Three-dimensional tools for analysis and conservation of ancient wooden stamps

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Abstract: This paper deals with the analysis and conservation of ancient wooden stamps from museum or library collections. The aim is to provide historians with tools that ease the process of handling and observation of very fragile and unique objects. By performing a three-dimensional imaging of stamps, data are processed in three different ways: (1) adaptive thresholding on the corresponding range image enables visualization for the first time of an image of the actual print produced by the stamp; (2) interactive enhanced rendering provides a realistic and non-photorealistic interactive visualization; and, finally, (3) rapid prototyping production gives a perfect geometrical facsimile of the stamps, preventing any hazards inherent in the handling of the originals.

Keywords: cultural heritage conservation, wooden stamps, 3D imaging, 3D rendering, rapid prototyping

1 INTRODUCTION

1.1 Context of work and motivation

The illustration of ancient books was carried out for a long time by techniques using engraved wood (from 1470 to ~1850), which had the advantage of being compatible with the typographical press. The identification of these illustrations is an important research tool in the field of book history. Indeed, the stamps used to print these images could have been moved around and used for several centuries, but also rebuilt when they were damaged, or copied for a competitor print studio. Stamp analysis is useful for clarifying economic relations between typographical studios. These methods were largely implemented in the second half of the 19th century, a time of publication of great bibliographical studies that are still considered reference works. The human eye was then the only available tool for performing analysis.

Recently, digitalization of old book collections has been launched by important French and other foreign libraries. This will create renewed interest in historical research on books, by providing easy access to image databases, ornaments, reference letters and character fonts. It is therefore interesting to have tools based on modern methods of image processing and image recognition which could facilitate and accelerate investigation. Researchers are also very interested in the analysis of stamps. Figure 1 is a photograph of a typical wooden stamp. There is a real need for modern techniques enabling a scientific approach to the study of stamps. The present paper describes the proposed development of such techniques.

1.2 Scientific approach

Libraries and museums preserve ancient wooden stamps and illustrations for which links are not established a priori. The association between images
and stamps is unknown for many stamps and, very often, the stamp is preserved by a library, while the images produced are preserved by other libraries. The problem is that there is no existing index of stamps and illustrations, so links rely only on the historians’ memories. It is therefore necessary to develop methods to enable: (1) the provision of images produced by stamps by analysing the stamp itself; and (2) simple access to stamps and illustrations. In other words, it consists of extracting the image produced by a stamp, starting from the engraved wood itself, and providing easy access to the results, allowing the analysis of the illustrations and stamps, whatever their origin and/or their current place of conservation.

The solutions depend, in particular, on the requirements of libraries and museums. Conservation and handling conditions are very strict. Stamp access and manipulation is really difficult because of the storage (stamps are stored in basements with controlled temperature and humidity) and the fragility of the objects (because of wood degradation). The main goal of this study is therefore to provide digital tools for researchers into the history of books to allow suitable access and manipulation of the stamps in order to facilitate and accelerate analysis. Another essential aspect of the proposed work is to allow the conservation of stamps. To do so, three main applications were developed during this work:

- virtual printing: to determine the image produced by an engraved wood starting from the stamp itself
- three-dimensional (3D) visualization: to allow interactive and realistic visualization of engraved stamps via local or remote access
- stamp duplication: to enable physical handling without risk and better conservation of the original objects.

The schematic in Fig. 2 summarizes the approach. The present paper is organized as follows. Section 2 describes the data-acquisition process. In section 3, the virtual printing application is detailed. Sections 4 and 5, respectively, explain how the 3D data are processed for visualization or duplication purposes. In each section, results illustrate the efficiency of the proposed solutions. Problems and limitations are also discussed. A discussion about enhancements is given in the conclusion. Other possible applications are also presented.

2 3D DATA ACQUISITION

Taking into account the brittleness and the patrimonial value of engraved wooden stamps, data acquisition must be carried out without any contact: one cannot coat the wood with a liquid or apply powder on the engraved surface. The technique of
information extraction has to remain perfectly respectful of the wood. Preliminary work showed that a luminance image of the stamp does not provide sufficiently usable information. The selected technique must also incorporate the geometrical information about the stamp. 3D scanners seem to be suitable tools. Such scanners are rapidly becoming more affordable and allow highly accurate models of real 3D objects to be built in a cost- and time-effective manner. This section describes the selected acquisition method and the means of measurement available during the project. Acquisition sessions are also presented.

2.1 3D acquisition technique

In the last few years, 3D laser scanners have been used increasingly in 3D reconstruction and reproduction, because very precise 3D data can be measured in very short time intervals. The geometry of the stamps is acquired using a non-contact optical sensor based on laser triangulation to determine target point depth. A laser light stripe is projected onto the stamp surface. The image of the stripe is observed through a calibrated camera, and the 3D positions of the stripe points are calculated by triangulation.

2.2 Artefacts features and scanning procedure

Stamps are made of engraved strong wood. They are formed as a rectangular prism typically to mm. The printing face is the only part of the stamp that needs to be documented. The printing face is a few millimetres thick, typically mm. Stamps are positioned on a table and observed by the 3D scanner with a viewing angle of only. Only two single scans are necessary to record the complete printing surface and to avoid occlusions. Scans are therefore performed with a 180° rotation of the stamps between the two views. The scanners used (see next paragraph) directly provide an optimized triangulated mesh. Post-processing, including single scan registration, merging and mesh smoothing to remove noise, is then applied. As the stamps’ surface is quite matt because of the ink, no major acquisition problems were observed.

The obtained 3D data set is either an ASCII point cloud or a polygonal mesh that can be stored in common 3D file format, depending on the targeted application (OBJ, VRML, STL etc.). The X–Y resolution path is typically 0.2 mm. High-resolution models of a typical stamp with dimensions mm are composed of ~100 000 vertices resulting in 200 000 faces.

2.3 3D digitalization equipment

Two 3D scanners were used for this project. These are based on laser triangulation by projection of a laser stripe.

2.3.1 Replica 500 scanner from 3DScanners

This scanner (Fig. 3) is provided with a sensor head made of a laser plane source and two CCD cameras (see principle in ‘3.2 Triangulation scanners—Double camera solution’ in Böhler and Marbs). The sensor system is mounted on a three-axis translation stage, allowing the sensor to be moved along the X, Y and Z axes. The object to be measured is placed on a table, and the sensor is moved across the object. At each step, the CCD cameras acquire two images of the stripe projected onto the surface of the object being scanned, and the system computes the resulting depth information. The precision is μm on the X and Y axes and μm on the Z axis. The useful working
2.3.2 VI-910 scanner from Konica–Minolta

This scanner (Fig. 4) is compact, portable and able to function autonomously (without any associated microcomputer). It enables the capture of the geometry and texture of 3D objects. The acquisition of the geometry is carried out by rotary sweeping of the laser stripe (see principle in ‘3.2 Triangulation scanners—Single camera solution’ in Böhler and Marbs9). The acquisition of colour texture is carried out by capturing three images through red, green and blue filters mounted on a wheel. The precision is 100 \( \mu \text{m} \) on the \( X \), \( Y \) and \( Z \) axes. This system enables the digitization of objects 10 mm to 1 m wide. The geometry and the colour texture are directly provided as triangulated meshes.

2.4 Data acquisition sessions

Two digitalization sessions were carried out. The first, in the laboratory in May 2002 with the Replica scanner, validated the feasibility of virtual stamping for a small number of stamps. The second (Fig. 5) was held in the Troyes library in December 2003. Twelve typical stamps from the first wooden stamps classified collection of the library were acquired with the Minolta scanner. These measures enabled the validation of the three applications of 3D digitalization for the analysis of engraved wooden stamps.

3 VIRTUAL PRINTING

The first method developed consists of extracting the produced illustration from the stamp itself. This (binary) image must be close to one produced by inking and using a printing press.

3.1 Data preprocessing

‘Virtual’ stamping is performed by first converting the 3D model to a range image. The starting data are the point clouds of digitized stamps. These sets of point coordinates are expressed in 3D space. These data can also be represented by a plane projection according to a point of view. This representation is called a range image. A range image is an image whose intensity is proportional to the height of the point under consideration. The range image obtained is actually the plane projection of a 3D surface and, consequently, the method of analysis presented is comparable with classical 2D image processing. The depth information in range images is grey-level coded, and the range image is interpreted as a 2D image.10 Figures 6 and 7, respectively, present the point cloud and the resulting range image of the ‘Pisces’ stamp (see photograph on Fig. 1).

3.2 Virtual printing process

The binarization is computed in order to simulate the printing process with black ink on white pages. As in
a stamp, the printing zones are high elevation ones; the high grey-level pixels in the range images have to be binarized as black (pixel=0). The non-printing zones must therefore be binarized as white (pixel=1).

A modified Niblack’s algorithm is used to binarize range images. The main task is to adapt the threshold over the image. The threshold is determined from the local mean and the local standard deviation, computed on a restricted neighbourhood for each pixel.

Define:

- $m$ the local mean computed on a $[w \times w]$ neighbourhood
- $M$ the global mean computed on the complete range image
- $s$ the local standard deviation computed on a $[w \times w]$ neighbourhood
- $t$ the local threshold for each pixel
- $k$ a user-defined parameter.

The binarization is computed as follows:

For each pixel of the range image Do

If $m > M$ Then $t = m + k \times s$ (the neighbourhood is in a high elevation zone)

Else $t = M + k \times s$ ($M > m$ and the neighbourhood is in a low zone)

End if

If pixel $>$ $t$ Then pixel $= 0$

Else pixel $= 1$

End if

End Do

The local threshold computing can be summarized by equation (1)

$$t = \max(M, m) + k \times s$$

By modifying the $k$ parameter, it is possible to simulate the inking and printing process for various conditions (ink quantity, paper quality or humidity, ink fluidity, exerted pressure etc.). Figure 8 shows the same range image as that used in Fig. 7, binarized for $k=0.1–0.8$. Note the ‘inking’ variations produced by the $k$ value modification.

### 3.3 Comparison between virtual and real stamping

In order to test the proposed method, the results of virtual printing were compared with real ones. For that, engraved wooden stamps whose actual printings are already known were used. Figures 9–12 show the...
results obtained for two stamps taken from the collection studied.

The images produced by virtual stamping are visually similar to the real ones. The quality of the results is sufficient to estimate the produced image, and historians are satisfied with the simulated images provided.

The results are of poor quality in the zones presenting fine detail, however, and, in particular, the zones which are striated to allow a dithering effect on the printed image. Investigations were conducted to identify which stage affects the results. Indeed, the results are better using the Replica 3D scanner instead of the Minolta scanner. The Replica 3D scanner has a better resolution than the Minolta scanner (see section 2.3). The post-processing stage and especially mesh smoothing have no significant influence on the results. Consequently, the lack of detail on the fine zones comes from the digitalization stage. Geometrical data obtained by 3D digitalization do not reveal the fine details, which are gummed by too weak a resolution of the digitalization system. Unfortunately, better results can be obtained by 3D
scanners that are not transportable, which is usually incompatible with the requirements of cultural heritage projects. In the conclusion, some possible enhancements for the 3D scanning procedure are proposed.

3.4 Conclusions on virtual printing

The more recent stamps, from the 18th to 19th century, are very refined and detailed in their design and are very difficult to analyse by this method (see the example of the ‘Exodus’ stamp). The proposed technique is therefore better adapted for ancient stamps, from the 15th to 17th century, which present rougher surfaces and less detail.

Results were validated by historians, who were very satisfied to obtain ‘unreachable’ images. Free software has been provided to load stamp data and to simulate interactively the inking variations in real time. The estimated quality of the image produced is sufficient for the research activities of historians.

4 VISUALIZATION

The goal of this application is to make stamps available to researchers but also open to the public, without removing them from collections. As mentioned by Sgrenzaroli and Wolfart, ‘Visualization is becoming ever more important in Cultural Heritage’. As cultural heritage institutions are usually spending taxpayers’ money, they face increasing pressure to justify and present their work. Using photorealistic 3D models for presentation over the Internet or on CD-ROMs is a way of educating and increasing the awareness of the public.

Interactive navigation around stamps must be provided to enable them to be studied in depth without any risk to the original artefacts. The data must also be available on the Internet to allow users to look at the stamps from distant locations. This section describes the method by detailing data processing, the viewer developed and proposed enhanced rendering.

4.1 Geometrical data processing

The acquisition method based on the Minolta scanner enables one directly to obtain a polygonal mesh. The acquired 3D models show a very high point density, resulting in a large file size. These models can reach several tens of megabytes. High-detail models are necessary for local exploitation to enable accurate exploration of the stamps. Low detail models must be generated to provide web access to the models. Low detail visualization requires a reduction in the amount of data to be transmitted. Mesh simplification is therefore performed to reduce the overall data size.

4.2 Texture mapping

The aspect of geometrical models is then defined by applying texture to the geometrical model (mesh). Texture acquisition and mapping must be performed with particular care, as they have an important impact on visualization. Special care must be taken in the lighting during 2D acquisition of texture. Professional photographic lighting equipment combined with intensity calibration and white balancing gives satisfactory results.

Two methods of texture acquisition and mapping were tested. The first consists in directly using the functionalities offered by the Minolta scanner. This method is completely automated in the digitalization process and enables immediate results, since the camera viewpoint for the texture is identical to the laser acquisition viewpoint. However, it provides low-quality texture because of the applied low resolution sensor (640 × 480 pixels).

The second method consists in using high-resolution digital photographs captured separately. Images are taken from a viewpoint approximately orthogonal to the stamp’s surface. The quality of texture mapping is therefore increased because of the high resolution of digital cameras. Libraries’ photographers who carried out texture acquisition provided images from 4 to 22 megapixels. These photographs are manually mapped on the geometrical models by picking several matching points on the wooden stamps texture and the polygonal representation. This last solution was chosen even though it involves a lot of manual work.

4.3 3D viewer

Visualization must allow an interactive exploitation of the engraved wood models on non-off-the-shelf computers. Local exploitation is provided on a standalone application and remote visualization via an Internet browser.

Two visualization solutions were evaluated in the analysis of Boehler et al. The first solution consists
in directly using plug-in technologies for visualization (e.g. from RapidForm software). This method is completely automated and enables publishable results to be obtained immediately. However, it works only under the Microsoft Windows operating system, and the functionalities offered are limited and fixed. The second visualization solution is based on Java3D software technology. It is performed using the Java programming language enriched by the Java3D software layer in order to develop visualization interfaces in a completely original way. It has been successfully used by other cultural heritage conservation projects. This method enables a personalized visualization of the 3D models to be obtained and has the huge advantage of running on a number of operating systems. It has been validated on the following operating systems: Microsoft Windows, Linux, FreeBSD and Apple Mac OS X. This solution has also the advantage of being based on free software solutions, which implies important economic advantages and flexibility in further enhancement for cultural institutions and project developers. The JAVA3D solution has therefore been chosen, enabling stand-alone application development and web-browser integration by building applets (Fig. 13).

As the stamp surface is covered with the ink that was used to print images, most of the models look very dark when they are displayed with photorealistic rendering. It has been demonstrated that photorealism combined with non-photorealism can completely enhance the visualization of virtual artefacts. Non-photorealistic rendering is a relatively recent but very active area in computer graphics. It is used in virtual heritage presentation to enhance special feature perceptions: stippling and local curvature-based rendering for stone age artefacts. Following the referenced methods, different rendering modes were set up to enhance the stamps visualization. Visualization rendering based on local curvature enables the tool marks on the surface to be observed and then different stamps to be compared to identify the manufacturing method. By increasing the brightness of the objects, one can highlight the detail of the stamps (Fig. 14). Different colour lightings are also available, and the shininess of the stamps can be modified. The observer can interactively switch between different rendering processes and parameterize them to have a full evaluation of the studied stamp.

4.4 Conclusions on visualization

The proposed visualization tools were confirmed as very useful by historians. They now have the opportunity to handle stamps virtually in a very simple way. This leads to a simplified procedure to get a stamp and to study it accurately.

3D visualization will now allow sharing of historical resources, easing the exchange of information or data between researchers, libraries and/or museum as well as providing a showcase for web-based presentations or general public exhibitions. Nowadays, the demand for this kind of approach is increasing in importance, as it provides an answer for both external communication and internal research issues.
5 DUPLICATION

Historians are very interested in the virtual presentation of artefacts. It was established in the previous section that it is a very useful tool. Nevertheless, historians are also interested in the opportunity to handle physical duplicates of artefacts. Handling physical objects will always remain a complementary way of analysing artefacts. Education and research can therefore benefit from the opportunity to perform real experiments on stamp duplicates for a better understanding of the inking and printing process.

According to historians, the ideal stamp facsimile would be made of wood and engraved. Investigations were made into computer numerical controlled machining (CNC). Unfortunately, this is not applicable for single items or small series productions because of the necessary data-processing time and the specialised equipment required. The evolution of rapid prototyping (RP) technologies has shown that this is now a powerful tool in the product development process.22 RP has been described as a technology for producing accurate parts directly from 3D models with little need for human intervention. It is therefore a suitable technique for manufacturing a small number of duplicates. It is successfully used in cultural heritage applications.23–25 The application of this process to duplicating stamps is now discussed.

5.1 Data conditioning for duplication

3D models provided by the 3D scanning procedure need to be processed in order to fulfil manufacturing criteria: in the RP application, they should not present any holes and the object must be closed, i.e. its geometry must be represented by a closed volume (cubic for example) and not by an open surface (square for example). RapidForm software, capable of finding holes and automatically filling them by adding new points and polygons in order to preserve the local curvature of the mesh was used.26 The 3D data obtained are finally exported as computer-aided design (CAD) models via STL format. STL is the reference standard format in RP.27 The full specifications are provided by 3D Systems Inc.28

5.2 Process of duplication

Different processes exist in RP; see Frank et al.22 and Egodawatta et al.29 for state of the art proven and experimental technologies. A layered manufacturing process30 based on the use of UV/radiation of curable resins was chosen. The Objet RP system was used.29 The process is based on inkjet technology. The inkjet head (print head) builds up the part layer by layer. The part is built by layer deposition of fine drops of UV curable material. Every drop of material is cured by a light source immediately after deposition. This procedure is repeated until the part is completed. The part is then ready for use, and no post-processing is required. This manufacturing process produces ABS plastic objects at a speed of ~1 mm/h. The finished model can possibly be polished, sandpapered and painted and/or can undergo other finishing. Figures 15 and 16 present the manufacturing results. The layer resolution is ~40 μm, which is widely sufficient for stamp duplication.

5.3 Conclusions on duplication

The results obtained in RP are very satisfactory. The quality of the duplicates has been approved by historians. However, the geometrical models...
obtained sometimes have insufficient resolution, involving no duplication of the detail of certain wooden stamps. This limitation comes from the scanning procedure, which needs to be enhanced as previously mentioned in section 3.

Being able to produce facsimiles of wooden stamps can prevent the loss of the stamp altogether in the event of theft or rough handling. There is a need for cultural heritage conservation, which is becoming urgent for the oldest stamps. This also allows facsimiles to be supplied to distant researchers or visitors. This will also enable researchers to carry out an inking and printing process in the manner of a typographical press.

6 CONCLUSIONS

The presented work has produced three families of digital tools based on the exploitation of 3D digitalization:

- virtual printing: to determine the image produced by an engraved wood starting from the stamp itself
- 3D visualization: to allow interactive, realistic and non-photorealistic visualization of engraved stamps via local or remote access
- stamp duplication: to duplicate stamps to allow physical handling without risk and still conserving the objects.

These tools provide a complete and automated solution for historians to analyse ancient wooden stamps and will change, or at least facilitate, their work. Indeed, virtual printing permits, for the first time ever, images produced by stamps to be shown to researchers (images that have not been seen for centuries). Moreover, 3D visualization will allow sharing and exchange of information or data between libraries from different cities or countries, and offers a showcase to libraries and museum, enabling web-based presentation, general public exhibitions and so on. Lastly, experience has shown the importance of stamp duplication for students and researchers: manipulation and direct observation of copies are pedagogically very important and heuristically useful, as they permit a more complete perception of the object. Not least from this point of view, these tools were validated by future users, who are researchers at the Written Cultural Heritage Laboratory from Troyes (FRANCE).

In order to make the documentation, analysis and conservation of stamps possible, some enhancement must be provided. Work to be carried out first relates to improvement in the quality of 3D acquisition of stamps presenting fine detail. Of course, scanners with higher resolution should give better results. Tests were performed using Arius3D technology, which scans the surface of an object with one focused beam, and records the reflected light. The Z-axis resolution is 25 μm, and final results are really enhanced. Some other scanners with higher resolution (<50 μm), such as Metris solutions, should be applicable. Unfortunately, for the moment, result enhancement can only be obtained by 3D scanners that are not transportable. This is usually incompatible with cultural heritage projects that need on-site scanning sessions. Future work also relates to the improvement of the texture digitalization process. The manual work which results from texture mapping remains a major problem. The Arius3D technology scans the surface of an object with three different laser wavelengths (red, green and blue) and provides very accurate colour texture. When this technology is transportable, it will supply very satisfactory results for on-site sessions.

The whole developed solution can be applied to any family of objects that need be conserved, presented and analysed. Other projects have been launched in the area of biology/geology (fossil study) and in the field of ancient book-binding documentation.

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