Documentation of a Numismatic Collection from the Period of the Roman Empire Using the Photogrammetry Method

Klára Rybenská[0000-0001-9333-3063], Barbora Borůvková[0000-0001-8449-9256], Klára Burianová[0000-0002-1344-0932]

Department of Auxiliary Sciences of History and Archival Studies, Philosophical Faculty, University of Hradec Králové, Rokitanského 62/26, 500 03, Hradec Králové 3, Czech Republic
klara.rybenska@uhk.cz, barbora.boruvkova.2@uhk.cz, klara.burianova@uhk.cz

Abstract. The article describes the possibilities of 3D documentation of historical monuments by photogrammetry on a selected sample of coins. It applies this selected method, verifies its suitability and describes some other digitization methods. It also contains a basic description of the methodology of creating 3D models of ancient coins.

Keywords: Photogrammetry, Numismatics, Digital Humanities, 3D, Memory Institutions.

1 Introduction

Ancient Roman coins, although often the subject of three-dimensional digitization, are usually documented only by means of two-dimensional photographs. These images, even at high resolution, cannot capture all the details, which limits the acquisition of complete information, especially the neglect of the edges of the coin. In contrast, 3D scanning offers the possibility of detailed digitization, but is associated with high costs and the need for specific knowledge, which complicates its wider use in memory institutions. The specific characteristics of coins, such as small size, lustre or intricate decoration, which can make scanning difficult, also pose problems.

As an alternative, the Reflectance Transformation Imaging (RTI) method is suitable for imaging inscriptions and reliefs but does not allow the creation of 3D models. The most accessible and frequently used method is photogrammetry, which allows the creation of 3D models of objects based on conventional photographs and innovative processing. Photogrammetry is also effective for numismatic studies because it allows non-contact analysis, avoiding damage to valuable or fragile originals.

The aim of this paper is to present and validate on a selected set of ancient coins different methods of digitization, with emphasis on photogrammetry, and to show its benefits and limitations. At the same time, the aim is to provide a basic overview of the methodology of creating 3D models of coins, which can help to better understand and preserve numismatic heritage.

2 Issues of Three-dimensional Digitalization of Coins

Coins are important evidence of ancient civilizations. Their study is essential for understanding economic history, especially in terms of incoherent production. With the help of coins, we can determine the chronology of production and many other pieces of information. Their documentation and identification is one of the basic procedures of numismatic studies. Coin typology is often difficult to recognize. It requires a lot of time and deep knowledge on the part of numismatists. For some coins it is almost impossible to spot the differences because they are too worn (Horache et al., 2021; Fitzwilliam Museum, 2023). Viewing the relief of a historically valuable coin is not always easy, as these relics are often housed in the collections of museums or archives and other memory institutions. Thus, the numismatist must travel or resign himself to seeing the coin in question only in a photograph. However, this may not always provide all the information available. The relief captured by modern digitization methods, i.e. the acquisition of a 3D model, can help the researcher to read more information from the coin and thus better classify and identify it. If these models are combined with high-resolution texture, the researcher can indeed obtain a lot of important information.

Scanning a similar object using standard methods, such as a 3D scanner, can also be very complicated, time-consuming and especially expensive, unless the memory institution is willing to invest hundreds of thousands in professional equipment, which often requires the necessary training. Then it is possible to choose to rent or purchase services from companies that deal with digitization. However, this may not be the best solution, not only because of the cost, but also because of the problem of the operation itself - a suitable 3D model is not always 100% guaranteed. For these reasons, the focus should be on choosing a method that is non-destructive, the model will be easy to read from, and the method will be affordable and user-friendly. There are several options in this respect.

Coins can, of course, be modelled. However, modeling copies of real coins on a computer requires a lot of knowledge, skill, and sometimes expensive modeling software *(there is also the option of using a 3D modeling program, which is essentially free. For example, Blender. However, this solution may not always be sufficient)* and above all time. As already mentioned, another option is to try 3D scanning. Here, however, we often run into the aforementioned price problem, because scanners with the ability to take high-resolution scans, which will be desirable for coin digitization, are not cheap at all. Alternatively, they work slowly or the output data has to be complexly edited. In addition, a good quality 3D scanner costs tens or hundreds of thousands, sometimes millions of crowns (for example, the Artec Micro 3D scanner with a digitization accuracy of up to 0.01 mm, designed primarily for jewellery or other small objects, which could potentially be considered for coin digitization, https://www.artec3d.com/).

A somewhat more sophisticated option, but one that is not suitable for every institution, is to create a custom 3D scanner using Arduino or Raspberry Pi miniature computers, combined with an external power supply, a high-resolution USB camera and knowledge of programming in, for example, Python. Even here, however, there can be problems in scanning the shape of the surface, especially if the relief is too shallow or deep (Halfacree, 2023; Mueller, 2023). Given that this would be a custom-built solution, it is uncertain whether it would be suitable for true, fast, systematic, and above all reliable digitization.

We cannot fail to mention a rather interesting method that stands at the interface between 2D and 3D, namely RTI or Reflectance Transformation Imaging. The RTI method can highlight the surface texture of the object being imaged, which has made it interesting for various fields of culture and research. It offers potential where 3D scanning might fail, such as scanning the surface of artworks or petroglyphs and hieroglyphs (Borůvková & Burianová, 2020). This method belongs to computational photography along with photogrammetry and High Dynamic Range (HDR) or multispectral imaging. The advantage of this technique lies in the possibility of viewing the created file (before the object is photographed), which can be observed by the resident from any direction thanks to interactive lighting, to investigate how light interacts with the surface. Thanks to filters and dynamic light, it is possible to reveal many details in the material and color of the surface that would be impossible to capture with the naked eye or in a regular photograph. Software such as RTIBuilder or the more recent Re-Light, which can be used to obtain a given view of the subject, uses a sequence of still digital photographs of the subject from a constant camera position. Each individual photograph is illuminated from a different angle, and a mathematical model of the surface of the subject is synthesized from this sequence of images. The output is thus a 2D image with three-dimensional information about the actual surface. This image can be considered as a kind of intermediate between 2D and 3D, i.e. a 2.5D representation of the surface of the object (Plzák, 2016).

As already written, 2D photographs of obverses and reverses of coins are still used for numismatic collections. With proper lighting, usually just two photographs are enough to provide enough information for basic research. However, in the case of detailed numismatic study, physical handling of the objects is usually necessary, as in this case it is possible to capture the three-dimensional aspects of the coin. Digitization methods, especially photogrammetry, are constantly evolving, providing new possibilities not only for numismatic research. With 3D models, researchers and students are able to view objects from a greater distance, studying coin models very closely and at very good resolution (Morris et al., 2022).

Photogrammetry is a measurement method concerned with reconstructing the shape, size and position of objects from their photographs and allows modelling in 3D space using 2D images. The very fact that in this case the measurement is not performed on the object but on the image has certain advantages. Measurements can be taken without direct contact with the object, and the information on the image captures the state of the object at that moment. The actual mapping takes place outside the object area and can be repeated. The processing procedure itself usually allows a high degree of automation. There are also many methods and uses of photogrammetry, for example in architecture, archaeology, in the capture of monuments through surveying and cartography, etc. (Bohannan Huston, 2022). The method of photogrammetry is popular, sought after and, in our opinion, quite suitable for the digitization of (not only) coins.

In some respects, digitization via mobile devices can still be considered a rarity. However, the development of both hardware and software has an exponential curve and therefore it is possible to look at possible digitization via mobile phone, for example, as one of the possibilities of the future. In particular, we are talking here about Apple devices (iPhone PRO or iPad PRO), which from 2020 (in the case of the iPad) and later for iPhones in version 12 PRO and later feature LiDAR technology (LiDAR stands for Light Detection and Ranging. This technology uses light in the form of a pulsed laser to measure the distance to the Earth (or an object). A LiDAR device basically consists of a laser, a scanner and a special GPS receiver. (American Geosciences Institute, 2022). This sensor (or group of sensors) can map nearby and distant objects and their surface, work with this information and transmit it, for example, to the display of the device. Such a device emits laser beams that bounce off surfaces and then return. By measuring the time it takes for the reflected beam to return, an iPhone or iPad, for example, is able to accurately determine the distance of a particular point on an object from its camera. Similar technologies are also used in Android phones, where the most common technology is ToF (Time of Flight), which works on a similar principle. It can be found in some Samsung devices, for example, but also in Microsoft's second-generation Kinect motion sensor. It is also used in autonomous vehicles and can also be found in drones (Digitální Technologie, 2022; Samsung, 2020).

In the aforementioned Apple devices, LiDAR is mainly used for photography. By being able to detect the distance of objects from the sensor, it is possible to achieve more accurate blurring of objects in the background and also reduce focusing time in low-light conditions. Last but not least, this sensor can be used in 3D digitizing, but only with specific software for now. There are several such applications (e.g. 3D Scanner App), but the Trnio (or Trnio+) application seems to us to be very interesting, although it is no longer being developed. The actual digitization via mobile devices is still in its infancy, but in some cases it may appear to be a fairly good competitor to more expensive 3D scanners (see Figure 2). The Trnio app (tested via the basic version) can work well with larger objects (see Figure 2). For smaller objects, digitization is not without problems (Figure 1). Trnio offers three digitizing options. The OBJECT mode option, which according to the developer is better for larger objects, ARkit mode (creates a point cloud) and is better for objects that are difficult to scan in OBJECT mode (often smaller objects), and photogrammetry from images taken from the iPhone/iPad camera (should be suitable for different sizes) (Styly Magazine, 2022). In Figure 1, you can see how each setup handled the digitization of the coins. The resulting 3D model still needs to be modified, but for basic data collection it could be worked with in some cases.

Fig. 1. When digitizing ancient coins with the Trnio app on the iPhone 13 PRO, the first attempt in OBJECT mode failed. A second attempt with ARkit indicated the possibility of success after editing. Photogrammetry yielded the best results, with up to 80 images merged into a 3D model, but the image would have required brighter lighting for better quality. For a complete 3D model, it is necessary to document both sides of the coin and merge the images in another program.

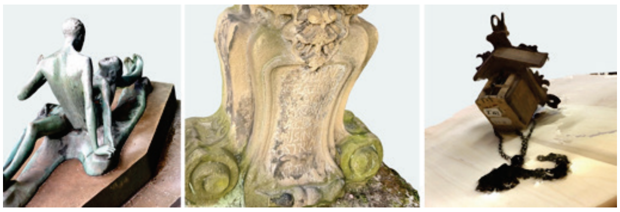


Fig. 2. The digitization using Trnio on the iPhone 13 PRO included objects in the Czech Republic: a statue in Hradec Králové, a tombstone from the cemetery in Broumov and a clock from the Náchod museum. The use of the ARkit mode was successful for the statue and the tombstone, whose models could be used for the presentation of cultural heritage after modification. However, the resolution is not sufficient for detailed research. For clocks, where photogrammetry or full scanning were necessary, digitization failed.

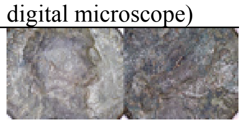
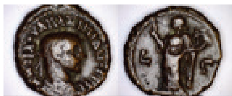
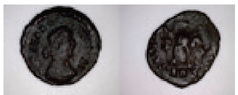
3 Selection of Coins to Digitize

Before we start to describe the selected collection of coins and also a brief digitization procedure, let us write a little information about ancient coins as such.

Ancient coins, especially those from the period of the Roman Empire, are an important testimony of ancient civilizations. Their study is key to understanding political history. Of course, coins were also used for economic purposes, but the distance from the centre of the given empire was important. The further from the border, the more their primary purpose was transformed. They were then not only used for payment (they often lost their determined value which was replaced by the value of the metal itself), but they were also a form of promotion (primarily of the sovereign and his actions). However, coins are also a very important source and insight into the culture of their time- depiction of clothing, hairstyles, artistic style (Kurz, 1998; Hlaváček et al., 2002).

Eight coins from a private numismatic collection were chosen for digitization. These coins were chosen mainly for their diversity (primarily coin size, relief height, coin thickness) with regard to the verification of digitization methods. These are coins from the period of the ancient Roman Empire. They are described without further specification, as it is not considered essential for this article.

Table 1. Summary of basic description of the coins that we digitized in our project.

Name of coin/Emperor	Coin dating	The reverse side of a coin	Obverse of the coin	Note	Photo of a coin (Photos were taken through a Toolcraft USB Microscope 5 Megapixel digital microscope)
Denarius-serratus				Without further specification	
As/Augustus	9-14	ROME T AVG	Lyon altar		
As/Domitianus	81–96	AEQVITAS AVGVST	Aequitas standing left		
Antoninian		CONCORDIA MILITVM		Without further specification	
Billion tetradrachm				Alexandria Mint	
Reduced follis/Licinius I.	308–325	IOVI CONSERVATORI AVG	Emperor seated on an eagle		
AE4/Theodosius I.	379–395			Mint of Siscia	
AE4/Arcadius	383–408			Mint of Aquilea	

4 Documentation of Coins Using Near Photogrammetry

Of the digitization methods, we finally chose the photogrammetry method for its wide use and also because it does not have to be too demanding on the user´s hardware or software. However, when digitizing the first coins, we found that a microscope would be more suitable for taking photos. *(We used The Toolcraft USB microscope 5 Megapixel, digital magnification max. 150x. The focal length of the microscope is 10 mm – 150 mm, it has an adjustable leg and it can also scan in parts (slightly larger coins).* Microscope take very detailed photos and assemble the resulting model from them. It includes 8 white LEDs for lighting the object and software for measurement (taking pictures or videos) (TOOLCRAFT USB microscope 5 Megapixel Digital magnification (max.): 150 x). Although our workplace usually uses a digital SLR camera (Canon 90D), we did not have it available at the time of the research. In addition, we still do not have a high-quality macro lens, so we did not have very good results from the resulting photos (see picture number 3).

Fig. 3. On the left, an unmodified 3D model of a coin (face) from a DSLR, in Agisoft Metashape, with fixing material on the edge. On the right, a sharper and clearer model of the same coin (face) from the microscope, still before adjustment.

In this regard, we proceeded to digitize with a microscope. For some coins, we even took photos in a digital microscope in parts (with maximum zoom). The results we achieved after processing in a program designed for photogrammetry were quite passable. We worked in the photogrammetry program Agisoft Metashape Professional Edition Educational License (hereinafter referred to as Agisoft Metashape), we also used the program Blender 3D (version 3.3.1) to combine the faces and reverses of the coins together and for some other retouching of 3D models. Last but not least, we also used the MicroCapture Plus microscope image capture program. Each of the 3D models (they were created for each side of the coin separately) was created from the number of 20-40 photos (depending on the complexity of the coin, its size and possibly damaged relief). First, we photographed the individual sides of the coins using a digital microscope, then we constructed models from the photographs (a sample of the creation process in Figure 4).

Fig. 4. On the left photography through a microscope (Micro-Capture Plus), in the middle a thick cloud in Agisoft Metashape showing the process of creating a 3D model, on the right an unedited 3D model of a coin with realistic texture and shape.

For some coins, taking pictures from a digital microscope was not possible without the need to take pictures in parts (see image number 5), that means to divide the coin into imaginary thirds, for example. We started to apply this method when the relief of the coin was too damaged, and it would not be possible to obtain such clear data from it. After processing the data (the two sides of the coin) it was always necessary to combine them together (often in Blender). This was also not without certain problems. So far, we have not been able to photograph the coins satisfactorily, so that even the edges are captured correctly. Therefore, when joining individual sides, it was not easy to reach the edge of the coin. Therefore, in some cases (where the edges are not so smooth that they merge) this deficiency can be recognized.

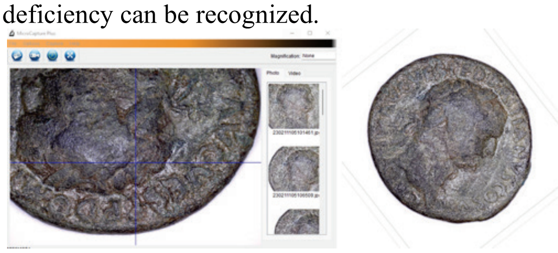


Fig. 5. On the left, an example of the MicroCapture Plus program and dividing a coin into parts while taking photos. On the right, the resulting 3D model of the obverse side of the coin.

Although the ravages of time have taken a very significant toll on some coins, it can be said that digitization using the photogrammetry method and the subsequent creation of a 3D model helps, in many cases, to read the erased relief better (can be seen in Figure 6). On the other hand, we assume that even greater readability could be achieved with higher-quality images in a higher number, or with another digitization method, for example RTI, even if these would not be typical 3D models.

Fig. 6. The obverse of the coin on the left, the damaged reverse on the right, presented at the Sketchfab Centre for Digital Historical Sciences for 3D models of cultural heritage. The coin is available at the following link: https://skfb.ly/oDUMI.

In this respect, it can be said that although digital photographs can in many cases serve as a suitable solution for digitization and subsequent research or preservation of data on similar objects, 3D models created by digital photogrammetry may be of greater predictive value. Therefore, at our department, 3D models of coins are used, for example, in teaching students or promoting study programs, not only in research and scientific activities.

5 Conclusions

Digitization of ancient artifacts is gaining importance in academic and public institutions due to its potential for research and presentation of cultural heritage. However, this process poses challenges related to the accuracy and quality of the digitized data, requiring not only technical skills but also knowledge of the latest methods. Photogrammetry is proving to be an effective and economical method for creating 3D models of a variety of objects, including small artefacts such as coins. Its advantage lies in the possibility of reconstructing objects if they are lost or damaged, making it a valuable tool for the preservation of cultural heritage. Yet, as the volume of digital data increases, questions arise about its management, archiving and accessibility for further research. The digitization process therefore requires a comprehensive approach, involving systematic work with data and the development of skills among professionals, in order to fully exploit the potential of digitization for the study and preservation of historical heritage.

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