# Museum Visitor Experiences based on Hyperspectral Image Data

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**Abstract.** Hyper- and multispectral imaging allows to collect data from specific wavelength ranges or across the electromagnetic spectrum, including frequencies that are imperceivable for humans. As non-invasive imaging techniques, it has been used in the field of art conservation and art history extensively in the past. In these areas application of hyperspectral imaging include for example conservation monitoring or pigment identification. In the context of museum exhibits, hyperspectral data of artworks offers a unique opportunity to enhance visitor experiences by providing new ways of engaging with artefacts, artworks, and cultural heritage. This paper presents design concepts for creating immersive and meaningful experiences using hyperspectral data. We used an expert led design workshop to explore the possibilities of museum experiences with such data, including considerations such as suited technologies, visitor types and visitor experience.

**Keywords:** Hyperspectral Imaging · Museum Experiences · Augmented Reality · Virtual Reality · Multispectral Imaging.

## 1 Introduction

The human visual system is limited in its ability to perceive the electromagnetic spectrum as it is only sensitive to a narrow range of wavelengths [18]. However, with the recent developments in hyperspectral imaging (HSI) technology, that allows to capture and analyze the spectral information of objects or scenes across a wide range of wavelengths, it is possible to gain more detailed insights into the properties and characteristics of materials. With this technology it is possible to take advantage of the fact that differing materials have unique spectral signature, allowing for identification and characterization [17]. By analyzing the different spectra in a hyperspectral image, valuable information about the constituents and surface properties of the material can be obtained. The technology has gained traction across a variety of fields where precise material analysis is critical for understanding the composition and condition of objects or surfaces, such as remote sensing, archaeology, forensics and especially art [17].

In art conservation and art history HSI has gained increasing popularity for nearly three decades, as it is a non-invasive technology, that allows to gain insights about specific material properties without damaging the artworks [19]. For example, if the specific pigments of an artwork need to be identified, to restore the artwork as closely to the original as possible, chemical methods such as gas chromatography or microscopy, require to take a small physical sample from the work, thereby damaging it. HSI on the other hand allows to determine the specific pigments by comparing the spectral properties to known pigments completely non-invasive [2, 7]. These possibilities led to the proliferation of the technology in art conservation [21] which means that an increasing number of museum are in possession of HSI data of their artworks.

Only little work has so far focused on using multi- or hyper spectral imaging in the field Human-Computer Interaction (HCI) to create interactive experiences or applications [11, 23]. The primary reason for the limited adoption of HSI in HCI could be attributed to the high cost (which can exceed $20,000) as well as the intricate nature of these systems. We propose that HSI data can be utilised to create immersive interactive experiences that could allow museum visitors to engage with artwork in new ways that foster exploration. However, developing meaningful experience requires not only a deep understanding of the art but also the technological capabilities of HSI. This work represents a first step in the exploration of HSI in which we develop a first mapping of application possibilities through an expert led design workshop.

## 2 Background

HSI has seen an increase in interest across a variety of different fields, however in this paper we only focus on the use in art and museum cases, for a more comprehensive overview of HSI application domains consider [17]. One of the most common application is to reveal information that is hidden under other parts of the painting, so called pentimenti. This can include, artworks that are painted on top of another painting on a canvas, original pencil sketches outlining the artwork, or major changes in the composition that were made during the painting [19]. It should also be mentioned that such investigations have been made since the 60's by using an infrared camera [4]. With its ability to capture both spatial and spectral information which relates to physical characteristics of materials, HSI also allows for the far more complex identification of pigments and their spatial distribution across the painting [6, 7]. As discussed above already, this is crucial in conservation and restoration of art works similar to the detection of damages and past interventions through inter-band comparisons [19]. This analysis can also be used to detect potential forgery [14]. Furthermore, old paintings also often exhibit cracks, also known as craquelure, which occur when the paint or pigment layer, as well as the substrate or varnish layer, break. These damages are primarily caused by aging, drying, and mechanical factors such as vibrations and impacts. Crack detection is crucial as these cracks diminish the perceived image quality of a painting and HSI has been used to detect these this as well [8].

Another application with a focus on art is to enable rendering of colour accurate images of paintings under any lighting conditions. Unlike a normal RGB image which can only capture an accurate colour image under the specific illumination used at the time, HSI data can be render in a variety of lighting condition. However, a major problems that arise from having hundreds of spectral bands available in HSI, is the visualization of them. They can only be made digitally visible for the human eye using three spectral channels for red, green, and blue (RGB) colors. Magnusson et al. presented an algorithm which creates realistic color images out of HSI data, using the CIE 1931 XYZ color space and D65 as the reference illuminant [20]. When replacing the illuminant it is also possible to create renderings of artworks that simulate other lighting conditions. Chen et al. even explored the possibilities to generate hyperspectral data from standard RGB imagery of artwork using deep neural networks with some success [5]. While we in this work focuses on museum that often have proper HSI data, such inference could enable similar experience for hobbyists and private art collectors.

Only a limited amount of prior work focused on using multi- or hyperspectral imaging in HCI. In comparison, the use of a limited amount of bands of the electromagnetic spectrum - for example using near-infrared for spectroscopy of sucrose contents drinks [15] - is much more common in HCI and UbiComp as such devices are cheaper, smaller and easier to integrate into end-user devices [15, 16, 13, 22]. An example of using multi-spectral imaging is SpeCam presented by Yeo at al. [23]. SpeCam uses the front-facing camera of a smartphone and the display as a multi-spectral light source to infer the material underneath the face-down lying smartphone. HyperCam by Goel et al, provides a low-cost implementation of a multispectral camera including software to automatically analyzes a scene and provide the user with a set of images that try to capture the salient information of the scene [11]. They demonstrate in two application cases how this can be used. In the first application case they identify individual users through the venous structure on the back of the users hand, that becomes visible in the near infrared area of the HSI data. For the second case they again used multiple bands of the near infrared spectrum to determine the ripeness of different fruits. To the best of our knowledge no previous work explored the use of HSI data as a basis for interactive experiences in a museum.

## 3 Design Concepts

The goal of this paper is to develop design concepts for interactive museum experiences that are based on the HSI data and knowledge available in museums.

### 3.1 Method

To investigate the possibilities of HSI data as the basis for novel museum experiences, we organized a full-day expert-led design workshop. Given the complexity and multiple approaches required to analyze HSI data, we decided to have an expert in this field guide the design workshop. Besides the expert we involved five participants that were never exposed to HSI technology before. The participants consisted of two female (aged 26 and 40) and three male (aged 36, 37 and 46) all coming from interaction- and graphic design background. The expert in hyperspectral image processing had a particular focus on its use in cultural heritage and art conservation (female, aged 34).

After the expert's introduction to HSI and its capabilities, we began with an initial brainstorming session to identify potential areas of interest for museum visitors based on HSI data. A number of application ideas were generated, which were subsequently organized into five themes, namely: *invisible information*, *human visual perception*, *alternative perceptions*, *art modification*, and *revealing the artistic process*. The participants were then challenged to create design concepts that included technical implementations for the different ideas. Additionally, they were asked to identify which of the five museum visitor types (Explorer, Facilitator, Experience seeker, Professional/Hobbyist, and Recharger), as presented by Falk [9], would be most interested in each concept and explain why. In the following section, we will discuss each theme and its associated designs and their relevance to specific types of museum visitors.

**Fig. 1.** Augmented Reality Example: Edvard Munch's Scream (1983) contains a pentimenti in Norwegian "Kan kun være malet af en gal Mand!" (English: "Can only be painted by a mad man!") written with a pencil, which can be made visible in the near-infrared spectrum. Here it is conceptualized how this could be utilized in a mobile AR application.

### 3.2 Invisible Information

The first experience that was conceptualized was providing access to concealed layers of an artwork that are not discernible by the naked eye but that can be revealed in HSI data. Thereby fostering a more immersive and enriched exploration of the artwork. Especially elements such as pentimenti (underdrawings) and underlying revisions or changes made by the artist in the original image, were deemed to be of high interest for museum visitors. Also, the results of more complex HSI analysis methods such as Principal Component Analysis (PCA) of short wave infrared data [12], which can for example reveal patterns in the substrate that a picture is painted on where deemed as interesting content in this application area. Another element, that were discussed, where anomalies that can be identified in HSI data should be highlighted, even if they are human visible. One example that peaked interest here specially bird droppings and wax stains that are on Edvard Munch's Scream (1893) [12]. While they are visible to the human eye they are unlikely to be identified as such, but rather mistake for accidental paint droppings.

While different technologies, such as project mapping or larger touch displays were discussed, there was reached consensus that the most suited technologies that was identified for this is the utilization of mobile Augmented Reality (AR) to spatially correct overlay HSI data onto the camera view, thereby effectively unveiling the underdrawings in the paintings (compare Figure 1). By leveraging AR to reveal these subtle modifications in the artwork, visitors can gain a deeper insight into the artist's creative process, potentially elevating their appreciation and enjoyment of the artwork. This concept was particularly seen as suitable for the visitor type of Explorer. These are driven by curiosity and the ability to find new information, which the AR application would support, by not simply showing all information in a plain format but rather let the user explore the information.

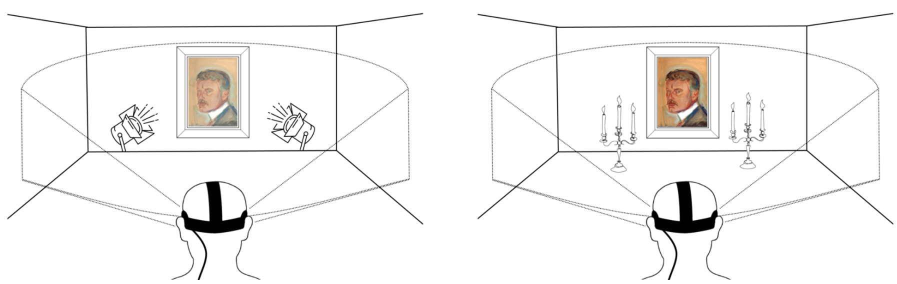

**Fig. 2.** VR Rendering Example based on Edvard Munch's Selfportrait (1905). Left: The user experiences the painting with artificial illumination that is common in museums. Right: The user experiences the painting in candle light, as Munch would have.

### 3.3 Human Visual Perception

The second larger theme that was discussed is the reflection on the human visual system, as through HSI data, the term colors became quickly quite abstract. Above, we discussed the issue of how to render visible images out of the HSI data [20], however, this issue can be used as an advantage. It can be used to render images with a variety of different illuminants, thereby imitating how the artwork would look in these different lighting conditions. Most museums use artificial light to protect the artworks from taking damage from too strong radiation of natural light [10]. However, this is stark contrast to how many artists experienced and created the artwork. For example, Munch was known for preferring natural light, and even leaving paintings out to fade as part of the artistic process [1], which resulted in the above discussed bird droppings.

The technology that was deemed most suited for this was Virtual Reality (VR). VR recently gained some traction in museum experiences [3], as it enable user-centred presentation and make cultural heritage accessible, especially in cases where physical access is limited or impossible. This would even enable remote experiences, independent from the original artwork, however, it was conceptualized by our participants as an experience that is supposed to be contrasted with their own real world experience. In order to give the audience the best impression to what the artist originally intended and present renderings of the artwork using different luminants, multiple other technologies, such as a public large display would be also suited. However it was agreed that through the use of VR the visitors would not only get a more immersive experience but also it would allow to present it in proper contextual environments showing the lighting sources (compare Figure 2). By doing so, visitors would be given the opportunity to perceive the impact of different light sources on the artwork and compare it against their real-world encounters. Such an immersive experience could facilitate contemplation on the intricate interplay between pigments and the human ocular visual system, fostering a deeper understanding of the artwork's visual dynamics. Here besides visitor type of Explorer, it was also highlighted as important for Facilitators as means to use it as an educational tool to reflect on the human visual system for example. Furthermore, Professional/Hobbyist could also benefit from this, reflecting on their own practice and light use.

### 3.4 Alternative Perceptions

The preceding discussion concerning the impact of the human visual system and its role in art perception generated a closely related theme: the possibility of rendering HSI image data to mimic the visual systems of other animals. This application could expand on the previous concept by generating renditions of the artwork as it would be perceived through the visual systems of various animals, providing visitors with a distinctive perspective, such as observing the artwork through their dog's eyes. For example, Figure 3 illustrates the variations in false-color images of "The Scream" (1893) as it would be perceived by different animals. This approach would permit visitors to explore how the artwork might appear from diverse visual standpoints, thereby deepening their appreciation for the subjective nature of perception and expanding their understanding of the artwork's visual impact across various species. While VR technology would be a fitting choice, participants suggested that a large interactive display would be even more appropriate. In contrast to the previous concept of different illuminants, context is less relevant here, and it would be simpler to compare the various visual systems. Moreover, this idea was seen as highly promising for

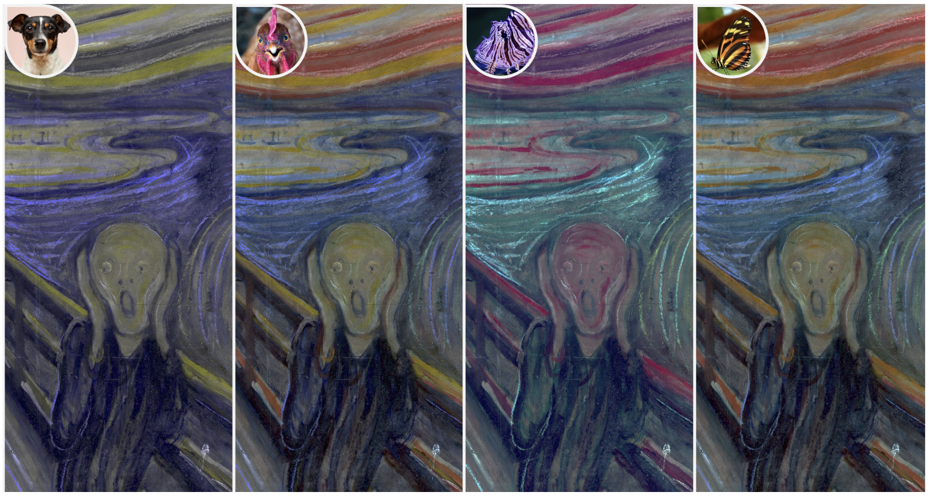

**Fig. 3.** Four examples of how animals would perceive Edvard Munch's Scream (1893). From left to right: Dog, Chicken, Zebrafish and Butterfly.

Facilitators and the visitors they cater to, as it would enable a more in depth discussion involving multiple visitors simultaneously. For example, in the case of a teacher visiting the museum with their students, everyone simultaneously perceiving the same different renditions, could allow for deeper reflections on visual systems. Additionally, this would be suitable for Experience Seekers who are typically drawn to the most prestigious exhibits, and this could potentially attract their attention if it was a highly visible feature positioned near these artworks.

### 3.5 Art Modification

Another application that was considered involves the identification of specific pigments using HSI data. As pigments tend to fade over time, the visual appearance of the artwork also undergoes significant changes. A prime example of this is cadmium yellow, a pigment that is particularly susceptible to fading and becoming transparent, resulting in a dramatic alteration of the artwork's overall appearance [1]. By identifying the various pigments in the artwork through spectral analysis [12, 6, 7], the corresponding spectral values of the pixels can be substituted with the original pigment values. When rendered as an RGB image [20], the resulting visualization would more accurately resemble the original appearance of the artwork. This idea also sparked discussions about giving visitors the ability to swap various pigments and create their own rendition of the artwork. In addition, the aforementioned application could be further extended to include the ability to generate the new image using different luminants or based on different visual systems. By incorporating these three concepts, visitors would have access to a vast array of possibilities and ample room for experimentation. A large multi-touch display was deemed the most suitable technology for this purpose, as it would enable multiple users to assess various versions simultaneously. This application would mostly appeal to the Facilitator visitor type, as well as Explorers. Finally, the large multi-touch display approach was also seen as a quick and easily accessible method that may also entice the Recharger visitor type, provided it is implemented in a manner that supports "peace and psychological uplift" [9, p. 176].

### 3.6 Revealing the Artistic Process

Finally, the idea to disclose the creative process, encompassing the transient order of the painting, as well as elements such as brushstrokes inferred from the HSI data, was discussed. Although this idea did not receive significant attention during the preliminary phase, it emerged as a highly favored concept for visitors categorized as Hobbyists/Professionals during the subsequent phase. These visitor types typically seek information that is content-oriented, a criterion that this idea precisely fulfills. However, the expert pointed out that while this is feasible to a certain extent, it may be challenging or even impossible to reconstruct underlying pigments in cases where dark and highly opaque pigments are applied over lighter ones, as these absorb a significant portion of the electromagnetic spectrum. Moreover, it soon became apparent that obtaining additional insights from experts such as art historians and conservationists (e.g., see [1]) would be necessary to appropriately explicate the process and create a potential explanatory application.

## 4 Conclusion

In this paper we presented design concepts that utilize HSI data as there basis, namely: *invisible information*, *human visual perception*, *alternative perceptions*, *art modification*, and *revealing the artistic process*, that are the result of an expert led design workshop. We outline the rich possibilities that these hold to create unique experiences for museum visitors, and discuss which museum visitors types would be most receptive to them. Although our participants were unable to reach a consensus regarding the most appealing concept, it was observed that the first three options garnered the greatest degree of interest among the participants. For future we aim to implement these applications and gather real museum visitor feedback, furthermore these concepts will enable other researchers and museum curators to develop new experiences and refine these concepts. Another important aspect that emerged during the design workshop was the recognition that the development of such experiences necessitates the involvement of experts in cultural heritage and art conservation, which luckily was present in our case. Nonetheless, as previously noted, the knowledge and HSI data required for these purposes are frequently accessible within museums; their full potential, however, remains largely untapped as our design concepts clearly outline.

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