Intercultural Understanding, 2018, volume 8, pages 7-16

Method of visualizing landscapes from tombs of the Final Kofun period with a high-definition three-dimensional model by SfM and three-dimensional GIS: A case study of three tombs in the Kawachi area

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Keywords: digital elevation model (DEM), digital surface model (DSM), landscape simulation, structure from motion (SfM), tombs of the Final Kofun period, unmanned aerial vehicle (UAV)

Abstract: We visualized landscapes from three tombs of Japan's Final Kofun period (the latter part of the 6th century through the end of the 7th century) in the Kawachi area (Kannonzuka, Hachibuseyma-nishimine, and Okameishi Tombs) with a high-definition three-dimensional model by structure from motion (SfM) multi-view stereo photogrammetry and three-dimensional GIS to analyze the relationship of the axial directions of the tombs and their views. We clarified the following points: 1) By SfM with photographs from an unmanned aerial vehicle (UAV), we generated georeferenced digital surface models (DSMs) with about 1-cm resolution and orthophotos with about 0.5-cm resolution to express the microtopography of the three tombs. 2) We overlaid DSMs and orthophotos by SfM on a 5-m digital elevation model (DEM) and orthophotos by GSI using three-dimensional GIS and visualized landscapes from the three tombs at that time, although their views are now obstructed by trees. 3) Considering the surrounding obstacles, shooting photos with a manual pilot is more suitable than with an auto pilot for reproducing the shapes of the stones and the tomb mounds.

1. Introduction

1.1. BACKGROUND AND OBJECTIVE

This paper proposes a method that visualizes landscapes from the tombs of Japan's Final Kofun period (the latter part of the 6th century through the latter part of the 7th century) using a high-definition three-dimensional model based on structure from motion (SfM) multi-view stereo photogrammetry[1] and three-dimensional GIS to analyze the relationship of the axial directions of the tombs and their views. In the future, we plan to clarify the characteristics of landscapes from the tombs of the Final Kofun period by the method proposed in this paper, and classify them to identify the principles for locating the tombs in relation to ancient thinking (on life and death) and natural landscapes.

After the trend of keyhole-shaped tombs faded and a national governance system based on ritsuryō codes began, many of the tombs constructed in the Final Kofun period seem smaller and more integrated with the natural landscapes than tombs constructed in the early and later Kofun periods when large-scale tombs were predominant. Although these tombs are precious cultural assets that convey ancient thoughts and culture and emphasize harmony between artificial objects and nature, except for a few well-preserved examples, most are now in ruins and their preservation conditions and surrounding natural landscapes remain unsatisfactory. We must preserve not only the tomb mounds themselves but also their surrounding natural landscapes.

Kawachi (present Kashihara, Habikino, and Tondabayashi cities and Taishi town located in the southeast of Osaka Prefecture) was the one of the centers of politics in the Final Kofun period. Therefore, we assume that identifying of the locating principles of the tombs of the Final Kofun period will shed light on the relationships between locations of tombs and their underlying thought on the harmony between nature and artificial objects possessed by the imperial family and the other powerful families of the period.

1-2. RELEVACE TO PAST LITERATURE

Most previous studies on the locations of tombs focus on two-dimensional maps instead of three-dimensional analyses (Mori, 1973, 1998 and 1996; Hosokawa and Imao, 2011; Imao, 2012; Kawakami, 1998; Kitamura, 2001 and 2004; Shimomura, 2006). On the other hand, the even three-dimensional terrain models in a few past studies using three-dimensional GIS are limited to a very small area surrounding a tomb, and other research, which focused on a wider area around a tomb, only analyzed slope angles and altitude on two-dimensional maps (Kaneda, 2001; Shiraishi et al., 2008; Teramura, 2005 and 2014). Judgments of tomb locations were based on landscapes rather than on maps. Although previous studies were primarily map-based analysis, our study presents a method for studying tomb locations from a landscape viewpoint.

A previous study by the author (Tembata, 2016) analyzed landscape views from 20 tombs of the Final Kofun period in Japan's Kawachi area using three-dimensional GIS to determine their characteristics and the relationship between the landscape and each axial direction. Unfortunately, that work encountered the following two problems: 1) a three-dimensional model based on a 5-m DEM of Fundamental Geospatial Data by Geospatial Information Authority of Japan (GSI) can't represent small-scale tomb mounds. 2) The position coordinates of single positioning by GPS have an error rate of about 10 m. This paper extends its methodology and develops more precise terrain models of small-scale tombs by SfM with photographs taken from a small UAV and a Global Navigation Satellite System (GNSS) [2] survey with cm accuracy. This method can be applied to studies on locations of tombs throughout Japan from a landscape viewpoint, and will also provide fundamental knowledge for city planning regulations (land usage regulations and view preservation regulations) for the preservation of natural landscapes around tombs to enhance regional characteristics.

2. Methods

2.1. RESEARCH OBJECT

Our target ancient tombs are three tombs in the Final Kofun period located in the Kawachi area, Kannonzuka, Hachibuseyama-nishimine, and Okameishi Tombs (Fig. 1), after obtaining flight permission for a UAV. All three tombs have a Yokoguchi-shiki Sekkaku (a stone sarcophagus with a side entrance), a stone sarcophagus that opens in the axial direction, and good viewing places, but these views are partially blocked by their surrounding trees.

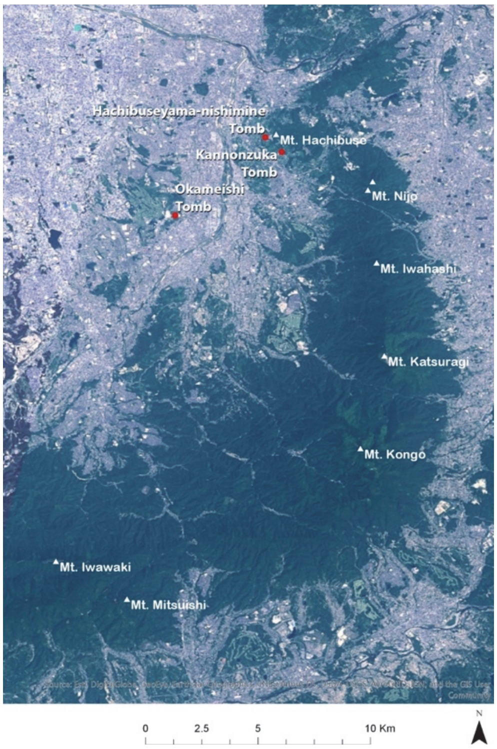


Fig. 1. Location map of target ancient tombs

2.2. METHODS

We conducted the following field surveys: the Kannonzuka Tomb on February 19 and 21, 2018, the Hachibuseyama-nishimine Tomb on February 19 and 22, 2018, and the Okameishi Tomb on February 26 and March 2, 2018.

Aerial photographs were taken by a small UAV (DJI Phantom 4 Pro camera :1 " CMOS, effective number of pixels: 20 million pixels) with both auto pilot and manual pilot from various heights and distances. 45-cm square air photo signals were used as ground control points (GCPs) and checkpoints. Such local features as white lines on road were used as checkpoints. Geographical coordinates of GCPs and checkpoints were obtained by post-processing the observed raw data by two GNSS receivers (Emlid Reach RS: one used as a base, and the other as a rover) with RTKLIB. [3] The coordinates have errors of cm accuracy.

High-definition three-dimensional models of the tombs (including the surrounding topography) were reconstructed based on aerial photographs with SfM software（Agisoft PhotoScan Professional version 1.4.4), and georeferenced DSMs and orthophotos were generated.

We overlaid the high-definition DSMs and the orthophotos of the tombs on a 5- or 10-m DEM of Fundamental Geospatial Data and orthophotos by GSI with GIS software (ESRI ArcGIS Pro version 2.2) and generated landscape simulation images viewed from the tombs. We examined the resolutions of the DSMs and the orthophotos for visualizing landscapes from tombs through a comparison with landscape simulation images generated by each shooting method with a small UAV.

3. Results

3.1. KANNONZUKA TOMB

3.1.1. Present State of Kannonzuka Tomb

Kannonzuka Tomb is a 3-m high, round mound with 13-m diameter, and has a Yokoguchi-shiki Sekkaku made of andesite on the hillside of the southern slope of Mt. Hachibuse. It was probably built around the 7th century (Yamamoto, 1998). Figs. 2 and 3 show 360 or 180 degree photos of it. The axial direction (opening direction of the Yokoguchi-shiki Sekkaku) faces the mountain, but the view to the southwest direction is obstructed by the surrounding trees.

Fig. 2. 360 degree photo of Kannonzuka Tomb in front of Yokoguchi-shiki Sekkaku (taken on February 21, 2018)

Fig. 3. 180 degree photo of Kannonzuka Tomb on the top of the tomb mound (taken on February 21, 2018)

3.1.2. GNSS Survey and Photo Shooting with Small UAV

A GNSS survey of the ground control points (GCPs) and checkpoints was conducted from 12:50 to 13:20 on February 19, 2018 and from 9: 30 to 12: 00 on February 21, 2018. Fig. 4 shows a GNSS survey of GCPs with a Reach RS. The Coordinates (X, Y, Z) of the GCPs and the checkpoints were calculated by RTKLIB using RAW data acquired with the GNSS receivers. Altitude data were obtained by subtracting the geoid height from the Z value.[4]

Fig. 4. GNSS survey of GCPs with Reach RS (taken on February 21, 2018)

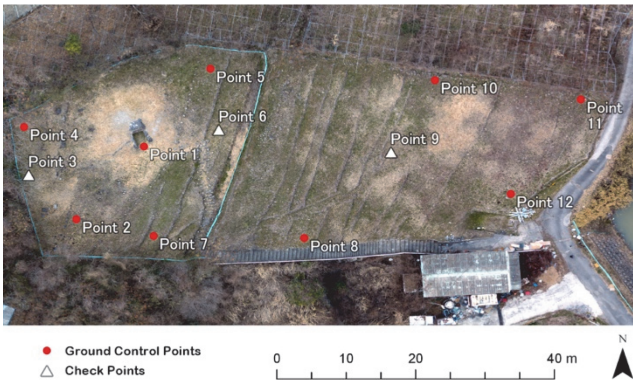


Fig. 5. Positions of GCPs and checkpoints

Figure 5 shows the positions of the GCPs and the checkpoints. Photos with a small UAV by both vertical shootings by auto pilot as well as vertical and oblique shootings by manual pilot were taken from 12:00 to 14:00 on the second day. The details of each shooting method are shown in Table 1. To reproduce the three-dimensional shape of the Yokoguchi-shiki Sekkaku and the tomb mounds, photos must be taken with multi-angles from a short distance. Due to such numerous obstacles as the surrounding trees, the photographs were taken by vertical shooting with an auto pilot and vertical and oblique shooting with a manual pilot.

3.1.3. Reconstruction of Three-dimensional Model by SfM

We reconstructed of a three-dimensional model by the following procedures:

1) Estimation of camera location and direction: We estimated the shooting position and the direction of the photos from multiple photos with SfM software. Fig. 6 shows the screen after calculating the estimated shooting position and the direction of each photograph for auto pilot. Fig. 7 shows them for manual pilot. Each blue square represents the position and the direction of each photo. The camera locations are calculated based on the extracted feature points (point cloud).

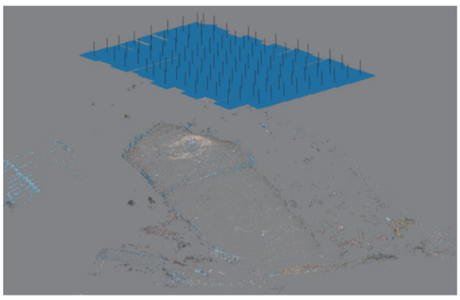


Fig. 6. Estimated camera location and direction for auto pilot (shooting method: a-2)

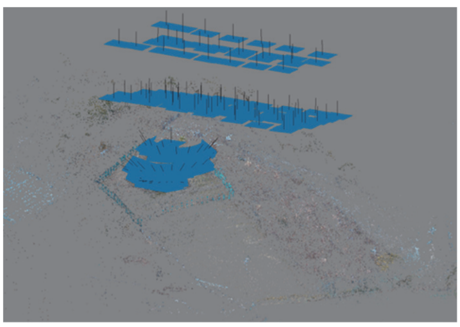


Fig. 7. Estimated camera location and direction for manual pilot (shooting method: m-4)

2) Build dense cloud： Fig. 8 shows the screen after calculating the dense point cloud, which is generated from the point cloud generated in the above procedure 1).

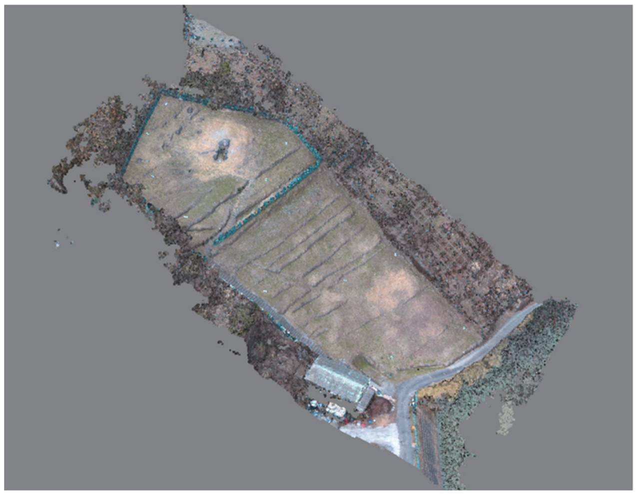


Fig. 8. Dense point cloud (shooting method: a-2)

3) Import coordinate data of GCPs and checkpoints: Fig. 9 shows the screen after GCPs and checkpoints have been placed on the dense point cloud. By importing the geographic coordinates obtained by a GNSS survey, a georeferenced three-dimensional model can be created.

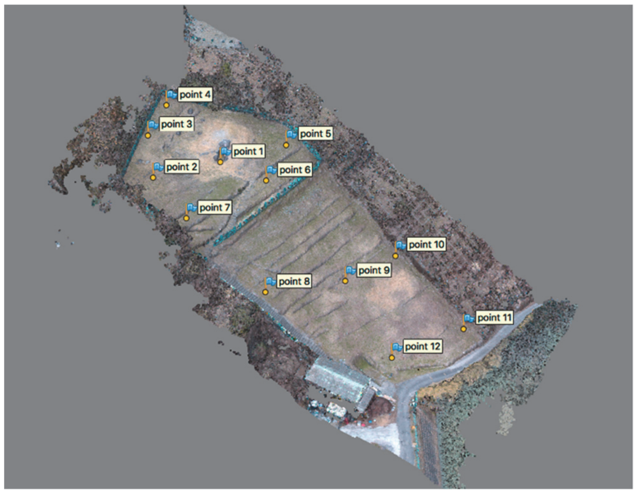


Fig. 9. GCPs and checkpoints setting in dense point cloud (shooting method: a-2)

4) Build mesh and texture： Fig. 10 shows a textured three-dimensional model. This step completes a three-dimensional model. By displaying the texture, it becomes a real three-dimensional model. This procedure can be omitted for building digital surface models (DSMs) and orthophotos.

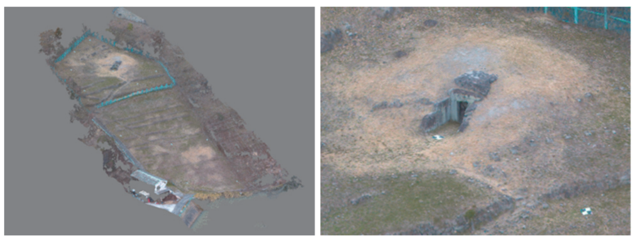


Fig. 10. Textured three-dimensional mesh model (shooting method: a-2)

5) Build DSM and orthophoto：Fig. 11 shows a DSM image. Fig. 12 shows an orthophoto image.

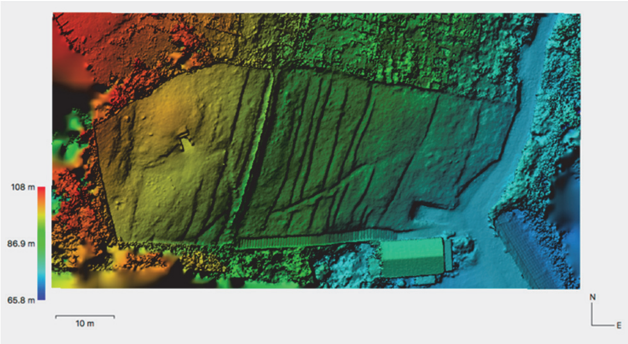


Fig. 11. DSM (shooting method: a-2)

Fig. 12. Orthophoto (shooting method: a-2)

6) Export of each data: Point clouds, textured three-dimensional models, georeferenced DSMs, and orthophotos can be exported. In this paper, the author mainly used DSMs and orthophotos, which are easy to use in three-dimensional GIS. Table 1 lists the resolution of the DSMs and the orthophotos by each shooting method.

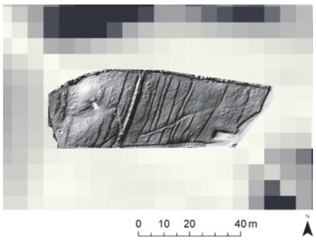
Table 1. List of shooting methods and resolution of DSMs and orthophotos

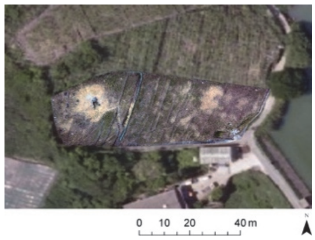
Method	Auto		Manual				
Direction	Vertical		Vertical			Vertical & Oblique	
No.	a-1	a-2	m-1	m-2	m-3	m-4	m-5
Height or Distance (m)	50	40	70	45	30	4 to 70	1 to 20
Number of photos	46	104	23	29	53	158	39
DSM resolution (cm/pix)	3.09	2.5	4.26	2.75	1.83	2.03	1.1
Orthophoto resolution (cm/pix)	1.54	1.25	2.13	1.37	0.916	1.01	0.552

3.1.4. Visualization of Landscape by Three-dimensional GIS

The landscape was visualized by three-dimensional GIS by the following procedures:

1) Overlaying a high-definition DSM and an orthophoto on a 5-m DEM and orthophotos by GSI: Using three-dimensional GIS software, we generated a DSM and an orthophoto by SfM and overlaid them on a 5-m DEM and orthophotos by GSI. Fig. 13 shows a shadow-relief map with a DSM by SfM with a shooting method (a-1) overlaid on the 5-m DEM by GSI. Fig. 14 shows an aerial photo map with an orthophoto by SfM with a shooting method (a-1) overlaid on an orthophoto by GSI. These maps can express the shapes of the Yokoguchi-shiki Sekkaku and the tomb mound clearly.





Left: Fig. 13. Shadow-relief map with 3.09-cm DSM by SfM (a-1) overlaid on 5-m DEM by GSI; Right: Fig. 14. Aerial photo map with 1.54 cm orthophoto by SfM (a-1) overlaid on an orthophoto by GSI

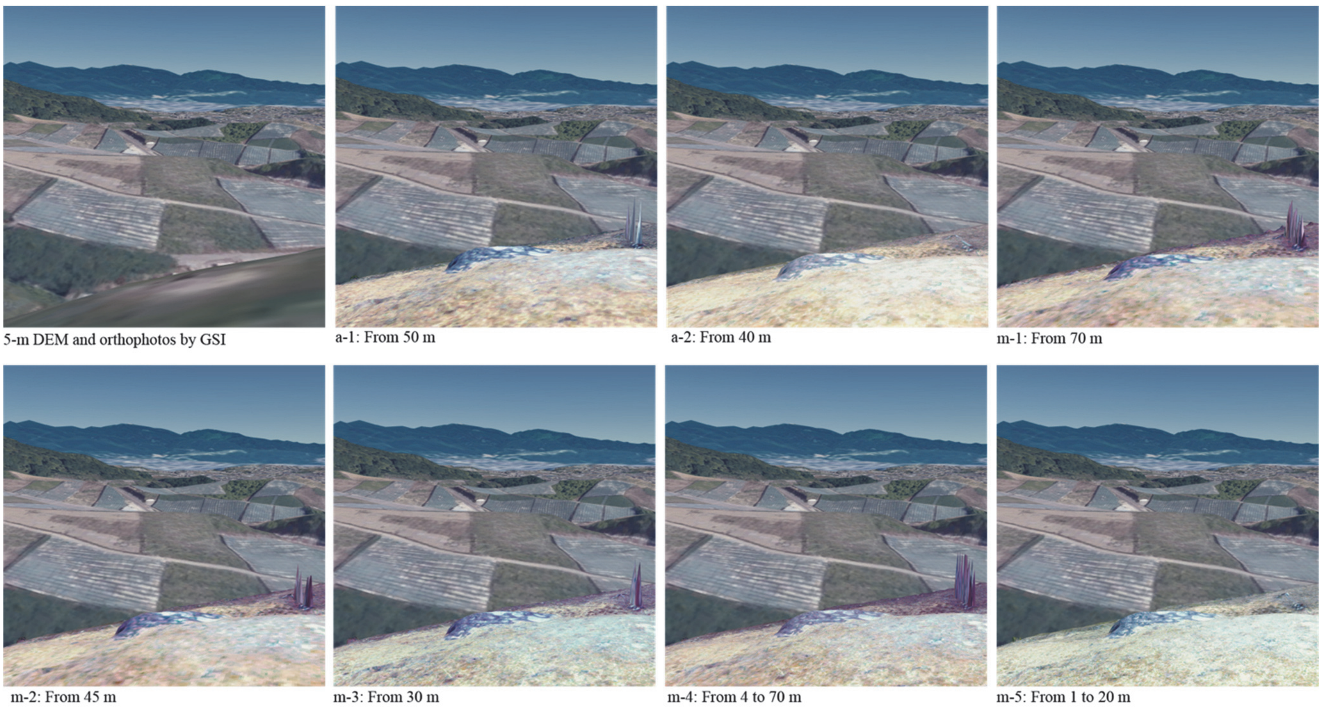
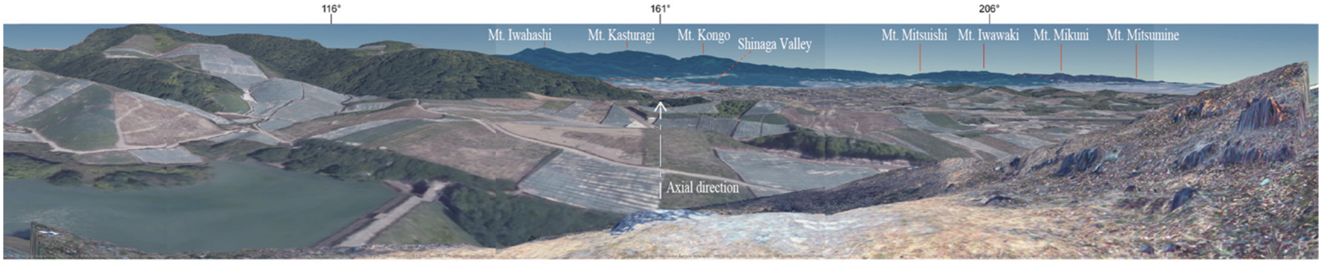


Fig. 15. Comparison of landscape simulation images from Kannonzuka Tomb by each shooting method

Panoramic image from Kannonzuka Tomb based on 5-m DEM and orthophotos by GSI



Panoramic image from Kannonzuka Tomb based on a DSM and an orthophoto by SfM with manual shooting method (m-5) overlaid on 5-m DEM and orthophotos by GSI

Fig. 16. Comparison of landscape simulation panoramic images from Kannonzuka Tomb

2) Generating landscape simulation images seen from tomb: Using the above overlaid three-dimensional GIS data, landscape simulation images seen from the Kannonzuka Tomb were generated. Fig. 15 shows the landscape simulation images from Kannonzuka Tomb only in the case of a 5-m DEM and orthophotos by GSI and a high-definition DSM and an orthophoto by each shooting method overlaid on them. A landscape simulation image based on only 5-m DEM and orthophotos by GSI can represent a distant view to the mountains, but it can't represent the shape of the stones that constitute the Yokoguchi-shiki Sekkaku and the tomb mound. The landscape simulation images based on a high-definition DSM and an orthophoto by SfM overlaid on a 5-m DEM and orthophotos by GSI can represent the shape of the stones and the tomb mound. The DSM and orthophoto resolution differ depending on the shooting height, and for shooting method (m-5) with the highest resolution, the shapes of the stones and the tomb mound can be expressed more clearly.

Figure 16 shows the landscape simulation panoramic images from the Kannonzuka Tomb for the only 5-m DEM and orthophotos by GSI and a high-definition DSM with 1.1-cm resolution and an orthophoto with 0.552-cm resolution by a manual shooting method (m-5) overlaid on them[5]. The latter image reproduces the relationship between the opening direction of the Yokoguchi-shiki Sekkaku and the landscape seen from the tomb. The view to the Kii Mountains (Mts. Mitsuishi, Iwawaki, Mikuni, and Mitsumine) is obstructed by trees now, but during the Final Kofun period the Kannonzuka Tomb had a distant panoramic view of the Kongo and Kii Mountains over an intermediate view of the nearby hills and the mountains. The axial direction of the Kannonzuka Tomb faces the Kongo Mountains (between Mts. Katsuragi and Kongo).

3.2. HACHIBUSEYAMA-NISHIMINE TOMB

3.2.1. Present State of Hachibuseyama-nishimine Tomb

Hachibuseyama-nishimine Tomb is a square, 20-m mound with a Yokoguchi-shiki Sekkaku on the hillside of the western slope of Mt. Hachibuse. It was probably built around the 7th century (Ito, 1998). Fig. 17 shows a 180 degree photo of it. The axial direction (opening direction of the Yokoguchi-shiki Sekkaku) faces the Osaka Plain, but the view to the northwest direction is obstructed by the surrounding trees, and the view to the southwest direction is also partially obstructed by the surrounding trees.

Fig. 17. 180 degree photo of Hachibuseyama-nishimine Tomb from the back of Yokoguchi-shiki Sekkaku (taken on November 9, 2017)

3.2.2. GNSS Survey and Photo Shooting with Small UAV

Figure 18 shows the positions of the GCPs and the checkpoints. We conducted a GNSS survey of them from 10:20 to 12:00 on February 19, 2018 and from 10: 00 to 12: 30 on February 22, 2018. Photos were taken with a small UAV by both auto pilot and manual pilot from 12:30 to 14:00 on the second day. The details of each shooting method are shown in Table 2.

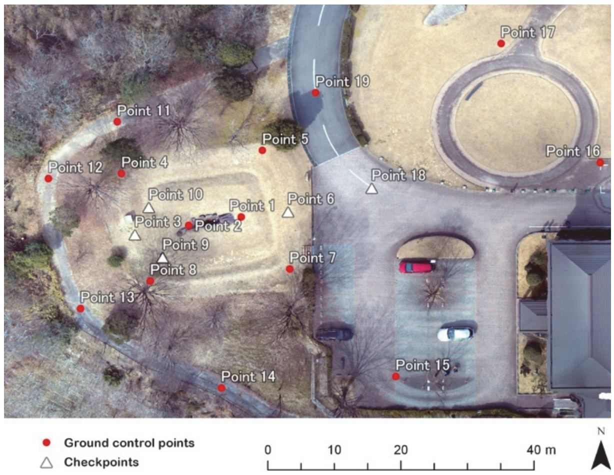


Fig. 18. Positions of GCPs and checkpoints

3.2.3. Reconstruction of Three-dimensional Model by SfM

Based on aerial photographs from a small UAV, three-dimensional models, DSMs and orthophotos of the Hachibuseyama-nishimine Tomb were reconstructed by SfM. Figs. 19, 20, and 21 show examples of each. Table 2 lists the DSM and orthophoto resolution by each shooting method.

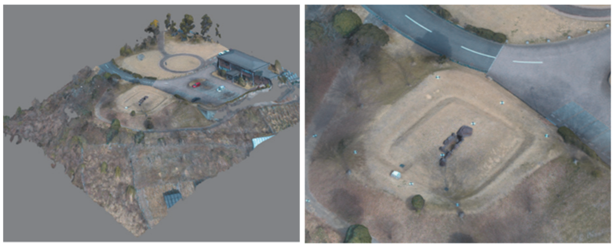


Fig. 19. Textured three-dimensional mesh model (shooting method: m-4)

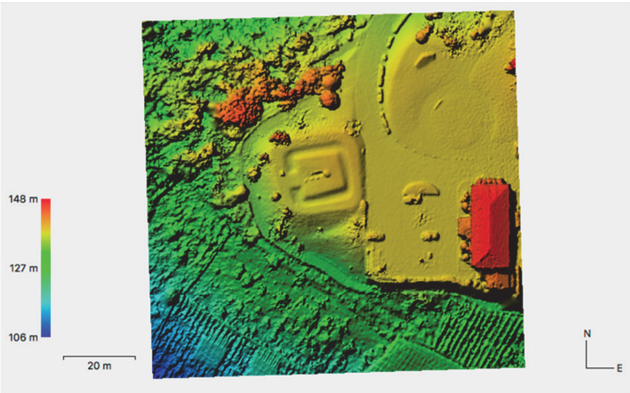


Fig. 20. DSM (shooting method: m-1)

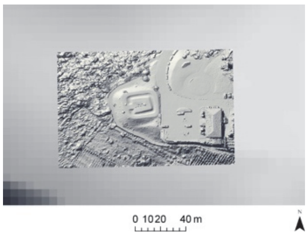
Fig. 21. Orthophoto (shooting method: m-1)

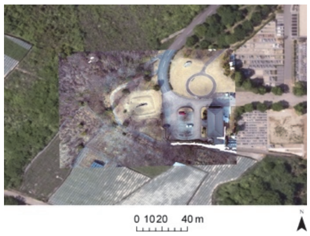
Table 2. List of shooting methods and resolution of DSMs and orthophotos

Method	Auto		Manual				
Direction	Vertical		Vertical			Vertical & Oblique	
No.	a-1	a-2	m-1	m-2	m-3	m-4	m-5
Height or Distance (m)	50	40	90	50	30	1 to 50	1 to 30
Number of photos	55	75	7	20	29	117	60
DSM resolution (cm/pix)	2.72	2.24	5.39	2.79	1.64	1.6	0.958
Orthophoto resolution (cm/pix)	1.36	1.12	2.7	1.39	0.821	0.798	0.479

3.2.4. Visualization of Landscape by Three-dimensional GIS

Figure 22 shows a shadow-relief map with a DSM by SfM with a shooting method (m-4) overlaid on a 5-m DEM by GSI. Fig. 23 shows an aerial photo map with an orthophoto by SfM with a shooting method (m-4) overlaid on an orthophoto by GSI. These maps can express the shapes of the Yokoguchi-shiki Sekkaku and the tomb mound clearly.





Left: Fig. 22. Shadow-relief map with 1.6-cm DSM by SfM (m-4) overlaid on 5-m DEM by GSI; Right: Fig. 23. Aerial photo map with 0.798-cm orthophoto by SfM (m-4) overlaid on an orthophoto by GSI

Figure 24 shows the landscape simulation images from the Hachibuseyama-nishimine Tomb only in the case of a 5-m DEM and orthophotos by GSI and a high-definition DSM and an orthophoto by each shooting method overlaid on them. The landscape simulation image based on only the 5-m DEM and orthophotos by GSI can represent a distant view to the mountains, but it can't represent the shape of the stones that constitute the Yokoguchi-shiki Sekkaku and the tomb mound. The landscape simulation image based on a DSM and an orthophoto by SfM with a shooting method (m-1) can roughly express the stone shape and the tomb mound, because of low resolution of the DSM and the

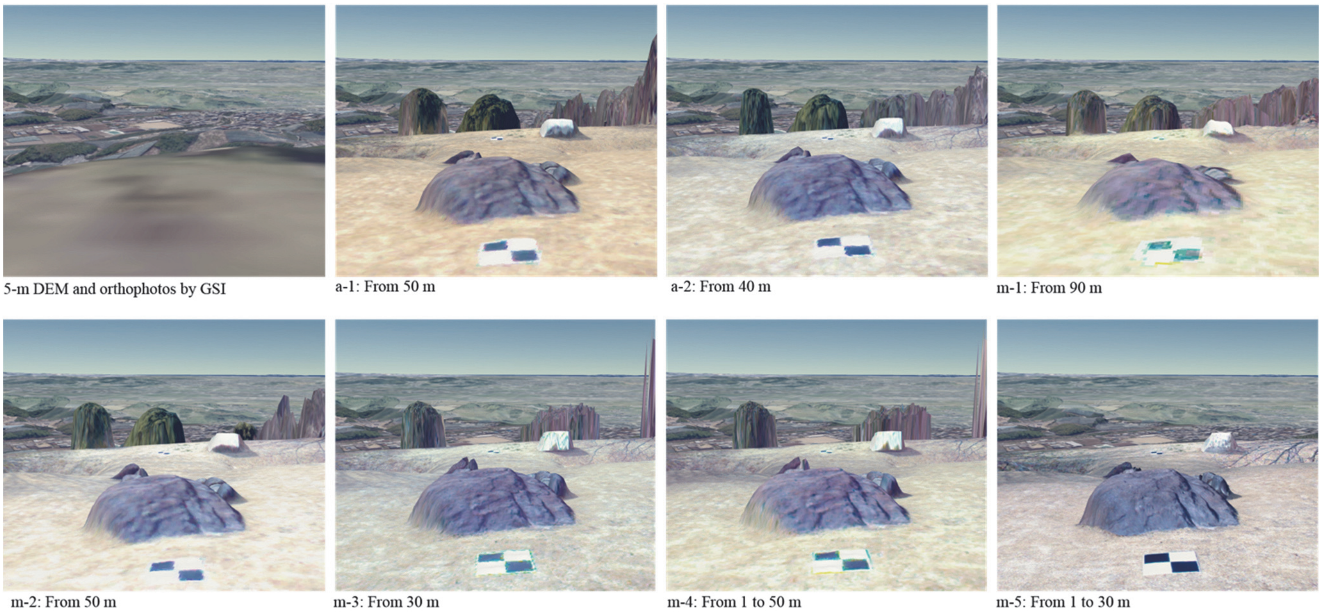
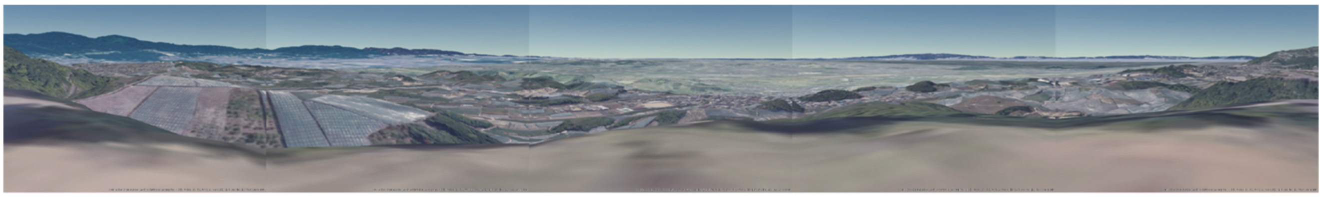
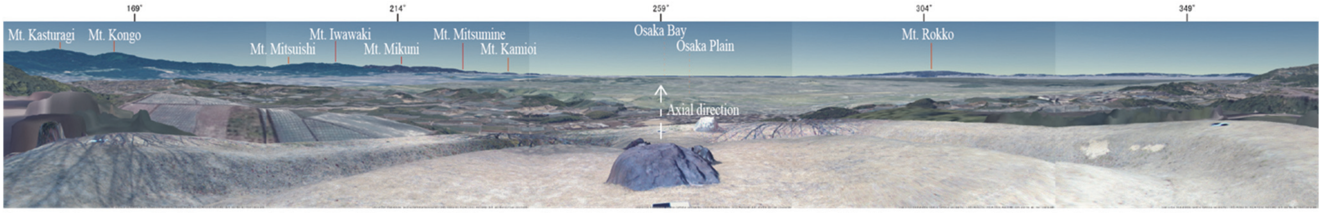


Fig. 24. Comparison of landscape simulation images from Hachibuseyama-nishimine Tomb by each shooting method



Panoramic image from Hachibuseyama-nishimine Tomb based on 5-m DEM and orthophotos by GSI



Panoramic image from Hachibuseyama-nishimine Tomb based on a DSM and an orthophoto by SfM with manual shooting method (m-5) overlaid on 5-m DEM and orthophotos by GSI

Fig. 25. Comparison of landscape simulation panoramic images from Hachibuseyama-nishimine Tomb

orthophoto. The landscape simulation images based on the DSMs and the orthophotos by SfM with shooting methods a-1, a-2, m-2, m-3, and m-4 have higher reproducibility than shooting method m-1. But the rising part of the stones can't be reproduced. For shooting method m-5 with the highest resolution, the shapes of the stones can be expressed more clearly, including the rising part and the tomb mound.

Figure 25 shows the landscape panoramic simulation images from the Hachibuseyama-nishimine Tomb for the only 5-m DEM and orthophotos by GSI and a high-definition DSM with 0.958-cm resolution and an orthophoto with 0.479-cm resolution by SfM with a manual shooting method (m-5) overlaid on them. The latter image can reproduce the relationship between the axial direction of the Yokoguchi-shiki Sekkaku and the landscape seen from the tomb. The view to the Kongo Mountains (Mts. Katsuragi and Kongo) and Kii Mountains (Mts. Mitsuishi, Iwawaki, Mikuni, and Mitsumine) is partly obstructed by the surrounding trees and the view to the northwest direction is also currently obstructed by the surrounding trees, but during the Final Kofun period, the Hachibuseyama-nishimine Tomb had a distant panoramic view of the Kongo and Kii Mountains and Mt. Rokko over an intermediate view of the nearby hills and the mountains and the Osaka Plain. The axial direction of Hachibuseyama-nishimine Tomb faces the Osaka Plain and Bay.

3.3. OKAMEISHI TOMB

3.3.1. Present State of Okameishi Tomb

Okameishi Tomb is a square mound with 21-m sides and a Yokoguchi-shiki Sekkaku on a ridge projecting southeast from the Habikino hills. It was probably built around the 7^{th} century (Kambayashi, 2003). Figs. 26 and 27 show 360 or 180 degree photos of the Okameishi Tomb. The views to the axial and southeast directions are partially obstructed by the surrounding trees and the view to the southwest is also obstructed by the surrounding trees.

Fig. 26. 360 degree photo of Okameishi Tomb in front of Yokoguchi-shiki Sekkaku (taken on February 8, 2018)

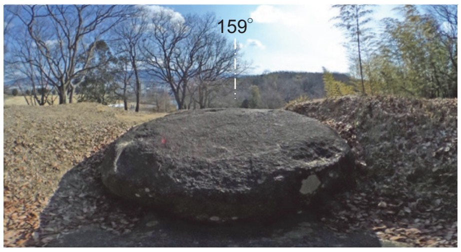


Fig. 27. 180 degree photo of Okameishi Tomb from behind Yokoguchi-shiki Sekkaku (taken on February 8, 2018)

3.3.2. GNSS Survey and Photo Shooting with Small UAV

Figure 28 shows the positions of the GCPs and the checkpoints. We conducted a GNSS survey of them from 10:20 to 12:00 on February 26, 2018 and from 9: 30 to 12: 00 on March 4, 2018. Photos were taken with a small UAV by both auto pilot and manual pilot from 12:00 to 14:00 on the second day. The details of each shooting method are shown in Table 3.

Fig. 28. Positions of GCPs and checkpoints

3.3.3. Reconstruction of Three-dimensional Model by SfM

Based on aerial photographs from a small UAV, three-dimensional models, DSMs and orthophotos of the Okameishi Tomb were reconstructed by SfM. Figs. 29, 30, and 31 show examples of each. Table 3 lists the resolution of the DSMs and the orthophotos by each shooting method.

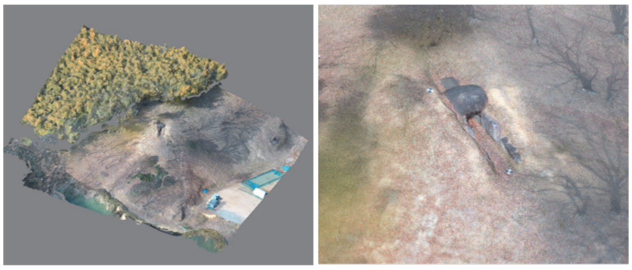


Fig. 29. Textured three-dimensional mesh model (left: a-1, right: m-4)

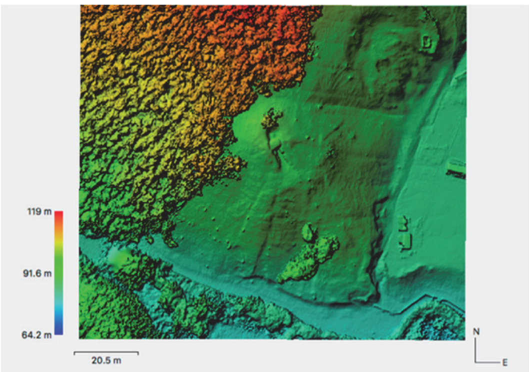


Fig. 30. DSM (shooting method: a-1)

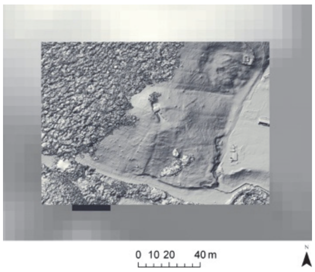
Fig. 31. Orthophoto (shooting method: a-1)

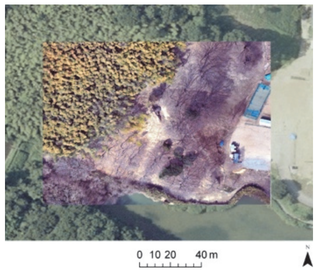
Table 3. List of shooting methods and resolution of DSMs and orthophotos

Method	Auto		Manual				
Direction	Vertical		Vertical		Vertical & Oblique		
No.	a-1	a-2	m-1	m-2	m-3	m-4	m-5
Height or Distance (m)	60	30	70	25	1 to 70	1 to 25	1 to 25
Number of photos	102	161	36	119	192	158	65
DSM resolution (cm/pix)	3.79	2.43	4.19	1.83	1.91	1.31	0.957
Orthophoto resolution (cm/pix)	1.9	1.22	2.1	0.914	0.956	0.656	0.479

3.3.4. Visualization of Landscape by Three-dimensional GIS

Figure 32 shows a shadow-relief map with a DSM by SfM with a shooting method (a-1) overlaid on a 5-m DEM by GSI. Fig. 33 shows an aerial photo map with an orthophoto by SfM with a shooting method (a-1) overlaid on an orthophoto by GSI. These maps can express the shapes of the Yokoguchi-shiki Sekkaku and the tomb mound clearly.





Left: Fig. 32. Shadow-relief map with 3.79-cm DSM by SfM (a-1) overlaid on 5-m DEM by GSI; Right: Fig. 33. Aerial photo map with 1.9-cm orthophoto by SfM (a-1) overlaid on an orthophoto by GSI

Figure 34 shows the landscape simulation images from the Okameishi Tomb only in the case of a 5-m DEM and orthophotos by GSI and a high-definition DSM and an orthophoto by SfM with each shooting method overlaid on them. The landscape simulation image based on only the 5-m DEM and orthophotos by GSI can represent a distant view to the mountains, but it can't represent the shape of the stones that constitute the Yokoguchi-shiki Sekkaku

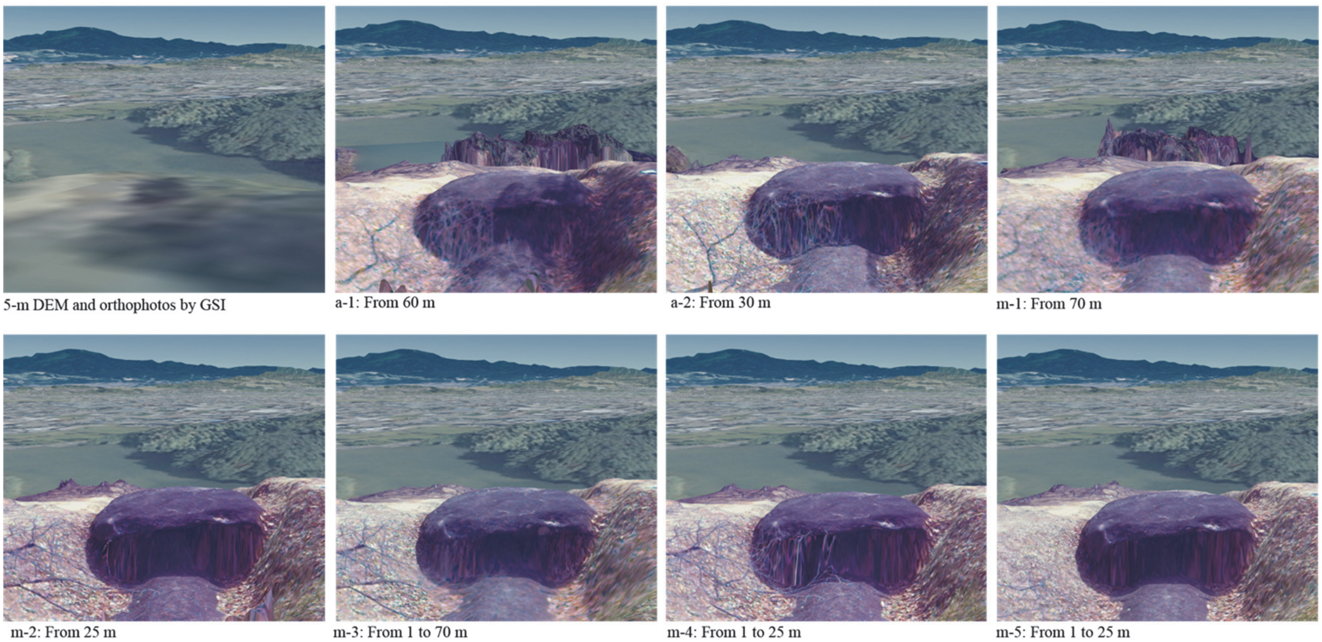
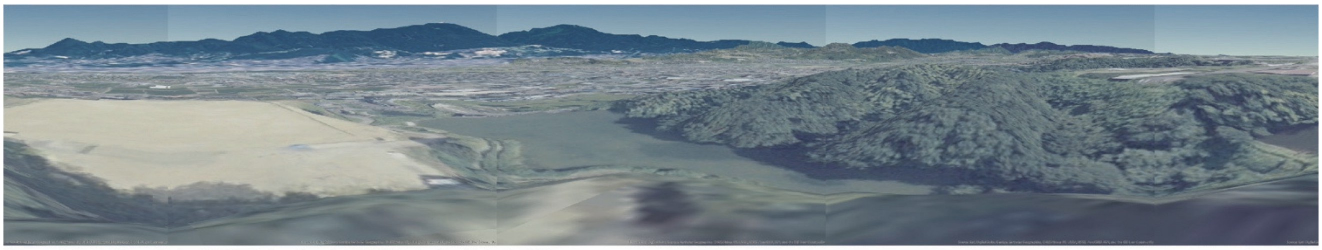
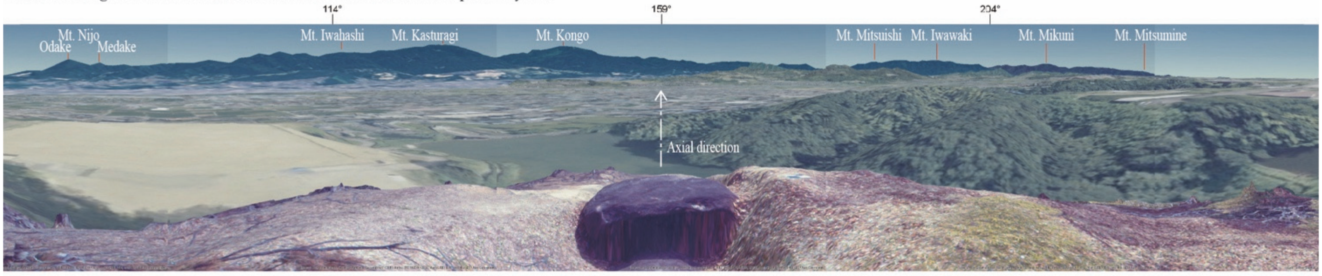


Fig. 34. Comparison of landscape simulation images from Okameishi Tomb by each shooting method



Panoramic image from Okameishi Tomb based on 5-m DEM and orthophotos by GSI



Panoramic image from Okameishi Tomb based on a DSM and an orthophoto by SfM with manual shooting method (m-5) overlaid on 5-m DEM and orthophotos by GSI

Fig. 35. Comparison of landscape simulation panoramic images from Okameishi Tomb

and the tomb mound. The landscape simulation images based on DSMs and orthophotos by SfM with shooting methods a-1 and m-1 can roughly express the shapes of the stones and the tomb mound, but because of the low resolution of the DSMs and the orthophotos, their reproducibility is low. The landscape simulation images based on DSMs and orthophotos by SfM with shooting methods a-2, m-2, m-3, and m-4 have higher reproducibility than with shooting methods a-1 and m-1. But these orthophotos have low reproducibility of the texture, especially because the branches of the nearby trees are projected for the stone's rising part. For shooting method m-5 with the highest resolution, the shapes of the stone including the rising part and the tomb mound can be expressed more clearly and properly.

Figure 35 shows the landscape panoramic simulation images from the Okameishi Tomb for only the 5-m DEM and orthophotos by GSI and a high-definition DSM with 0.957-cm resolution and an orthophoto with 0.479-cm resolution by SfM with a manual shooting method (m-5) overlaid on them. The latter image reproduces the relationship between the axial direction of the Yokoguchi-shiki Sekkaku and the landscape seen from the tomb. The view to the Kongo Mountains (Mts. Nijo, Iwahashi, Katsuragi, and Kongo) is partially obstructed by the surrounding trees, as is the view to the Kii Mountains (Mts. Mitsuishi, Iwawaki, Mikuni, and Mitumine), but during the Final Kofun period, the Okameishi Tomb had a distant panoramic view of the Kongo and Kii Mountains over an intermediate view of the nearby hills and the mountains. The axial direction of the Okameishi Tomb faces the Kongo Mountains on the eastside of Mt. Kongo.

4. Discussion

We generated high-definition georeferenced DSMs and orthophotos by three-dimensional models by SfM with aerial photographs from a small UAV and cm accuracy GNSS surveys, and reproduced the shapes of stones that constitute the Yokoguchi-shiki Sekkaku and the tomb mounds. By overlaying high-definition DSMs with a maximum of about 1-cm resolution and orthophotos with a maximum of about 0.5-cm resolution by SfM and a GNSS survey, on the 5-m DEM and orthophotos by GSI, we generated landscape simulation images that show the relationship between the shapes of the stones and the tomb mounds, the axial directions, and the panoramic view from the tombs. For generating landscape simulation images that reproduce the shapes of the stones and the tomb mounds, the shooting distance should be shorter than at least from 40 m to generate a DSM with resolution of about 2.5 cm or higher and an orthophoto with resolution of about 1.3 cm or higher resolution. It is difficult to lower the shooting height when such surrounding obstacles as trees exist in the auto pilot, which is suitable for reproducing a wide range area around the tombs. Therefore, to reproduce the three-dimensional shapes of the stones and the tomb mounds, shooting with a manual pilot is more effective and generates higher resolution DSMs and orthophotos.

The following issues must be examined in the future: 1) Since the sky above all of the three tombs is open, it was possible to take aerial photographs from a small UAV. On the other hand, since the sky above the tomb in the forest isn't open, no aerial photographs of the tomb mound can't be taken. 2) No effective method has been found for overlaying the three-dimensional model itself on the terrain model. Currently, it is very easy to overlay a DSM and an orthophoto generated from a three-dimensional model by SfM on the 5-m DEM and orthophotos by GSI using three-dimensional GIS to generate a landscape simulation image from the tombs.

5. Conclusions and future plans

We visualized landscapes from three tombs of the Final Kofun period in the Kawachi area (Kannonzuka, Hachibuseyma-nishimine, and Okameishi Tombs) with a high-definition three-dimensional model by structure from motion (SfM) multi-view stereo photogrammetry and three-dimensional GIS for analyzing the relationship of the shapes of the stones and the tomb mounds, the axial directions of the tombs, and their views. We also clarified the following three points:

1) By SfM with aerial photographs from a small UAV and a cm accuracy GNSS survey, we generated georeferenced DSMs with about 1-cm resolution and orthophotos with about 0.5-cm resolution at most, which can express the microtopography of the three tombs.
2) With overlaying DSMs and orthophotos by SfM on a 5-m DEM and orthophotos by GSI using three-dimensional GIS, we can quickly visualize landscapes from the three tombs at the Final Kofun period at low cost, although their views are now obstructed by such surrounding obstacles as trees.
3) Shooting with a manual pilot is more effective and generates higher resolution of DSMs and orthophotos than shooting with an auto pilot for reproducing the three-dimensional shapes of the stones and the tomb mounds. Lowering the shooting height

in the auto pilot is difficult when such surrounding obstacles as trees exist.

In the future, we plan to visualize landscapes from more tombs of the Final Kofun period by the method proposed in this paper, and analyze them to clarify the characteristics of tombs of the Final Kofun period from a landscape viewpoint.

Acknowledgements

I thank the Cultural Properties Protection Division of Habikino City, Kato Co., Ltd, and the Cultural Properties Division of Tondabayashi City for their cooperation on GNSS surveys and UAV flights. I am grateful to S. Uchiyama from the National Research Institute for Earth Science and Disaster Resilience for valuable advice on SfM photogrammetry and GNSS surveys. I also thank Y. Kawasaki and K. Ohara from the Graduate school of Human Environment, Mukogawa Women's University who supported the field surveys and helped generate the three-dimensional models of the tombs. This work was supported by JSPS KAKENHI Grant Number JP 17K18276.

Endnotes

1. The structure from motion (SfM) is a technique for estimating the three-dimensional shape and shooting position based on image processing (Uchiyama, 2014). By taking low-level aerial photos from multiple viewpoints using a small UAV and analyzing the parallax of the object to be photographed, a high-definition three-dimensional model can be generated.
2. Global Navigation Satellite System (GNSS) is used for real-time positioning (latitude, longitude, and altitude) from the radio waves from satellites (Hayakawa, 2014).
3. RTKLIB is an open source program package for standard and precise positioning with a global navigation satellite system (GNSS) developed by T. Takasu, for more details about on RTKLIB see the following site: RTKLIB: An Open Source Program Package for GNSS Positioning http://www.rtklib.com/
4. The geoid height was calculated using the coordinate data obtained by GNSS survey at the following site: Geoid calculation-GSI https://vldb.gsi.go.jp/sokuchi/surveycalc/geoid/calcgh/calc_f.html
5. For a method that generates panoramic images in ArcGIS pro, refer to the following site by Y. Haneda. https://www.wingfield.gr.jp/blog/2018/08/31/p8852/

References

Haneda, Y. ArcGIS Pro ni yoru panorama gazou seisei tool no sakusei [Creation of panorama image generation tool by ArcGIS Pro] from https://www.wingfield.gr.jp/blog/8852/ access on October 3, 2018.

Hosokawa, S & Imao, F. (2011). 5 Kinki [Part 5 Kinki area] Kouza Nihon no Kokogaku 7: Kofun Jidai Jyou [Course of Japanese Archeology part 7: Kofun Period part 1]. Aokishoten. 243-317.

Hayakawa, Y. (2014). Genchi chousa niokeru chikei jouhou syutoku no tameno GNSS to TLS [GNSS and TLS for acquiring topographic information in field surveys] from http://topography.csis.u-tokyo.ac.jp/resources/140808_kashiwa/slides/140808-04_hayakawa.pdf

Imao, F. (2012). Asuka Fujiwara no Funbo [Tombs in Asuka and Fujiwara area] Kodai no Miyako 1: Asuka kara Fujiwarakyo e [Ancient capitals part 1: From Asuka to Fujiwarakyo]. Yoshikawakobunkan. 222-254.

Ito, M. (1998). Chousa hokoku: Habikinoshi Hachibuseyama-nishimine kofun [Survey report: Hachibuseyama-nishimine Tomb in Habikno city]. Kawachiasuka to Syumatsukikofun: Yokoguchi-shiki Sekkaku no nazo [Kawachiasuka and tombs of the Final Kofun period: Mystery of Yokoguchi-shiki Sekkaku]. Yoshikawakobunkan. 136-153.

Kambayashi, S. (2003). Kawachi: Syumatsukikofun to sonojidai [Kawachi area: Tombs of the Final Kofun period and their period], Kakuchi no syumatsukikofun [Tombs of the Final Kofun period in various places]. *Kikan Kokogaku 2003* [Quarterly Archeology 2003]. 58-62.

Kaneda, A., Tsumura, H. & Niiro, I. (2001). Kokogaku no tameno GIS Nyumon [Introduction to GIS for archeology]. Kokinshoin.

Kawakami, K. (1999). Syumatsukikofun no Ricchi to Fusuishiso [Locations of tombs of the Final Kofun period and Feng-shui thought], Tsukamyoujinkofun no kenkyu [Research on Tsukamyoujin Tomb]. 175-193.

Kitamura, T. (2001). Todai Koteiryo no kenkyu [Study on the Emperor's Tomb of Tang Dynasty]. Gakuseisha.

Kitamura, T. (2004). Fusui to Tennoryo [Feng-shui and Tombs of Japanese Emperor]. Kodansha.

Mori, K. (1973). Ronshu Syumatsukikofun [Articles of tombs of the Final Kofun period]. Hanawashobo.

Mori, K. (1988). Zenpokoenfun to Heijokyo no sanzan [Keyhole shaped tombs and three mountains around Heijokyo] *Journal of Archaeological Institute of Kashihara, Nara prefecture part 9.* Yoshikawakobunkan. 513-523.

Mori, K. (1996). Tennoryokofun [Tombs of Japanese Emperors]. Taikosha.

Shimomura, S. (2006). Nishinihon no Syumatsukikofun [Tombs of the Final Kofun period in Western Japan]. Cyugokushoten.

Shiraishi, T., Sakai, R., Ueno, K., Senda, Y., Usui, T., Kishimoto, N. & Fukunaga, S. Research Group of KAKENHI "Fundamental Studies on the large tombs group in the Kinki district". (2008). Kinki chiho niokeru ogatakofungun no kisotekikenkyu [Fundamental Studies on the large tombs group in the Kinki district]. Rokuichishobo.

Tembata, H (2016). LANDSCAPE ANALYSIS OF TOMBS OF THE FINAL KOFUN PERIOD IN THE KAWACHI AREA USING A THREEDIMENSIONAL MODEL. Paper presented at the 4th International Conference on Archi-Cultural Interactions through the Silk Road, Nishinomiya, Japan. Abstract retrieved November 30, 2016, from http://www.mukogawau.ac.jp/~iasu2016/pdf/iaSU2016_proceedings_202.pdf

Teramura, H. (2005). Kofunjidai no isekiricchi ni kansuru keikan kokogakuteki kenkyu [Landscape archaeological study on the archaeological site of the Kofun period]. Doctoral dissertation, Okayama University.

Teramura, H. (2014). Keikan kokogaku no houhou to jissen [Method and practice of landscape archeology]. Doseisha.

Uchiyama, S., Inoue, H., & Suzuki, H. (2014). Approaches for Reconstructing a Three-dimensional Model by SfM to Utilize and Apply this Model for Research on Natural Disasters. *Report of NIED*, *81*, 37-60.

Yamamoto, A. (1998). Kawachi no Yokoguchi-shiki Sekkaku [Yokoguchishiki-Sekkaku in the Kawachi area]. Kawachiasuka to Syumatsukikofun: Yokoguchi-shiki Sekkaku no nazo [Kawachiasuka and tombs of the Final Kofun period: Mystery of Yokoguchi-shiki Sekkaku]. Yoshikawakobunkan. 22-37.