HIGHLY DETAILED 3D SCANNING OF ANCIENT COINS

M. Kampel[a, *], S. Zambanini[a]., M. Schlapke [b], B. Breuckmann [c]

[a] Vienna University of Technology, Pattern Recognition and Image Processing Group, Vienna
(kampel, zamba)@prip.tuwien.ac.at

[b] Thüringisches Landesamt für Denkmalpflege und Archäologie, Weimar, Germany, SchlapkeM@tlda.thueringen.de

[c] Breuckmann GmbH, Meersburg, Germany, bernd.breuckmann@breuckmann.com

KEY WORDS: 3D Vision, 3D data acquisition, numismatics

ABSTRACT:

Numismatics deals with various historical aspects of the phenomenon Money. Computer vision explores the theory and technology to obtain and interpret information from images. Nowadays, numismatics is at a point where it can benefit greatly from the application of computer vision methods, and in turn provides a large number of new, challenging and interesting conceptual problems and data for computer vision.

In general, coins can be analyzed in two and in three dimensions. The advantage of 3D coin data is that it allows a more detailed and reliable analysis due to an exact description of the coins' surface, which is a great benefit for any automated classification or recognition task. However, 3D acquisitions are more laborious and expensive and, to our knowledge, 3D vision approaches applied to 3D databases of coins do not exist at the moment. Furthermore the accuracy necessary for 3D inspection of ancient coins is a challenging problem for any 3D acquisition technique. Therefore 3D acquisition has to be investigated as well because the shapes of ancient coins might not be as regular or flat as their present day counterparts or the surface of the coin is coarse enough to allow 3D measurements by a 3D scanning device. This leads to new perspectives of studying ancient coins as well as new strategies for representing them. There have not been many attempts to develop a reliable method for the 3D documentation of coins. Difficulties are caused by the reflectance of the metallic surface which makes it difficult for light projection or the insufficient accuracy of state-of-the-art scanning devices. Recent advances in rangefinder technology, together with algorithms for combining and processing 3D data, allow us to propose new strategies for numismatics.

The acquisition method proposed for estimating the 3D shape of a coin is a combination of shape from structured light with stereo vision as proposed by stereoSCAN-3D-HE. A very simple technique to achieve depth information with the help of structured light is to scan a scene with a laser plane and to detect the location of the reflected stripe. The depth information can be computed out of the distortion along the detected profile. For 3D coin acquisition synchronous acquisition of 3D data and texture/color information is needed. This allows the subsequent combination of 2D and 3D image analysis. Furthermore texture mapping of high quality 2D images leads to a realistic representation of a coin and fulfills numismatists' needs. Portability of the equipment is essential since coin acquisition has to take place at the museum where the coins are kept.

In this paper we describe a 3D acquisition setup for ancient coins and how we analyze 3D coin data for numismatic research. An approach for automatic analysis based on 3D data is given. We show results based on real 3D coin data.

KURZFASSUNG:

In der Numismatik werden unterschiedliche historische Aspekte des Phänomens Geld untersucht. „Maschinelle Sehen" beschäftigt sich mit der Theorie und Technologie, um aus Bildern Informationen zu gewinnen und diese zu interpretieren.
Schon heute kann die Numismatik einen großen Gewinn aus den Anwendungen der Bildverarbeitung ziehen, es ergeben sich daraus aber auch viele neue und interessante konzeptuelle Probleme und Daten für technische Fragestellungen.

Allgemein können Münzen im zwei- oder drei Dimensionen analysiert werden. Der Vorteil der 3D-Daten liegt in der detaillierten und zuverlässigen Beschreibung der Münzoberfläche (der Prägung), diese Daten sind auch ein Mehrwert für die automatische Klassifikation oder Erkennungsaufgaben. Die Aufnahme von 3D-Daten ist aufwendiger und teurer und zurzeit gibt es noch keine Datenbanken mit 3D-Daten von Münzen. Ebenso ist die notwendige Genauigkeit bei der 3D-Beschreibung von antiken Münzen eine

---

* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

Herausforderung für alle 3D-Aufnahmetechniken. Die Genauigkeit bei antiken Münzen ist wichtig, da deren Rand oft nicht regulär ist, wie bei heutigen Münzen, auch ist ihre Prägung oft nicht so flach.
Das Ziel der Arbeiten sind neue Möglichkeiten um antike Münzen zu studieren und digital darzustellen. Bisher wurden noch keine Methoden zur 3D-Dokumentation von Münzen entwickelt. Schwierigkeiten ergeben sich durch die Reflektionen der metallischen Oberflächen, welche die Lichtprojektion von „state-of-the-art"-Scannern betreffen, ebenso die dort möglichen Genauigkeiten. Aktuelle Fortschritte in der Scanner-Technologie machen heute zusammen mit den Programmen für die Be- und Verarbeitung von 3D-Daten neue Strategien für die Anwendung in der Numismatik möglich.
Für die Erfassung der 3D-Oberfläche einer Münze wird eine Kombination von strukturiertem Licht mit Stereokameras vorgeschlagen, wie sie im Stereo-SCAN-3D-HH eingesetzt wird.

Eine sehr einfache Technik Tiefeninformationen mit der Hilfe von strukturiertem Licht zu erfassen, ist das Scannen einer Szene mit einem Laserstrahl und das Erkennen der Positionen der Reflektionsmuster. Die Tiefeninformation kann dann aus der Verzerrung entlang der erkannten Profile berechnet werden. Für die 3D-Datenerfassung von Münzen sind sowohl die 3D-Daten als auch die Erfassung des Oberflächenbildes und deren Farbe notwendig. Dies erlaubt die gleichzeitige Anwendung von Verfahren zur 2D und 3D-Bilderkennung. Zusätzlich kann man durch das „Aufbringen" des 2D-Bildes eine realistische Darstellung der Münze erzeugen und die Anforderungen der Numismatiker an Münzbilder erfüllen. Die Mobilität der Ausrüstung ist notwendig, da die Datenerfassung in den Museen erfolgen soll, wo die Münzen aufbewahrt werden.

In diesem Dokument beschreiben wir einen Vorschlag für die 3D-Erfassung von antiken Münzen und wie wir die 3D-Daten für die numismatische Forschung analysieren. Es wird ein Ansatz für die automatische Analyse basierend auf 3D-Daten vorgestellt. Wir zeigen die Resultate basierend auf realen 3D-Münzdaten.

1. INTRODUCTION

Numismatics deals with the historical study of the phenomenon money. As a consequence, central objects of numismatic work are coins and nowadays their digital capturing is a major issue. In digital coin databases usually images are added to the text-based descriptions to increase the informative value. Besides collection purposes, the digital capturing of coins has also the potential to automate and improve their analysis.

In order to quantitatively describe the relationship between 2D image structures and their corresponding real world structures, methods for extracting 3D information have to be investigated. According to Marr [Mar82] we see 3D vision as a 3D object reconstruction task to describe 3D shape in a co-ordinate system independent of the viewer. The shape of a 3D object is represented by a 3D model. Two main classes of 3D models are identified [SHB07]: volumetric models represent the "inside" of a 3D object explicitly, while surface models use only object surfaces. Unlike 3D models, depth maps or range images describe relative distances from the viewer of surfaces detected in the scene [Mar82]. For 3D object reconstruction the following three major steps, are identified: (1) data acquisition, (2) range image processing and (3) model reconstruction.

Data acquisition (1) is the first and one of the most important tasks in a chain of 3D reconstruction tasks, because the data quality of the sensed images influences the quality of the final results [BAG01]. El. Hakim specifies in [HBP02] the quality of data by a number of requirements: high geometric accuracy, capturing all details, photo-realism, full automation, low cost, portability, flexibility in applications, and efficiency in model size. The techniques that aim to recover shape from intensity images are described by Shape from X [SHB07], in [B04] F. Blais reviews the last 20 years of range sensor development.
Each view acquired by a range sensor represents a portion of the object. Multiple views of one the same object have to be combined to produce a complete model of the object. The process of combining range data into one single coordinate system is called *range image registration* [CM92]. The approximate transformation between the views can be obtained either automatically by a calibrated robot or shifting unit or by the computation of the rigid transformation that maps the data from one view into that from another view. The most commonly used algorithm for registering is the Iterative Closest Point (ICP) algorithm [BK92]. ICP iteratively improves the registration of two overlapping surfaces by calculating the unique transformation that minimizes the mean square distances of the correspondences between the two surfaces.

The final step *model reconstruction* (3) refers to a surface fusion process, which consists of multiple tasks like reducing large data sets, outliers removal, surface triangulation, hole filling, etc. The goals are to minimize a global registration error, caused by the propagation of noise from one surface patch to the other and to preserve the topology of the original object.

An overview and discussion of useful applications for automatic image-based analysis in Numismatics was recently given in [ZKS08]. First attempts for the image-based recognition of ancient coins were made on coin identification [KHMZ09] and coin classification [KZ08]. These methods were applied on 2D images since 2D acquisition is simple and cheap and large inventories exist already. However, although the results of the image-based methods for coin recognition are promising, they suffer from the loss of information due to the 2D image acquisition. Ancient coin surfaces are reliefs visualizing inscriptions and symbols. Therefore, the appearance of coins in 2D images is highly influenced by the lighting conditions. Different lighting directions make small patterns on the coin look very different which limits, for instance, the use of local image features for coin recognition. 3D scans of coins would lead to new perspectives for processing and studying historical coins as well as new strategies for representing them.
In the past, there have not been many attempts to develop a reliable method for the 3D documentation of coins. Hossfeld et.

al [HCEA07] presented the so called Three-Color Selective Stereo Gradient method: the objective is to classify EURO coins based on a comparison of specially measured and processed 3D surface information with characteristic topographical data stored in a database. On historical coins, initial research for an improved visualization was conducted by Mudge et al. [MVSL05] by applying Polynomial Texture Mapping (PTM) [MGW01]. They used a setup able to photograph a coin 24 times with different illumination directions to obtain the according PTMs. With interactive viewing software the assembled PTMs are used to obtain a photorealistic visualization of the coin. PTM imaging can also be combined with shape from structured light to acquire more accurate 3D coin models.

In this paper we present preliminary results on creating full 3D models of historical coins using a state-of-the-art scanning device and discuss their possible use for numismatic research and documentation. 25 coins from both the Roman and the medieval age were scanned using an active stereo vision scanner providing high-accuracy models of the coins despite of the challenging constitution of this kind of objects. Typically, historical coins have a diameter of about 15-30 mm and highly specular surface since they were made of metal.

The remainder of the paper is organized as follows: Section 2 describes the scanner and the acquisition process used for obtaining our 3D coin models. In Section 3 the final results are presented and discussed from a numismatic point of view and the fields of application for 3D coin acquisition are identified. A conclusion is finally given in Section 4.

2. 3D SURFACE SCANNING

For the semi-automatic digitization of the coins we have used a topometrical high definition 3D-surface scanner, based on fringe projection technique, in combination with a rotation/tilt table. Figure 1 shows the principal setup of this configuration, the specifications of the scanner, a stereoSCAN-3D-HE system of Breuckmann, are summarized in Table 1.

Figure 1: Setup with stereoSCAN-3D-HE system and rotation/tilt table

	stereoSCAN-3D-HE
Field of View (FOV)	60 mm
Camera	2 x 5 MP CCD camera
Light source	100 W halogen
Sensor weight	6 kg
Operating distance	380 mm
Acquisition time	5 sec per scan in HDR-mode
X,Y-resolution	20 µm
Depth resolution	3 µm

Table 1: Specifications of the used stereoSCAN-3D-HE system

The coins have been fixed on the rotation/tilt table and the first site has been scanned automatically in a first loop from 8 viewing directions. The different scans were aligned automatically by an ICP algorithm [CM92, BK92], with the pre-alignment given by the position of the table. Next, the second site of the coin has been scanned in the same way in a second loop. The two sites were then pre-orientated interactively by the 3D geometry of the border, which was recorded in both loops (see figure 2). All 16 scans were finally aligned by an ICP algorithm and merged into a polygon mesh

For the 3D data acquisition of the shiny surfaces of the coins we have used a modified HighDynamicRange technique. Thus it was possible to scan all coins without any kind of coating or treatment. The total acquisition time for each coin, 2 times 8 scans, including the handling and interactive pre-orientation, was about 5 min.

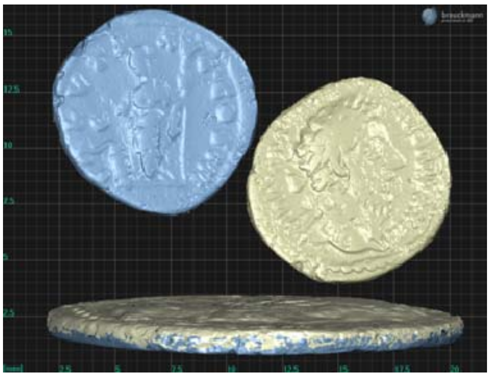


Figure 2: Orientating the two sides of a coin by means of the 3D geometry of the border

3. EXPERIMENTS

In total 25 coins were scanned: 16 ancient coins from the Roman era and 9 tornese coins from medieval age. Views showing the obverse and reverse of five Roman and a tornese coin are shown in Figure 3 and 5. Please note that, for example, the Roman coin of Figure 3 (a) and the tornese coin of Figure 5 (c).

In the subsequent sections we address the parts of numismatic work where high-accuracy coin models like the ones presented here can be used to improve the effectiveness and impact of research. This includes the fields of documentation, coin measuring and coin identification.

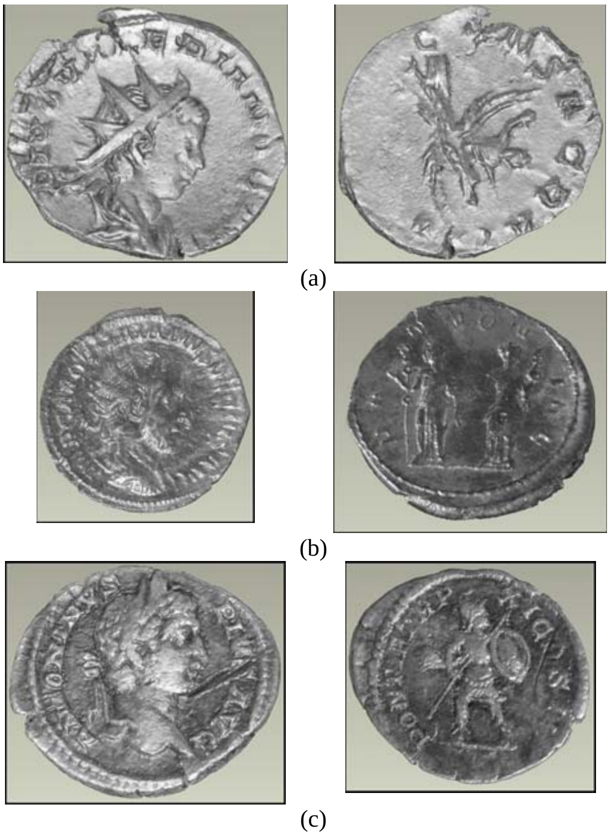


Figure 3: Front and back views of six generated coin models: (a) Roman Antoninian of Valerianus II (253-255 AD), (b) Roman Antoninian of Traianus Decius (249-251 AD), (c) Roman Denarius of Septimius Severus (193-211 AD)

3.1 Documentation of Coins

Today the prevalent method for coin documentation in Numismatics is to capture images of both coin sides. However, the problem of this documentation method is that important features might get lost. For instance, highlights due to the metallic surface decrease the quality of the images and handicap any analysis where the real coin is not available. With 3D scans detailed models of both coin sides are obtained which allow for a more accurate analysis [AGB07], see Figure 4 for 3D views of coins with and without texture. As an example, a sufficient documentation of the coin edge is only possible by accurate 3D models. The edge of a coin is very important to recognize its production process or to identify counterfeits.

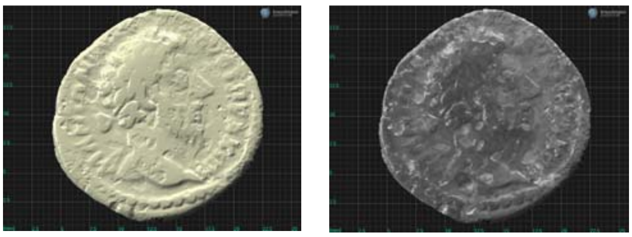


Figure 4: Two 3D views of a coin: (a) without and with (b) texture

If real copies of the coins are needed for studying, nowadays numismatists usually produce plaster casts of certain coins of interest. In a second step a positive copy is produced which shows all details of the original except its color. However, 3D coin models allow a more realistic representation and can be reproduced and transferred electronically which gives them the potential to replace plaster casts in the future.

Figure 5: Front and back views of three generated coin models: (a) Roman Aureus of Herennius Etruscus (251 AD) (b) Roman Antoninian of Philippus I (244-249 AD), (c) French gros tournois (1290-1295 AD).

Another benefit of 3D coin models is that they allow a fast and easy visualization for publication and documentation. Once a coin model has been acquired, the coin or certain features of it can be made visible from any viewpoint and in any scale. For a comparison between a traditional 2D coin image and its 3D model see Figure 6: the view of the 3D model of a Roman Denarius shown in Figure 6 (b) gives a more informative impression of the coin's 3D structures than the 2D image of the same coin shown in Figure 6(a).

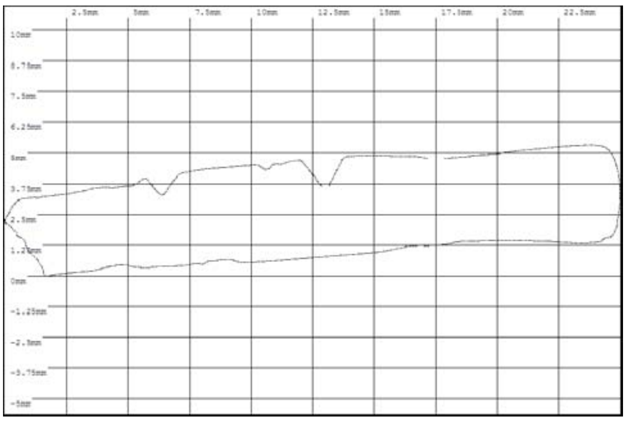
Figure 6: (a) 2D image of a Roman Denarius, (b) acquired 3D model of the same coin (visualized without texture).

3.2 Measurement of Coins

3D coin models offer a simple way to accurately measure the diameter or other features like the thickness of the coin. However, the most useful aspect is the accurate measurement of the coin volume. The volume is relevant to calculate the density of the coin to identify differences between the theoretical and the real density when coins were plated (for instance, a silver over a copper core).

3D data is also useful to analyze changes on the coin surface. The example in Figure 7 shows a Roman coin which has been used as metal resource in a German settlement in Thuringia. You can see deep cuts to separate parts of the coin (Figure 7(a)). To show these cuts adequately a plot of the coin profile can be generated (Figure 7 (b)).

(a)

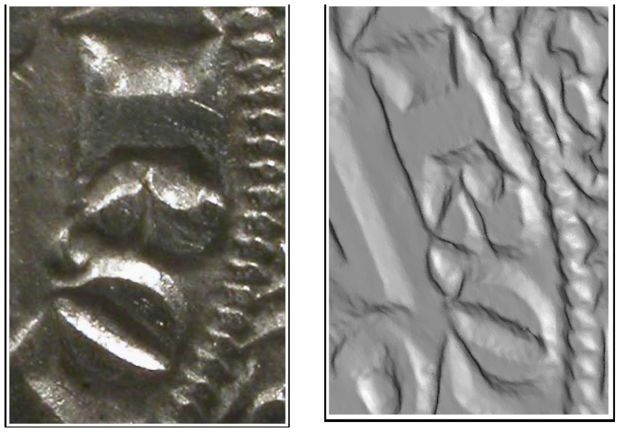


(b)

Figure 7: (a) 3D model of a coin with cuts, (b) profile of the same coin.

3.3 Identification of Coins

3D coin models can be used also to identify ancient coins in a better way as traditional images or very small originals. To recognize all features of small coins a numismatist has to use a microscope on the real coin or a high-resolution image. Given a sufficient resolution of the acquisition device some details like inscriptions or symbols are potentially more visible on a close-up view of the model as in reality, as exemplarily shown in Figure 8. The 3D close-up view of the letters shown in Figure 8(b) gives a better understanding how these letters have been created using punches of letter parts than the 2D image (Figure 8(a)).



(a) (b)

Figure 8: Close-up view of letters on a tornese in a (a) 2D image and (b) 3D model (visualized without texture).

Interactive 3D models help the numismatists to recognize the coins because the models, like the originals, can be viewed from any viewpoint and in any scale. Additionally, multiple light sources visualize the stamping better then a 2D image. Another important feature is that 3D models show the difference between the obverse and reverse axis. Ancient and medieval coins were hammered, thus obverse and reverse axis are not necessarily aligned.

4. CONCLUSION

In this paper preliminary results on the acquisition of high-accuracy 3D models of historical coins have been presented. We furthermore described the use of such models in the documentation, measuring and identification of coins. The achieved results suggest that accuracy of the active stereo scanner used is high enough to fulfill numismatist's needs for an improved scientific documentation and analysis of coins.

For future research, a more detailed evaluation of the results is planned. Additionally, techniques allowing an automatic analysis, e.g. coin identification, on the coin models will be investigated.

5. ACKNOWLEDGEMENT

This work was partly supported by the European Union under grant FP6-SSP5-044450.

6. REFERENCES

[AGB07] D. Akca, A. Gruen, B. Breuckmann, Ch. Lahanier, "High definition 3D-scanning of arts objects and paintings", Optical 3-D Measurement Techniques VIII, Zurich, Switzerland, 2007 B. Breuckmann, L. Bereczky, Zs. Vegvari, "High Definition 3-dimensional Scanning and printing Technologies in Arts and Cultural Heritage, Archaeology and Palaeontology", EVA 2007 Berlin, pp 95-100

[B04] F. Blais. A Review of 20 Years of Range Sensor Development. Journal of Electronic Imaging, 13(1):231–240, 2004.

[BAG01] J. A. Beraldin, C. Atzeni C., G. Guidi, M. Pieraccini, and S. Lazzari S. Establishing a Digital 3d Imaging Laboratory for Heritage Applications: First Trials. In Proc. of the Italy-Canada 2001 Workshop on 3D Digital Imaging and Modeling Applications, Padova, 2001. on CD-ROM.

[BK92] P. J. Besl and N. D. McKay. A method for registration of 3d shapes. IEEE Transactions on Pattern Analysis and Machine Intelligence, 14(2):239–256, 1992.

[CM92] Y. Chen and G. Medioni. Object modelling by registration of multiple range images. Image Vision Computing, 10(3):145–155, 1992.

[HBP02] S. F. El-Hakim, J. A. Beraldin, and M. Picard. Detailed 3D Reconstruction of Monuments using multiple Techniques. In W. Boehler, editor, Proc. Of ISPRS-CIPA Workshop on Scanning for Cultural Heritage Recording, pages 13–18, Corfu, 2002

[HCEA07] Hossfeld M., Chu W., Eich M., Adameck M.: Fast 3D-vision system to classify metallic coins by their embossed topography. Electronic Letters on Computer Vision and Image Analysis 5, 4 (2007), 47–63.

[KHMZ09] Kampel M., Huber-Mörk R., Zaharieva M.: Image-based retrieval and identification of ancient coins. Intelligent Systems, IEEE 24, 2 (March-April 2009), 26–34.

[KZ08] Kampel M., Zaharieva M.: Recognizing ancient coins based on local features. In Advances in Visual Computing, 4th International Symposium, ISVC 2008, Las Vegas, NV, USA, December 1-3, 2008 Proceedings, Part I (2008), pp. 11–22.

[MGW01] Malzbender T., Gelb D., Wolters H.: Polynomial texture maps. In Proceedings of the 28th annual conference on Computer graphics and interactive techniques (2001), ACM New York, NY, USA, pp. 519–528.

[MVSL05] Mudge M., Voutaz J.-P., Schroer C., Lum M.: Reflection transformation imaging and virtual representations of coins from the hospice of the grand st. bernard. In Proc. Of VAST'05 (2005), pp. 29–39.

[SAB 07] Stoykova E., Alatan A., Benzie P., Grammalidis N., Malassiotis S., Ostermann J., Piekh S., Sainov V., Theobalt C., Thevar T., et al..: 3-D Time-Varying Scene Capture Technologies - A Survey. IEEE Transactions on Circuits and Systems for Video Technology 17, 11 (2007), 1568–1586.

[SSc] http://www.breuckmann.com/index.php?id=stereoscan, last visited: 05/18/2009.

[ZKS08] Zambanini S., Kampel M., Schlapke M.: On the use of computer vision for numismatic research. In Proc. Of VAST'08 (2008), pp. 17–24.

[Mar82] D. Marr. Vision - A Computiational Investigation into the Human Representation and Processing of Visual Information. Freeman, San Francisco, 1982.

[SHB07] M. Sonka, V. Hlavac, and R. Boyle. Image Processing, Analysis, and Machine Vision. CENGAGE-Engineering, third edition, 2007.