Functional Algorithm Model Mumford-Shah for Facial Recognition and Image Segmentation in Low Light Conditions, Lima 2023

Paulo Sergio Jair Cano-Sampén[1], Edwin Baldeon-Mateo[1], Neicer Campos-Vásquez[1,2], Ruben Kevin Manturano Chipana[1,2]

[1]Universidad Privada del Norte, Facultad de Ingeniería, Perú
[2]Grupo de Investigación Desarrollo e Innovación UPN -IDIUPN
Email: N00171263@upn.pe

Due to the technological advances of the past 10 years, which have ushered in the 4th Industrial Revolution, one of the most significant developments is emerging technologies. We will focus on facial recognition and, together with the Mumford-Shah functional model and its algorithmic method for image segmentation, address the issues currently faced by the city of Lima due to the high crime rate in various districts of the capital. The Mumford-Shah algorithm is used for the segmentation and reconstruction of images with low visibility, testing the efficiency of this functional model. Its main objective is to smooth, segment, and recognize the edges of an image to detect features and details that can aid in facial recognition and image reconstruction in the city of Lima, focusing on the current crime situation.

Keywords: Artificial Intelligence, Facial Recognition, Emerging Technologies, Mumford-Shah Algorithm.

1. Introduction

The rapid advancements in technology over the past 10 years have ushered in the Fourth Industrial Revolution, bringing with it a strong presence of fully digitized and automated work, tasks, and processes, including machine learning, big data, internet-connected accessories, and most importantly, emerging technologies for the development of innovative work, increasing speed, efficiency, and consequently, productivity. Emerging technologies have various uses and applications, the most developed of which currently include virtual reality, augmented reality, intelligent processes, artificial intelligence, and robots [1].

The development of these emerging technologies brings a wide range of benefits, providing

multifaceted solutions to problems that people could not solve immediately [2]. This is why the development of emerging technologies has led to the use and improvement of facial recognition and image segmentation due to the ease of collecting information, processing it, analyzing it, and generating large-scale results that are highly useful in various fields [3]. Finally, thanks to technological advancements, we have developed the ability to recognize basic forms of human expressions [4].

The development of algorithmic processes is present throughout our lives in all areas, helping and guiding us to make decisions from the most difficult to the easiest. Algorithms are digitally constituted and culturally functional, meaning they can perform and solve different types of operations, which are highly associated with technology by reconstructing a series of steps to accomplish a task [5].

Therefore, thanks to technological advancements and the functionality of algorithms, it is proposed to investigate the relationship between the Mumford-Shah functional algorithmic model and artificial intelligence for facial recognition and image segmentation. The Mumford-Shah algorithm is a functional model used to segment images into subregions, modeling the image as a piecewise smooth function. By minimizing the functional, an optimal image can be computed. This functional was proposed by mathematicians David Mumford and Jayant Shah [6]. The Mumford-Shah functional is mathematically defined as follows..

$$E(f,\Gamma) = \nu \int_{\Omega\setminus\Gamma} (f-g)^2 + \lambda \int_{\Omega\setminus\Gamma} |\nabla f|^2 + \mu.|\Gamma| \quad \text{Formule 1. Mumford Shah}$$

These two scientists indicate that "Ω" is the domain and "G" is the original image taken for grayscale work. "Γ" represents the set of edges of the image, while "F" is the representation of the smoothed but discontinuous figure along the perimeter of the image "Γ". |Γ| denotes the edges or the set of edges, and finally, ν, λ, and μ are the weights applied according to the desired strength for each of the terms mentioned above, which will depend on the intended application of the functional. This functional algorithm consists of three terms:

Fidelity level term

$\int_{\Omega\setminus\Gamma} |\nabla f|^2$ Smoothness level term

$\int_{\Omega\setminus\Gamma} (f \ |\Gamma|')^2$; Edge Length Term

Mumford-Shah offers this alternative for the case of multiple regions where there are an infinite number of zero-level sets, where the framework of the level sets can be replaced by graphical or convex relaxation algorithms. These methods can find good solutions concerning the curve evolution, even finding a global optimal solution for two or more regions [7].

The study and application of this Mumford-Shah algorithmic method, combined with current technology, would benefit all fields of research, both studied and to be studied. Therefore, the

primary objective of this work is to understand the influence of this algorithmic method applied to our society. Below, we present an image with segmentation, applying the Mumford-Shah functional algorithm, which could be optimally used for facial and image recognition in low-light conditions, focusing on public safety in Lima, 2023.

Fig 1. Student Edwin Baldeon Mateo of the UPN

Fig. 2. Avenue Jr. Sicuani - San Juan de Lurigancho

Fig. 3. San Juan de Lurigancho - citizen immobilization due to high crime, extortion and hired assassination rates, September 2023

There are various methods for image recognition and segmentation, which can be used in different industrial sectors. For example, the Canny operator, when combined with the Watershed segmentation algorithm, is used in the agricultural sector for the segmentation, registration, and delimitation of agricultural fields, playing a vital role in food security [8]. Similarly, the 3D Chan-Vese model, a hybrid model, is used for multiple organ segmentation in the medical sector [9]. The Chan-Vese model, which is based on the Markov chain, is also

an excellent tool for precise image segmentation in medical research. However, there are many efficient methods like the Mumford-Shah functional algorithm that are excellent for image segmentation and reconstruction [10].

Given the points mentioned above, the following research question is proposed: How effective would it be to implement the Mumford-Shah functional algorithm for facial recognition and image segmentation in the city of Lima? The answer will be addressed in the results section.

The Mumford-Shah functional algorithm was selected because it has the unique ability to recreate objects in spatial dimensions using the information collected from each image, making it more effective when reconstructing images, especially in low-light conditions.

2. Methodology

The research conducted is based on scientific articles selected and reviewed through a systematic review, carried out meticulously and thoroughly to ensure the accuracy of the work. The systematic review was conducted using various information meta-search engines such as IEEE Xplore, ScienceDirect, Scopus, and ProQuest, focusing on recent years to address the proposed research question.

The search in these meta-search engines was conducted using the following keywords: Artificial Intelligence, Facial Recognition, Emerging Technologies, Mumford-Shah Algorithm. After applying restrictions such as keywords, time intervals, and publication languages (English and Spanish), the following results were determined, ensuring the accuracy, quality, and reliability of the applied methodology.

Table 1. Compilation Of Keyword Information from Databases.

Nº	DATABASE	TOTAL QUANTITY	SELECTION FOR THE RESEARCH
1	Science Direct	152	1
2	IEEE Xplore	133	2
3	Scopus	180	3
4	ProQuest	891	4
	TOTAL	1356	10

As shown in Table 1, the systematic review results from the meta-search engines yielded a total of 1356 research and scientific articles related to the research keywords. ProQuest provided the most results with 891 articles, followed by Scopus with 180, ScienceDirect with 152, and IEEE Xplore with the least relevance, offering 133 scientific articles. Additionally, a filtering process was conducted for the detailed selection of scientific articles related to the research topic to address the proposed problem.

Based on the selection, 4 articles from ProQuest, 3 articles from Scopus, 2 articles from IEEE Xplore, and 1 article from ScienceDirect were chosen for this work.

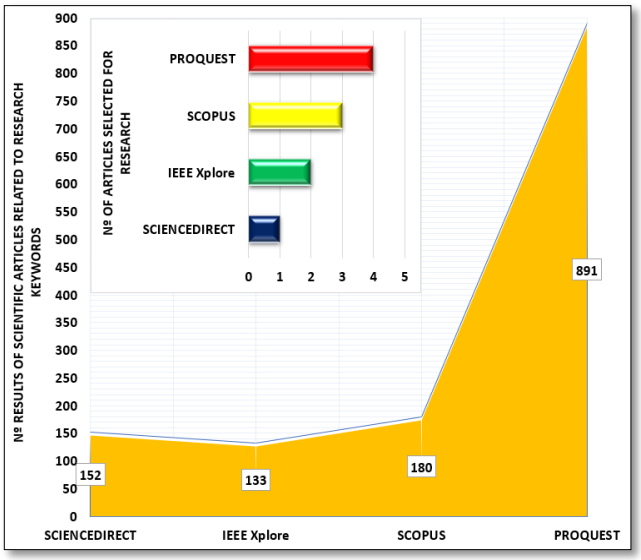


Fig. 4. Compilation of information and selection of scientific articles for research

Below are the scientific articles selected for the systematic review according to the year of publication.

Table 2. Number Of Articles By Year Of Publication.

Base Datos	2001	2009	2016	2021	2022	2023
Science Direct			1			
IEEE Xplore	1	1				
Scopus				3		
ProQuest					1	3
Total	1	1	1	3	1	3

DATABASE	2001	2009	2016	2021	2022	2023
Science Direct			1			
IEEEXplore	1	1				
Scopus				3		
ProQuest					1	3
TOTAL	1	1	1	3	1	3

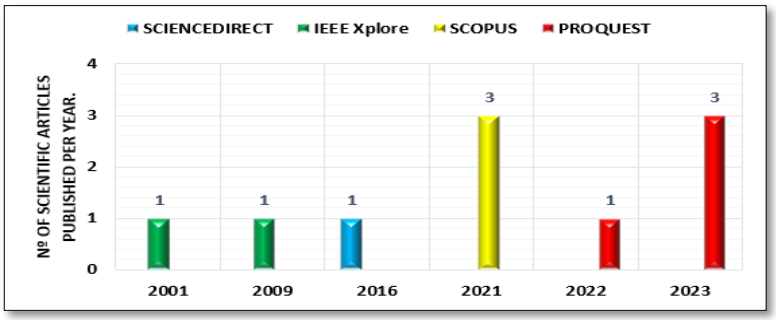


Fig. 5. Compilation of scientific articles by year of publication

Figure 5 shows the number of publications per year selected for this research. It can be seen that 4 scientific articles from the year 2023 were chosen, and for the years 2022, 2021, 2016, 2009, and 2001, one scientific article per year was selected respectively.

3. Results

The Mumford-Shah algorithm has been utilized in various research studies, with one of the most notable applications being in image segmentation. We can trace back to the approach proposed by researchers S. Geman and D. Geman, where they addressed the correct restoration of images. This is where the work of Mumford and Shah comes into play, providing a better approach to noise elimination to accurately restore the edges of an image continuously.

Assessing the complexity level of the algorithm when presenting results, we can observe the difference between the real and altered images with the Mumford-Shah algorithm function. The first image depicts the original image (G), the second image shows the constant approximation of the smoothed image (F), and the third image illustrates the parameter of edge lengths for each image "Γ." Determining the procedure for applying the Mumford-Shah algorithm to a face.

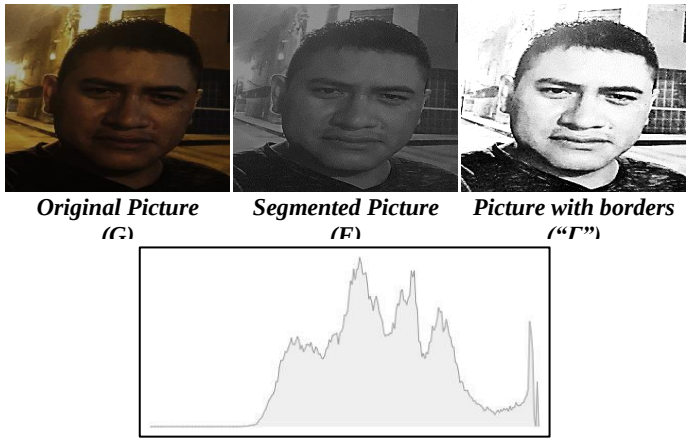
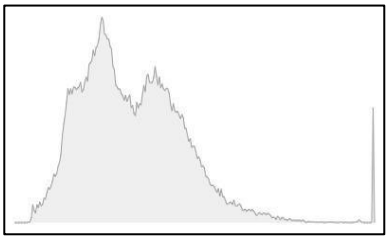


Fig. 6 Image Segmentation 1

As we can appreciate from the represented objects, the segmentation has been really good, as it can distinguish in this case the face from the background of the image, successfully separating each of the objects present, among the most prominent being the eyes, eyebrows, nose, lips, and hair.

Result of the procedure of applying the Mumford-Shah algorithm to a poorly lit avenue on Jr. Sicuani Avenue in the San Juan de Lurigancho district, with a high crime rate.

Original Picture (G) ***Segmented Picture (F)*** ***Picture with borders ("Γ")***



Histogram of Segmented Picture

Fig. 7 Image Segmentation 2

We can appreciate that the segmentation of the main components in this synthetic image successfully distinguishes its parts, among which we can highlight the sidewalks, road, lampposts, and houses. Next, in the image, we can see the procedure for discretizing the equations for the images.

$$\frac{\phi_{i,j}^{t+1}-\phi_{i,j}^{t}}{\Delta t}=\delta_{\varepsilon}(\phi_{i,j}^{t})\left[\frac{\mu_1}{h^2}\Delta_{-}^{x}\cdot\left(\frac{\Delta_{+}^{x}\phi_{i,j}^{t+1}}{\sqrt{\frac{(\Delta_{+}^{x}\phi_{i,j}^{t})^2}{h^2}+\frac{(\phi_{i,j+1}^{t}-\phi_{i,j-1}^{t})^2}{(2h)^2}}}\right)+\frac{\mu_1}{h^2}\Delta_{-}^{y}\cdot\left(\frac{\Delta_{+}^{y}\phi_{i,j}^{t+1}}{\sqrt{\frac{(\phi_{i+1,j}^{t}-\phi_{i-1,j}^{t})^2}{(2h)^2}+\frac{(\Delta_{+}^{y}\phi_{i,j}^{t})^2}{h^2}}}\right)-\left[\left(\nu_1(g-c_{11}(\phi^t,\varphi^t))^2-\nu_3(g-c_{01}(\phi^t,\varphi^t))^2\right)H(\varphi^t)+\left(\nu_2(g-c_{10}(\phi^t,\varphi^t))^2-\nu_4(g-c_{00}(\phi^t,\varphi^t))^2\right)\left(1-H(\varphi^t)\right)\right]\right]$$

$$\frac{\varphi_{i,j}^{t+1}-\varphi_{i,j}^{t}}{\Delta t}=\delta_{\varepsilon}(\varphi_{i,j}^{t})\left[\frac{\mu_2}{h^2}\Delta_{-}^{x}\cdot\left(\frac{\Delta_{+}^{x}\varphi_{i,j}^{t+1}}{\sqrt{\frac{(\Delta_{+}^{x}\varphi_{i,j}^{t})^2}{h^2}+\frac{(\varphi_{i,j+1}^{t}-\varphi_{i,j-1}^{t})^2}{(2h)^2}}}\right)+\frac{\mu_2}{h^2}\Delta_{-}^{y}\cdot\left(\frac{\Delta_{+}^{y}\varphi_{i,j}^{t+1}}{\sqrt{\frac{(\varphi_{i+1,j}^{t}-\varphi_{i-1,j}^{t})^2}{(2h)^2}+\frac{(\Delta_{+}^{y}\varphi_{i,j}^{t})^2}{h^2}}}\right)-\left[\left(\nu_1(g-c_{11}(\phi^t,\varphi^t))^2-\nu_2(g-c_{10}(\phi^t,\varphi^t))^2\right)H(\phi^t)+\left(\nu_3(g-c_{01}(\phi^t,\varphi^t))^2-\nu_4(g-c_{00}(\phi^t,\varphi^t))^2\right)\left(1-H(\phi^t)\right)\right]\right]$$

Fig. 8. Discretization of differential equations of picture

Pseudocode was proposed for image segmentation.

Algoritmo 4 Algoritmo de Segmentación Mumford-Shah
Entrada: Imagen g
Salida: Imagen segmentada f

1: **Procedimiento** SEGMENTACIÓNMUMFORDSHAH(g)
2: Inicializar ϕ_1^0 y ϕ_2^0 con la función de distancia con signo, $t = 0$
3: $anterior = 0$
4: $actual = 10000$

Fig. 9. Part of the Mumford-Shah picture segmentation pseudocode

In research applications where the Mumford-Shah functional algorithm has been used, there has been a positive influence, optimizing the separation of the most prominent objects provided by the main object and the background of the original image. On one hand, the efficiency of this functional model is acceptable, as evidenced by the frontal facial image where the most significant dimensions such as the eyes, eyebrows, nose, lips, and hair were determined and preserved, resulting in a synthetic image simpler than the original one optimally.

On the other hand, the efficiency in the original image of Jr. Sicuani Avenue is acceptable as it manages to preserve and visualize optimally the most prominent dimensions and features such as sidewalks, road, lampposts, and houses. Finally, the efficiency of this Mumford-Shah functional algorithm model has influenced and optimally improved image segmentation and recreation in a homogeneous and suitable manner in the various research studies where it has been applied.

4. Conclusions

This research achieves several very useful outcomes regarding image processing, the ability to detect a geometric figure in motion and relate it to another in order to obtain its position within the plane and determine its direction or angle individually. An initiative worth considering and leveraging is real-time facial recognition and segmentation. All the research will be channeled into the workforce, serving as experience towards solving real problems, estimating goals better, considering setbacks, and minimizing errors for continuous improvement despite everything, being consistent and persistent in the work.

As we observed in the results, the proposed method based on the one-dimensional Mumford Shah algorithm is capable of segmenting images in two dimensions by decomposing the image into lines of pixels. Moreover, the method is capable of obtaining the corresponding approximate image, which has been smoothed in such a way that it somewhat resembles a caricature, as expected.

In comparison to other image segmentation methods such as Canny and Chan-Vese, it was observed that while similar results are obtained in edge detection and image smoothing, the Mumford Shah functional algorithm yields more optimal results compared to other methods. The methods of Chan-Vese and Mumford Shah were compared, and it can be determined that the former method struggles to segment images into regions correctly and therefore does not detect edges clearly, while the Mumford Shah method correctly fulfills both characteristics of

regionalizing images, smoothing images, and detecting edges accurately.

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