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Surveying Imaging Workflows and Software in Cultural Heritage

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Abstract

This work presents insights into the imaging workflow from cultural heritage domain experts, gathered from an online survey. Non-invasive 2D imaging technology has become a cornerstone in the analysis and documentation of cultural heritage artefacts. Techniques such as hyperspectral imaging (HSI) and X-ray fluorescence (XRF) can investigate material properties, artistic processes, and conservation states. Existing analysis and visualisation tools offer functionality for specific data types but lack integration for holistic multimodal analysis. To address these limitations, we conducted a structured survey targeting researchers and practitioners in CH working with imaging technology. The survey explores their workflows, imaging technology usage, and software preferences. This study identifies key trends, challenges, and feature requirements.

Introduction

Non-invasive imaging technology has become a crucial tool for analysing and documenting cultural heritage (CH) artefacts. For these artefacts, e.g., paintings, multimodal data analysis supports various tasks e.g., condition and treatment documentation for conservation monitoring [1], material analysis and identification for technical studies of artists practices [2-3] and authentication of art objects [3].

Various technologies can be used to observe, analyse, and document the material properties of CH artefacts, as exemplified once again by paintings. X-ray fluorescence (XRF) and Macro-XRF provide insights into the distribution of elements and compounds across a painting surface [4], useful to investigate the painting technique of an artist [5]. Further, other imaging tools in 2D and 3D can contribute to the mapping of surface patterns and degradation processes [6]. Technologies like hyperspectral imaging (HSI) provide opportunities to capture information by extending the measurable spectrum beyond visible light to ultraviolet (UV) and infrared (IR-NIR) regions. By analysing the resulting hyperspectral cubes (x, z, λ), it is possible to classify different types of materials [4], e.g., for pigment identification and mapping [7-9].

While the discussed publications focus on individual technologies, recent publications now use multimodal analysis. “Multimodal” refers to data acquisition systems using, e.g., different sensors each as a distinct modality. This approach is valuable to investigate different aspects of an object and overcome the limitations of specific modalities [10]. Also, in CH, each imaging technique has its strengths and weaknesses. For instance, HSI for paintings cannot reveal the chemical composition of a pigment. Yet, it can identify specific fluorescence behaviour unique to certain paint materials or uncover invisible features that suggest the use of particular materials, both of which are crucial for pigment identification among other findings. That is why XRF analysis is important to complement the results from HSI investigations [11]. Hence, a holistic multimodal approach promises to deliver complex results which would not be possible just with a single technique. Brocchieri *et al.* [12] present, for instance, a combined approach using XRF, multispectral imaging, and SEM/EDS to analyse the artistic techniques of a painting. The study found that the artist used a cadmium yellow ground layer for depth and did not pre-sketch the artwork, which was later confirmed by the artist. Pérez *et al.* combine HSI, UV fluorescence photography, X-ray radiography, and spot analytical techniques to study pigment use, creation processes, and conservation states of a painting.

However, multimodal data analysis is a complex procedure that requires distinct acquisition systems and analysis pipelines for each modality. Several tools and customisable libraries exist to analyse individual data types. For HSI processing, tools like ENVI [14] and GLIMPS [15] offer several features to view, process, and analyse geospatial imagery data. However, e.g., ENVI was developed for remote sensing, so not all its features support the analysis of painting data. For XRF, datamuncher [16] provides possibilities for digital analysis and processing of XRF data of paintings, based on PyMCA. MOVIDA [17] is a desktop software that allows recording, elaborating and analysing data visually from in situ multi-technique investigations of, e.g. manuscripts in several interactive views. However, it does not provide an automatic analysis pipeline for, e.g., pigment identification. Now, there are also the first multimodal tools for painting data, e.g., IIPMooViewer [18], which can display multiple imaging data layers, e.g., HSI and XRF, through a web interface as exemplified in in the work by Pillay [19]. IIP can also combine imaging data from XRF and HSI in a layered visualisation and display, e.g., the spectral signal, but it cannot process and analyse the data.

A pattern to be recognised is that each software is developed for a specific type of data and/or imaging. Moreover, no tool yet can manage and analyse multiple data types at the same time. Additionally, the discussed publications view the tools from a technical perspective without considering their usability. Even though the tools were developed by domain experts, this can lead to a mismatch between the target audience and the intended usage, potentially making working with these tools challenging.

This study addresses this gap by conducting user research through a survey to investigate the imaging workflows of researchers and practitioners in CH working with imaging technology. This includes, e.g., conservators, museum photographers, and conservation scientists. The insights gained will reflect the demand, practices and challenges for software and tools in this domain.

Methodology

The usage of user research to explore target audiences within CH is not fully explored for the target audience of domain experts, but it is for end consumers such as, e.g., visitors. For instance, Konstantakis and Caridakis [20], survey how, among other things, user research is applied to visitor engagement in CH institutions, e.g., museums. They conclude that questionnaires are the most commonly used method to evaluate user experiences, next to, e.g., user observations or field studies. To develop the same understanding for the target audience of field experts, this section describes the concept of the survey questionnaire.

Survey Objectives

The objectives and methodologies of user research are discussed in detail by Marsh [21]. Similarly, this survey seeks to better understand the user base by addressing the following research questions: 1. Who are the users? 2. What are the users' needs? 3. What are they trying to do? 4. How are the users currently trying to do things? 5. How would the users like to do these things? Following Marsh [21], a survey has been chosen for a widespread user response, leading to quantitative and structured data on attitudes and opinions. Further, the demographic questions of this survey are modelled after the survey presented by Gigilashvili *et al.* [22], which investigates the criteria experts use to match textile fragments in artefact reconstruction, and explores how these insights could inform computational algorithms.

Survey Preparation and Execution

Three domain experts evaluated the survey to check its wording and structure. Afterwards, it was set up in Nettskjema, an online survey platform, and distributed to our network via e-mail and social media platforms, e.g., Facebook groups and LinkedIn.

Structure of the Survey

The questionnaire of the survey consists of three individual sections. The first is the section "User Profiles", it collects background information about the survey participants to target research question 1. This includes questions on demographic information and general information about the participants' professional background. e.g., the type of artefact they analyse or years of experience in CH and imaging, and occupation. The goal is to gather data for sample quality evaluation and to understand the participants' professional background.

Second, the section "User Needs and Motivation" focuses on job responsibilities and workflows to address research questions 2 and 3. This section primarily investigates why the target audience engages with imaging. Further, it aims to identify positive factors in the survey participants' day-to-day work, while also addressing potential frustrations. The information collected will be used for requirements assessment.

Third, the section "Imaging Practices and Software Use" investigates the individual's imaging workflow and software preferences to tackle research questions 4 and 5. This section asks not only what imaging technologies the individual is using and has experience with, but also what is available at their institution. Similarly, the survey investigates the individual's imaging software usage. It assesses satisfaction with existing products and identifies pain points, essential features, and potential improvements. The section also gathers insights for competition analysis and ideas for future software development.

Survey Analysis

Due to the diverse range of questions, this survey uses multiple methods to analyse the survey data. The primary analysis of close-ended questions, e.g., for the demographic, was done with the automatic survey report of Nettskjema. The open-ended questions were evaluated through close reading and word clouds with natural language processing in Python.

Results and Discussion

Overall, the survey gathered 82 responses. This section provides an overview and discussion of the collected data.

User Profiles

In terms of location demographics, this survey gathered 82 replies from Europe (70,7%), North America (23,2%), Africa, South America and Oceania (each less than 2%). The survey received responses from a diverse range of countries, with the highest numbers from Norway (13 mentions), France (12 mentions), and the USA (11 mentions), and individual replies from Germany, the UK, Portugal, Ethiopia, Romania, and Italy.

Then, employment information was collected (82 replies). Most of the participants are employed professionals (75,6%), while some participants are students (12,2%) or independent researchers (7 replies). Fig. 1 shows the distribution of occupation among the survey participants. Additional occupations (open-ended) include, e.g., professor, teacher, or archaeologist. Further, the vast majority (67,1% of 82 replies) have more than 10 years of experience in CH. Likewise, for experience in imaging (57,3% of 82 replies) and experience in current job or role (53,7% of 82 replies). Many of the participants work in academia, cultural institutions and industry (45,1%, 42,7% and 7,3% of 82 replies).

Fig. 2 shows that, based on multiple choice, paintings and manuscripts are the most common artefacts to work with among the survey participants. As shown in the graphic, many participants also reported other types of artefacts, e.g., photographs, film, archaeological artefacts, architectural elements, inscriptions, and musical instruments. Most likely, the participants work on multiple types of artefacts throughout their careers.

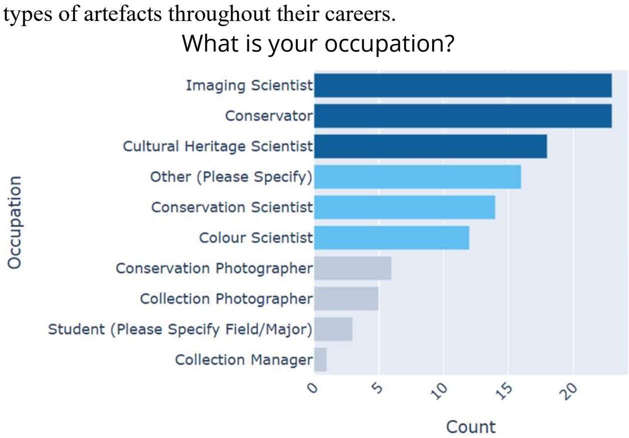

Fig. 1 *Distribution of occupations among the survey participants.*

Finally, the demographic highlights the diversity of the cultural heritage field, especially for the type of artefacts. Due to our spreading method, the demographic has limitations to geographic and experience-based diversity.

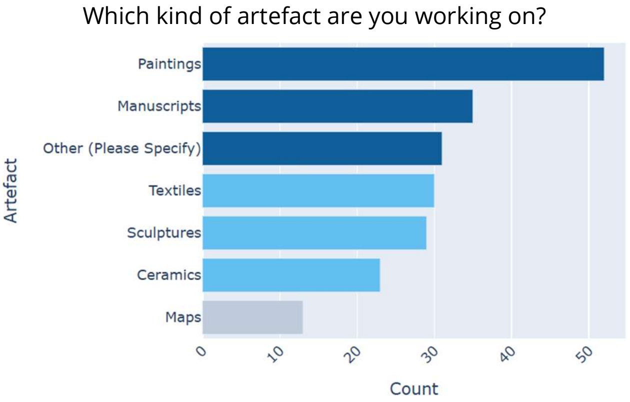

Fig. 2 Distribution of artefacts among the participants.

User Needs and Motivation

The most reported primary job responsibilities out of the multiple-choice question (82 replies) are research (81,7%), data analysis (43%), documentation (47,6%), project management (46,3%) and data collection (45,1%). Other responsibilities include teaching (35,4%), conservation (32,9%) and communication (19,5%). Additional reported responsibilities include, e.g., photography, product development and consultancy. This represents a diverse range of job responsibilities among the participants.

The open-ended questions regarding the motivation and research objectives for imaging provide a wide range of reasoning why the participants engage with imaging. Fig. 3 and Fig. 4 show the word cloud visualisation of the topics in the research objectives. Under close reading, the replies can be categorised into several categories. **1. Documentation and preservation:** Includes condition monitoring before, during, and after conservation treatments. According to the responses, this also helps in treatment planning, e.g., to assess damage and plan interventions. It is further helpful to track changes happening to the artefact over time, e.g., cracks or lighting damage. **2. Archival purposes and digitisation:** These are important motivations for imaging, as, for instance, high-resolution and multispectral images serve as permanent digital records for knowledge sharing and creation. **3. Research and artefact analysis:** this includes material characterisation, e.g., identifying pigments, binders, and substrate on painting surfaces. This is useful for the aforementioned technical studies. Further, this is also useful for scientific inquiries, e.g., for supporting studies in chemistry, physics, and materials science applied to CH. A few replies also reported a use for computer science, e.g., data fusion, or algorithm application through classification and segmentation. The replies for the research objectives also highlighted specific use cases, participants provided rich qualitative responses that illustrate the diversity of imaging applications, e.g. pigment mapping, 3D reconstruction, virtual restoration, object recreation and authentication. Last, the replies imply that imaging is part of professional practice, e.g., as a routine part of the job responsibilities and education, e.g., as part of PhD studies. Very few replies also reported commercial interest, e.g., for consulting and selling imaging equipment. Last, while most responses were technical, a few participants expressed personal passion and motivation.

Fig. 3 Word cloud visualisation for question “Why are you doing imaging?”

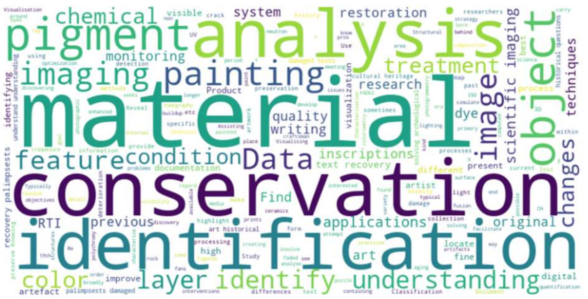

Fig. 4 Word cloud visualisation typical research objectives using imaging.

In terms of their typical workflow, the open-ended responses provided various examples. Some respondents emphasised the lack of a “typical” workflow, citing the need to tailor processes to each artefact and research question. A few participants mentioned that some aspects of their workflows are highly standardised (e.g., laboratory standards), while others reported that their conditions are experimental and adaptive.

However, upon close reading, the majority of the replies do emerge into a pattern consisting of 6 different stages: **1. Planning**: Here, the respondents define research questions and imaging goals and consult with curators, conservators, or researchers and assess object condition and accessibility and imaging equipment. **2. Data acquisition:** This includes system calibration (e.g., white balance, flat-fielding) and capture of images using various techniques, e.g., visible light, UV, IR, X-ray, RTI and HSI/MSI and photogrammetry for 3D-reconstruction. Further, the capturing process includes the use of targets, filters, and controlled lighting. **3. Preprocessing:** Conversion of raw files to TIFF or other archival formats. Apply corrections, e.g. white balance and noise reduction. Last, this can also include stitching and mosaicking for large artefacts. **4. Data analysis:** This includes steps like spectral analysis of a surface, e.g., pigment mapping and clustering or 3D modelling. This can also include comparison of modalities (e.g., overlaying IR and visible). **5. Interpretation:** This includes sharing and discussing preliminary results with stakeholders and potential refining of the previous steps. **6. Documentation & and potential publication.** This includes generating reports, visualisations, and publications. Also, participants reported the archiving of data and metadata, e.g., IIIF manifests, and preparing materials for outreach or conservation planning.

This workflow complexity is also reflected in the reasoning why projects go well or fail. As seen in Fig. 5, the data shows that the key factors for project success are first well-functioning tools before clear communication and a supportive team environment. Hence, technology is important to our survey participants. On the opposite side, as seen in Fig. 6 the biggest challenges in imaging projects include lack of time and urgent deadlines, handling too many projects, while software and hardware-related issues follow later.

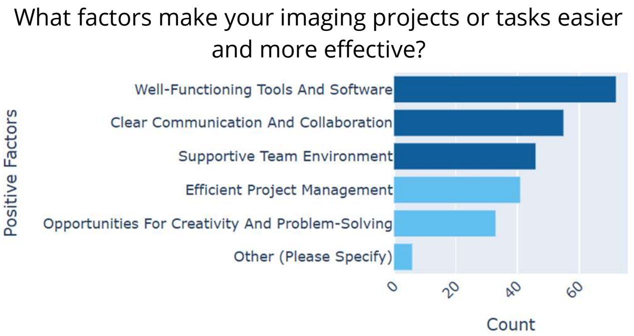

Fig. 5 Visualisation of the positive factors in CH imaging projects.

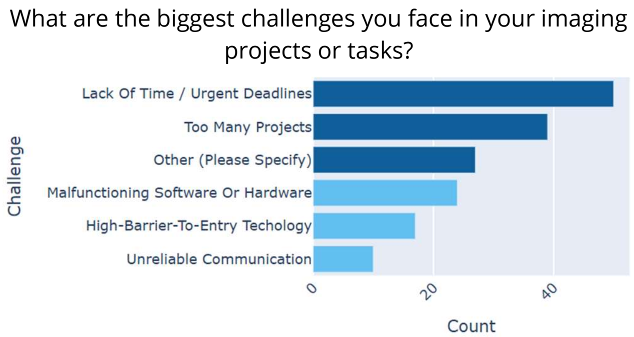

Fig. 6 Visualisation of the challenges in CH imaging projects.

To investigate the other challenges and success factors, the survey also collected open-ended additional comments. A major factor in why projects go well or fail is the budget and funding situation, which results in personnel, equipment and/or software shortcomings in projects. Furthermore, this also leads to a shortcoming in education and knowledge development. In that way, clear goals and expectations for the project, as well as decent project management with clear workflows, responsibilities and communication, are a key factor for project success. Further, some respondents also reported that access to the acquisition object can be a challenge.

Another challenging factor is the format and amount of data to be processed. Some replies reported that there is a lack of institution-wide standardisation in terms of the data format, storage and management, but also for the image acquisition (e.g. the lighting conditions). Further, for some the amount of data can be also a problem for the processing in terms of the software performance. Here, some participants also said that they don't have access to GPUs, making this not only a software, but also a hardware issue. In that sense, some respondents also reported that upgrading also became an issue, since due the individual camera setup, not every software works for the specific system and vice versa.

Imaging Practices and Software Use

In terms of imaging and software preferences, this survey first presents an overview of imaging technologies in the following categories: **1. Availability at institution:** the top 3 technologies are Ultraviolet Induced Fluorescence (48 responses), DSLR photography (42 responses) and multispectral imaging (40 responses). **2. Currently using**: DLSR (40 responses), Ultraviolet induced fluorescence (38 responses) and mobile phone camera photography (36 responses). **3. Experienced in the past:** RTI and MSI (both 29 responses), point- and short camera photography (25 responses). This leads to the trend that many individuals and, hence, institutions have multiple types available and, in the context of the previous questions, might even use multiple imaging types in their workflow.

In terms of expertise in those imaging techniques, the survey gathered varying levels. While some participants do not claim to be experts, others did so, either for imaging technique types (e.g., MSI, HSI, SEM, X-ray fluorescence), then also more general fields (e.g., photography or computer vision) and sometimes also in contexts, e.g., in systems for museums or for the role as a trainer for multiple imaging types. The answers were very individual, though the majority of the replies had some kind of expertise.

The most commonly used imaging software (82 replies) among respondents includes Adobe Photoshop (70,7%), ImageJ (40,2), programming languages (e.g., Python, MATLAB) (37,8%), GIMP (32,9%) and MATLAB Software (31,7%). Some respondents also use additional software (48,8%), e.g., Capture One, MeshLab, PyMCA, Adobe Lightroom Classic. Meanwhile, Hirox (6,1%), Datamuncher (4,9%), XpeCAM CLOUD (3,7%), GLIMPS(1.2%), and MOVIDA (0%) received little to no reported usage. This data highlights a preference for a mix of commercial software, open-source tools, and custom programming for imaging tasks.

As seen in Fig. 8, most of the responses are neutral or satisfied with the software. Furthermore, Fig. 7 indicates that a significant portion of the sample perceives the software as helpful for their work. To understand the reason behind the ratings, this survey also investigated user feedback regarding the products and services they use.

Fig. 7 Visualisation of the results for whether the software the participants are using is helpful in their work.

Fig 8. Visualisation of the satisfaction of the participants with the software they are using in their work.

In additional open-ended questions, the respondents could insert their favourite (60 replies) and least favourite software (49 replies). In terms of the favourite software, Adobe Photoshop (12+), MATLAB (8+ mentions), ImageJ / Fiji (6 mentions), Capture One (4 mentions), ENVI (4 mentions) and Python (3 mentions), Datamuncher (+ PyMCA) were most frequently mentioned. Other mentioned software includes MeshLab, OpenCV, RTIViewer, Spectronon, XpeCAM Cloud and Hoku. For the least favourite software, MATLAB (8 mentions), GIMP (6 mentions), RTI Viewer (5 mentions) Adobe Products (4 mentions), ENVI (2 mentions) and Blender (2 mentions). This leads to a diverse software landscape within CH and supposedly very individual experiences with each software used. One participant reported that the software can be challenging to teach or learn, and they need to use often use multiple programs.

Additional open-ended responses highlight both positive and negative aspects of the software they use. Again, upon close reading, the topics in these replies can be categorised as follows: **1. Usability:** issues with user interfaces. Additionally, frequent changes in menus and features can be confusing in some software, e.g., Photoshop. Additionally, users mentioned the user interface as a factor for both negative and positive experiences with the software. **2. Software performance:** The reliability of the software is a crucial factor in the satisfaction of the software, e.g., slow processing due to software performance is indicated as a negative aspect. **3. Cost-effectiveness and Documentation:** Some replies reported the use of open-source software and highlighted documentation as an important factor for their software preferences. This implies a need for transparency, flexibility, and cost-effectiveness. Further, this can also help in tackling the problem of a lack of funding for projects and hence discontinuity of software projects in CH. If the software is well-documented, it can be continued by the community in other projects. **4. Customisation & Flexibility:** Users appreciate the ability to put their ideas into practice. The open-ended questions further reveal that some survey participants like to work with custom scripts or even systems and workflows tailored to their needs. **5. Feature Scope:** The participants report the lack of specific features, e.g., an adequate colour sampler, and reported limitations in the software for doing all work steps in one software.

The survey further asked for responses (46 replies) if the users have a custom setup in their software. Here, the replies were mixed. For the users that reported a custom setup, these replies ranged from use of a custom set-up for each job in terms of hardware and software, to the use of custom scripts, plugins and user interface customisations and settings, e.g., dark mode.

Overall, the results of this section lead to the conclusion that the software preferences are as diverse as the workflow, and the needs and demands for them highly depend on the workflow where they are used. However, there are also trends visible in the data for the demand for more usability, customisation and optimised software, preferably cost-efficient as, e.g., open-source solution.

Conclusion

In summary, this study investigated the target audience for imaging and related software in the CH field. The survey showed that the target audience's cultural heritage is highly diverse, gathering multiple participants from various professional backgrounds and types of artefacts.

This diversity is also reflected in the reported workflows. The results from the survey and the discussed literature show a tendency towards individual workflows in imaging projects in cultural heritage, while still following similar patterns, e.g., first planning, then data acquisition, analysis and discussion and publication. This leads to many challenges in projects, e.g., the lack of standardisation between institutions and individuals in data acquisition, management and storage. This is also a major factor for success and failure in CH projects, among budget, personnel and time factors, other technological barriers (e.g., hardware) and knowledge are further important factors. The investigation of software preferences and workflows revealed that, while overall satisfaction with current software leaves room for improvement. Many replies reported concrete problems with hardware and software, e.g., the usability and performance of the software, and general feature scope. Further, there are also wishes for improvement of the software, e.g., for automation and usage of AI-based algorithms.

Finally, this survey demonstrates the demand for standardised and user-friendly and scalable solutions for CH imaging. Future research can therefore investigate to a wider extent workflows and standards for each imaging technology and software, tagging along user groups and artefact types.

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Irina Crina Anca Sandu is a Conservation Scientist (PhD in Chemistry, 2003) at Munch Museum in Oslo since 2016. She led several projects on the scientific study of the museum's Collection. She is the author/co-author of more than 130 peer-reviewed publications and more than 145 conference presentations.