

## Original article

# A color image segmentation method as used in the study of ancient monument decay

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**Abstract**

In the cultural heritage area, it is of fundamental importance to characterize and classify the conservation state of the materials constituting ancient monuments, in order to study and monitor their decay. Generally, the decay diagnosis is provided by “naked eye” analysis done by expert scientists “walking around” the artifact and recording the conservation state of each individual element they observe. In this paper, a color image segmentation approach, based on histogram threshold and edge detection techniques is presented, to extract degradation regions, characterized by holes or cavities, from color images of stone-materials. The goal is to provide an aid to the decay diagnosis by segmenting degraded regions from color images, computing quantitative data, such as the area and perimeter of the extracted zones, and processing qualitative information, such as various levels of depth detected into the same zones. Since color is a powerful tool in the distinction between objects, a segmentation technique based on color, instead of intensity only, has been used to provide a clearer discrimination between regions. The study case concerns the impressive remains of the Roman Theatre in the city of Aosta (Italy). In particular, we have processed and analyzed some color images of the theatre puddingstones, acquired by a camera.

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*Keywords:* Edge detection; Thresholding histogram; Puddingstone decay; Naked eye analysis; Roman Theatre

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**1. Introduction**

In cultural heritage research, the use of image analysis appropriate techniques offers an important contribution when used with the traditional methods, by the experts for studying and diagnosing the decay of stony materials that constitute ancient monuments.

The detection of material degradation of historical building is classically focused on the “naked eye” analysis performed by an expert to estimate the state of conservation of each single element he is observing [1]. In addition to this kind of investigation, the application of an image segmentation strategy to color images of stony materials can be used in order to extract decay regions characterized by holes or cavities [2].

The present work is part of the Italian National Research Project SIINDA (Ricerche e Sviluppi di Sistemi Innovativi di

Indagine e Diagnosi Assistita) financed by MIUR (Ministero della Istruzione, Università e Ricerca). The general purpose of the research developed in this project is to produce and test an integrated system of knowledge, constituted by a set of methods, functions and data, for the investigation of the conservation state of a monument exposed at the open air [3].

The study case is the Roman Theatre in the city of Aosta (Italy) being a typical case for the decay of stony materials due to natural agents which has been examined by the experts for many years.

In order to diagnose monument conservation state regarding the action of atmospheric agents over long periods of time, it is important to develop a processing strategy based on the application of image analysis techniques for the generation of surface maps demonstrating holes and cavities. Of course, this type of decay investigation leads to various image acquisitions of the same scene to be made in various times.

The problem is that, changing lighting conditions or acquisition equipment, the comparison of images acquired at different times is no longer possible.

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For this reason, the project planned the experimentation of techniques for acquisition of chromatically and geometrically correct images by using photo and digital TV cameras.

In this preliminary stage of investigation, we have utilized test images acquired before the project with the aim of testing a procedure that provides useful indications to use with images acquired in the project.

In this research, processed test images represent pudding-stone ashlar characterized by fine, medium and coarse grain of the material, and by fissures and cavities.

Due to the conservation state they show, we have preferred to use color images of the stony material rather than gray images, in order to utilize a greater amount of information present in the images. In fact, color image provides three times more data than gray level image, since it can be represented by the three monochrome components defined by RGB, HSV, XYZ or CIELUV color spaces. Taking into account every color system has both advantages and disadvantages, we have chosen to represent the color images in RGB components since widely used for its simplicity [4].

The realized procedure is based on the combination of the recursive thresholding and color edge detection techniques [5–8] to extract the decay zones and obtain both quantitative information, such as area and perimeter, and qualitative information about surface characteristics.

The paper is structured as follows. In Section 2, the Roman Theatre, the traditional method of decay analysis and the characteristics of color images of puddingstones are described. In Section 3, the methodological choices carried out are presented. In Section 4, the recursive thresholding technique and computation of both area and perimeter of extract regions are illustrated. In Section 5, the edge detection method used is introduced. The integration of thresholding and edge detection techniques and its results are reported in Section 6. Finally, a conclusion is drawn.

## 2. Study case: the Roman Theatre in Aosta

In the investigation of decay events and pathologies present in historical and monumental buildings, a fundamental step is to draw a general picture of the conservation and decay state, integrating knowledge taken from different research areas.

Our goal in the SIINDA Project is the development of techniques and methodologies focused on detection of information data for studying and analyzing decay events. The scientific challenge is to support the traditional methods using image analysis techniques, in order to contribute to the design and realization of innovative solutions for the restoration and conservation of the monuments.

The Roman Theatre placed in the city of Aosta (Fig. 1) is the ancient building we are studying. This monument of August age (I century A.D.) is a rare example of the Roman architecture of covered theatre. It conserves the tiers, the foundations of the scene and the rest of the facade, 22 m high,



Fig. 1. Roman Theatre of Aosta City.

whose architecture is composed of a series of arcades and three overlapping orders of windows separated by buttresses. The materials used for the carrier structures are essentially puddingstone (a conglomerate of fluvial origin) and travertine (pure limestone). Both materials are very porous and can distribute burdens avoiding the formation of particularly solicited zones. The conservative situation of the theatre is critical. Because of its typical composition compounded by different materials, the monument is a study remarkable study example of the ancient building decay.

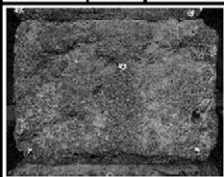
### 2.1. Traditional method for the decay analysis

A traditional diagnosis method of a building decay status is the “naked eye” (or direct) analysis made by an expert, who walks around the artifact and records the state of the conservation of each single element he is observing. An example of classification of degradation (Table 1) shows the result of the naked eye analysis of a sample stone of the theatre. In each column, important information such as material type, grain, conservation state, structure, decay type and localization are stored.

### 2.2. Aspects of image acquisition in the project

In the monitoring of the monument conservation state, it is of fundamental importance to define a methodology that guarantees the comparison of images acquired in different times. For this reason, as mentioned above, the project has

Table 1  
An example of naked eye analysis

Material	Grain	Preservation state	Structure	Decay Type	Decay Quality	Specific Type	Localization
Puddingstone	Fine	Bad	Vertical bedding with East-West direction; irregular for ancient and recent lodes	loss of material	erosion		ledge part
				loss of material	decohesiveness plates	course	south part
				addition of material	encrustations	thin	low part
				addition of material	superficial deposits	black	

planned the development and experimentation of an activity related to “Acquisition of techniques by digital TV cameras”. This activity concerns the realization of techniques for acquisition of chromatically and geometrically correct images by using photo and digital TV cameras, using colorimetric target and under controlled light conditions [3].

### 2.3. Images of puddingstones

The images we used were acquired before the project and are snapshots that represent puddingstone ashlar of different grain placed on the south, east and north facades of the theatre.

The photos have been taken by a reflex NIKON FM2 camera, size  $24 \times 36$ , focal 100 mm, Kodak Color 100ASA roll, at about 2 m from the monument. The color prints of the images obtained have been digitalized with an HP Scan Jet IIC scanner, A4 format at high spatial and photometric resolution (600 dpi). For each image, we can know the corresponding measurement in centimeter of the single pixel.

## 3. Methodological choices

For many years, the segmentation methods have been focused on gray scale images, primarily due to the fact that, until recently, computer systems were not powerful enough to display and manipulate large, full-color data sets. With the advent of more powerful and easily accessible hardware, a shift in the current research has come toward the more widely applicable and more complex problem of color segmentation. Much of the work currently being pursued involves the extension of various gray scale methods to the realm of color images [4].

It is known that the segmentation process consists of partitioning an image  $I$  which contains  $P$  pixels  $p_i$ , into  $N$  disjoint and meaningful regions, denoted  $R_1, R_2, \dots, R_N$ , containing uniform characteristics [9–11]. In the color image segmentation, the characteristics are extracted and computed from the color features of the pixels.

Due to the conservation state shown by the puddingstones, we have preferred to use color images of the stony material rather than gray images, in order to better utilize information present in the color images. In fact, a greater amount of data can facilitate the process of segmentation and improve the research of meaningful features.

The color images are, generally, acquired in the RGB space. Concerning the set of coordinates used to represent color images for segmentation, each color representation provides advantages and disadvantages, since there is no color representation better than others for segmenting all kinds of color images. We have preferred to use the RGB components, which, even if they present drawbacks (lack of a metric, missing human notion of color) have the advantage of being easy and convenient for use in display.

According to the experts, the examined images present two kinds of decayed zones characterized by uniformly dark

regions and little lighter areas respectively. Both types of regions are areas of interest to be extracted by appropriate segmentation techniques.

The experts claim that the former is related to holes or fissures while the latter is related to the less deep areas or material addition of black color.

We have chosen to apply the histogram thresholding technique to our color images, described by the three monochrome images of the RGB space, in order to extract those regions that are well differentiated from the background. As regards this technique, the image is composed of objects with different gray level ranges, so its histogram can be divided into a number of peaks, each corresponding to one object, in which the thresholding value corresponding to the valley between the two adjacent peaks can be computed. From the partitioned regions, the boundaries can be easily extracted. Moreover, we have utilized an edge detection approach to locate points with rapid changes of intensity, in order to detect further information about decay by means of intensity variation (discontinuity) also at a local level, in each component.

In short, a threshold technique and a color edge detection technique have been applied separately to images of the degraded ashlar of the theatre. Furthermore, the resulting outputs have been combined.

The advantage of the threshold method is that it does not need a priori information on the image. Its disadvantage, however, is constituted by the lack of local spatial information that can be supplied minutely by the edge detection technique. On the other hand, edge detection technique works well for images having good contrasts between regions, since the edge detection needs well-connected edge pixels representing the boundary of the region to be extracted.

A combined application of the two techniques has been realized to obviate both the problem of the lack of local spatial information of the threshold method as well as possibly insufficient connection between the pixels delineating the edges of the cavities in the edge detection method.

Furthermore, area and perimeter are computed based on the results obtained by the integrated procedure.

## 4. Histogram threshold method

We used the recursive histogram thresholding method [5], based on discriminant analysis (for more details, see Otsu approach in Appendix A). This method has been chosen because it allows us to obtain a segmented image automatically.

The procedure, separately applied to three RGB channels, combines the red, green and blue images into a resulting color image that visualizes the overlapping of the channels.

The threshold operation allows the pixels of each image to be divided into two classes  $C_0$  (object) and  $C_1$  (background) at gray level  $t$ ,  $C_0 = \{0, 1, \dots, t\}$  and  $C_1 = \{t+1, t+2, \dots, l-1\}$ ,



where  $l = 256$  is gray levels number. Indicated with  $\eta$ , the ratio between the between-class variance  $\sigma_B^2$  and the total variance  $\sigma_T^2$ , the optimal threshold value  $t$ , determined by minimizing the criterion function  $E$  with respect to  $t$ , is:

$$t^* = \underset{t \in G}{\operatorname{argmin}} \frac{\sigma_B^2}{\sigma_T^2} = \underset{t \in G}{\operatorname{argmin}} \eta$$

where  $G = \{0, 1, \dots, l - 1\}$ .

The maximum value of  $\eta$ , indicated with  $\eta^*$ , can be used to define the separability of classes  $C_0$  and  $C_1$  in every monochrome image. The separability factor  $E^*$  is a number ranging from 0 to 1. If  $\eta^* < 0.95$ , the threshold  $t$  is utilized to subdivide the starting image in classes  $C_0$  and  $C_1$ . The result is a new image. The computation of  $\eta^*$  and  $t$  and the consequent subdivision is then repeated for the new image and recursively for all the resulting images until  $\eta^* \geq 0.95$  and image cannot be further segmented [6]. In the new image, isolated pixels and small areas, which are not relevant, have been eliminated. To proceed in this operation, each connected component has been numbered and the number of the pixels constituting each area counted.

The areas having a surface smaller than the 0.5% of the overall decay obtained after the processing have been suppressed. The starting image is transformed until a resulting cleared image is obtained. The image obtained (Fig. 2b) by the starting image (Fig. 2a) represents the result of the application.

In the opinion of experts, this procedure has the advantage that significant regions of decay can be automatically individuated.

## 5. Edge detection method

A method for the extraction of the decayed zones from color images is represented by the classical procedures of *edge detection* aimed to segment gray level images.

In an image, the edges of the objects are intensity discontinuities. There are spatial local operators for the contours extraction, which are based on the local evaluation of the gradient. In those methods, the edge pixels are defined as those points whose intensity is locally greatest in the gradient direction.

In our study, we have realized a procedure for the edge detection based on the Canny edge method [7,8] (for details, see Canny edge detector in Appendix A). The implemented algorithm involves the following steps:

- smoothing the image with an opportune Gaussian filter to reduce chosen image details;
- computing the gradient magnitude and direction at each pixel;
- marking the pixel as an edge, if the gradient magnitude at a pixel is larger than those at its two neighbors in the gradient direction; otherwise, marking the pixel as the background;



Fig. 2. (a) Original image of puddingstone ashlar. (b) Decay areas.

- eliminating not significant edges by hysteresis thresholding.

The realized procedure requires the specification of three parameters: the standard deviation of the Gaussian filter ( $\sigma$ ) and the maximum ( $t_{\text{high}}$ ) and minimum ( $t_{\text{low}}$ ) value of the threshold. Best results, confirmed by experts, have been obtained using the same values for all processed images, in particular  $\sigma = 0.5$ ,  $t_{\text{high}} = 0.3$ ,  $t_{\text{low}} = 0.1$ .

Varying such values, it is possible to augment the information extracted from the resulting image. The explained procedure, also if rather articulated, has a certain convenience that can be found in the three criteria that characterize it. They are:

- the individuation of the pixels, that makes sure no important edge is neglected;
- the localization of the pixels, that imposes the distance between the individuated pixels is lowest;

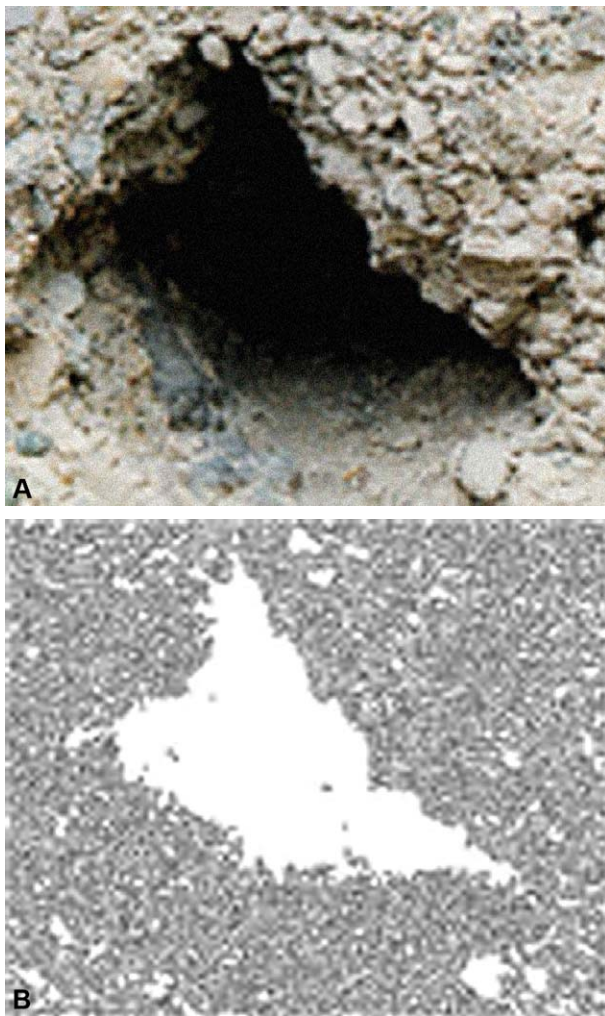


Fig. 3. (a) Original image of puddingstone ashlar. (b) Result of edge detection.

- the elimination of the spurious pixels generated by the noise that solves the so-called *streaking* problem.

The result of the edge detection application (Fig. 3b) is obtained by the corresponding starting image (Fig. 3a).

The resulting image shows a white uniform region that, in the opinion of experts, detects a zone lacking in texture and another zone characterized by edges that define a surface area.

## 6. Integrated procedure

The threshold algorithm has the advantage of facilitating the extraction of the cavity contours with regard to the edge detection method, due to the possible insufficient connection between the pixels delineating the edges of the cavities. On the other hand, the edge detection method allows the identification of sharp brightness variation also below the calculated threshold.

In order to obtain more accurate information, an integrated procedure, that takes advantage of the two methods combining them, has been developed. The edge detection

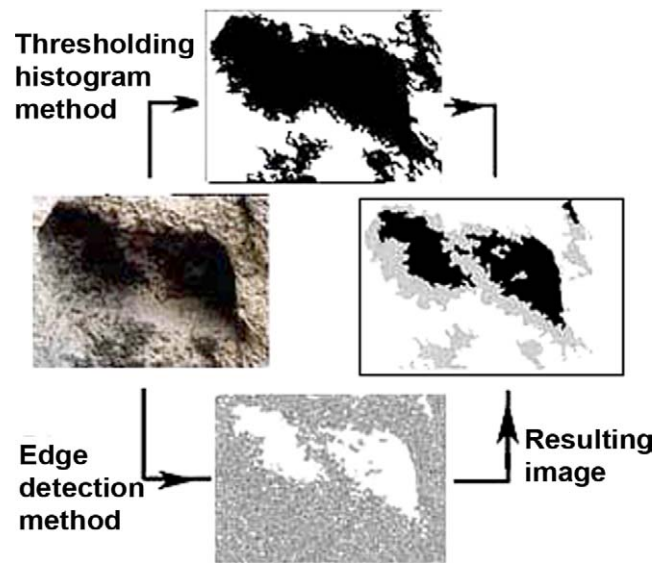


Fig. 4. Steps of the integrated procedure.

result has been superimposed to the image resulting by the thresholding procedure in the regions where the brightness was below the threshold in each color channel.

Overlapping the results obtained from threshold and edge separately permits the detection of more detailed information related to the cavity (Fig. 4).

The resulting edge image identifies regions with texture and regions lacking in texture.

In relation to resulting image, the experts claim that the regions colored in black are zones of deep decay and the gray regions are zones of surface decay.

The images (Fig. 5) present contours of blue color delimitating cavity regions and contours of red color delimitating the more inside zones of the cavities.

## 7. Conclusion

The goal of this work has been to focus on a processing strategy in order to provide a map of the cavities decay present on the ashlar of the Roman Theatre.

In fact, the indication of the number of the cavities, the computing of quantitative parameters such as area and perimeter and the qualitative information of various depths present into these regions provide useful elements of decay analysis. Such elements can be utilized along with results of “naked eye” analysis, which represents the traditional tool of decay analysis.

A map serves as a reference document of the state of a specific type of decay at a known date. Of course every map has to use geometrically and chromatically correct images.

For this reason, in order to allow the comparison and utilization between images of the same scene, but obtained in different times, the Project SIINDA has defined a standard methodology of color images acquisition.

Within the SIINDA Project, this study represents a first approach in the generation of a decay map of the theatre that,



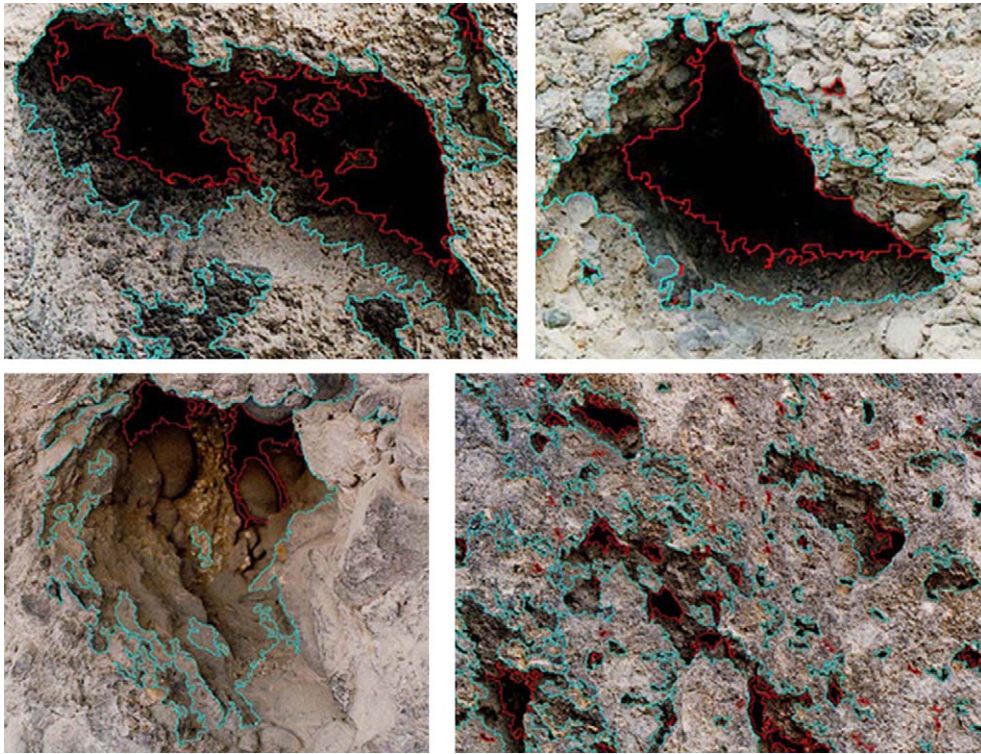


Fig. 5. Contours of the cavities extracted by puddingstones images.

using images acquired in different times but in standard conditions, allows us to compare the variations of the decay because of the action of atmospheric agents.

#### Appendix A. Otsu approach

This method, as proposed in Ref. [5], is based on discriminant analysis. The threshold operation is regarded as the partitioning of the pixels of an image into two classes  $C_0$  and  $C_1$  (e.g., objects and background) at gray-level  $t$ , i.e.,  $C_0 = \{0, 1, \dots, t\}$  and  $C_1 = \{t+1, t+2, \dots, l-1\}$ . Let  $\sigma_w^2, \sigma_B^2, \sigma_T^2$  be the within-class variance, between-class variance, and the total variance, respectively.

An optimal threshold can be determined by minimizing one of the following (equivalent) criterion functions with respect to  $t$ :

$$\lambda = \frac{\sigma_B^2}{\sigma_W^2}, \quad \eta = \frac{\sigma_B^2}{\sigma_T^2}, \quad k = \frac{\sigma_T^2}{\sigma_W^2}$$

Of the above three criterion functions,  $n$  is the simplest. Thus, the optimal threshold  $t^*$  is defined as:

$$t^* = \underset{t \in G}{\operatorname{argmin}} \eta$$

where

$$\sigma_T^2 = \sum_{i=0}^{l-1} (i - \mu_T)^2 P_i, \quad \mu_T = \sum_{i=0}^{l-1} i P_i$$

$$\sigma_B^2 = w_0 w_1 (\mu_0 - \mu_1)^2, \quad w_0 = \sum_{i=0}^t P_i, \quad w_1 = 1 - w_0$$

$$\mu_1 = \frac{\mu_T - \mu_t}{1 - \mu_0}, \quad \mu_0 = \frac{\mu_t}{w_0}, \quad \mu_t = \sum_{i=0}^t i P_i, \quad P_i = \frac{n_i}{n}$$

and  $n_i$  is the number of pixels with gray-level  $i$ , and  $n$  is the total number of pixels in a given image defined as  $n = \sum_{i=0}^{l-1} n_i$ . Moreover,  $P_i$  is the probability of occurrence of gray-level  $i$  defined as  $P_i = n_i/n$ .

For a selected threshold  $t^*$  of a given image, the class probabilities  $w_0$  and  $w_1$  indicate the portions of the areas occupied by classes  $C_0$  and  $C_1$ . The class means  $\mu_0$  and  $\mu_1$  serve as estimates of the mean levels of the classes in the original gray-level image. Moreover, the maximum value of  $n$ , denoted by  $n^*$ , can be used as a measure to evaluate the separability of classes  $C_0$  and  $C_1$  in the original image, and it is uniquely determined within the range

$$0 \leq n \leq 1$$

The lower bound (zero) is obtained when and only when a given image has a single constant gray level, and the upper bound (unity) is obtained when and only when two-valued images are given. This property is an important criteria that will be used in extending Otsu approach [6]. In digital images, the uniformity of objects plays a significant role in separating these objects from the background. In fact, Otsu method in thresholding gray-level images is efficient on the basis of uniformity measurement between the two classes  $C_0$  and  $C_1$  that should be segmented.

### Canny edge detector approach

Canny edge detector [7] includes the following steps:

- smoothing the image with an opportune Gaussian filter to reduce desired image details;
- computing the gradient magnitude and direction at each pixel;
- if the gradient magnitude at a pixel is larger than those at its two neighbors in the gradient direction, mark the pixel as an edge. Otherwise, mark the pixel as the background;
- eliminating insignificant edges by hysteresis thresholding.

More in detail let  $G(x,y)$  be a 2D Gaussian smoothing function

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-(x^2+y^2)/2\sigma^2}$$

where  $\sigma \in (0,1)$  and let  $G_n$  be the first derivative of  $G$  in direction  $n$ :

$$G_n = \frac{\partial G}{\partial n} = n \cdot \nabla G \quad (1)$$

Direction  $n$  should be oriented perpendicular to the edge. If  $g$  is the image, the normal to edge  $n$  is estimated as:

$$n = \frac{\nabla(G * g)}{|\nabla(G * g)|} \quad (2)$$

The edge location is then at the local maximum of the image  $g$  convolved with the operator  $G_n$  in direction  $n$

$$\frac{\partial}{\partial n} G_n * g = 0 \quad (3)$$

Substituting in Eq. (3) for  $G_n$  from Eq. (1), we get:

$$\frac{\partial^2}{\partial n^2} G * g = 0 \quad (4)$$

This operation is defined as non-maximal suppression.

The magnitude of the gradient of the image intensity function  $g$  is measured as:

$$|G_n * g| = |\nabla(G * g)|$$

Including low and high thresholds with hysteresis permits less meaningful edges to be eliminated and the final result, that is the binary image of the contours, to be generated.

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