, such as stone corners and joints, were selected from the coordinates of the recorded photograph and the 3D model. For the internal parameters, the centre of the image was set to half of the vertical and horizontal pixels of the recorded photo, and the initial value of the focal length was set to 1.0 mm. The value of the focal length was updated by 0.1 mm until the outline of the photograph and the 3D data overlap precisely. Finally, an estimated viewpoint was adopted, so that minimizes the reprojection error between the feature points of the image and the corresponding points of the 3D model. When the superimposed display result is confirmed, it can be confirmed that both are precisely overlapped in the range in which the feature points are selected.

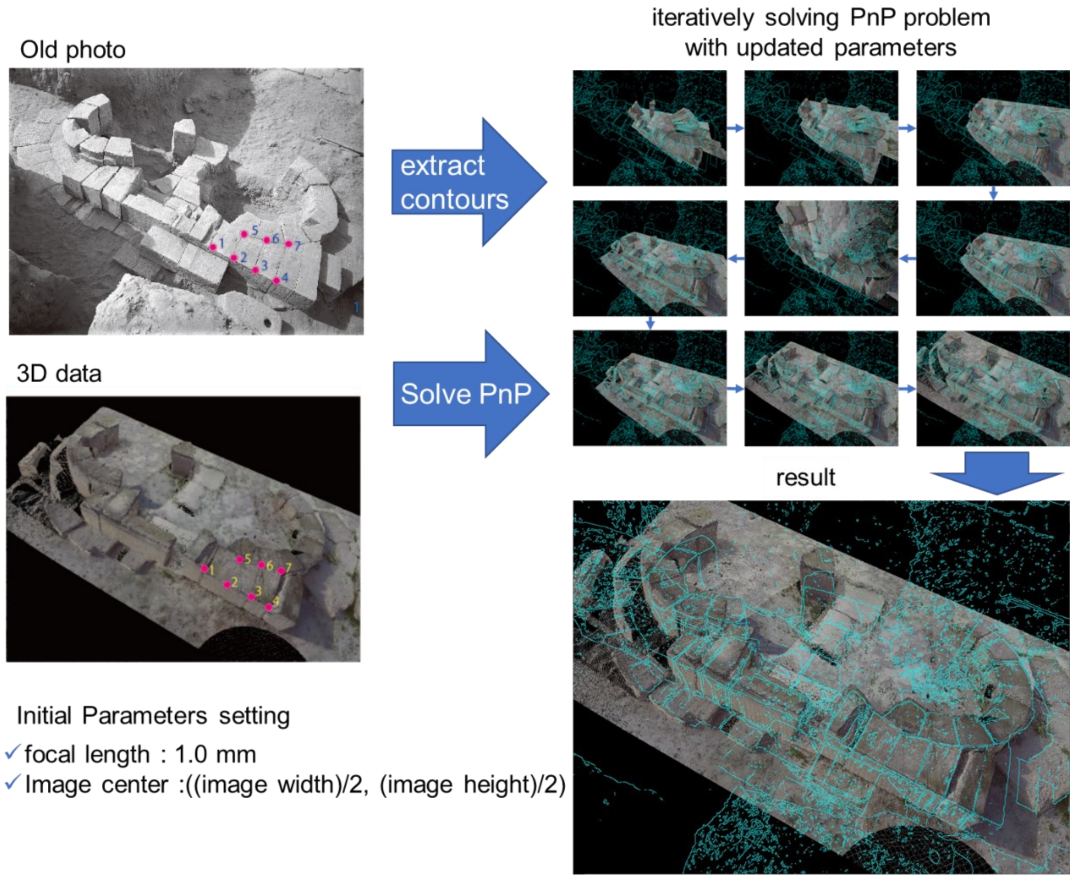
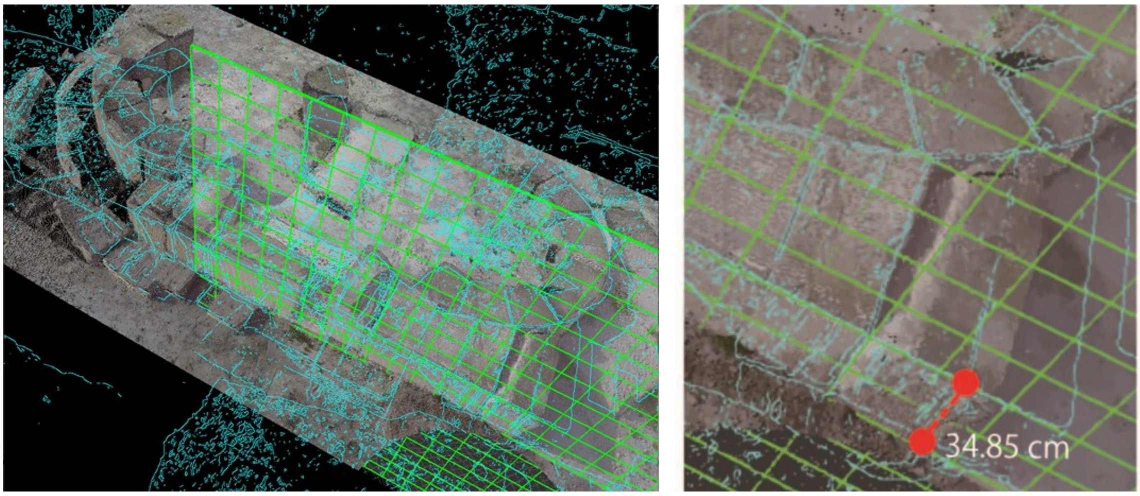
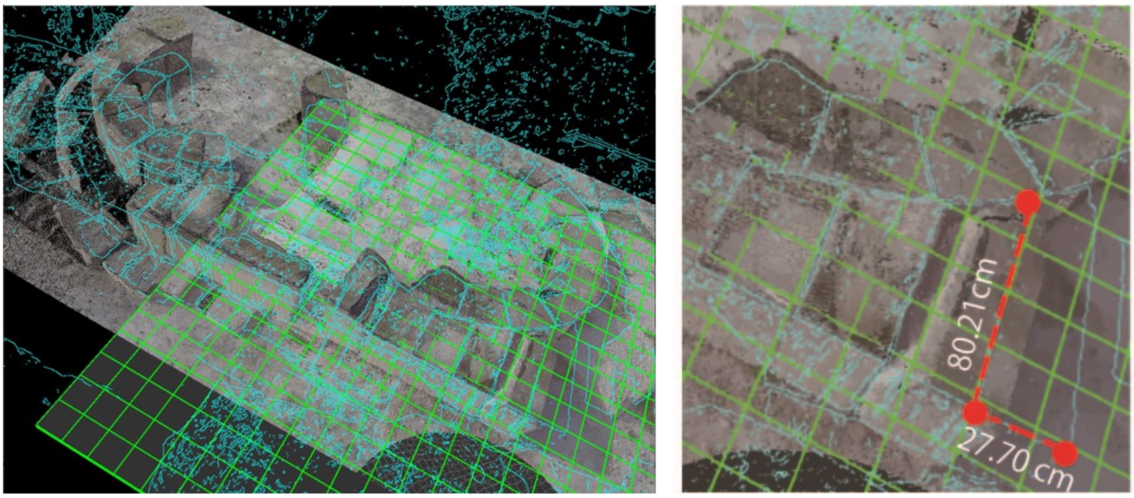


Fig .5. Process flow of superimposed display screen generation (© N. Mori et al.).

The right edge of the stone in the 3D model is correctly positioned next to the contour of the missing stone. In order to measure the width, height, and depth of the rightmost stone represented by the outline, the grid was arranged by plane approximation using the side and top surfaces of the stone of the offering table as sample ranges. *Fig. 6* shows the rendering scene when the grid is placed on the side, and the right side is an enlarged view of the left side. (a) shows when the grid is placed on the side, and (b) shows when the grid is placed on the top. The dimensions were measured based on the upper left corner of the stone. The red markers in *Fig. 6* represent the points to be measured. The results of each measurement were 27.70 cm in width, 34.85 cm in height, and 80.21 cm in depth.



a) Grid placement on the side



b) Grid placement on the top

Fig. 6. Grid placement and measuring result (© N. Mori et al.).

Accuracy verification experiment

The displacements quantified by the proposed method include some ambiguities, such as the distortion of the photograph as an image, the current 3D measurement error, and the viewpoint estimation error. Therefore, assuming the past and present changes, we prepared an experimental environment that grasped the grand truth value of the amount of displacement and verified the accuracy of the proposed method. The experiment was held at a rest space on the campus of Kansai University, which is made of stones like the Barbar Temple site. For preparing a grand truth of physical change in the structure, a platform with rails that moved exactly 5.20 cm was prepared, and brick, as a target object, is placed on the platform. First, we took an image that resembled a photograph taken in the past, moved the bricks based on aging, and integrated the 3D data measured from four viewpoints to obtain as the current record. Nikon COOLPIX L820 was used for photography, and the Focus 3D X330 was used for 3D measurement as conducted in the Barbar Temple site. The process from setting the grid surface to calculating the 3D distance was defined as one measurement trial, and the average of five measurement trials was used.

Fig. 7 shows the shooting position and orientation of the camera. In this experiment, the measurement target is the displacement of the upper left corner of the block. To analyze the effect of the camera direction on the proposed method, photographs were taken from the 15 different camera directions. The process from setting the grid surface to calculating the distance was defined as one measurement trial, and the average of five measurement trials was used. In Fig. 9, the horizontal axis is the angle between the camera direction and the displacement direction, and the vertical axis is the average error and standard deviation from the grand truth value in the measurement. The numbers shown on the horizontal axis correspond to the numbers shown in Fig. 8. The maximum error was 2.54 cm (see No. 14). In this measurement, the angle between the line of sight and the displacement direction was as narrow as 12.4 degrees, and the two points to be measured overlapped on the line of sight, making it challenging to obtain 3D coordinates. In other results, both the average error and the standard deviation were within an error of 2 mm.

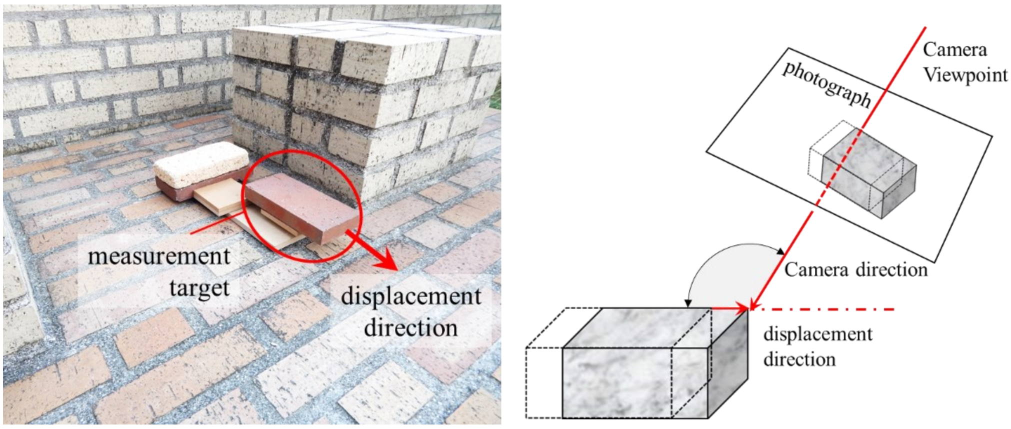


Fig. 7. Camera position and orientation for the verification experiment (© N. Mori et al.).

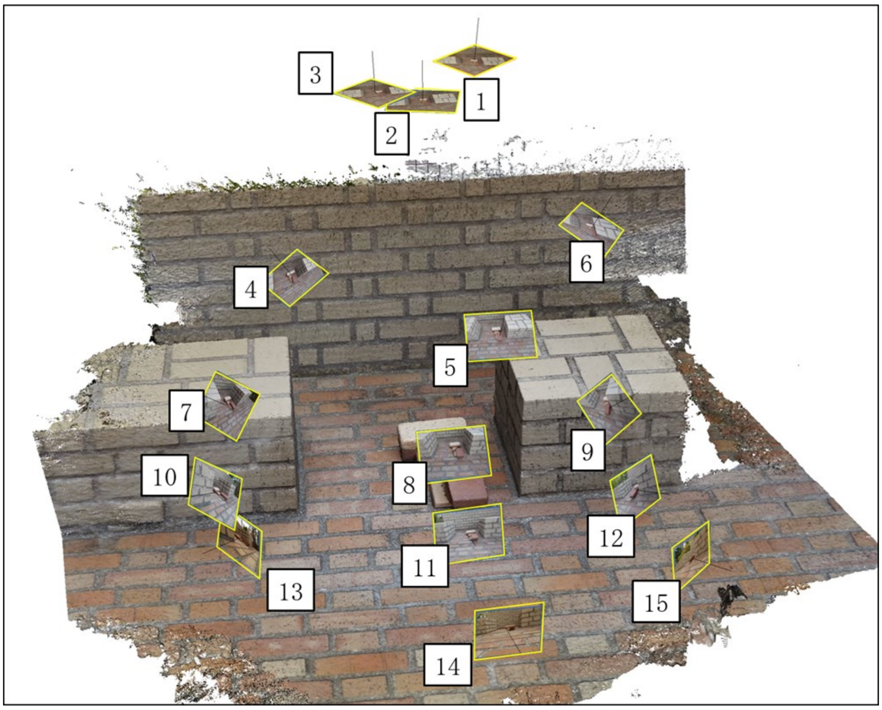


Fig. 8. Camera position and orientation for the verification experiment.

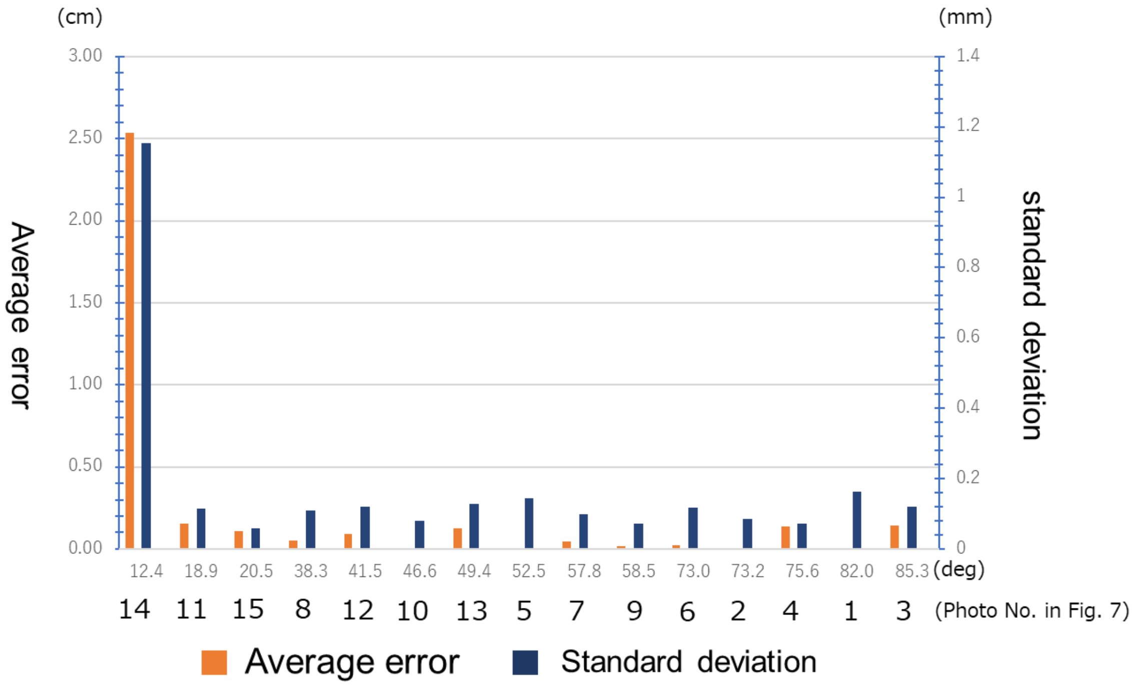


Fig. 9. Average error and standard deviation during measurement of each photo (© N. Mori et al.).

Discussion

The laser scanner used in this experiment has a maximum ambiguity of about 2.0 mm when measuring a wall 10 m distant. The error in alignment for integrating scanned data was 1.7 mm. The angle between the displacement direction to be measured and the line of sight of the photo applied at the Barbar Temple was 48.9 degrees. In the case study mentioned above, the line-of-sight angle is within the effective range verified in this experiment, so it is expected that the same accuracy was obtained. Similar effects can be expected by applying this method in various places in the field. Nevertheless, it is vital to select a reliable and sufficient number of reference points. Therefore, evaluating the reprojection error due to the PnP problem's solution is necessary each time.

As a proposal of archaeological information modelling based on 3D measurement, recorded photos can be integrated into the current 3D space, and both maintenance and structural information can be managed in a relational database. As a user-interface to this database, data browsing and data updating functionalities can also be integrated on a Web-based system Fig. 10 and Fig. 11.

Conclusion

In this study, by superimposing photographs taken in the past on the current 3D model, it was possible to confirm changes in the appearance of structures over several decades from the excavation to the present. By applying this method to archaeological sites where the state at the time of the excavation cannot be three-dimensionally restored, the secular change could be shown in an easy-to-understand manner. In addition, it was possible to reconstruct the local but two-dimensional shape information of a photograph as a three-dimensional shape by combining it with a real-sized virtual space that reproduced the scene.

Our future work is to measure the variety of secular differences not only simple displacements but also curvature and volumetric changes, such as appeared on stone walls. Also, our project plans to extend the implementation of the information model toward Heritage-BIM by incorporating a mechanism to directly define the objects not only in photos but also in arbitrary regions on the 3D surface of the measured structure.

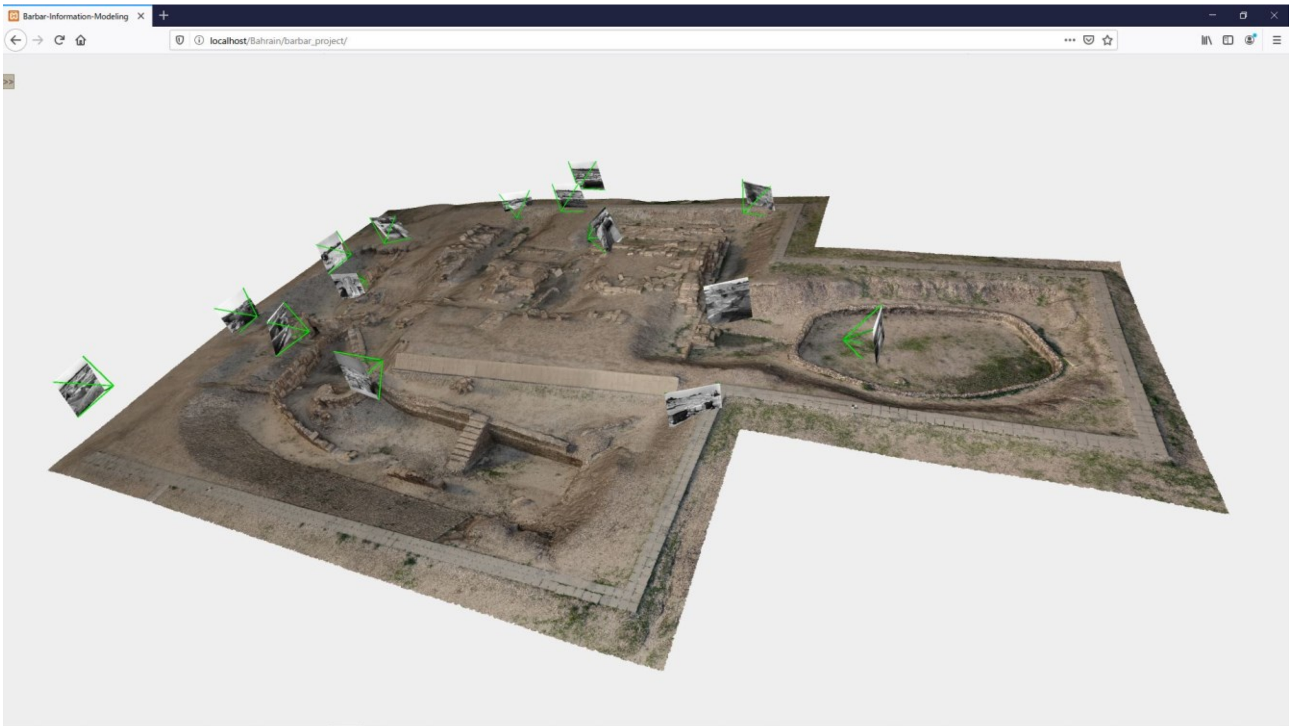


Fig. 10. Survey record visualization interface (© N. Mori et al.).

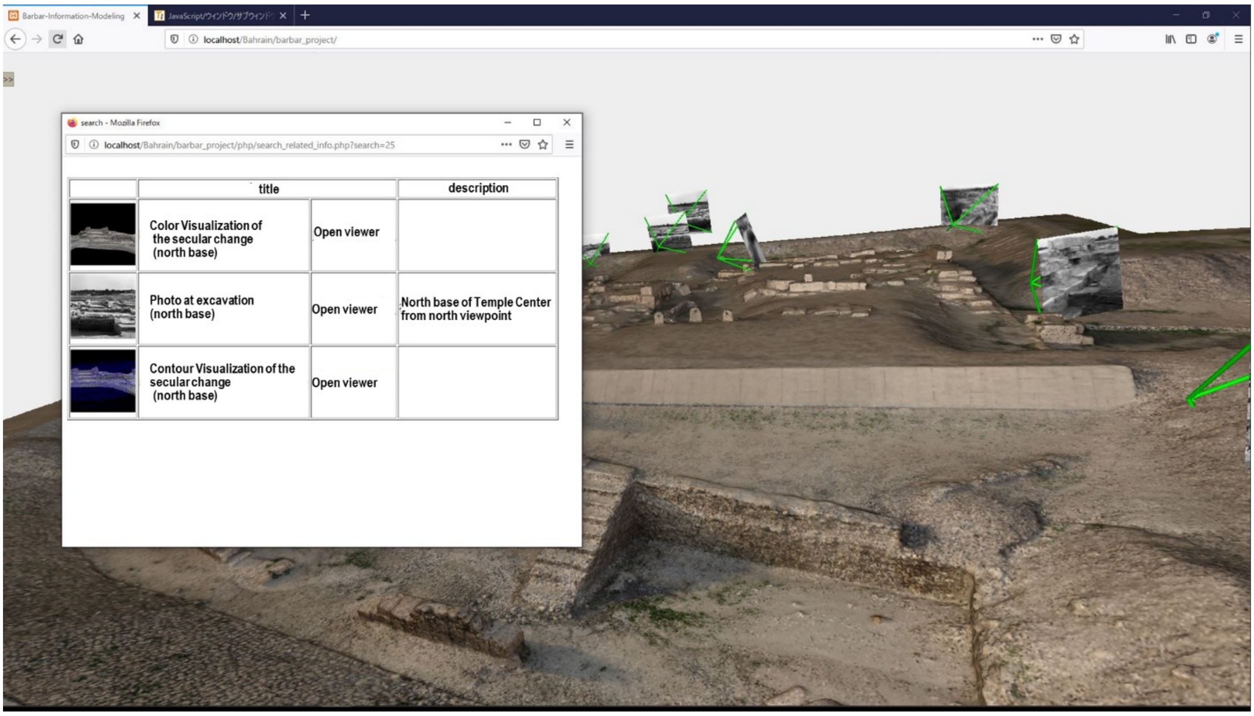


Fig. 11. Pop-up of related information (© N. Mori et al.).

References

Andersen H. and Hojlund F. (2003). 'The Barbar Temples, Jutland Archaeological Society Publications', Aarhus University Press.

Canny J. (1986). 'A Computational Approach To Edge Detection', IEEE Transactions on Pattern Analysis and MachineIntelligence (PAMI), 8 (6) pp. 679–698.

Fischler M. A. and Bolles R. C. (1981). 'Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography' Comm. of the ACM, Vol. 24, No.6, pp. 381–395

Glowienka E. et al. (2017). 'Use of LIDAR Data in the 3D/4D Analyses of the Krakow Fortress Objects, Materials Science and Engineering Conference Series, Vol.245, Oct., pages:042080.

Hartley R. and Zisserman A. (2004). 'Multiple View Geometry in Computer Vision', Cambridge University Press.

Mori N. et al. (2018). 'Visualization of the Past-to-Recent Changes in Archaeological Heritage based on 3D Digitization', *23rd International Conference on Cultural Heritage and New Technologies,* Vienna, 10pages. Available at https://www.chnt.at/ebook_chnt23_mori.pdf (Accessed: 31 January 2019).

Murphy M. et al. (2009). 'Historic building information modelling (HBIM)', Structural Survey, 27(4), pp. 311–327.

Rodríguez P. et al. (2018). '4D Reconstruction of Cultural Heritage Sites' *Latest Developments in Reality-Based 3D Surveying and Modelling*, pp. 119–140, (2018).

Tomasi C. and Kanabe T. (1992). 'Shape and motion from image streams under orthography: a factorization method', International Jounal of Computer Vision, Vol. 9, No. 2, pp. 137–154.

Volk R. et al. (2014). 'Building Information Modeling (BIM) for existing buildings—Literature review and future needs', Automation in Construction, Volume 38, March 2014, pp. 109–127.

Yasumuro Y. et al. (2016). 'On-site AR interface based on web-based 3D database for cultural heritage in Egypt', GCH 2016 – Eurogrphics Workshop on Graphics and Cultural Heritage, pp. 183–186.