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# RTI beyond relighting: Image analysis for archaeological Oseberg textiles

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**Abstract.** Reflectance Transformation Imaging (RTI), a non-destructive imaging technique, captures data rich in geometric and appearance information. However, it has traditionally been limited to relighting. We demonstrate RTI's expanded potential through analysis of the Oseberg textiles, degraded and fragmented archaeological artifacts that present analysis challenges under conventional imaging methods. We present feature maps by applying statistical and geometric analysis to RTI data and a visualization tool. The computational analysis of RTI data can reveal textile characteristics that remain obscured under traditional photography.

## 1 Introduction

RTI is a 2.5D imaging modality that offers richer geometric and appearance information than colour photography while being less expensive and complex than 3D imaging. Photography is the transformation of a 3D world into a 2D plane, which loses absolute depth and geometry information. Surface texture and material properties like reflectance behaviour, gloss, roughness, etc, are also challenging to model accurately in photography. RTI, although based on multi-light image collection of 2D images, addresses these issues in a better and effective way.

In this paper, we use RTI data to analyze Oseberg textiles. These textiles were excavated from the Oseberg mound, located on the west side of the Oslo Fjord and about 95 km south of Oslo, Norway [1, 2]. They are highly degraded and fragmented textiles, which makes it challenging to analyze them and interpret their motifs.

## 2 Related Work

RTI has been used primarily for visualization, documentation and investigating artifacts [3, 4, 5] in CH. Siatou et al. [6] and Nurit et al. [7] proposed the idea of RTI data analysis to monitor changes in CH artifacts. RTI has also been used for inspection in engineering surfaces [8, 9], for detection and analysis of visual anomalies on surfaces [10].

There have been some works to understand the Oseberg textiles to gain insights into Viking society and culture from the perspective of historians [11, 12, 13, 14, 15]. Research suggests that these textiles consist of woollen tapestry and plant fibres, although the plant fibres have largely decomposed [16]. RTI can be instrumental in the context of investigation by enhancing the visibility of surface details on highly

symbolic Oseberg textile fragments. Different modalities of imaging have been used to document and analyze them. Gigilashvili et al. [17, 18] used 2D colour images to enhance the visualization by classical image processing algorithms and addressed the virtual reconstruction. Righetto et al. [19] tested their neural-based RTI relighting algorithm to visualize Oseberg textiles. However, they did not do any RTI data analysis for Oseberg textiles. Based on the mentioned works, we see a research gap in exploiting RTI for a better understanding of Oseberg textiles. We address this gap by introducing an integrated RTI analysis framework that goes beyond relighting and enables statistical, geometric, and machine learning-based RTI analysis for cultural heritage textiles. Technical features, such as thread count, spinning and twisting direction, and weaving pattern, that human experts rely on for their analyses [20], can be better visualized and extracted from the RTI data, which will facilitate textile documentation and analysis

### 3 Methodology

The setup of RTI consists of 3 parts (camera, object, light source). The camera and object are fixed while the illumination direction changes during the entire acquisition of the RTI dataset. The Oseberg textile collection contains many fragments, out of which some are highly degraded, without discernible motifs. Therefore, to demonstrate the effectiveness of RTI in textile analyses as a proof of concept, we picked a fragment named 1D (TexRec naming criteria) that still enables us to discern patterns and motifs to a certain extent. The dataset of 50 images (JPEG format,  $6240 \times 4160$ ) was captured using RTI dome and Fujifilm X-T4 digital camera.

#### 3.1 RTI Data Analysis

The first type of data analysis carried out is the statistical data analysis of RTI data. The second type of data analysis is geometric analysis. This includes estimating the normal maps and derivative maps. This work is built on literature and methods proposed from [21, 7, 5]. The theory and necessary background of statistical and geometric feature maps are explained in the supplementary material. The details about these RTI analysis methods and their significance are explained in the following subsections.

*3.1.1 Statistical Analysis* The statistical analysis of RTI data can give us valuable information about the surface, material, and geometry. We create feature maps from this statistical analysis, which can help us interpret the textiles better. Some of these feature maps are max map, min map, median map, mean map, standard deviation map, and skewness map. This work is built on literature from [7, 5].

*3.1.2 Geometric Analysis* Geometric analysis helps us understand the shape and texture of surfaces in images. One of the most important geometric features map that can be estimated from RTI data is the normal map. Normal map determines the orientation of the surface at each point by estimating surface normals from reflectance variations under different lighting conditions using the Lambertian reflectance model, as explained in the supplementary material. Further analysis of normal maps can give directional derivatives that can help us understand surface geometry changes along various axes, revealing slopes and feature orientations. Second-order derivatives (curvature maps) provide insights into surface curvatures. Principal curvatures, calculated from the eigenvalues of the Hessian matrix, classify surface shapes as convex, concave, flat, or saddle-shaped. Additional metrics like mean curvature (average bending), Gaussian curvature (intrinsic shape property), and melhum curvature (orientation-independent feature detection) further characterize the surface geometry in detail. This work is based on the literature from [7, 5].

*3.1.3 Classification of Reflectance response* The classification of reflectance response can help understand the thread structure in the textiles better. This classification work is built on [21]. The illumination variation data is classified according to their similar signal and are clustered together. This algorithm uses Self Organizing Map (SOM) neural networks [22]. Self-Organizing Maps (SOMs) are unsupervised neural networks that transform complex, high-dimensional data into simplified, grid-based representations while preserving the topological relationships between input patterns [23]. The classification methodology is shown in Figure 1. Signals with similar behaviour were clustered together as one class. This helps us understand various textile features in Oseberg textiles, like weaving patterns, geometry, differences in weaving at different places, etc. The results of classification results are shown in section 4.

### 4 Results

The analysis of the Oseberg textile fragments using RTI data yields multiple perspectives on their surface characteristics. The following sections discuss the results of statistical and geometrical analysis. A

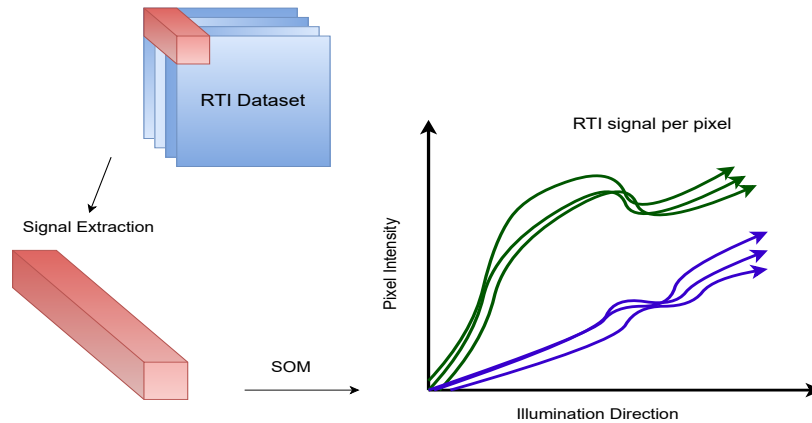


Figure 1: Workflow for classification of RTI data. These signals extracted from the region of interest (ROI) of RTI dataset are processed through a Self-Organizing Map (SOM), which clusters signals with similar reflectance behaviour. The resulting classification shows how different surface materials or properties (here, for instance, two classes: green and purple) exhibit distinct RTI signal patterns when plotted against illumination direction, enabling characterization of surface features.

visualization tool is also developed for an interactive investigation of the surface using these maps, which is explained in section 4.4.

#### 4.1 Statistical Analysis

The feature maps from statistical analysis of RTI offer a better understanding of degraded regions, amplify visualization of subtle colors and intricate properties of the material or geometry, as shown in Figure 2. Skewness (Figure 3), further analyze RTI data for material properties, and enable differentiation between matte and reflective surface areas.

#### 4.2 Classification of reflectance response

Classifying the reflectance responses aids in understanding the thread structure, weaving pattern, and identify materials, and investigating geometric and appearance features of the textiles. Figure 4 shows one such example of classifying reflectance response on a representative fragment.

#### 4.3 Geometric Analysis

Our geometric analysis utilizes normal maps and their derivatives to understand surface characteristics. The process of extracting normal maps from the RTI dataset is explained in the supplementary material. From these normal maps, we compute various differential geometric properties, including directional derivatives and curvature measurements. Figure 5 illustrates these derived geometric maps for a representative textile fragment, which can be useful in understanding the thread structure, weaving patterns, and can intuitively visualize geometric structure.

#### 4.4 Visualization Tool

These maps provide valuable insights into surface characteristics and material properties, which would be very useful if there were a visualization tool to visualize these maps with a click of the mouse and investigate the surface. We have created a Graphical User Interface (GUI) on MATLAB, which is an application by itself and is provided in the supplementary material. Figure 6 demonstrates the GUI.

The interface consists of two main visualization panels: the left panel displays the feature maps computed from the RTI dataset, while the right panel shows the RTI dataset for comparison. A slider at the top of the interface allows users to navigate through the RTI dataset, displaying different illumination directions. The 'Load LP' button enables loading of the Light Position (LP) file along with the RTI dataset. The 'Analyze RTI data' button triggers the statistical and geometric analysis of the dataset, with results viewable through a dropdown menu labeled 'Analysis Maps'. This interface provides cultural heritage professionals with an intuitive tool for examining multiple aspects of the RTI data simultaneously.

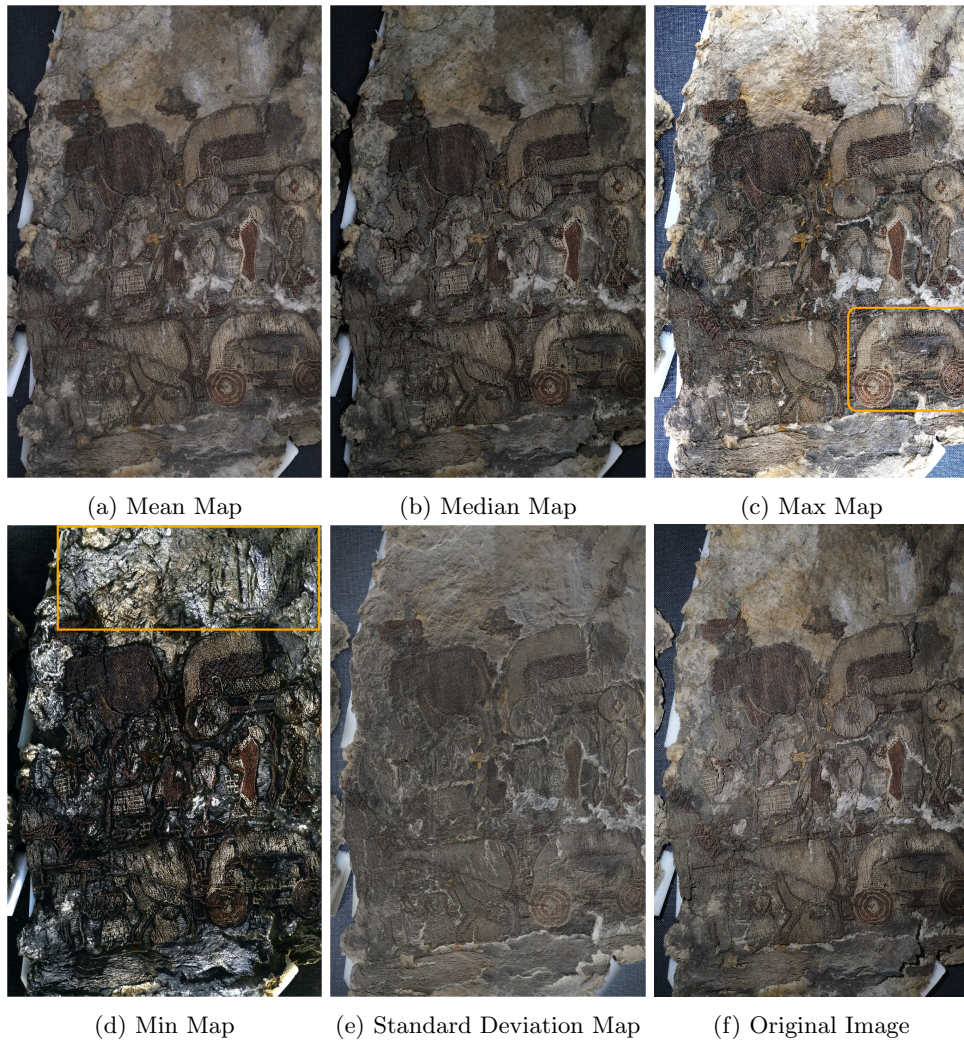


Figure 2: Feature maps from statistical analysis of RTI data for representative fragment. Each feature map highlights the appearance and geometric properties of the surface. Min map highlights the degraded regions. The max map enhances the dull colours of the surface. Mean and median maps represent the central tendency of pixel intensities across the RTI dataset, offering a balanced view of the surface characteristics, making subtle features more apparent. The standard deviation map is effective at identifying regions of high variability in surface response to different lighting directions, which can indicate changes in material composition, surface texture, or geometric features. For example, degraded regions tend to have higher standard deviation in this fragment.

## 5 Conclusion

The statistical and geometric analysis of RTI data revealed surface details in the Oseberg textiles that are not apparent in standard photography (Figure 2,3 & 5). The mean and median maps show better quality images for perception. Standard deviation maps effectively differentiated regions with varying surface and geometric properties, while skewness maps identified areas with distinct reflectance behaviors. The min map was useful in enhancing surface features of the degraded regions in the textiles. The classification algorithm provided insights into thread structure and weaving patterns. The geometric maps also provide good insight for understanding the thread and weaving structure of textiles by utilizing directional derivatives. This work offers an opportunity for archaeologists to investigate artifacts using RTI data other than the relighting visual experience.

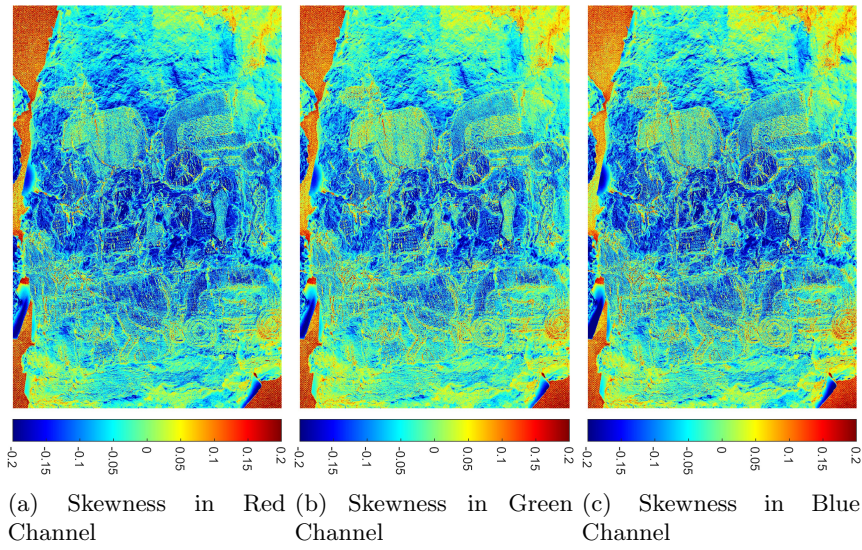


Figure 3: Skewness maps of RTI data for a representative textile fragment. Areas with skewness indicate asymmetry in the reflectance response, which helps differentiate matte regions from glossier ones. This differentiation can help identify material variations and potential zones of degradation on the textile surface. In the maps, blue regions correspond to glossier surfaces, while red regions indicate matte areas.

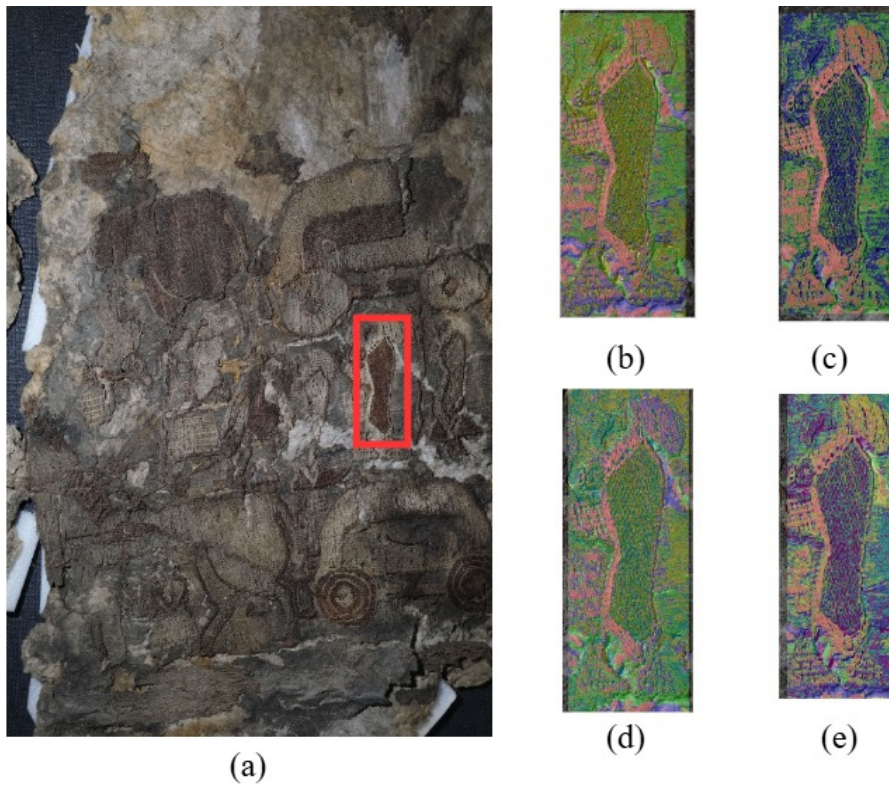


Figure 4: (a) Representative Fragment illustrating a ceremonial procession featuring human and animal figures moving toward the left [12]. A red rectangle highlighting a human figure was selected for classification analysis. The right panels (b-e) show classification results with different numbers of classes, where classified pixels are masked according to their class: red (1), green (2), blue (3), yellow (4), cyan(5), and magenta(6). (b) 3 Classes (c) 4 Classes (d) 5 Classes (e) 6 Classes

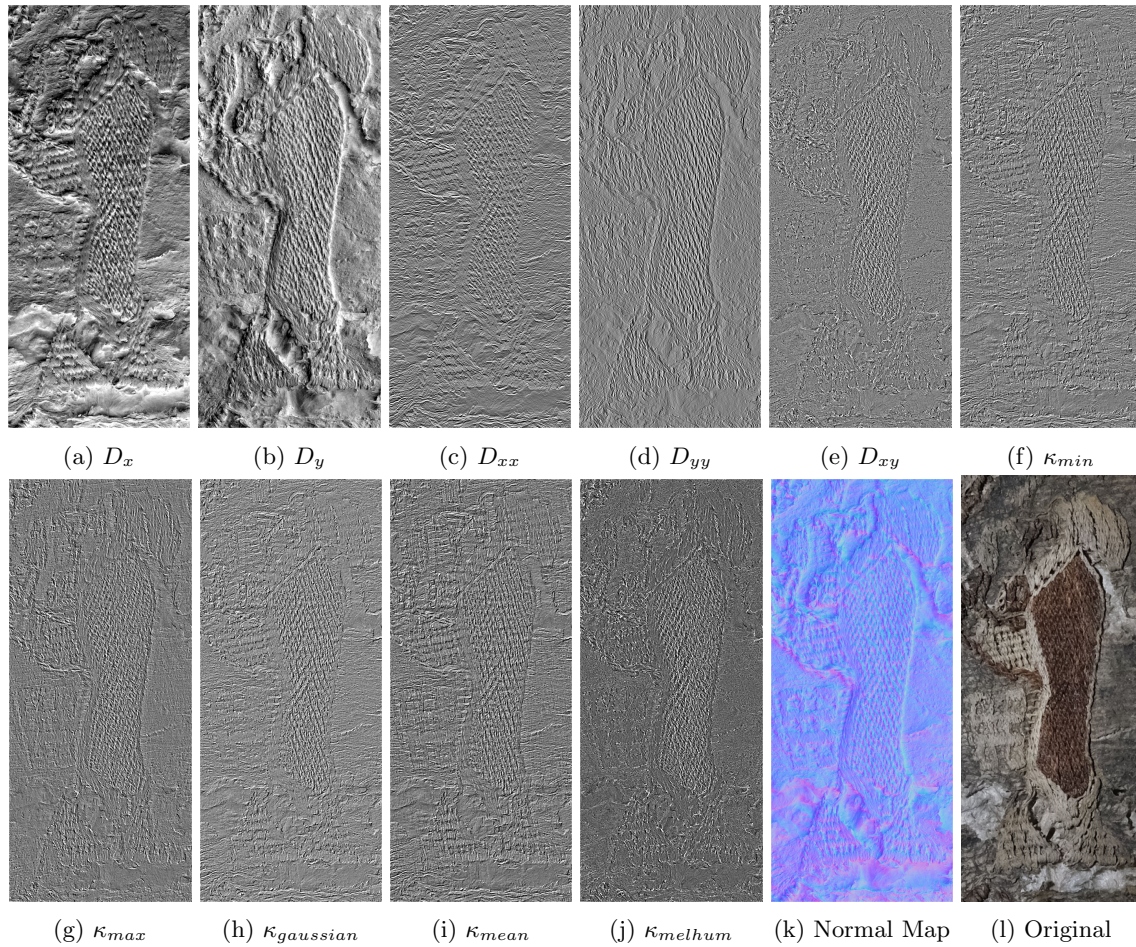


Figure 5:  $D_x$ ,  $D_y$ ,  $D_{xx}$  and  $D_{yy}$  are directional slopes and double directional derivative signifying directional sensitivities in surface.  $D_{xy}$  is directional sensitivity in xy direction ( $45^\circ$ ). The principal curvatures,  $\kappa_{min}$  and  $\kappa_{max}$ , represent surface convex curvature and concave curvature. Average principal curvatures,  $\kappa_\mu$ , signify bending in the surface.  $\kappa_{gaussian}$  is product of principal curvatures.  $\kappa_{melhum}$  indicates surface features independent of orientation. They all signify the thread structure, weaving pattern, and its directional sensitivities, which is important in understanding textiles.

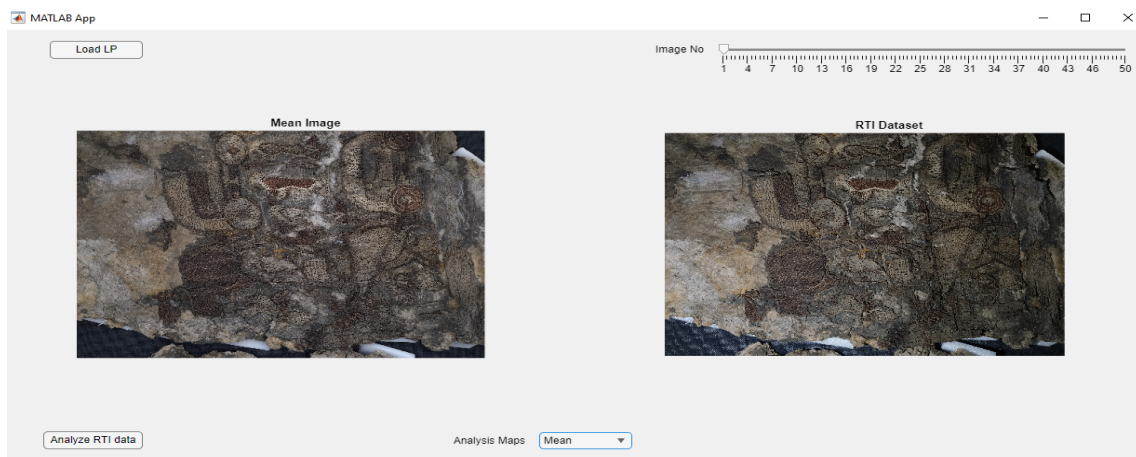


Figure 6: Interactive visualization interface for RTI feature map analysis developed to enable cultural heritage professionals to explore and examine multiple feature maps simultaneously.

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### **Online Resources**

The code and supplementary materials for this project are available in the [GitHub repository](#).