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Ancient Purépecha petroglyphs analysis using contextual shape descriptor

Análisis de petroglifos purépechas antiguos mediante un descriptor contextual de formas

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Abstract

This article introduces an innovative approach to analyzing Purépecha petroglyphs through interdisciplinary collaboration between computer vision and archaeology. The research addresses the practical needs of archaeologists and scholars who require critical support for searching and recovering collections of ancient Purépecha images. The paper begins by providing an overview of the interdisciplinary approach aimed at enhancing the documentation, analysis, and preservation of Purépecha pictographic data. Subsequently, it presents an objective evaluation of the contextual descriptor's performance in image retrieval tasks, utilizing a set of 14 images featuring Purépecha petroglyphs. In summary, the proposed approach shows promise by enhancing performance in retrieval tasks and can be validated from an epigraphic perspective, offering the potential for novel insights in archaeology and practical solutions for academia.

Cultural heritage, Purépecha empire, Image recovery, Shape descriptor, Archeology, Epigraphy

Resumen

Este artículo presenta un enfoque innovador para analizar petroglifos purépechas mediante la colaboración interdisciplinaria entre la visión por computadora y la arqueología. La investigación aborda las necesidades prácticas de arqueólogos y académicos que requieren apoyo crítico para la búsqueda y recuperación de colecciones de imágenes antiguas Purépecha. El artículo comienza proporcionando una visión general del enfoque interdisciplinario dirigido a mejorar la documentación, análisis y preservación de los datos pictográficos Purépecha. Posteriormente, se presenta una evaluación objetiva del desempeño del descriptor contextual en tareas de recuperación de imágenes, utilizando un conjunto de 14 imágenes con petroglifos purépechas. En resumen, el enfoque propuesto se muestra prometedor al mejorar el desempeño en tareas de recuperación y puede ser validado desde una perspectiva epigráfica, ofreciendo el potencial para nuevas perspectivas en arqueología y soluciones prácticas para la academia.

Patrimonio cultural, Imperio purépecha, Recuperación de imágenes, Descriptor de forma, Arqueología, Epigrafía

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Introduction

The examination of profoundly significant historical materials through the application of digital technologies constitutes a highly relevant and interdisciplinary field of study with profound implications for society at large. (Vicent & Torruella, 2015). Incorporating automatic and semi-automatic visual recognition algorithms into search and exploration tools has the potential to significantly streamline the daily tasks of scholars in the humanities and arts. This includes professionals such as historians, archaeologists, anthropologists, linguists, conservators, and photographers, who frequently engage in tasks such as consulting, annotating, and cataloging visual documents or captured images. Moreover, the application of computer vision algorithms holds the promise of generating new knowledge by identifying and uncovering patterns and connections within and between elements of a digital collection. This, in turn, enriches existing theories within humanistic disciplines. (Brarda, 2018). Ultimately, the integration of visual search and navigation has the potential to cultivate educational systems that offer value to both experts and the public alike.

The Purépecha Empire, also known as the Kingdom of the Purépechas or Tarascos, was an ancient pre-Columbian civilization that flourished in what is now the Mexican state of Michoacán, as well as in some regions of the surrounding states (Carot, 2008). Its heyday took place during the Late Postclassic, approximately between the 12th and 16th centuries AD. The petroglyphs, on the other hand, are an important aspect of the artistic and cultural legacy of the Purépecha. These are inscriptions or engravings made on rocks, particularly at the archaeological site of Tzintzuntzan, which was the capital of the Purépecha Empire. (Hernández Díaz, 2011). Purépecha petroglyphs include symbols, human figures, animals, and decorative elements, and offer valuable information about the cosmology, religion, and daily life of this civilization. These stone-engraved representations have been instrumental to archaeologists and scholars in their understanding of Purépecha culture and history.

This article encompasses two primary contributions. Firstly, it outlines an interdisciplinary approach aimed at developing automated techniques to address a series of challenges related to the analysis, documentation, and preservation of Purépecha pictographic data. Notably, these tasks have not been previously undertaken and involve the integration of computer vision and archaeology. Secondly, the article delves into the analysis of the Contextual Shape Descriptor (CSD), a shape descriptor that has demonstrated successful applications in image processing and computer vision. Grounded in the representation of spatial information pertaining to contour points in digital images, the CSD measures the distribution of contour points around each reference point in a shape.

Our proposed method undergoes evaluation within the realm of automatically analyzing Purépecha petroglyphs, a significant aspect of ancient rock art. The Contextual Shape Descriptor (CSD) emerges as a promising methodology for tackling the intricacies of petroglyphs, characterized by their challenging nature—whether as painted remnants or engravings on rocks—owing to the complexity and diverse range of pictorial content. Moreover, the method demonstrates its efficacy by producing a more robust and computationally efficient representation of the engraving shapes.

Historical framework of the Tarasco-Purépecha people

The Purépecha empire was consolidated between the 15th and 16th centuries AD. as part of the strong cultural groups of ancient Mexico, in its postclassical phase; This society also developed with outstanding resistance to the Mexica empire of the central Mexican highlands, thus achieving its territorial autonomy. Within the Purépecha worldview, there is the way in which they perceive the occupation of their territory, and how this influences their religious conception, as Father Francisco Ramírez explains in his work "*Relación sobre la residencia de Michoacán"*, in the words of Vargas Uribe (2018, pp. 112-113) and "*Monumenta Mexicana"* (1959) at Le Clezio (1986), the division of the territory has been determined into "right hand" and "left hand", and supported by the myth of the creation of the quadripartite world.

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The Purépecha empire had its last administrative capital in the settlement called Tzintzuntzan next to the great lake of Pátzcuaro, being a settlement built with large terraces and large platforms that were accommodated on the slopes of the Yarahuato and Tariacueri hills, identifying ritual spaces arranged in plazas and in the pyramidal basements called yácatas (Mediateca INAH, 2023); the five existing yácatas have a mixed T-shaped plan, alluding to what was mentioned with the goddess of the earth, whose orientation in the ceremonial complex seems to be an anthropomorphic body whose head points to the west, and its extremities (the arms) towards the north and the south, Punzo (2018, pp. 136) cited by Martínez Vázquez, Punzo Diáz, & Valdés Herrera (2020, pp. 20). Of the materials used in the pyramids, a study carried out by Hernández Díaz (2006, pp. 197) in 2000, records and confirms the presence of engraved or bas-relief slabs, most of them geometric called janamus -in Purépecha-, polished basalt stones cut with precision at right angles and rectangular shapes, whose average measurements are 45x32 centimeters and a thickness of 15, currently visible as a covering of isolated pieces, on the walls of the yácatas and the former Franciscan convent in the town; being then, the janamus from the historical point of view for the former convent, a reuse material ratified by López García (2013, pp. 114). Certain janamus referred to in this study are located in the former convent, whose ornamentation can be varied, with a single motif, simple or elaborate, and others with separate designs, mostly abstract, in basic categories: spiral, circle, elongated wavy lines , reticulated, geometric-figurative (flower, star) and anthropomorphic (Hernández Díaz, 2006, pp. 204-205); from what is perceived in the lithic engravings, a synthetic association of the worldview with its natural territorial environment. These engravings or stone inscriptions made by the ancient Purépecha civilization, in what is now the Mexican state of Michoacán (Morales, 2016). Figure 1 shows some Purépecha engravings used in the proposed method.

Figure 1 Purépecha Petroglyphs - A significant testament to the culturally rich heritage of this pre-Columbian civilization

The aim of this project is to apply computer vision technology to aid in deciphering Purépecha petroglyphs. Through the fusion of technological and cultural heritage studies, the anticipated outcome is the development of a diverse set of research tools specifically crafted to address distinct archaeological tasks. (Robles Ruiz). Among these valuable tools, a crucial aspect would be addressing one of the primary needs in contemporary decipherment: the creation of a catalog featuring refined and regularly updated petroglyphs. This catalog should have the flexibility to incorporate contributions from multiple scholars actively engaged in deciphering these engravings.

Methodology

The current study comprises 14 images of Purépecha petroglyphs captured in Tzintzuntzan, Michoacán. The accurate delineation of image contours is crucial, yet certain engravings show signs of erosion over time, while others exhibit less distinct shapes. Therefore, an image processing phase has been implemented to enhance these characteristics. The goal is to enable the Contextual Shape Descriptor (CSD) to swiftly, precisely, and definitively identify edges and contours (Tepper, 2011). This procedure entails the application of two stages of digital filtering, aimed at enhancing the image's characteristics and detecting its contours. The initial stage involves the application of edge detection filters to amplify contours and enhance overall image quality. Figure 2 provides a visual representation of the various filtering techniques applied to the original image, contributing to the enhanced identification of the engraving (Oltra & Mellado, 2008).

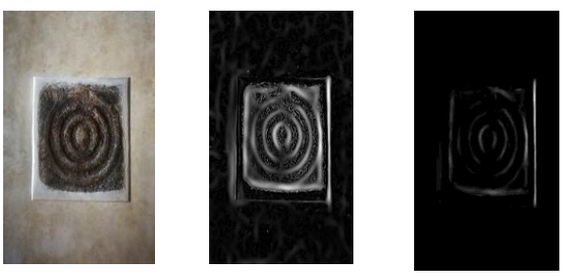

Figure 2 Filters Applied for enhanced contour detection in the original Image. Utilizing Meijering filter (middle image) and Frangi filter (right image)

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The second processing phase focuses on refining the morphological attributes of the image. To achieve this, morphological filters are applied to minimize the binary noise in the images and fine-tune their structures for improved clarity. Morphological filters, recognized operators in image processing and mathematical morphology, play a key role in this aspect (Ruiz Fernández, 2020). These techniques are grounded in mathematical set theory and are employed for manipulating and analyzing the structure and shape of objects in binary images, where the objects of interest are depicted in white against a black background. Figure 3 illustrates the morphological filters utilized in conjunction with the filters presented in Figure 2.

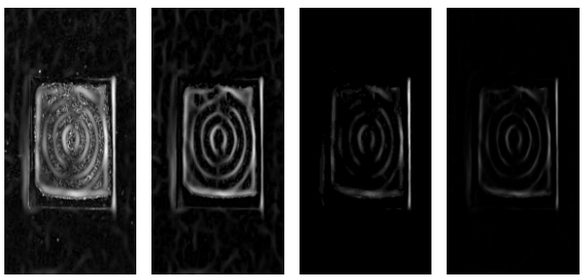

Figure 3 Morphological Filters - Utilizing dilation and erosion for denoising, feature extraction, and shape analysis. (First two) Meijering filter with the morphological filter's dilation and erosion, respectively. Frangi filter (last two) with the morphological filter's dilation and erosion, respectively

Contextual shape descriptor

This algorithm, developed by Serge Belongie and Jitendra Malik in 2000, is employed to describe and compare shapes in digital images (Belongie, Malik, & Puzicha, 2000). It has played a pivotal role in computer vision, finding applications in fields such as object detection, image retrieval, and object identification within intricate environments. Overcoming limitations in geometry-based shape matching, it facilitates more robust correspondences between shapes in images. CSD takes as input a finite set of n $2-D$ points, representing the contours of a given shape, and describes it as a set of n histograms. More precisely, for each point p_i of the shape P, its histogram sc_i^P, called the shape context descriptor, is calculated as the distribution of the relative position of the $n-1$ points with respect to p_i. In other words, the k-th entry $sc_i^P(k)$ of sc_i^P is defined as (Belongie, Malik, Puzicha, & intelligence, 2002):

$$sc_i^P(k) = \frac{\left|P_i^k\right|}{|P|-1}, \qquad k = 1, \dots, K. \qquad (1)$$

Where $|.|$ denotes the set cardinality, $\boldsymbol{K}$ is the number of bins in $\boldsymbol{sc_i^P}$ y $\boldsymbol{P_i^k}$ denotes the set of points of $\boldsymbol{P}$ that fall in the spatial bin $\boldsymbol{k}$ with respect to the point $\boldsymbol{p_i}$:

$$p_i^k = \{p_j \in P : p_j \neq p_i, (p_j - p_i) \in bin\,(k)\} \qquad (2)$$

Where $\boldsymbol{p_j - p_i}$ is a vector difference. This histogram is calculated in 5 normalized distance intervals that in total cover twice the average pairwise distance of all points in the image, and 12 angular intervals that cover a complete perimeter around the reference point. This Results in a histogram of $\boldsymbol{K = 60}$ bins, which are uniform in polar space, making the descriptor more sensitive to nearby points than to farther ones. The construction process of the CSD is illustrated in Figure 4.

Figure 4 Shape context process for description and coincidence of two Mayan glyphs
Source: (Roman-Rangel, Pallan, Odobez, & Gatica-Perez, 2009)

Results

In the initial phase of our experiments, we conducted an analysis to assess how effectively the contours of Purépecha petroglyphs were portrayed when compared to Mayan glyphs at various sampling rates (K). We attempted to depict the contours using 2%, 3%, 5%, 10%, and 15% of the original shapes' point count. It was observed that proportions less than 5% resulted in many Mayan glyphs being represented with fewer than 100 points, leading to relatively inadequate depictions. Conversely, percentages of 10% and higher produced robust representations but also contributed to a slower CSD. Empirically, a 5% sampling rate strikes a good balance between accurate representation and computational efficiency. Consequently, for the experiments, we opted for sampling rates of 5% and 10%, setting a minimum limit of 100 points (i.e., $n = \max(100, 5\%)$ y $n = \max(100, 10\%)$.). Figure 5 visually depicts the model constructed with Mayan glyphs.

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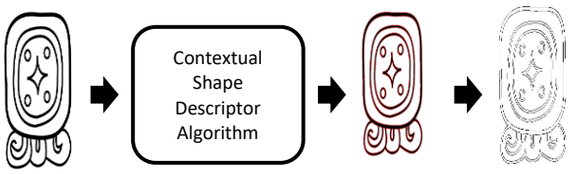

Figure 5 Proposed Model showcasing the outcomes of the curve recovery process applied to the detected contours of Mayan glyphs. (From left to right) The original image undergoes the CSD algorithm, identifying the image contours; the resulting output image displays the contours previously detected by the algorithm, facilitating the recovery of the original image.

The model was employed on a series of images featuring Purépecha petroglyphs. Through the application of morphological filters to the original images, results are obtained that reveal effects not discernible to the naked eye. The identified shapes are elaborated upon in Figure 6.

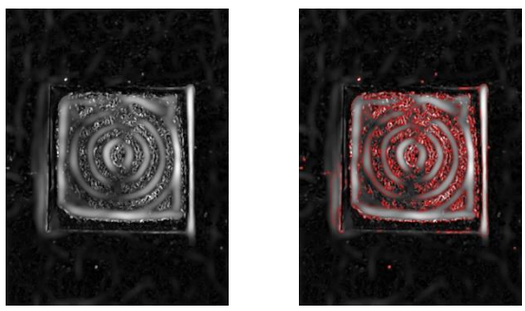

Figure 6 Application of morphological filters to the original image that show patterns that are not observed in simple view of the original image, such as concentric circles, but in the filtering process they are observed as "C" forming the circle.

In general, with all filters, the following Results are obtained:

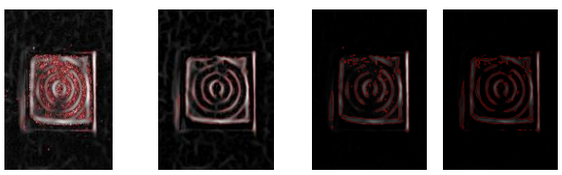

Figure 7 Implementation of the model with CSD for contour detection in Purépecha petroglyph images. (First two) Detected contours using the Meijering filter and morphological dilation and erosion filters, respectively. (Last two) Detected contours using the Frangi filter and dilation and erosion morphological filters, respectively.

The results obtained from the application of the CSD algorithm to Purépecha petroglyph images are promising, underscoring the efficacy of the technique.

The amalgamation of preprocessing methods, including Meijering and Frangi filters, has proven successful in enhancing image edges, a crucial aspect for emphasizing key features in petroglyphs. Additionally, the deployment of morphological erosion and dilation filters has played a significant role in noise reduction and the enhancement of detected contour quality. The capability to accurately detect contours in the images is a noteworthy achievement, suggesting that the employed method effectively captures the shapes and intricate details present in the petroglyphs. These findings hold considerable importance for the preservation and study of Purépecha culture, as the details within petroglyphs often contain valuable insights into their history and cultural practices.

This work represents a step toward integrating computer vision techniques into the analysis of ancient Purépecha cultural heritage materials. Our approach addresses genuine needs and open problems in archaeology and epigraphy, fostering interdisciplinary collaboration between archaeology, epigraphy, and computer science. Future research will focus on evaluating the robustness and stability of this approach under diverse conditions, such as variations in illumination and image quality. Additionally, collaboration with experts in Purépecha culture will be sought for a more precise cultural interpretation of the detected petroglyphs and the creation of an interpretative database. In essence, this study presents a promising avenue for the preservation and analysis of Purépecha culture through the application of image processing technology.

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