Visualizing and Transcribing Complex Writings through RTI

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***Abstract*—This paper presents our digital publishing process and its editing system developed for a specific use case – the scholarly digital edition of a set of Roman inscribed lead tags – but suited for analyzing a broad variety of text-bearing objects. This pipeline covers the spectrum of the activities from data acquisition of the visual aspects to complex analysis of the writings and text of incised inscriptions. It employs a two-dimensional medium, Reflection Transformation Images (RTI), to support visual analysis. The visual and textual data it generates are open access, ready to be used for machine learning processes.**

***Index Terms*—Language technologies for Cultural Heritage, Digital Epigraphy, Digitization, Visualization, Reflection Transformation Images, Digital Autoptic Process, Paleography**

I. INTRODUCTION

Inscriptions offer deep insight into our social, historical and cultural roots. Some of their aspects appear complex to process in a computer system, since inscriptions combine written, textual and contextual information to convey their message. A formal and systematic organization adapted for computer representation of these kind of heterogeneous datasets, that could be extracted from any inscription, was proposed by [1], [2], in order to work on the corresponding writing system (wSystem), textual system (tSystem) and contextual system (cSystem) and describes a former proposal of an epigraphic Digital Autoptic Process (DAP), a careful inspection of the inscription using computer systems.

In addition to this genuine complexity, inscriptions sometimes contain difficulties that come directly from the society that produces such inscriptions. Since ancient time, inscriptions offered a large variety of writings and today's urban graffiti could be viewed as particularly difficult. With time, inscriptions also become degraded (eroded or broken), and therefore incomplete. These aspects have been codified in a set of practices in the field of epigraphy that must be taken into account in the overall digital process as a fourth system (epigraphic system or eSystem). We do not deal with the epigraphic system here as the discipline has already set up standards to encode its scholarly information (see EAGLE [3] and the use of XML with the TEI subset EpiDoc [4]).

This paper presents the software tools we developed for the scholarly digital edition Tesserarum Sisciae Sylloge (TSS) available at **https://tss.amz.hr**. The TSS comprises a set of 1123 Roman lead tags from Siscia (modern day Sisak). Dated between the first and third centuries CE, these are conserved at the Archaeological Museum in Zagreb (AMZ) and published on both print and digital form [5]. They are small, rough rectangles of lead sheet, a couple of centimeters on each side, pierced with a hole. They were attached to materials and cloth during processes of dying and cleaning, and they indicate mostly personal names, the type of merchandise, colours, prices, quantities and weights. Usually both sides carry lightly incised inscriptions, sometimes in multiple overwritten layers. They are composed using capital letters or the older Roman cursive letters or both. This writing system allows different glyph for a same letter, adding ambiguities: each sign of this Roman writing system is represented by two to thirteen different forms. For example, two vertical strokes could correspond to the Roman number 2 or the Latin letter E.

Our project required effective instruments for the digitization of the tags and for supporting the visual inspection of these documents at diverse distances and illuminations. Beyond the primary visualization, we face the challenge of adapting some of the traditional methods in epigraphy. The system needs to support the following functions: recognizing and recording the shapes of the glyphs on the inscriptions, identifying the related textual content, and properly archiving these data.

The paper is organized as follows: Section II presents our visual data acquisition approach, based on RTI representations; Section III describes the Digital Autoptic Process through the visualization and annotation tool, *Markout*; Section IV presents some possible extensions and the contribution of Machine Learning technology to inscription decoding and analysis. Finally, brief concluding remarks are presented in Section V.

II. VISUAL DATA ACQUISITION

The choice of the digitization and visualization technology depends on the state and type of the surface of the inscriptions under study. In this case, the small size of the media and the peculiar material of the incised tags make this corpus particularly hard to represent in standard photography (Fig. 1). Just as a person who inspects a badly-worn coin will naturally turn it in the light in order to see its many contours, a photo taken from a single angle does not fully capture all of the coin's features.

Fig. 1. A standard RGB photograph of tag n.12582

According to our tests, current standard 3D scanning technologies do not have the required resolution to fully sample these very thin incisions.
In contrast, we expected that Reflectance Transformation Imaging (RTI) would be a method able to represent the incisions effectively, since it samples the surface reflectance under different light conditions, much like the person we described inspecting a coin. A number of digitization projects concerning cuneiform tablets [6], [7] and rock art or graffiti [8]–[11] has similarly chosen the RTI representation.

A. Reflectance Transformation Imaging - RTI

RTI encodes a sampling of the surface reflection characteristics. It is a particular case of surface reflection acquisition, where we choose a single view over a scene/object and we acquire that area under different lighting conditions. Therefore, RTI allows the user to interactively relight the image at visualization time. RTI were proposed in a pioneer work and initially called Polynomial Texture Maps (PTM) [12] because this initial work proposed a simple bi-quadratic polynomial interpolation. More sophisticated basis functions have been studied afterwards to better represent the reflectance, like spherical (SH) and hemispherical harmonics (HSH) [13].
More recently, we proposed a new interactive representation (Relight) based on Radial Basis Functions and Principal Component Analysis, which guarantees a better reproduction of materials presenting specular reflections, such as metals (e.g. gold, silver) [14].

Manual or automatic (i.e. with a dome) processes for RTI acquisition are both pertinent strategies. But, because of the type, quantity and size of the inscriptions under study (Siscia Corpus lead tags), the RTI acquisition was done with a dome structure providing 116 computer-controlled lights and a holder for the azimuthal digital camera (Figure 2). Each set of acquired photos was processed to create the final RTI image. We used the RTIBuilder open source software available at the Cultural Heritage Imaging website [15].

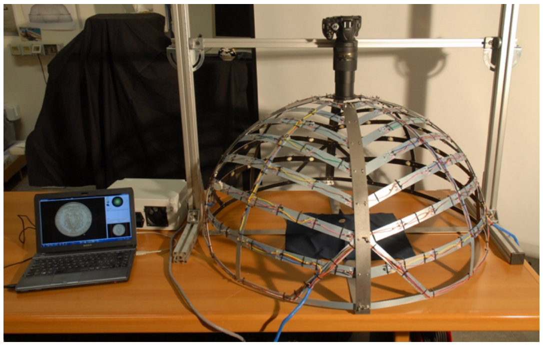

Fig. 2. The dome for the acquisition of RTI images (CNR-ISTI)

Fig. 3. RTI visualization under different light directions

III. VISUALIZATION AND TEXT HARVESTING

The online visualization of RTI data requires the conversion of each RTI file into a multiresolution Web format that permits an efficient and asynchronous loading of the image. This approach was developed for the presentation of an RTI-encoded set of coins on the web [16] or to allow scholars to publish easily RTI data on the web, with the automatic Visual Media Service [17], [18]. The plain RTI dataset is also available for download and inspection using the desktop software RTIViewer [15], developed by CHI and CNR.

Visualization is the first component of our system: the overarching goal is to support scholars with a system able to recreate some of the traditional methods of observation in the digital domain. The result of this transfer of methodology is a process called Digital Autoptic Process (DAP). It provides functionalities to mimic the observers strategy sufficiently to identify the features on the object, decypher the signs, and by natural extension the tools to semantically record such data.

A DAP needs to distinguish and link the information

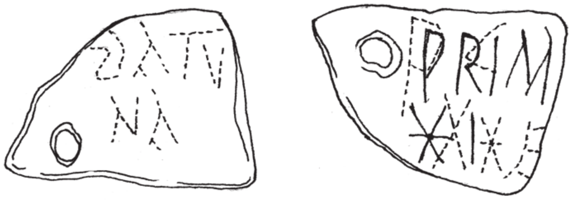

Fig. 4. An example of a handmade illustration of a tag. Dotted lines are used to mark erased or overwritten text [5].

pertaining to different systems. In the specific case of a DAP oriented on epigraphic data, those are:

- The contextual system (cSystem), in the specific archaeological case of the TSS, the digital representation of the text bearing object only
- The writing system (wSystem), such as the various handwritten letter shapes,
- The textual system (tSystem), such as the text it composes, such as a linguistic token, and
- The epigraphic system (eSystem) that provides the semantics of each system and also some semantics for the conveyed message, such as citizen, names, status or nationality.

Another feature we deem important is the ability to record hypotheses about parts of the object that are degraded or lost, in our case written signs that have disappeared or just not fully visible anymore. Finally, a last feature consist in facilitating the confrontation of interpretations and the discussion between users.

Most available systems focus on visualization only [19], while systems providing DAP functionalities for the identification and archival of scripted text are much less common [20] and the recent guidelines for 3D in Cultural Heritage are not yet taking into account this kind of annotation [21].

Thus, we have recently developed ”Markout” a more sophisticated tool that supports visualization, analysis and encoding as well as the meaningful connection between each step. This tool could be extended to other objects (with or without writings), exploring the potentialities offered by the proficuous association of DAP with RTI.

A. The Markout Tool

The printed edition of the TSS accompanies each tag translation with a hand drawn illustration (see Figure 4). This format is not suitable enough for the analysis of the shape of the letters (wSystem) and proves to be inconvenient when applying Machine Learning approaches over the recognized text. Therefore, we decided to develop a web system, named Markout, aimed at supporting the user while tracing letters and symbols on the tags as well as keeping the relationship between the position and the shape of the glyph (wSystem) on the digital artifact (cSystem) and its transcription in the tSystem (in Unicode). Markout is developed on top of the RTI visualization tool, since providing all the RTI visualization feature is needed in the recognition and tracing phase.
The main features provided by Markout are:

- *Multiresolution RTI Viz:* the Markout tool adopts the last version of CNR’s web based visualizer and the related efficient data encoding / transmission approach. High resolution RTI is needed in the recognition and tracing phase, and those data have to be interactively explored with a web interface, consuming limited bandwidth. Common high resolution images are also supported with multiresolution.
- *Vector drawing:* accurate tracing with a mouse in brushing mode (i.e. following the shape of the characters) is difficult and tedious. Conversely, a vector drawing mode makes it easier to select and adjust the profile of the marks. In this mode, the user selects a chain of points over the inscription, later on converted into a polyline. The current implementation provides editing capabilities, which allows him or her to modify the vectorial polyline easily and better adjust the set of points to the shape of the specific incised character.

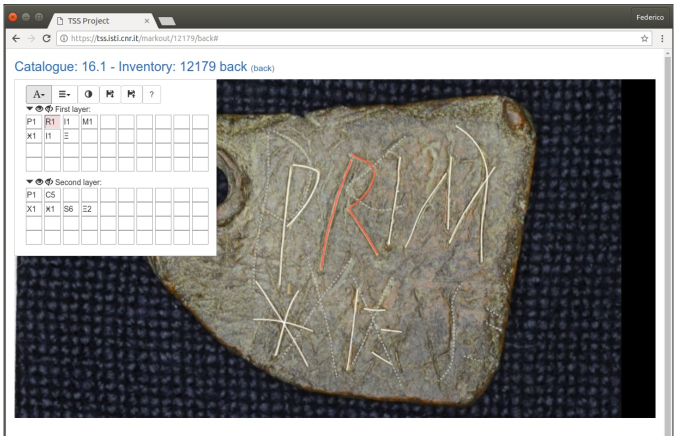

Fig. 5. The interface of the **Markout** tool.

- *Transcription:* each symbol is assigned an UTF-8 character and a classification. Here was also stored information about the editor’s confidence in the decipherment or in the reconstitution of the writings. In this way, the relationship between the wSystem and tSystem is preserved.
- *SVG input/output:* the tracing and transcription can be saved and restored or shared through an SVG file.
- *Archival and indexing:* the transcription are automatically archived and indexed for both graphical and textual analysis.

The kind of Digital Autoptic Process offered by Markout is an improvement over the more traditional production of graphical illustrations: we do not have in output a drawing, but we have a tool that allows one to check the result of the annotation superimposed with the original image. The goal is to support documentation of research results and provenance of the data. Moreover, Markout’s results are in digital forms (SVG files) and could be reused for further applications or computations.

The shape and position of the characters’ marks are precisely positioned over the RTI; in this way, from an epigraphic standpoint, the relationship between the cSystem and the wSystem is maintained.

Associating individual character shapes with the transcription makes it possible to propose shape classification and analyze shape correlations to validate for example character shape changes over the span of time. A similar operation was made by manually cutting the individual characters from the illustrations into separate images, erasing the extraneous mark and labeling the files according to character, character shape, label, position etc. This work-intensive process lost the relative positioning information and due to the 'dotted line' convention used for palimpsest half of the images are not really suitable for shape analysis.

Because it uses RTI visualization, it provides an accurate alignment of the tracing and the image and it keeps the connection between the individual characters in the transcription, their shape and their location on the tag, this system provides scholars a remote and immediate access to the transcription hypothesis. This allows much stronger capabilities of understanding and validating each transcription hypothesis.

Fig. 6. A proposed classification of different shapes of the letter A

This system has proven especially well-suited for teaching students new to the study of epigraphy. Over the past six years, Roman history students at Mount Allison University in Canada have accessed the TSS corpus through Markout as an introduction to Latin epigraphy. They come to appreciate the painstaking nature of the work required to transcribe these documents but also enjoyed being able to record their own readings. These tasks naturally lead them to broader, largely unsolved, questions, for instance studying the history of Roman handwriting as illustrated in the variety of letter shapes (Figure 6), the wool dying industry itself, or the social history of the customers listed in these tags.

The best way to show the characteristics of an interactive system is by means of a video. A short video clip, captured while demonstrating the use of Markout, is available on YouTube at: **https://youtu.be/Busy_Yh1jAE**.

IV. OPEN ACCESS DATASET AND MACHINE LEARNING

Here some comments on how this dataset might be reused for further machine learning computations.

The TSS dataset can be downloaded from the website https://tss.amz.hr. It contains:

- Transcriptions of all the 1,123 tag in the corpus (front and back) in JSON format (catalog, side, raw text) for a total of about 20,000 characters, where 10% of the latter are marked as uncertain;
- Language model containing only the sequence of identified characters in a single text file;
- The corresponding archaeological illustrations in PNG format;
- RTI dataset for the 40 tags in *.rti* format along with the 116 raw photos used for RTI creation;
- 1,400 letters and symbols manually extracted from the illustrations of the 40 tags which have been digitized and are available in PNG format. The naming (see examples in Fig. 7) follows the scheme:<number>-<tag>-<side>-<layer>-<row>-<position>[-<last>]-<symbol>, where:
  - *number*: chapter and number of the tag in the catalog (eg. 01.20 first chapter 20th tag);
  - *side*: front or back side (AV or REV);
  - *layer*: F stands for older layer, S recent layer;
  - *row*: row number;
  - *position*: position of the symbol in the row;
  - *last*: FR for last character in a row, FF for last one in a layer;
  - *symbol*: character, or currency symbol (SES for sestertius, DEN for denarius, DUP for dupondius) followed by the type number, or NOT for a mark either not transcribed, unintelligible or just an erasure mark.

A Markout transcription process for all the digitized tags is planned and the resulting SVG paths will be made available together with the rasterization of the individual letters and symbols.

We expect this data might be useful for a number of Machine Learning applications. The automatic detection of marks using image-based algorithms might be enhanced by the RTI data structure and validated against user-supplied tracing. Such an algorithm might be integrated into the Markout interface to aid scholars and students as they identify and trace the symbols.

Secondly, a Machine Learning language model for this corpus, one that takes into account the position of the letters in the tag and the surrounding letters already deciphered, might be used to suggest probable hypothesis for problematic characters. We suspect, however, that the transcribed corpus, containing only thousands of characters, is, at present too limited to build a truly helpful language model. In the long run, however, a larger Latin epigraphical language model may prove very effective in that field.

A more practicable, though still useful, Machine Learning application is "Intelligent Character Recognition" (ICR), provided as assistance to users as they trace glyphs on these tags. We envisage a feature wherein the user only need trace these and an ICR assistant fills in the corresponding letter identification. Alternatively, this ICR assistant might propose alternative letter identifications for particularly ambiguous glyphs.

Training data for this tool is available in the data set described above. The training would be simplified by the fact that this set comprises a small number of categories (under thirty), because the tags use only the Latin alphabet and do not use upper- and lower-case letters; moreover only a small number of currency signs are used. An approach based on a neural network would likely be highly accurate, and has the advantage of allowing the system to be retrained automatically as additional glyphs are traced. It is hoped that such a classifier could respond to an editors tracings in real time, thereby providing updated information as the editor interacts with the document.

This tool could be extended to other objects (with or without writings), exploring the potentialities offered by the proficuous association of DAP with RTI. Such a first exploration was set up with a demonstration organized during the Journées Nationales de l'Archéologie in France, **http://jna18.isti.cnr.it**.

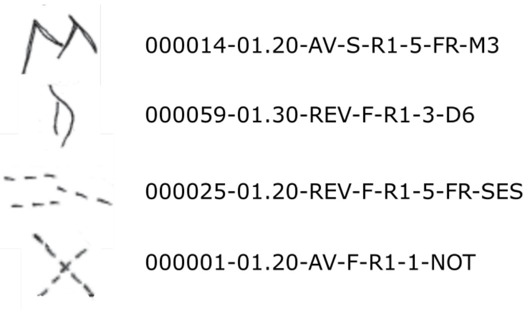

Fig. 7. A few examples of the letters transcribed (on the left) and the corresponding encoding adopted for archival purposes.

V. CONCLUSION

This short paper has presented the work done to digitize and to support the digital autoptic process of a collection of small lead tags presenting Roman inscriptions. We have experimented with and assessed the use of RTI on these specific specimens; as well, we have designed a specific web tool supporting both the visual inspection and the tracing of each single inscription character. The tool has been already used by scholars and students and the results of these first experimentations were extremely good. Among the most appreciated characteristics are the possibility to work remotely on the system by means of a web interface and to keep the results of the decoding and recognition phase aligned with the overall digital image representation.

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