Treatment and mathematical analysis of Ecuadorian paintings using MATLAB®

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SUMMARY

The value of Ecuadorian pictorial manifestations is invaluable and often their valuation is made through subjective analysis, however, for marketing or restoration purposes, more precise mathematical procedures must be developed for the analysis of national works of art. In this sense, works attributed to the artist Miguel de Santiago exhibited in the churches of Quito that use contemporary techniques with dark gray tones and works by Rafael Troya that focuses on the naturalism of natural regions were analyzed through the use of MATLAB® software. Through this computer program, the paintings were mathematically contrasted, using the proposal of González and Woods, for the processing of images using the techniques: detection of segments using edges and morphology, segmentation based on the color space L*a*b* and k-means and the regression model was applied to determine the trend curve of red colors, green and blue. The results obtained showed the dispersions of main colors used by the artists and segments were identified in some paintings that were retouched or added. The validation of this mathematical model for the analysis of paintings will allow its application for the characterization of works by other national and international artists based on multivalent techniques such as multiple regression and discriminant analysis, facilitating the authentication of the work, its value and identification of treatment and restoration processes previously carried out.

Keywords: images, models, restoration, treatment, assessment.
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ABSTRACT
The value of the Ecuadorian pictorial manifestations is invaluable and its valuation is often done through subjective analysis, however, for marketing or restoration purposes, more precise mathematical procedures should be developed for the analysis of national works of art. In this sense, works attributed to the artist Miguel de Santiago exhibited in the churches of Quito were analyzed using MATLAB® software, using contemporary techniques with dark gray tones and works by Rafael Troya that focus on the naturalism of natural regions. By means of this computer program the paintings were mathematically contrasted, using the proposal of Gonzalez and Woods, for image processing using the techniques: segment detection using edges and morphology, segmentation based on the color space L*a*b* and k-means and the regression model was applied to determine the trend curve of red, green and blue colors. The results obtained showed the dispersions of main colors used by the artists and segments were identified in some paintings that were retouched or added. The validation of this mathematical model for the analysis of paintings will allow its application for the characterization of works by other national and international artists based on multivalent techniques such as multiple regression and discriminant analysis, facilitating the authentication of the work, its value and identification of treatment and restoration processes previously carried out.
Keywords: images, models, restoration, treatment, valuation.

INTRODUCTION
Art is a universal manifestation present in all areas expressedin different ways: painting, sculpture, dance, photography and poetry. In the Ecuadorian case, painting is one of the most important artistic manifestations (Torres-Castillo, 2021), highlighting works by artists such as Oswaldo Guayasamín (Álvarez et al., 2021); Miguel de Santiago (Romero et al., 2021) and Rafael Troya (Peñalosa, 2019), given the importance of these works, it is necessary to make analyses that allow us to know their authenticity, economic value, as well as the identification of treatment or restoration processes to which the painting has been subjected.
To carry out an objective analysis of the Ecuadorian plastic arts, it is necessary to establish an evaluation standard that allows the identification and assessment of particular characteristics objectively, in this sense the technological advance in terms of computational processing capabilities allows image processing to be carried out efficiently (Alonso-Sierra and Castaño-Saavedra, 2021).
The INPC has a research laboratory where they perform chemical analysis and has specialists in history, chemistry, archaeology, conservation; architects and photographers dedicated to the research of cultural heritage, however, lack mathematical professionals with mastery of the exact sciences and particularly in image processing through the use of the MATLAB® application, which has been successfully used for the analysis of work of other artists, in other countries (Amura et al., 2020)).
Despite having mathematical tools, the analysis of painting until a fewors years ago was based on stories and facts raised with plastic artists, although these works contribute to the social, visual and historical field of the paintings and do not describe processes of mathematical analysis in the treatment and modeling of trend curves that show the use of specific colors in the paintings (Flores et al., 2019).
However, in recent years it has gained momentum with the advancement of

technology, the use of computational tools such as MATLAB, which is based on the manipulation of matrices in order to extract information; the images are formed by matrices and there are functions to manipulate the matrices formed by the images (Cuevas et al., 2016), which allows using the Matlab function box to detect lines, edges of polygons and circles with different radii; in texture analysis it is used through the entropy that exists in the pixels of its vicinity using a gray level

The use of computer applications has allowed the processing of images in different areas such as medicine (Borja et al., 2019), microscopy (Infante et al, 2017), industry (Tarazona and Sandoval, 2019), satellite (Figueroa-Figueroa et al., 2020), transport (Drammeh, S. , 2022), astronomy (Carpenter, 2022; and Arbona, 2019), among others; the study is broad and each area has its deepening, the processing consists of applying mathematical algorithms and thus obtain relevant information which allows the extraction of data and information for statistical calculations.

In this sense MATLAB® applied to statistics according to Baillo and Grané (2008), contains descriptive statistics functions allowing to obtain means, standard deviations, variance, correlation, covariance, correlation coefficients. It also allows to determine incoherent or atypical data of a data set, linear correlation to determine the relationship between the independent variables and the dependent one, linear regression applying least squares and determine the representative mathematical model of the two variables.

Therefore, this research focused on the processing of color images to identify and compare the properties of the paintings made by Ecuadorian artists and obtain the mathematical model used by the Quito painter Miguel de Santiago, which will be used for the analysis of paintings by this author such as those made by Rafael Troya, which will serve for its validation and subsequent use for the analysis of paintings by other artists, allowing to authenticate the work, establish its value and identify the restoration treatments to which this work has been subjected.

MATERIALS AND METHODS

Works of art to analyze

Obtaining the works of art and the selection of a sample of the paintings attributed to the artist Miguel de Santiago and Rafael Troya, two leading artists in Ecuadorian painting with their alignments to the events in which they lived and performed their functions; the artworks of Miguel de Santiago have an affinity to the religious field, while Rafael Troya to naturalism, which are cited in table 1.

Table 1. Works to analyze by the artists Miguel de Santiago and Rafael Troya

Miguel de Santiago	Raphael Troy
St. Jerome appears to St. Augustine and St. Augustine to him	Picnic lunch
The Miraculous Fountain	The Coastline
Consecration of saints	AgoyWaterfall
Light from the doctors	The Flood
The cursing bishops	
Light from waxes	
Santo presides over the conference of Carthage	
Apparition of Christ to St. Augustine	
Vision of Saint Veronica of Binasco	
The saint visits the Hermits	
St. Augustine Raptured writes	

Bishop Sigisbert and the relics of the Saint
The 3 miracles of St. Augustine
The Saint saves 2 men
The dedication
Vision of Saint Gertrude.
St. Augustine ascends to the third heaven
Holy Deceased appears to the Duke of Mantua.
The torment of the martyrs
Transfer of the body of the Count of Orgaz
The funeral of St. Augustine
Saint Augustine between blood and milk
Conversion of St. Augustine
Virgin of Loreto
The miracle of the Virgin in the Sanctuary
Immaculate Eucharist

Characteristics of the works to be analyzed

The selected sample of the paintings must allow to analyze the color, shape, luminosity, lines and among other characteristics, considering that the works of art do not present deterioration and lack of luminosity, 30 samples were obtained with the previous characteristics taking care that they do not harm the analysis of segments and the spaces of the colors used by the artists.

Description of the analysis

The methodology of applied research at work is quantitative. Image processing is formed by stages proposed in (Morales and Azuela, 2012). which was adapted from González and. Woods (2018), these stages are for the analysis of an image; the stages begin with the obtaining of digital images, processing and segmentation, extraction of characteristics and identification of elements and ends with the analysis of the results obtained. The four stages are presented in Figure 1 below.

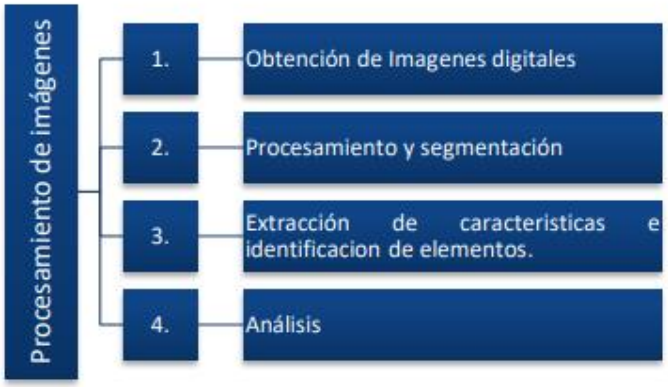


Figure 1. Stages in image processing.

Source: Morales and Azuela (2012)]

Processing

Being segmentation the process of dividing a digital image, groups of pixels are extracted for the analysis of specific characteristics, three algorithms are applied to the paintings of Miguel de Santiago and Rafael Troya: a) segmentation in the color space L*a*b*, b) color-based segmentation using K-means grouping and c) element detection using edge localization and morphology. These

types of segmentation have their own stages of application that allow to highlight in a painting objects with groupings of colors to extract average values in the RGB color spaces of the paintings attributed to the artist Miguel de Santiago, which allows to determine the trend of the colors used in his works of art, for this the data adjustment models are used and allows to determine the most efficient.

Segment determination using edge and morphology detection

The elements in a painting are detected when the degree of difference in hue is high and this happens in the colors used in a painting. Figure 2 shows the steps to follow in segment detection using the MATLAB® application:

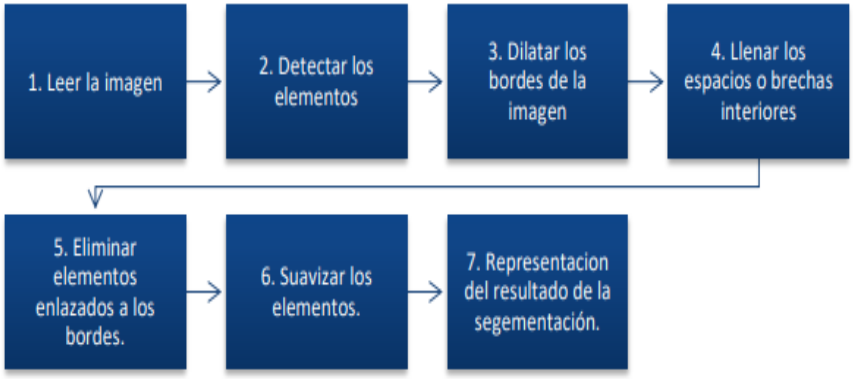
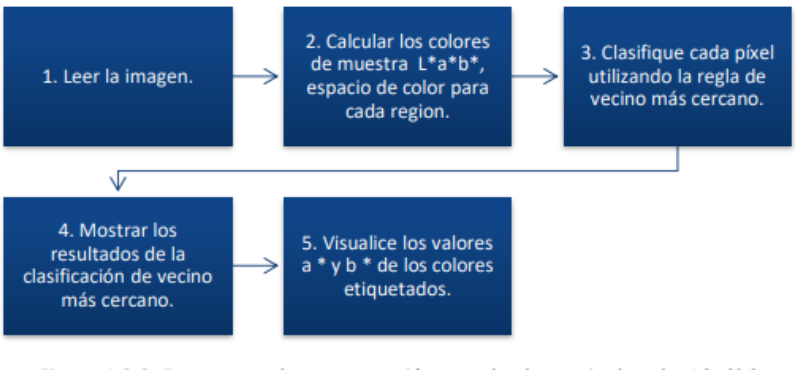


Figure 2. Stages for segment detection using edges and morphology

Segmentation using the L*a*b* color space

This algorithm shows how to identify different colors in the image, by analyzing the color space L ∗a ∗b (Figure 3).

Figure 3. Stages for segmentation using the L*a*b* color space



Color-based segmentation using K-mean grouping

The color segmentation in an automated way using the color space L*a*b* and the grouping of K-means was carried out following the stages shown in Figure 4.

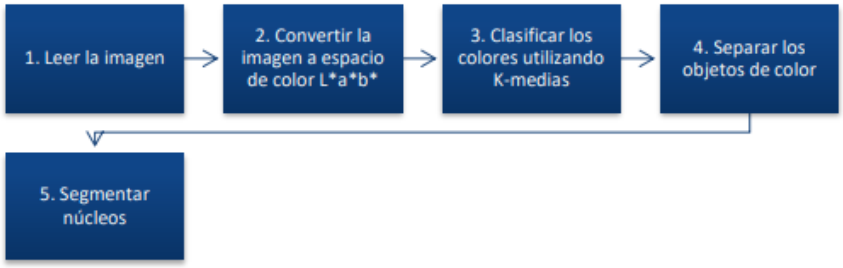


Figure 4. Stages of color-based segmentation using K-mean grouping

Analysis

With the use of the three algorithms, the shades of color used by the artists are evidenced and the doubt raised by Poynton (2012) regarding the authenticity of the image of the washerwoman that appears in the central part of the painting with a different tonality to that used by the artist Rafael Troya and that is segmented by the MATLAB® application is verified.

Using the mask of Sobel determines the gradients in the paintings attributed to Miguel de Santiago and Rafael Troya, this method allows to observe continuous lines formed by the related neighboring pixels, which details the edges in the objects and elements of the works of art.

Scatter plots of segmented pixels are determined in the L*a*b* color space, with the grouping and percentage corresponding to the colors: 1. Black, 2. Red, 3. Green, 4. Purple, 5. Magenta and 6. Yellow and e analyzes the means corresponding to the three colors using the type of adjustment: linear, quadratic, cubic, exponential, potential, rational and Fourier, to determine that the best fitting lines are the Fourier with 0.8709, then the cubic with 0.8214 and the smallest fit is the linear with 0.1535 for the red space, the lines of best fit for the green color are: Fourier with 0.8622, and the cubic with 0.8493, being the smallest adjustment linear with 0.2891, the lines of best fit for the blue color are: Exponential with 0.8357, then Fourier with 0.7083 and the smallest fit is linear with 0.2891.

The regression models generated, is analyzed in two parts, the first is studied between the combinations of the three colors and determines the green and blue variables for linear regression, where the blue color is the independent variable and green the dependent variable. The second analysis is applied according to each painting and determines the equations for each color, being for red and green Fourier and for exponential blue, whose equations are:

Red:

$f(x) = 96.17 + 35.01 \cos(0.1961\, x) + 15.68 \sin(0.1961x)$

Green:

$f(x) = 97.17 + 37.67 \cos(0.1426\, x) - 19.67 \sin(0.1426x)$

Azul:

$□(□) = 135.8□^{-0.08067□} + 4.033□^{0.09657}$

Data fitting models based on linear regression

The types of adjustment applied are: linear, quadratic, cubic, exponential, power, rational and Fourier polynomial regression. The evaluation of the model determines whether the values fit the regression equation and considers the errors and the sum of squares. Below is the 5th of the ways to evaluate a regression model.

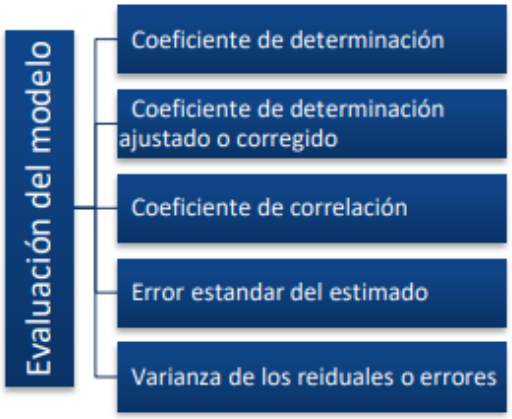


Figure 5. Ways to evaluate a regression model.
Source: Estebaranz (2010)

RESULTS AND DISCUSSION

Processing and segmentation

In the processing and segmentation of the paintings attributed to Miguel de Santiago and the works of Rafael Troya is done in the application of MATLAB® for determination of gradients using different masks, segment detection using edge detection and morphology, then describes the result of applying the aforementioned algorithms

Gradients in paints using edge detection masks

The works attributed to Miguel de Santiago are analyzed with gradients for the detection of the edges generated in the continuous lines of the colors used by the artist. Below are the figures from the original image along with the gradients using the masks of Sobel and Canny.

Figure 6. (a) St. Augustine among blood and milk. (b) Magnitude of the gradient

The composition of work 1 (figure 6) is an inverted triangle with the enhancement of the saint at the lower vertex, Christ and the Virgin are accompanied by the cherubs found at the top, typical of artists who address the religious theme (Estebaranz, 2010). By using edge detection, the horizontal and vertical lines recently made are highlighted to determine the location and know the dimensions of the segments of the work, the elements located in secondary planes generate depth to the work. The shield of the work that is often found in the paintings attributed to Miguel de Santiago stands out.

In the analyses and studies carried out on painting, lines have been drawn between the Saint, the Virgin and Christ.

Figure 7. (a) St. Augustine ascends to the third heaven. (b) Magnitude of the gradient

The detection of edges presented in the shows the elements that form the diagonal arrangement with the gaze of St. Augustine towards the two Saints who have in the middle a dove indicating where it should go (figure 7). By the time they already had knowledge of the rotation of the planets with respect to the sun, the curvatures tend to be elliptical with the location of stars agglomerated in a layer. It recognizes the touches indicated in quadrants and the deteriorated and erased part of the shield that is in the lower right.

Figure 8. (a) Picnic lunch. (b) Magnitude of the gradient

The figigura 8 of the picnic lunch that is rich in customs of that time in the field, the detection of the edges is observed the curved lines forming the mountains and the volcano that are at the bottom of the painting, also the degradation or deterioration of the painting in the upper parts of the work of art is evidenced. They present the lines of shadows created by the illumination of the sun, what is lost is the lagoon that is next to the volcano. In the work the absence of straight lines is evident because it is a work of naturalistic art very different from the works of the artist Miguel de Santiago has greater use of geometric lines (Estebaranz, 2010).

Figure 9. (a) The Flood. (b) Gradient magnitude

In Figure 9 (a) entitled the deluge in the detection of edges with the magnitude of gradient, the groups of people in different places trying to save themselves from the rising waters resulting from the rains are highlighted, in the upper right part the trajectory of the lightning that arrives near the house that is flooding is reflected. Due to the resolution of the image, segments are lost in the detection of lines in the upper left, the trajectories of the rains are concentrated mostly on the right side, very different from the left part.

Segment detection using edge and morphology detection

Miguel de Santiago. In the detection of segments with different background contrast, edges and morphology are used in the processing of works of art. Below, the results of the most relevant works of Miguel de Santiago are presented.

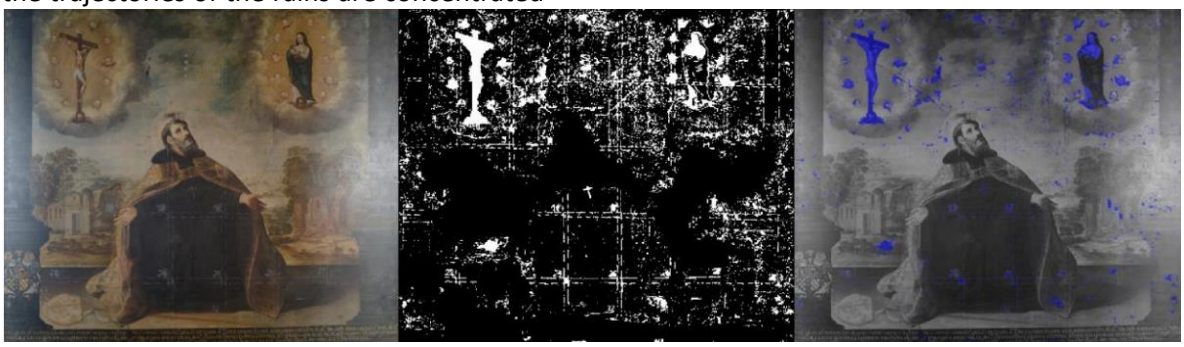


Figure 10. (a) St. Augustine among blood and milk. (b) Borders and (c) Segments with different contrast.

The work presented in the fig10 of St. Augustine between blood and milk of inverted triangular composition is made up of the use of different shades of color space to those used by the main author, the main idea of the author with the look to address the virgin and Christ, the doubt arises if the virgin and Christ together with the cherubs were painted by Miguel de Santiago or They were later added by his students or other painters, what is shown is the different use of shades of color to those used by the artist, different from the lower part of the work. To get to the image (c) on the right, you go through the detection of edges and then dilate those continuities.

Figure 11. (a) Miracle of waxes. (b) Linear expansion of edges and (c) Segments with different contrast.

Figure 11 presents three images starting from the left which is the original painting, followed by the image located in the central part is the detection of the dilated edges, the last painting presents the elements with the handling of color space tones is balanced with cold and warm colors that were of that time, Changes in tones are scarce in horizontal painting.

The first concentration is in the person who is inclined and ordering the papers, follows the next person who is standing highlighting his face and parts of the right leg, on the right side of the image decreases the change of tonalities, three groups of color change are highlighted and the others are presented in small proportions.

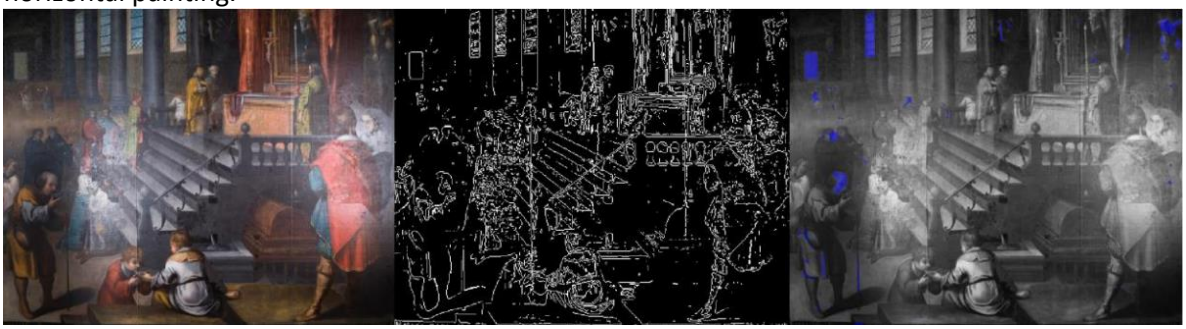


Figure 12. (a) The miraculous fountain. (b) Linear expansion of edges and (c) Segments with different contrast.

The changes of shades in the figment12 of the miraculous fountain represented with the detection of horizontal and vertical edges. In representation (c) the segments with different contrast are scarce, it occurs in the windows and the person who is drinking the liquid from the miraculous fountain. The use of background planes by the painter is evident when performing linear expansion of edges.

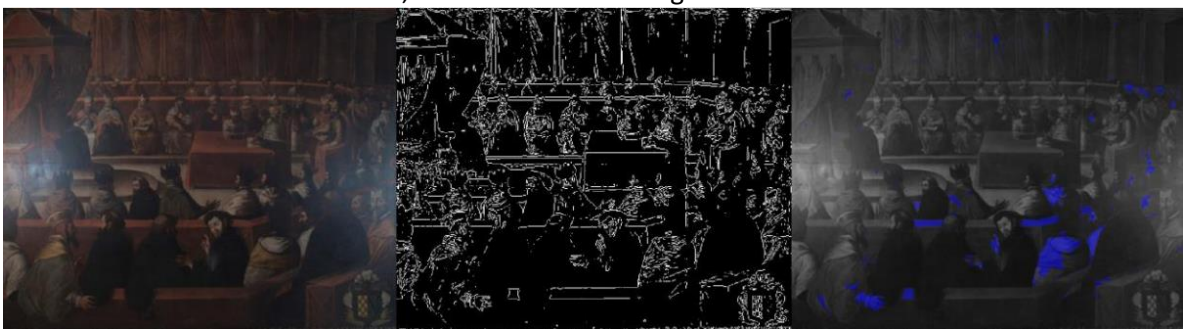


Figure 13. (a) Santo presides over the conference in Catargo. (b) Linear expansion of edges and (c) Segments with different contrast.

The painting of horizontal composition presented in page13 contains characters dialoguing in several groups, in (b) the lines formed by the gradients are shown and the horizontal and vertical lines used by the artist are highlighted, the use of different tonalities is evidenced in the highlighted segments of blue in (c), the most relevant group of segments are the incidents by light in diagonal direction, and a small group who are in the posterior direction of the incidence of light. The segments with different space in tonalities form a semicircle surrounding the Saint located in the center of the work

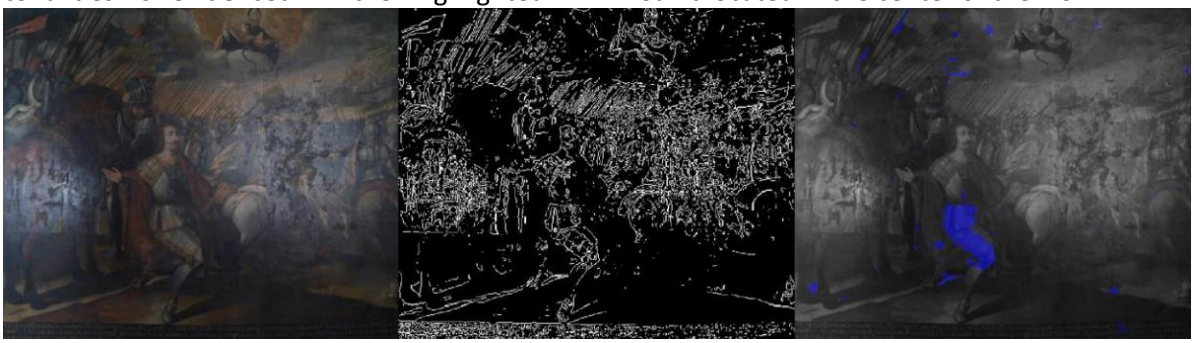


Figure 14. (a) Deceased saint appears to the Duke of Mantua. (b) Linear expansion of edges and (c) Segments with different contrast.

The painting of the Holy Dead appears to the Duke of Mantua presented in the 14th film, has its scenes in different planes, with the main performances of the Duke, the Saint with a spear pointing in the direction of the appearance of the Holy Deceased and the soldiers ready for combat. The dilation of the edges in (b) are highlighted in the arrows and in the two points of light that the photograph presents at the time of being captured, in these points the deterioration of the work of art showing spots is more evident. The changes of tonalities in (c) are concentrated in the Duke and segments near the arrows of the soldiers.

Rafael Troya. The detection of elements with different contrasts is analyzed in the works: the coast, the waterfall of Agoyán, the flood and the picnic lunch.

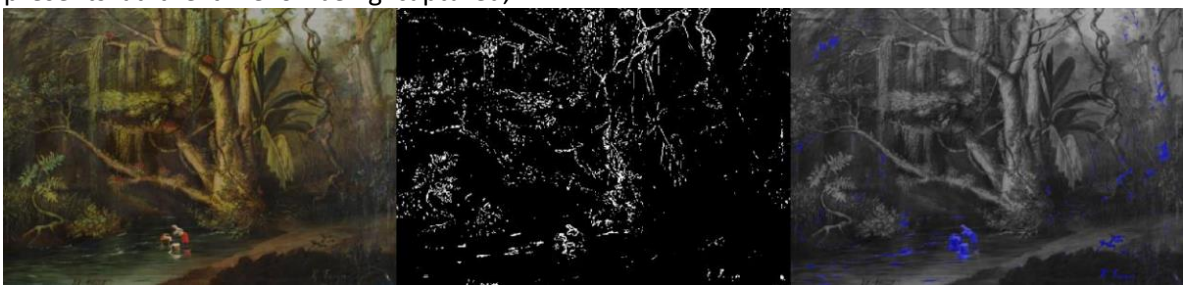


Figure 15. (a) The Coast. (b) Linear expansion of edges and (c) Segments with different contrast.

The figura 15 (a) made by Rafael Troya presents a naturalistic space with the majestic tree located on the bank of the river, the segments with changes of tonalities detected and the doubt raised by different researchers in their publications is verified as is the case of Puig (2015) in the lady located in the center of the river with a table washing clothes It was not painted by the artist, rather it was added by other artists. The changes in tonality increase to the right of the painting due to its deterioration and its greater light intensity compared to the other planes of the work of art.

Figure 16. (a) Picnic lunch. (b) Linear expansion of edges and (c) Segments with different contrast.

The painting of the picnic lunch on figment16, shows a space with high luminosity, changes of tonality are reflected with evidence of error in the numerical values of the date captured from the painting with a photographic instrument, the changes of tones are evident in the wrinkled parts of the painting, and the horse that is in the background in the back of the conglomeration of the people located in the part center of the image. The expansion of edges helps to observe the grouping of the concentrated elements in the lower part of the right side of the work of art, the background planes that are the mountains accompanied by the volcano lose prominence.

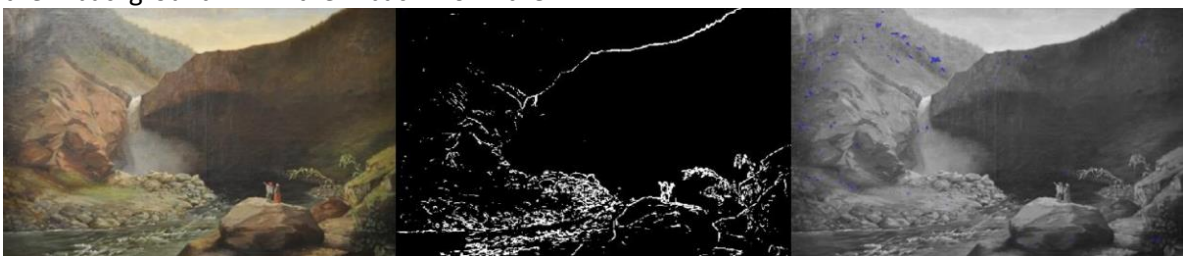


Figure 17. (a) Agoyan Waterfall. (b) Linear expansion of edges and (c) Segments with different contrast.

The Agoyán Waterfall in the figra17, presents few segments with different contrast that are concentrated on the upper left side and a small group in the lower right next to the plants. The central image shows the dilation of the edges presented in the curvature of the rock in which the waters slide and descends towards the bottom near the two people who are on the rock admiring the majestic waterfall that is in front of them, by the application of dilation elements that have darker tones compared to the light ones are lost.

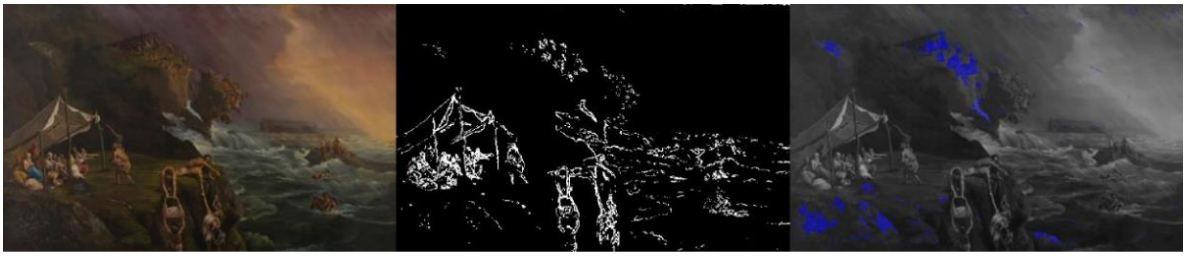


Figure 18. (a) The flood. (b) Linear expansion of edges and (c) Segments with different contrast.

The figura 18 (a) the flood applied the detection of edges and morphology in (c) presents a large part of segments with variations of tonalities, the most relevant is in the rock of background where people try to save themselves and help the others who are trapped in the landslide caused by the increasing rains, Some bursts of rain are also highlighted as changes in hues in colors. Linear dilation at (b) highlights the brightest elements, except for the path of lightning descending from clouds, groupings of people are visible, and the algorithm excludes dark-toned elements. The analysis applied to the

four works of art of Rafael Troya using the technique of detection of edges and morphology allows to establish elements with shades of color different from those used by the artist.

Scatter plots of segmented pixels

Miguel de Santiago. The paintings attributed to the artist present different distributions in the color space L*a*b*, the values of the color pixels to be analyzed are considered: 0 = Black, 1 = Red, 2 = Green, 3 = Purple, 4 = Magenta, and 5 = Yellow. The scatter plots of some paints in values a* for the horizontal axis and b* for the vertical axis are presented below.

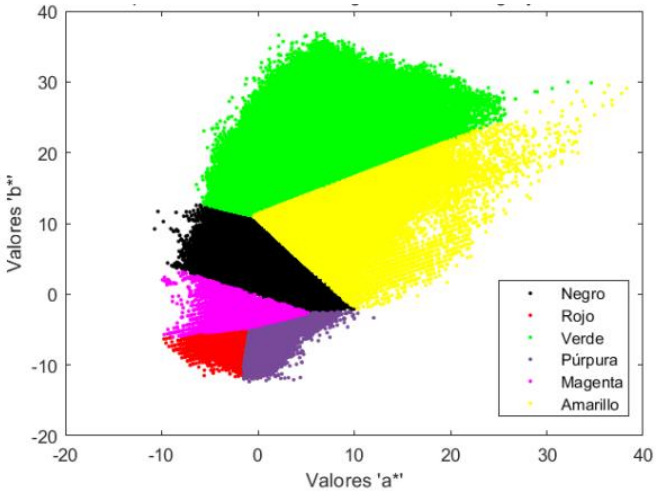


Figure 19. Color space a*b – St. Augustine between blood and milk.

The colors analyzed in the color space L*a*b* of the painting of Miguel de Santiago de San Agustín between blood and milk in the figura 19, the colors with greater dispersion used by the artist are yellow, green and black, and in small proportions purple, magenta and red. The average color of the red sample region in space 'a*b*' is [-1.850,-8.685], the pixel values of a matrix of 2907 × 3422 in the six colors are: [3928186, 310766, 2805229, 402814, 1043189, 1457570], the color pixels in percentages have the following values: [39.4882%, 3.1240%, 28.1996%, 4.0493%, 10.4867%, 14.6523%], The color black has less bias in its data along with the color green, although the dispersion of the color green and black are different.

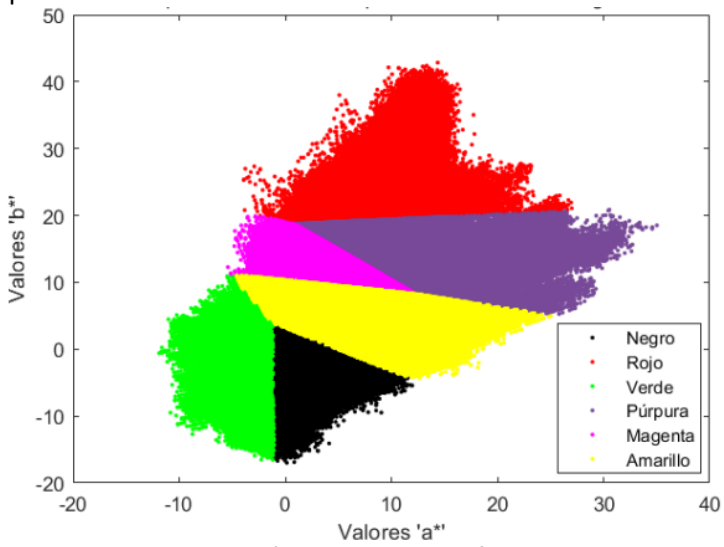


Figure 20. Color space a*b – Apparition of Christ to St. Augustine.

Graph20 presents the colors analyzed in the space L*a*b* of the painting "Apparition of Christ to St. Augustine", the distribution of colors used by the artist is similar. The average color of the red sample region in space 'a*b*' is [3.076, 19.838], the pixel values of a matrix of 2775 × 3296 in the six colors are: [2,599,049,402,960, 478,471, 923,174, 1,114,567, 3,628,179], the largest dispersion of colors is found in green followed by yellow. The color pixels in percentages are: [28.4161%, 4.4057%, 5.2312%, 10.0933%, 12.1859%, 39.6678%], the color with the highest pixels is yellow, followed by black, magenta and purple, finally red and green with percentages less than 10%.

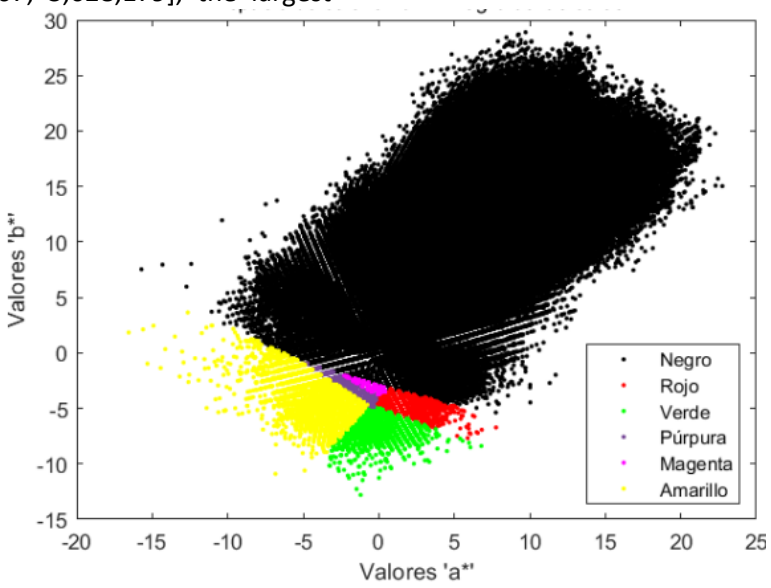


Figure 21. Color space a*b – Miracle of waxes.

The scatter plot of the segmented pixels in the L*a*b* color space of the painting on page21, shows the greatest dispersion in black, followed by green and yellow and to a lesser extent red, magenta and purple. The average color of the red sample region in space 'a*b*' is [−0.050, −3.821]; The pixel values of a 2844 × 3398 matrix are as follows: [8,784,322, 263,599, 221,955, 176,652, 112,930, 104,454]. The color pixels in percentages have the following values: [90.8982%, 2.7277%, 2.2967%, 1.8280%, 1.1686%, 1.0809%], the black color has a greater participation in the painting with 90.8982%, while the other colors have a participation of less than 5% each.

Rafael Troya. The dispersion of colors in the L*a*b* space of the works attributed to Rafael Troya is applied to with a reduction to 75 percent to the three paintings and for the painting of the deluge it is reduced to 15 percent due to the magnitude of their data.

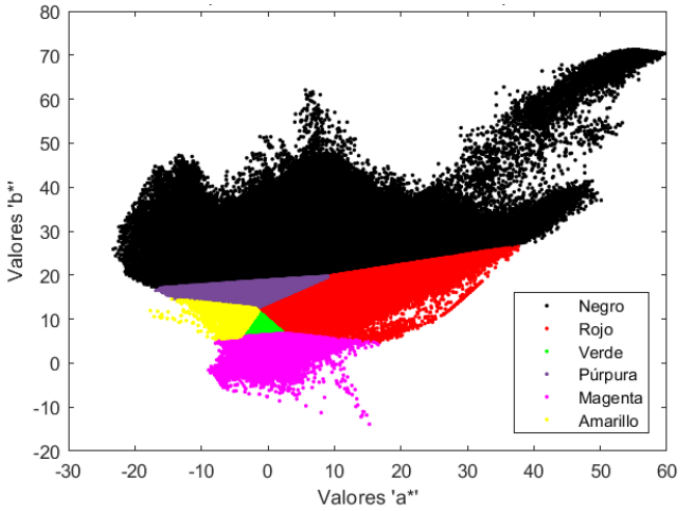


Figure 22. Color space a*b – Picnic lunch.

In the 22ndcentury the colors with the greatest dispersion are: black, red and magenta, followed by the colors that have less dispersion yellow, green and purple. The average color of the red sample region in space 'a*b*' is [0.225,11.913], the pixel values of a matrix of 1479 × 2272 are as follows: [920 723, 462 980, 226 468, 291 576, 1 327 686, 130 855], the largest dispersion of colors is in green followed by yellow. The color pixels in percentages have the following values: [27.4001%, 13.7780%, 6.7395%, 8.6771%, 39.5111%, 3.8942%], the black color has less bias in its data along with the green color, although the dispersion of the green and black colors are different.

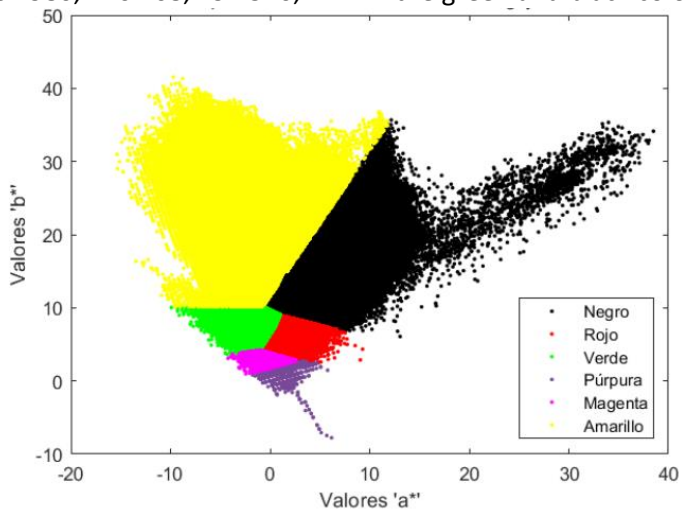


Figure 23. Color space a*b – ArgoyánWaterfall.

Graph23 shows the colors most used by the artist in painting is yellow and black, and in similar small proportions green, red, purple and magenta. The average color of the red sample region in space 'a*b*' is [0.551, 5.222], the pixel values of a matrix of 1335 × 2094 are as follows: [815 735, 519 225, 359 309, 78 604, 230 836, 791 781], the largest dispersion of colors is found in green followed by yellow. The color pixels in percentages are: [29.1804%, 18.5737%, 12.8532%, 2.8118%, 8.2574%, 28.3235%], the black color has an inefficient bias in the scatter plot and the pixel values reach a percentage of 29.18 being the purple is the one with the lowest participation in the painting.

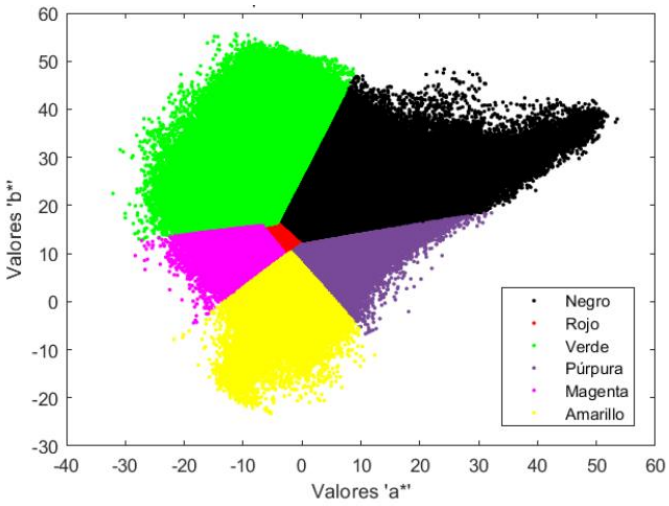


Figure 24. Color space a*b – El Litoral.

The colors analyzed in L*a*b* of the paint of the figura 24, the color with less dispersion is red, the other colors have similar proportions. The average color of the red sample region in space 'a*b*' is [-4.831, 13.365], the pixel values of a matrix of 2187 × 3078 are: [1 738 652, 292 010, 1 037 201, 1 552 713, 388 009, 1 723 001], the largest number of values is found in the color black, yellow and purple. The color pixels in percentages are: [25.8283%, 4.3379%, 15.4080%, 23.0661%, 5.7640%, 25.5958%], the values of the green color represent 15.40% compared to the purple that is 23.07%, presents bias in the data, having to be more efficient the purpura.

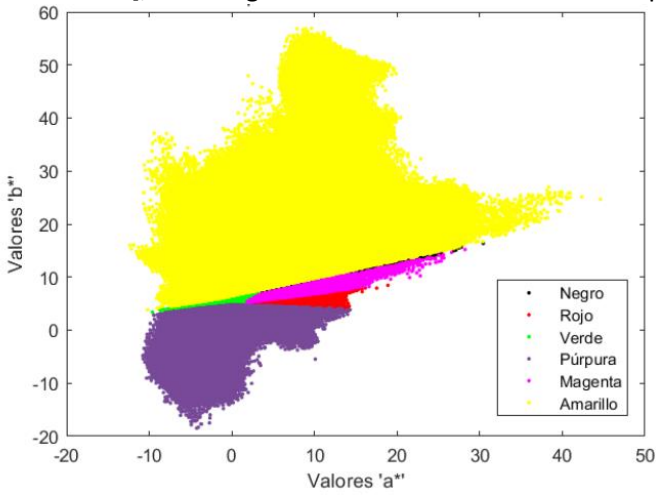


Figure 25. Color space a*b – The Flood.

The colors analyzed in the space L*a*b* of the work of the figura 25, shows the colors with greater dispersion used by the artist in the painting is yellow and purple, and in small similar proportions magenta, red and green. The average color of the red sample region in space 'a*b*' is [3.304, 4.919], the pixel values of a matrix of 3687 × 5878 are as follows: [874 843, 1 691 990, 1 034 119, 5 824 193, 1 199 533, 11 047 508], the greatest dispersion of colors is in yellow. The color pixels in percentages have the following values: [4.0367%, 7.8072%, 4.7716%, 26.8740%, 5.5349%, 50.9755%], the yellow color is the most used by the artist with a percentage of 50.96 percent, while green and magenta are the least used and is reflected in the scatter plot, with an absence in the pixels. The extraction of values in

secondary colors allows to better understand the use of colors in each work of art.

Color-based segmentation using K-mean grouping

In the segmentation using k-means for colors, the groupings of colors presented in the paintings of Miguel de Santiago and Rafael Troya are analyzed.

Figure 26. Color-based segmentation using k-media grouping – The Deluge.

In page26, three images are shown from left to right in the order of red, green and blue, it is the result of color-based segmentation using K-mean grouping. In the red colors the grouping is highlighted in the main elements that form the composition of the inverted triangle, next to the left shoulder the trees are located, the first tree is considered in the red grouping. The image of the center that is grouping green colors loses the main elements that form the composition, highlighting other objects such as the back of the saint that is the building and the shield. This image highlights the horizontal and vertical lines located later to analyze the quadrants and dimensions of the objects in the painting. In the blue grouping, the image is lighter in presenting its elements, although the virgin loses clarity and identification next to the cherubs and Christ shows missing elements of the main image.

Figure 27. Color-based segmentation using k-means grouping – El Litoral.

On page27 three images are shown in the RGB color space from left to right in the order of red, green and blue. In the first painting of red space it enhances the leaves of the central tree and the small shrubs with an absence of elements in the lower right; In the center shows the green grouping, the lady is observed washing clothes in the center of the river near the majestic tree. In the painting located on the right side is presented the two main elements that is the tree that is located on the bank of the river, also presents in an evident way the lady washing.

Figure 28. Color-based segmentation using k-means grouping – The miracle source.

On page28 three images are shown in the RGB color space. In the first painting of red space located on the left presents the elements achieving a circular trajectory, the central part of the stands loses lighting and is not evident; The central artwork tends to be dark gray with a high brightness describing the location of the elements in the secondary planes; The painting located on the right regroups the blue space showing the clothes of people with some faces forming the circular path.

Linear regression model

From the multivariate analysis, the linear regression technique was considered for the determination of the mathematical model that has the best fit to the RGB color space. The mathematical analysis was applied to a sample of 30 paintings by Miguel de Santiago made in the churches of San Agustín, Guápulo and San Francisco. Average values were generated in RGB color space for each image.

Figure 5.4.5 shows the linear regression applied to the colors blue and green, using the two variables for their greater correlation. The equation is expressed: v(a) = 1.001 ∗ to + 7.939, with a square R of 0.8999 and an adjusted R squared of 0.8963, where the p-value is 1.587and − 15 in the linear model. Applying Pearson's test yields a p-value of 1.587and − 15 with 95 percent confidence, the correlation is 0.9486407.

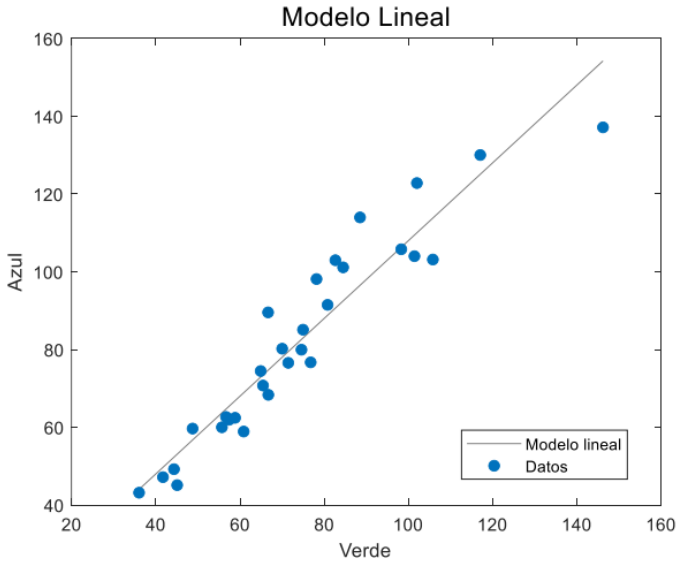


Figure 29. Linear model of blue and green color

The models applied to the RGB colors, present variations in their results, some fit more to the data and others are more distant. The types of adjustment applied in Table 2 are: linear, quadratic, cubic,

exponential, power, rational and Fourier polynomial regression.

Table 2. Summary of models

Adjustment	R2 Color Red	R2 Green Color	T2 color blue
Linear	0,1827	0,3137	0,3137
Quadratic	0,778	0,8522	0,7384
Cubic	0,8399	0,8649	0,7082
Exponential	0,7985	0,8527	0,8357
Fourier	0,8709	0,8862	0,7083

Of the selected models the most adjusted to the data is the Fourier for the red and green color with an adjusted R of 0.8709 and 0.8622 respectively, and for the blue color with a 0.8357 is the exponential adjustment. These models allow a more accurate perception of the handling of colors in the RGB space in his career as an artist of plastic works.

CONCLUSIONS

The description of the works is based on the composition and trajectory being the most used arrangements by the artist Miguel de Santiago, the horizontal, vertical, triangular and circular. These works of art have dark gray tones that highlight religious elements and spaces related to where the artist lived. Rafael Troya has an inclination to use naturalistic spaces in his works with tendencies to be more colorful compared to Miguel de Santiago, it is the result of the time and space in which they lived.

By detecting segments using edges and morphology in the processing of Ecuadorian paintings, finding color shades different from those used by artists, verifying the doubt raised regarding the authenticity of the image of the washerwoman using Sobel's mask, the gradients in the paintings attributed to Miguel de Santiago and Rafael Troya were determined. This method allows to observe the edges formed by the objects in the paintings.

The determination of the mathematical model was validated with the types of adjustment: linear, quadratic, cubic, exponential, potential, rational and Fourier, being the most acceptable for red and green the Fourier type and for blue the exponential adjustment,which allowedto apply the mathematical models in the RGB color space will allow the analysis of paintings by other national and international artists based on multivariate techniques such as multiple regression, discriminant analysis, among others.

REFERENCES

Alonso-Sierra, J & Castaño-Saavedra, D. (2021). Implementation of a computational model based on artificial intelligence for the representation of Boterismo in objects and living beings. Degree work – Undergraduate. Catholic University of Colombia. Institutional Repository Catholic University of Colombia – RIUCaC. https://repository.ucatolica.edu.co/items/065568ae-0cbb-4000-83fe-f8d9aec15392

Álvarez, A. N. R., Pilco, J. J. M., & López, L. K. J. (2021). Social and cultural significance of two pictorial works by Oswaldo Guayasamín. Mayeutica Scientific Journal of Humanities and Arts, 9(2), 33-51. https://revistas.uclave.org/index.php/mayeutica/article/view/3266

Amura, A., Luisa, L., Pisani, L., Soro, M. V., Zantedeschi, G., & Pagnotta, S. (2020). Image analysis applied to the planning of a painting on canvas restoration intervention. *Ge-conservation*, (18), 339-346. https://dialnet.unirioja.es/servlet/articulo?codigo=7766765

Arbona Camilleri, B. I. (2019). Development of a tool for the analysis of astronomical images. Degree work. University of Seville. https://idus.us.es/handle/11441/94290?show=full

Baillo, A., and Grané Chávez, A. (2007). 100 Solved Multivariate Statistics Problems Implemented in Matlab. Delta Publications. https://books.google.es/books?hl=es&lr=lang_es&id=mejciP3IAygC&oi=fnd&pg=PA1&dq=Baillo+matlab+estadistica&ots=U91ay46wPg&sig=qg3GeJyiBvQzIC2odPHjmpb0ssE#v=onepage&q=Baillo%20matlab%20estadistica&f=false

Borja Saavedra, M. C., Tapia Bonifaz, A. G., Paredes Castelo, L. E., & Martínez Cruz, D. I. (2019). Strategic planning of computational tools fused images SPECT-TC MATLAB conventional nuclear medicine area HCAM. Caribbean Social Sciences, (May). https://www.eumed.net/rev/caribe/2019/05/herramientas-computacionales.html

Carpenter Gutierrez, E. (2022). Morphological identification of galaxies in deep space using Deep Learning. Degree work. University of Valladolid. https://uvadoc.uva.es/handle/10324/53459

Cuevas, E., Zaldívar, D., & Pérez, M. (2016). Digital image processing with MATLAB & Simulink. Ra-Ma.

Drammeh, S. (2022). Intelligent transport system: Road control based on video surveillance with Raspberry Pi system. Degree work. University of Jaén. https://tauja.ujaen.es/handle/10953.1/18144

Estebaranz, J. (2010). The workshop of Miguel de Santiago in his early years: 1656–1675. Complutense Journal of American History, 36, 163-184.

Figueroa-Figueroa, D. K., Ramírez-Dávila, J. F., Antonio-Némiga, X., & González Huerta, A. (2020). Cartography of avocado in the south of the state of Mexico through digital image processing sentinel-2. Mexican Journal of Agricultural Sciences, 11(4), 865-879. https://www.scielo.org.mx/scielo.php?pid=S2007-09342020000400865&script=sci_arttext

Flores, M. A., Cadena, C., & Zúniga, J. (2019). Analysis of thermal images in the absorber of a Fresnel double reflection solar concentrator in the Matlab PDE Toolbox. Renewable Energy and Environment, 44, 59-64.

Infante Tavio, N. I., Escalona Veloz, R., Sierra Calzado, L., & Palacios Roque, G. (2017). Histomorphometric study of the cerebellar cortex with digital holographic microscopy. Medisan, 21(11), 3244-3250. http://scielo.sld.cu/scielo.php?pid=S1029-30192017001100014&script=sci_arttext&tlng=en

Morales, R. R., & Azuela, J. H. S. (2012). Digital image processing and analysis. First ed., Mexico. Alphaomega.

Peñalosa, X. P. (2019). Aesthetic and artistic analysis of five landscape paintings by Rafael Troya (1845-1920). National Academy of History Bulletin, 97(202), 115-137.

Peñalosa, X. P. (2019). Aesthetic and artistic analysis of five landscape paintings by Rafael Troya (1845-1920). National Academy of History Bulletin, 97(202), 115-137. https://www.academiahistoria.org.ec/index.php/boletinesANHE/article/download/34/68

Poynton, C. (2012). Digital video and HD: Algorithms and Interfaces. Elsevier.Gonzalez, R. C. y. Woods, R. E. (2018). Digital Image Processing, Fourth ed., New York: Pearson Education. https://dl.icdst.org/pdfs/files4/01c56e081202b62bd7d3b4f8545775fb.pdf

Puig, X. (2015). Rafael Troya: aesthetics and landscape painting.

Romero, M. E., Mármol, M. C., Vásquez, C. A., Espinoza, F. E., del Consuelo Díaz, R., & Robles, E. S. (2021). Approach to the context of production of the pictorial work "Miracle of the Virgin of Guápulo in her Sanctuary", attributed to Miguel de Santiago (XVII century). Ge-conservation, 19, 153-164. https://www.ge-iic.com/ojs/index.php/revista/article/download/728/1019

Tarazona, B., & Sandoval, C. (2019). Evaluation of cracks and fissures in concrete structures using a vibration analyzer and digital image processing. Between Science

and Engineering, 13(25), 85-94. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S1909-83672019000100085

Torres-Castillo, R. M. (2021). Religious art in Ecuador: connotations of good and evil. Journal of Research and Pedagogy of Art, (10). https://publicaciones.ucuenca.edu.ec/ojs/index.php/revpos/article/download/3815/2698