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Digitalizing Sculptures: A Photogrammetry Implementation Towards Ancient Mataram Statuaries in Central Java, Indonesia
Digitalisasi Arca: Implementasi Fotogrametri Terhadap Patung-patung Mataram Kuno di Jawa Tengah, Indonesia

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Abstract
The implementation of digital technology in cultural heritage in Indonesia started to develop in the past decade. However, Indonesia's iconography studies have not optimized to utilize these advanced approaches. In some other countries, iconographic documentation is upgraded to advanced methods, such as recording objects in 3D form and archiving it into secure digital data, thus making the data more natural and realistic in three-dimensional documentation. It also catches and records the shape from all perspectives to bring neither a specific nor comprehensive observation. Therefore, it can extend the analysis for interpretation and preservation purposes. This article discusses the implementation of photogrammetry towards sculptural objects in Indonesia. The object selection went to several sculptures from the Ancient Mataram period in Java, which ruled from the 8th to 10th centuries AD. Close-range photogrammetry successfully generates the sculpture data into three-dimensional digital form. The results could support the Ancient Mataram sculptures studies in particular and improve Indonesia's iconography studies in general.

Penerapan teknologi digital dalam bidang warisan budaya di Indonesia semakin berkembang dalam satu dekade terakhir. Namun, studi ikonografi Indonesia belum optimal untuk memanfaatkan pendekatan-pendekatan canggih tersebut. Sementara di beberapa negara lain, dokumentasi ikonografis ditingkatkan ke metode yang lebih canggih, seperti merekam objek dalam bentuk 3D dan mengarsipkannya ke dalam ruang digital. Teknologi digital juga memungkinkan warisan budaya direkam secara detail dan lengkap, sehingga dapat memperluas analisis untuk tujuan interpretasi dan pelestarian. Artikel ini membahas tentang penerapan fotogrametri terhadap benda pahat di Indonesia. Pemilihan objek dilakukan pada beberapa patung dari masa Mataram Kuno di Jawa yang memerintah pada abad ke-8 hingga ke-10 Masehi. Fotogrametri jarak dekat yang digunakan dalam penelitian ini berhasil merekam data pahatan ke dalam bentuk digital tiga dimensi. Hasil penelitian ini dapat mendukung kajian seni pahat Mataram Kuno pada khususnya dan meningkatkan kajian ikonografi Indonesia pada umumnya.

Keywords: photogrammetry, sculptures, statues, iconography, ancient Mataram | fotogrametri, patung, arca, ikonografi, mataram kuno

Introduction

The digital technology era has potential implications for the development of scientific disciplines by not only giving an improvement in the hard sciences but also the soft sciences. Archaeology, one of the branches of soft sciences that study culture and humanities, also tends to utilize technological facilities for its enhancement. Although archaeology deals with the remains of past civilizations, its methods' characteristics do not always have to be manual and traditional. Archaeology today requires various modern techniques to achieve more optimal results. For example, technological advances encourage archaeologists to conduct data recording that can capture the object in high-definition quality as comprehensive documentation, which aims to support an in-depth analysis to impact a more reliable and accountable interpretation.

Developed countries have expanded digital technology for archaeological data recording in the past decades. It was initially encouraged by museums to present more modern collection documentation to visitors. Digital documentation, especially in a three-dimensional form, is more accurate and detailed when compared to old-style documentation. It added exceptional values to the traditional documentation approaches, such as material for restoration and secure data archived in web-based virtual catalogs/digital libraries (Guidi et al. 2013; Gajski et al. 2016: 263).

Digitalizing sculptures as one type of archaeological data necessary to support iconography studies. These modern techniques could empower iconographic data to produce more interpretations. Since iconography accentuates the "form" aspects, pictorial documentation became essential. The accurate and systematic documentation would ease the observation and records when the researcher is no longer at the sites. Digital data also help to secure and archive the data.

One method for digitalizing iconographic data is photogrammetry, a 3D scanning technique. Many exercises have applied this. For example, the preliminary work using photogrammetry and 3D scanning to assess the metric accuracy of the digital model of the wooden statue "Maddalena" by Donatello, kept in the museum of the Opera del Duomo in Florence, Italy. This trial attempts to verify the three-dimensional object's metric reliability by using photogrammetry to refine the procedures for acquiring digital data that obtained global accuracy coherently consistent with the instrumentation (Guidi et al. 2001). Another benefit of digitalizing the data is to help the reconstruction of an art sculpture. The experiment using close-range photogrammetry represented a promising method for the 3D reconstruction of sculptures. Its potential areas of application include the digital documentation of cultural heritage, the restoration of damaged sculptures, the protection of art heritage, and the creation of a virtual museum/gallery (Santosi et al. 2015).

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In Indonesia, the implementation of digital technology in cultural heritage started to develop in the last decade. The Agency for Borobudur Conservation has conducted a very progressing and promising project during the previous ten years. They use instruments to capture Borobudur Temple and its landscape, such as terrestrial laser scanning, laser scanner, and close-range and aerial photogrammetry through unmanned aerial vehicles (Brahmantara 2017). Usage for each category depends on the needs in the field. Data collection and processing protocols are also essential to the archaeological documentation project. Systematic procedures can help project implementation run smoothly without longing to retrieve data in the field (Murtiyoso and Suwardi 2017: 255). Devices, tools, and human resources are available. The utilization has to be maximal to reach optimal results in archaeological research and cultural heritage preservation in Indonesia.

Nevertheless, Indonesia's iconography studies have not optimized to utilize these advanced techniques. Several projects in recording 3D sculptures have already been done, but only for documentation purposes, not for supporting iconography studies that can also extend the interpretation and reconstruction. Most of the time, the documentation techniques of iconographic data include only illustration sketches and photography. While in some other countries, iconographic documentation is upgraded to an advanced method, such as recording objects in 3D form and archiving it into digital data, thus the data more natural and realistic in three-dimensional documentation. This documentation also catches and records the shape from all perspectives to bring neither a specific nor comprehensive observation.

It is time for iconography studies in Indonesia to raise its standards. Some traditional techniques are still needed, but modern applications are also required. The technological touch would increase the resulting quality. This article discusses the implementation of photogrammetry towards sculptural objects in Indonesia. The object selection went to several sculptures from the Ancient Mataram period in Java, which ruled from the 8th to 10th centuries AD. Borobudur and Prambanan temples, inaugurated as world heritage by UNESCO, are some worldwide discoveries from this period. The results can support the study of ancient Mataram statues and supply the material for Indonesian iconography studies.

Methods

Digital data recording methods include various techniques. There are two well-known instruments for recording sculptures, i.e., laser scanners and photogrammetry. The first one is user-friendly, but the results highly depend on the device's quality. A sophisticated device will impact the quality, yet the price is relatively high. Another one is photogrammetry, a flexible, low-cost method that produces good quality, detailed, and precise documentation. This instrument captures the object's shape and dimension through photography techniques (Santamaria and Sanz 2011). In addition, photogrammetry could facilitate image measurement, reconstruction, and restoration of objects (Yilmaz et al. 2007). Thus, archeology can utilize photogrammetry for documentation, reconstruction, and dissemination of research results (Forlin, Valente and Kazmer 2018).

Several photogrammetry categories are close-range, aerial, underwater, and macro photogrammetry. It depends on the different kinds of data. Collecting sculptures and other artifacts are usually using close-range photogrammetry. It uses the main principle of overlapping measures between photos with different angles and measurements from the camera direction. The three-dimensional object results are affected by the overlapping areas between shots. A non-metric camera's calibration uses computerized assistance to recognize the camera's parameter and location, then obtain the value of the camera orientation measurement result (Aulejtner 2011 in Brahmantara 2017; Hendy 2014).

Overlapping photos generate point clouds through a computerized process shaping a three-dimensional model. In addition, the photography techniques also determine results. In creating an excellent 3D model, photos must be taken circling the object at the same distance and height. The close-range photogrammetry method has two main stages: recording and processing data (dissemination is complementary), as seen in the workflow below:

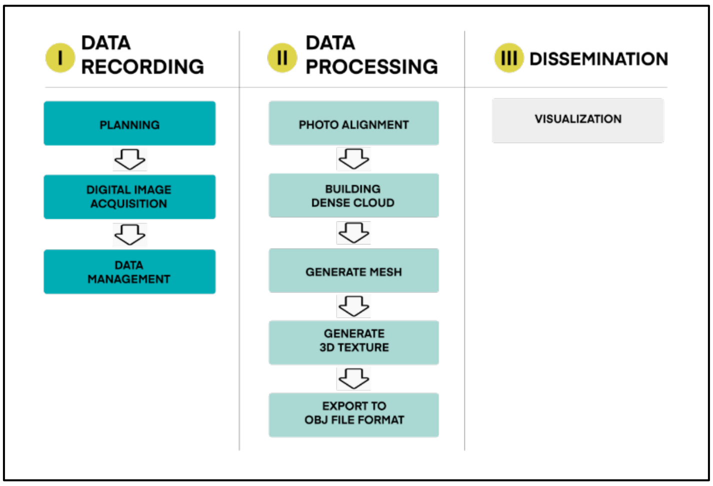

Fig. 1 Close-range photogrammetry workflow. Source: Illustration by R. Ahmad Ginanjar Purnawibawa, 2019.

In this research, the camera used is Sony ILCE-5100 with a 24.3 megapixel sensor to perform close-range photogrammetry. Also, external lights are used in several cases when the statues are located in a low-light room. These are meant to explore the use of the low-cost system to photogrammetry to obtain adequate results. In brief, photogrammetry on sculpture begins with taking photos of an object repeatedly at different angles, maintaining the same distance: the more shots and points, the more accurate and detailed results processing by software. The software used for the digital photogrammetry processes in this research is Agisoft Metashape.

Compared to the open-source software, the commercial software was selected due to its consistency in quality, precision, and representation of actual characteristics, materials, and colors on various shapes of objects (Djuric et al. 2021). The software processes the photo collection, starting with the searching points based on automatic features. The feature is a descriptor of dots in an image (Murtiyoso and Suwardi 2017: 243). The next step is a strict detection and elimination of each point and alignment to calculate the position and orientation of every photo shot (Chiabrando et al. 2015; Murtiyoso and Suwardi 2017: 243). After that, an algorithm produces dense point clouds, up to one point for each pixel (Achille et al. 2015). The vital part of photogrammetry work is an external orientation or aerial triangulation, which aims to determine the connection between the imaging system and the object system (Murtiyoso and Suwardi 2017: 243).

This study attempts to practice recording sculpture data through close-range photogrammetry. The three-dimensional documentation aims to observe each attribute from various perspectives as needed. In addition, the objects look more natural and realistic archived on a digital platform. Thus the examination can do where ever and whenever without having to be on the sites. This course

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examines 27 Ancient Mataram sculptures in Yogyakarta and Central Java. The sculptures selected are intact, and the art style is still clearly visible to represent the art style's uniqueness.

Results and Discussion

Photogrammetry towards only limited sculptures considered the masterpieces of the Ancient Mataram period. The definition of a masterpiece in this condition is that the objects are intact, with minimum damage, and the art style is dominantly visible. All sculptures are andesite stone materials stored in museums, conservation centers, and sites. The data collections are as follows:

No.	Name of Sculpture	Location	Size (h x l x w)	Picture
1	Agastya	Regional Office for Cultural Properties Preservation in D.I. Yogyakarta Province	86,2 x 45,6 x 28,8 cm	
2	Sri		74,6 x 49,6 x 37,1 cm	
3	Narasimha		85,4 x 39,3 x 25,7 cm	
4	Ganesha		64,8 x 45,2 x 30,8 cm	
5	Siva and Parvati		70,8 x 35,2 x 25,8 cm	
6	Wisnu Triwikrama		87,7 x 41,9 x 27,3 cm	
7	Agastya		75,8 x 31,6 x 28,6 cm	
8	Durga	Prambanan Museum	121 x 51 x 31 cm	
9	Siva		78,7 x 22,1 x 19,5 cm	

10	Garuda		66,5 x 65,5 x 72,2 cm	
11	Mahakala		101,5 x 44,6 x 32 cm	
12	Nandisvara		86,6 x 39,4 x 27,2 cm	
13	Visnu		106 x 40 x 28 cm	
14	Goddess/Tara		76 x 31 x 21 cm	
15	Ratnasambhava		96 x 53 x 43 cm	
16	Siwa		165 x 56 x 31 cm	
17	Durga		66,2 x 30,5 x 17,4 cm	
18	Brahma		254 x 89 x 68 cm	
19	Durga	Prambanan Temple	245,5 x 149 x 80 cm	

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20	Ganesha		181 x 161,5 x 127 cm	
21	Agastya		180 x 92,5 x 111 cm	
22	Durga	Karmavibhanga Borobudur Museum	103,4 x 53,2 x 31,4 cm	
23	Unfinished Buddha			
24	Ganesha	Agency for Borobudur Conservation	74 x 57,5 x 26,5 cm	
25	Dhyani Boddhisatva	Sonobudoyo Museum	71,8 x 38,3 x 31,7 cm	
26	Visnu and Laksmi	Sonobudoyo Museum	80,2 x 52,8 x 32,7 cm	
27	Aksobhya	Plaosan Temple	114,5 x 64 x 54,5 cm	

Table 1 Data collected

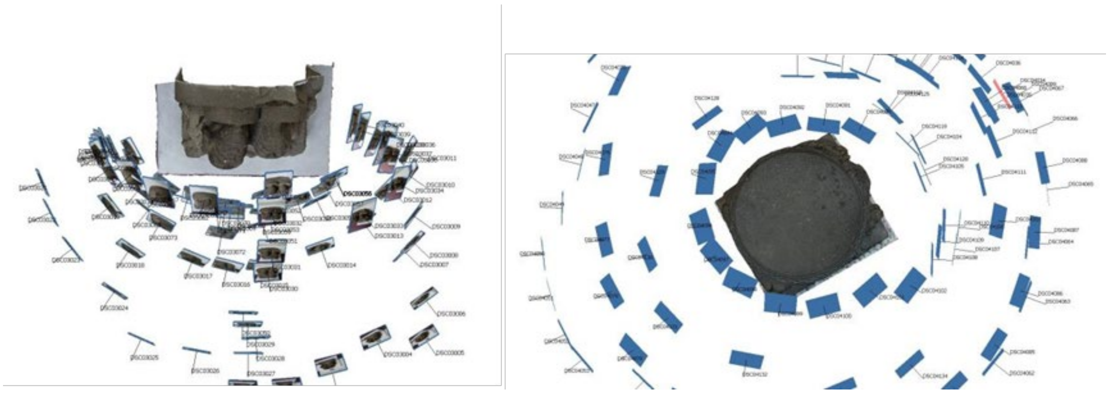
As mentioned before, the close-range photogrammetry method has two main stages: recording and processing data. Below is a brief discussion.

a. Data Recording

The stage of data recording includes planning and image acquisition. The data sources are in several locations, such as museum exhibitions, conservation centers, temples, and open spaces. Thus, the preparation and planning strategy is essential regarding the equipment, techniques, and data management. The photos are captured sequentially to gather as many details as possible. To help preserve the photos' details and quality, the photographers prefer physical zoom rather than optical/electronic zoom.

Figs. 2-3 Data recording process. Source: Photograph by Atina Winaya, 2019.

The main requirement of the photo for photogrammetry processes is overlapping pictures, with approximately 60% overlap. Ideally, the photographer takes the photos using the 360° technique, where the camera circled the target. However, if the situation is impractical, then 180° technique shooting is possible. This strategy accurately captures sculptures attached to the wall, such as in the temple's chamber and museum's exhibition room, since taking full-round pictures was impossible. The different main results of these techniques are the results where the 360° technique provides the complete object, where the other left gap in the rear parts of the object (due to lack of data).



Figs. 4-5 180° photo shoot technique (left) and 360° photo shoot technique (right). Source: Illustration by R. Ahmad Ginanjar Purnawibawa, 2019

b. Data Processing

Processing images into three-dimensional objects uses Agisoft Metashape software. The data processing workflow consists of photo alignment, dense cloud formation, and texture creation. The photo-alignment mechanism use algorithm to identify points that have similar pixel value. The exact value pixels are defined as tie points. The photo density around the tie points and the combination between points based on their height values form the dense cloud. The dense cloud displays tighter points that tie points. Several parameters such as quality and depth filtering exist in the formation of the dense point cloud model. The photo density around the tie points and the

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combination between points based on their height values form the dense cloud. The dense cloud displays tighter points that tie points. Several parameters, such as quality and depth filtering, exist in the dense point cloud model. The following process is texture creation to show the appearance of the physical condition or photo coverage area. Processing texture data depends on the photo results. The higher the photo resolution, the more detailed texture will be.

Fig. 6 The data processing consists of photo alignment, dense cloud formation, and texture creation (left to right). Source: Photogrammetry by R. Ahmad Ginanjar Purnawibawa, 2019.

Fig. 7 Various perspectives through photogrammetry. Source: Photogrammetry by Brahmantara and Dian Effendi, 2019.

Photogrammetry generates 3D models, which are very helpful in observing sculptures' attributes from diverse perspectives. One sculpture can be "inverted" to examine each part or feature in detail, especially in positions that are difficult to observe directly at sites. Digital visualization simplifies the examination process. A more in-depth observation is significant during post-field analysis activities, such as crosschecking the data to optimize the results.

Conclusion

The technology application in Indonesia's archaeological research is growing today. One of its technological advances is a documentation method involving hardware and software to obtain better quality data, such as photogrammetry. Its technique is practical, flexible, and inexpensive as well. Photogrammetry aims to capture and process an object using specific software to produce it in a three-dimensional form. Archaeology benefits photogrammetry as a medium for recording data valuable for digital data archives, reconstruction/preservation materials, and in-depth analysis and interpretation.

Archaeological data recording targets include sculptures to support iconography studies in Indonesia. Iconography studies need detailed yet comprehensive pictorial documentation since the main focus object is the form aspect. So far, photogrammetry towards sculptures is still infrequent, especially for iconographic analysis and interpretation purposes. Recording sculpture data uses close-range photogrammetry could generate sculpture images into 3D digital data. This kind of data helped the data examination become more profound and detailed as desired by researchers. Also, they could observe slowly and carefully anytime and anywhere without meeting the object directly on the field. The data collection is safely secure in the web-based catalog. This approach brings it to another level.

This article presents the photogrammetric results of 27 stone sculptures in the Ancient Mataram style in Central Java. Ancient Mataram statuaries, dating from the 8th to 10th centuries AD, are one of the archaeological remains in Indonesia considered masterpiece findings. Characteristics had a particular style that differs from India and other mainland Asia regions. Hopefully, this result can positively support the analysis and interpretation to comprehend the Ancient Mataram statuaries in Central Java. The documentation of 3D sculpture is quite a breakthrough in Indonesia's iconography studies development.

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