Advances in Intelligent Systems and Computing 1078

Jyrki Nummenmaa ·
Federico Pérez-González ·
Bruno Domenech-Lega · Jean Vaunat ·
Félix Oscar Fernández-Peña *Editors*

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Editors
Jyrki Nummenmaa
Faculty of Information Technology
and Communication Sciences
Tampere University
Tampere, Finland

Federico Pérez-González
Faculty of Engineering in Bilbao
University of the Basque Country
(UPV/EHU)
Bilbao, Spain

Bruno Domenech-Lega
Department of Management,
Escola Tècnica Superior d'Enginyeria
Industrial de Barcelona (ETSEIB)
Universitat Politècnica de Catalunya
Barcelona, Spain

Jean Vaunat
Division of Geotechnical Engineering
and Geosciences; Department of Civil
and Environmental Engineering
Universitat Politècnica de Catalunya
Barcelona, Spain

Félix Oscar Fernández-Peña
Faculty of Software, Electronics
and Industrial Engineering
Universidad Técnica de Ambato
Ambato, Ecuador

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Preface

The impact of the convergence of computer science, electronics and industrial engineering in the efficiency of the industry is undeniable. Nevertheless, the mankind is facing the problem of how to wisely support the technological development in a nature-friendly basement for the sustainability of modern societies. This challenge is even greater for the economies of developing countries.

Within this scenario, the Technical University of Ambato, located in the central, and one of the most important industrial regions of Ecuador, made a call for scholars and researchers from around the world to participate in the First International Conference on Computer Science, Electronics and Industrial Engineering CSEI 2019. With the participation of invited speakers from Chile, Colombia, France, Japan, Spain, Portugal and USA, this academic event was born to become an important forum to discuss recent contributions to the sustainable industrial and social development based on the convergence of computer science, electronics and industrial engineering.

This volume comprises three sections with relevant contributions of special value for scholars and practitioners interested in knowledge representation, the use of metaheuristic for non-deterministic problem solutions, software architectures for supporting e-government initiatives and the use of electronics in e-learning and industrial environments. These contributions are not limited to scientific contributions but take into consideration, as well as, specific technical solutions for issues that impact the sustainable development of ICT-based industry.

In this edition, the CSEI Conference received 159 submissions of authors from 13 different countries. All these papers were peer-reviewed by the CSEI 2019 Program Committee made up of internationally renowned researchers coming from seven different countries. Sixty-six of these submissions were considered for the Springer publication. Based on the results of a double-blind peer review, the program chairs finally accepted the publication of 23 of the submissions as part of this book.

Sponsoring Institutions

Guest Speakers

Artificial Intelligence and Industry 4.0

Néstor Duque

Director of the GAIA Research Group, UNC, Colombia

The development of communications technologies in the twenty-first century, the massification and intensification of using Internet, renewable energy and wide automation of industrial processes give rise to what is known as the *Third Industrial Revolution* or *Third Technological Revolution*. A few years after, with the accelerated scientific and technological changes, a new industrial revolution is happening. Industry 4.0, as this new industrial revolution is known, has its technological bases, among others, on the Internet of things (IoT), additive manufacturing and 3D printing, big data, robotics and augmented reality. Artificial intelligence is pointed out as a central element of this transformation, intimately related to the increasing accumulation of large amounts of data (big data), the use of algorithms to process them and the massive interconnection of digital systems and devices. Advances in AI are not presented as more; they are the agglutinating axis.

Data is central in decision making. They open a new spectrum of possibilities but also responsibilities to the research community; the type of research projects faced nowadays must be adapted to the new conditions that allow the development of the economies of developing countries. It is an opportunity. AI was never before so well known, so named and so necessary.

What are these techniques and how do they manifest in the new industrial revolution? What are the challenges? What are the risks? Are these technologies reducing or widening the gaps among countries? These questions and examples were addressed in this talk.

Building a Temporospatial Software-Defined Network (TS-SDN)

Josua Emele

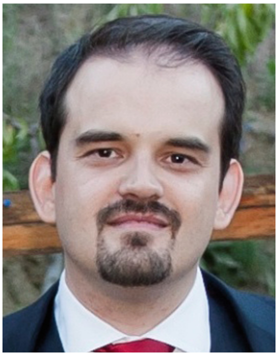
Senior Software Engineer, Loon LLC, USA

In this talk, an application of temporospatial SDN (TS-SDN) to high-altitude platform station (HAPS) networks was described. Airborne platforms (airplanes, airships, balloons) are used to carry wireless communication systems to provide direct to user as well as backhaul connections. Ground platforms equipped with directional steerable transceivers provide air-to-ground links needed to connect the wireless network to terrestrial networks. Platform movement and the impact of the environment on wireless channels lead to time-dynamic link metrics and availability. As platforms move, the network topology and routing need to adjust to maintain connectivity. Similarly, as the wireless environment changes (due to weather and interference) wireless parameters such as frequency, bandwidth and modulation coding scheme must adjust to maintain connectivity. Physical constraints of the system, such as time required to steer antennas, make reactive repair more costly than in terrestrial applications. Instead, TS-SDN models the physical evolution of the system to proactively adjust the network topology in anticipation of future changes. Using airborne networks under development at Google as an example, the benefits of the TS-SDN approach compared to reactive repair in terms of network availability were discussed. Additional constraints one needs to account for when computing the network topology were also identified, such as non-interference with other stationary and moving sources.

Use of Artificial Intelligence and Data Science in the Future of Online Education

Pablo Moreno

Director of the Chair of Data Science applied to Education, UNIR, Spain



This talk introduced different areas of the educative process in which the artificial intelligence (AI) and data science can involve a significant advance. From the perspective of the educative management, AI can be present from the students recruiting to the optimization of their own learning. From the perspective of the appropriate follow up from the facilitators, AI can be used for detecting students with special needs, anomalies in class performance or for developing automatic assessment techniques (stealth assessment). Finally, from the perspective of the transversal management, AI and data science allow to identify the differences among education districts, education institutions with performance issues, or dispersion patterns of students considering their social–economic profiles. During this talk, different data exploratory techniques were introduced as well as results of their use in recent research projects on educational innovations.

Exploring Millimeter and Terahertz Waves for Communications and Sensing

Tadao Nagatsuma

Professor at Graduate School of Engineering Science, Osaka University, Japan

This talk described how effectively photonics technologies are implemented not only in generation, detection and transmission of millimeter and terahertz (THz) waves, but also in system applications such as communications, measurements and imaging. In addition, some unique approaches, which utilize concepts or physical phenomena established in the light wave region in order to enhance functionality and performance of millimeter-wave and THz applications, were presented. Finally, in order to make millimeter-wave and THz systems more compact and cost-effective, recent challenges in photonic integration technologies were described, which include monolithic and hybrid integration schemes.

Understanding Value Hierarchies and Their Interrelationships—A Glance in the Managerial Multi-objective Processes

Alexis Olmedo

Head of the Engineering School, UNAB, Chile

It is said that the interaction between value hierarchies determines the target involved in decision-making processes. This process is influenced by the type of required strategic decision and how the attraction and commitment effect, described by Simonson, act on the stakeholders. This talk proposed to carry out a field-work with manipulation of the factors affecting the goal achievement. This way, the information gathering process is achieved. A focus group research with middle-ranking officials of different companies is proposed for determining the main present factors in the process of managerial decision. Meanwhile, the implementation of a work environment written interview is applied to managers of different organizations and a three-dimensional scale is used for objectives addressing (domain, performance focus and performance avoid).

The use of the analytic network process methodology, proposed by Thomas Saaty, allows us to interpret the gathered information. From the management perspective, based on the consumer behavior theory, it is expected to reliably estimate the relative weight of the meaning and the relationship among the values presented in the choice of managers in the presence of the attraction and commitment effect.

Model for the Quality of Local e-Government Services

Álvaro Rocha

President of AISTI, Portugal

One of the main challenges underlying different electronic government forms is the provision of a quality public service. In the local government context, local authorities allow for an adjustment between the characteristics of public services and the specificities of local communities, letting populations define their own priorities, which vary from community to community based on objective elements but also subjective by nature. The quality of these services in their electronic format should be analyzed and taken into consideration to potentiate and elaborate a strategy capable of improving offered services, increasing the satisfaction of the recipients. This talk presented a new and innovative model for the quality of local e-Government services, based on a literature review, where we analyzed seventeen approaches for e-Government services quality, as well as an empirical study involving a group of experts and users of local government services.

Smart Industry: The 4.0 Data-Centric Revolution

Genoveva Várgas

Senior scientist, CNRS, France

The idea of smart industry is based on the notion of Industry 4.0 that denotes technologies and concepts related to cyber-physical systems and the Internet of things (IoT). In smart industry, there are sensing systems that monitor physical processes, they create a virtual copy of the physical world, a "datified" version of it, and make decentralized decisions. With IoT, monitoring systems communicate and cooperate in real time.

This talk introduced the architecture of a smart industry based on communication layer and software later that integrate physical entities. Each physical entity is seen as an intelligent and autonomous agent that embeds programs for letting it evolve in workshops. Thereby, the physical world composed of connected things and the digital universe consisting of computing, storage and memory resources are combined.

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Contents

Computer Science

Method for Edges Detection in Digital Images Through the Use of Cellular Automata

Karen Angulo[1(✉)], Danilo Gil[1], and Helbert Espitia[2]

[1] Systems Engineering, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
{kvangulos,dggils}@correo.udistrital.edu.co
[2] Faculty of Engineering, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
heespitiac@udistrital.edu.co

Abstract. In the present article, an algorithm based on cellular automata for noise elimination and edge detection in grayscale images is proposed. However, the focus of this project will be on the process of identifying contours, since this represents a higher challenge at the research level. Also, the cellular automaton has an adaptive behavior, which allows it to expand when it considers that the information coming from its initial neighbors is insufficient to determine if the pixel in evaluation is a "border pixel" or not, as this is an important feature together with a set of transition rules useful to accentuate relevant details within the image. By integrating these characteristics, we find the results obtained by the Proposed Algorithm presented greater similarity compared to images with ideal borders, since the edge recovery ranges between 92.30% and 97.21%, which indicates that MEDCA is in general terms, more efficient compared to similar algorithms.

Keywords: Cellular automaton · Digital images · Image processing · Edges

1 Introduction

In the field of image processing, edge detection is a relevant and widely used application because it is considered a low-level processing operation [1]. In other words, a contour is located in the first operation of the algorithm on the image, when examining each pixel and determining whether it has the properties of an edge. Thus, the main emphasis of this tool is to focus and identify sharp discontinuities present in the image [2]. These discontinuities are defined by some authors as abrupt changes in the intensity of the pixels and are the main characteristic to find the limits of the objects that are immersed in an image. From this concept arises the need to denote an edge as which limits and segments the different regions or objects within the image under evaluation [2]. Edge detection is usually the first step of many of computer vision algorithms (edge-based facial recognition, edge-based obstacle detection, edge-based objective recognition, and image compression, among others).

Considering that the quality of an identified edge is directly related to the content of the image and the user requirements, the development of a method for edge detection

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that meets all the desired results is a subjective process [2, 3]. Consequently, it is difficult to compare the performance of two algorithms that have the same purpose. However, it is common for researchers to compare the results with those of Sobel, Prewitt, and especially Canny. The problem of these is that, despite the results obtained by these researchers are remarkable, there is no consistency when comparing the data obtained in algorithms or methods that do not have the same characteristics.

Despite the subjectivity immersed within the algorithms, some authors have chosen to use cellular automata to generate as many possible edges within the image, given its practicality and behavior; an automaton can be seen as a regular grid of cells that contains a finite number of possible states. The state of the cell under evaluation is synchronously updated in discrete time steps and is also determined by the previous states of the surrounding neighborhood [4]. The rules that generate the transition of states of the central cell (in evaluation), are considered as finite state machines, and generally, such rules specify the configuration of the neighborhood states [4, 5].

Thanks to the details provided above and to the fact that cellular automata are discrete dynamic systems used to simulate different behaviors and phenomena in different areas of science, from this arose the idea to Wongthanavasu and Sadananda [6], which use an algorithm to change the pixel in evaluation, if and only if the whole neighborhood has the same value and just one iteration is necessary for the result to be obtained, since the other iterations do not modify the image. In spite of its simplicity and effectiveness, this algorithm shows flaws when the images have noise, since it prevents the proper functioning of the automaton. It should be noted this method implemented a Von Neumann neighborhood.

In another type of approach, they focused on finding optimal transition state rules, for this, the use of genetic algorithms is quite common, which can present considerably satisfactory results. Selvapeter and Hordijk [7] used this method to train cellular automata; in addition, this algorithm has the ability to perform their work on images with different noise levels. At the technical level, Selvapeter and Hordijk used a noise filter based on cellular automata, and they later trained another cellular automaton for edge detection, whose results are comparable with the methods of Sobel, Prewitt and Canny, despite the fact that these methods work directly on the image with noise and it was not previously filtered.

In an analogous way, Batouche, Meshoul and Abbassene [8] generated a more efficient solution, when established a generic algorithm based on a cellular automaton for edge detection, which did not require such a high amount of training patterns (In a Moore neighbor it requires $2^9 = 512$). The operation of this, in general terms, consisted of combining patterns according to a threshold of similarity which reduced to 15 the amount of training patterns, and later the image was rotated every 90° applying the same rules. Thanks to this, processing time was reduced and the results are obtained correctly, although the edge is a little thick.

Within the multiple existing variations for edge detection, Slatnia, Batouche and Melkemi [9] adopted a methodology similar to that used in [8], because they established symmetrical patterns to the same rule; however, the set of rules were trained in different way. Instead, they trained a genetic algorithm with a single generic rule, in which the central pixel changes its state only when its Moore neighborhood matches a specific pattern, and analogously they obtained the same rule as Wongthanavasu and Sadananda. For this case, the results are compared with those of Canny, which visually do not have the same quality.

On the other hand, Yang, Ye, and Wang [10], established an algorithm based on cellular automata taking into account the neighborhoods of both Moore and Von Neumann, which can be defined in two steps: the first step consists of an iteration in which it evaluates if three contiguous neighbors of the central pixel have the value one (1) and the other three neighbors symmetrical respect to the central pixel have the value zero (0), then the pixel in evaluation maintains its state, otherwise it changes it. In the next step, several iterations are performed based on a rule in which the pixel in evaluation is considered edge if exactly two pixels in the Von Neumann neighborhood are pixels, and if the other neighbors in a Moore neighborhood are not edges.

From another point of view, the images are often affected by impulsive noise, which can occur or be caused by different factors such as errors or interference when transmitting the information bits, memory locations defective in the hardware, errors associated to the equipment used for capturing images or pixel malfunction in the camera sensors [11]. An image, as well as any type of data can reveal valuable information in any field and the presence of noise can significantly affect the results that are expected from it, thus, it is important to efficiently suppress these interferences [12]. Within the classification of impulsive noise there is a special and well known case named “salt and pepper noise”. This can be perceived in a contaminated image when the pixels take maximum or minimum values of the scale; that is, they usually appear as black and white dots on the image [11, 13].

One of the solutions to this type of situation can be represented by means of cellular automata through the coupling of different methods that allow not only the identification of noise, but an efficient restoration of the image quality. This work, in different cases, can be carried out by means of a series of iterations on the image by the cellular automaton. In the first instance, for this particular case, the cellular automaton advances through each pixel, identifying the maximum and minimum values to modify the value depending on the configuration of their neighbors and, subsequently, different iterations are performed (depending on the noise level) where the quality of the image is improved thanks to the use of the average.

Like the previous ones, there are countless of other works in which the subject of contour detection is covered, which encompass this situation from different perspectives, keeping in mind that today there are different types of images with scales of varied intensities. Then, given the diversity and challenges in this field, in addition to the strong relationship between cellular automata and image processing, this paper aims to generate a proposal for an algorithm based on cellular automata that eliminates noise and detects edges of digital images.

2 Background

2.1 Cellular Automata

The concept of cellular automaton was introduced and put into practice in the computational field of physics by the Hungarian-American mathematician Von Neumann in the 1950s [14]. This is defined as a simple mathematical model that is based on the concepts of self-organization and self-reproduction [14]; moreover, conceptually it is seen as a dynamic system that is not only discrete in time, but also in space [15].

Regarding the operation of a cellular automaton it can be said that the state of the cell under evaluation, at time t + 1, will be determined by the current state of the surrounding neighbors. This will be updated synchronously in discrete time intervals [15, 16]. That is, from a more formal and mathematical perspective, an automaton is defined as 3-tuple like this:

$$A = (S, N, \delta) \tag{1}$$

Where, S it is a set of non-empty states, N is the neighborhood, and $\delta : S^N \rightarrow S$ is the local transition function (or rule) that defines how a cell changes its state.

As mentioned above, the automata can be seen as a set of $D - dimension$ cells, where the cells that will be part of it are located. Figure 1 shows cellular automata of dimension, $D = 1$, $D = 2$ and $D = 3$. Currently, the case that is most frequently used in the various applications of the investigative sciences, particularly in the processing of images, is simulated in a two-dimensional space.

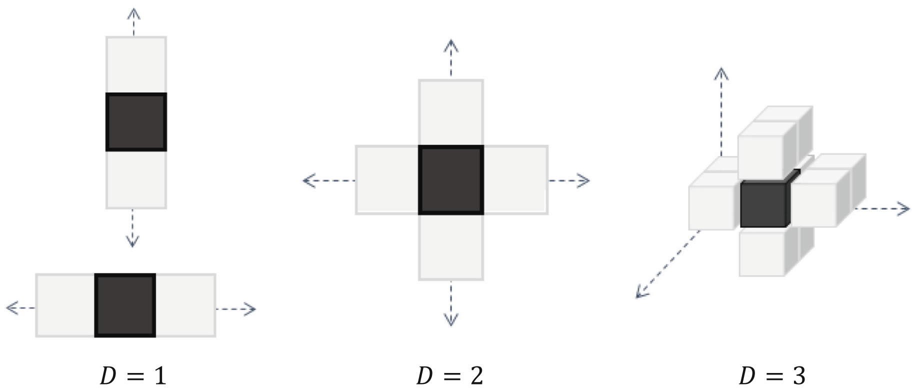

Fig. 1. Dimensions of cellular automata.

Regardless of the chosen dimensions, every cellular automaton has a certain basic structure, which is composed of three parts: (a) set of cells or lattice, (b) a set of adjacent neighbors or neighborhood, and (c) a set of rules for local transitions [17].

a. Set of cells or lattice, which has a finite number of possible states or values for each cell, for binary images 1 or 0, and for grayscale images from 0 to 255.

b. Set of adjacent neighbors or neighborhood, such as the Von Neumann neighborhood (4 neighbors) or the Moore neighborhood (8 neighbors).
c. A group of rules for local transitions (local functions of transition, transition of the state of the cells or table of transitions of the states of the cells). In synthesis, within the groups of rules there are two particularities to be highlighted: (i) the communication between the central cell and its neighbors is local, uniform and synchronous, and (ii) the global evolution of the system through a discrete time step is deterministic [17].

Over the last 60 years, a number of researchers (including Stanislaw Ulam and John Von Neumann, John Holland, Stephen Wolfram, and John Conway) have investigated issues related to the properties and variations that a cellular automaton can have, but in particular there are large studies on neighborhoods, of which the neighborhoods of Von Neumann and Moore stand out, since these have been the most used applications over the years.

- Von Neumann Neighborhood: A cross-shaped neighborhood on a grid of two-dimensional with $l \times l$ size is used to define the set of cells that surrounds the cell under evaluation (x_0, y_0). The Von Neumann neighborhood of rank r is defined by Eq. (2).

$$N_{x_0,y_0} = \{(x, y) : |x - x_0| + |y - y_0| \leq r\} \tag{2}$$

This means that at its most elementary level it has 4 neighbors from the central pixel as shown in Fig. 2. However, in many cases this neighborhood can be extended n times, searching so that by means of the previously established rules a greater amount of information can be handled as shown in Fig. 3.

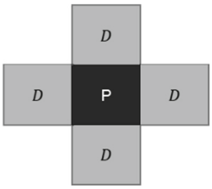

Fig. 2. Von Neumann neighborhood.

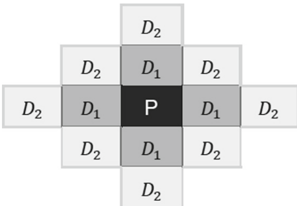

Fig. 3. Von Neumann extended neighborhood ($n = 2$).

- Moore Neighborhood: A square neighborhood on a two-dimensional $l \times l$ grid is used to define the set of cells that surrounds the cell under evaluation (x_0, y_0). The Moore neighborhood of rank r is defined by Eq. (3).

$$N_{x_0,y_0} = \{(x, y) : |x - x_0| \leq r, |y - y_0| \leq r\} \tag{3}$$

In the case of the Moore neighborhood, its essential form considers 8 neighbors from the base cell, which facilitates the handling of edges and corners; in addition, the information that can be managed with this neighborhood is greater than the one of Von Neumann due to the consideration of four additional cells, as shown in Fig. 4. In the same way as it happens with the configuration of Neumann, this neighborhood also presents extended versions in n cells, which obey to the formula $(2n+1)^2-1$. In the following example, the expanded neighborhood can be appreciated in $n = 2$ (see Fig. 5).

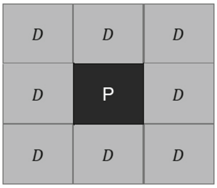

Fig. 4. Moore neighborhood.

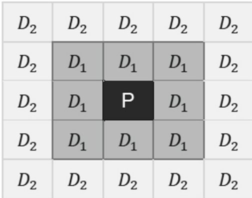

Fig. 5. Moore extended neighborhood ($n = 2$).

Having clear the neighborhood types and their concepts, it was determined that in accordance with the needs of the algorithm, the Moore neighborhood is more useful and efficient, since it offers greater advantages over the others, in terms of the amount of information that you can get from your neighbors; thus giving the pixel under evaluation the option of being detected as a possible "edge pixel" and of being corrected efficiently.

2.2 Edge Detection

Within the sensorial capacities that human beings possess, the sight is probably the most important among all of them, thanks to the fact that through this we acquire a considerable quantity of information of our environment, such as colors, shapes, sizes, distances, etc. Of the above, the variation between intensities is one of the features that stands out, even though an image lacks three-dimensional information such as texture or shadows, it is possible to identify objects by means of borders or silhouettes [1, 18]. This is why the borders detection has a key role in image processing as through the existing methodologies it is possible the identification of objects, pattern definition or segmentation of information inside the images [2].

Within the scope of this research work, a pixel can be considered as an edge, when there is a noteworthy difference between the levels of gray intensities within the image [1, 2, 19], said the change is recognized as a boundary between two different regions in an image.

In gray scale images edge detection can be done by generating an identification of changes in light intensity over the number of pixels under evaluation [20]. That is, if there is a linear series of pixels with intensities of: 255, 248, 252, 76, 73, 79 an edge or discontinuity would be expected between pixels with intensities of 252 and 76. Within some texts, these pixels are referred to as "edge points" and these may be useful at the time of analyzing the image.

Given the importance of this process of digital analysis in the images, over the years several basic methods for edge detection have emerged, among the most outstanding, the following can be mentioned:

- Method based on the first derivative (gradient): In this method the intensity has greater magnitude than the predefined threshold of the image. The largest peaks in the image are searched. The gradient of an image at a point indicates the maximum variation of the function at that point [21], which is defined by:

$$\nabla f(x, y) = \left[G_x G_y\right] = \left[\frac{\delta f}{\delta x}\frac{\delta f}{\delta y}\right] \quad (4)$$

  Where, $G_x = \frac{\Delta f}{\Delta x}$ y $G_y = \frac{\Delta f}{\Delta y}$.
- Method based on the second derivative (Laplacian): The intensity has crossing by zero. Unlike the first derivative method, it does not require a threshold value to have a more effective approach. The signs changes where an edge is found [21]. Mathematically it is defined by Eq. (5):

$$\nabla^2 f(x, y) = \left[\frac{\delta^2 f}{\delta x^2}\frac{\delta^2 f}{\delta y^2}\right] \quad (5)$$

Figure 6 shows a relation of the behavior of these methods when variations in intensity are detected.

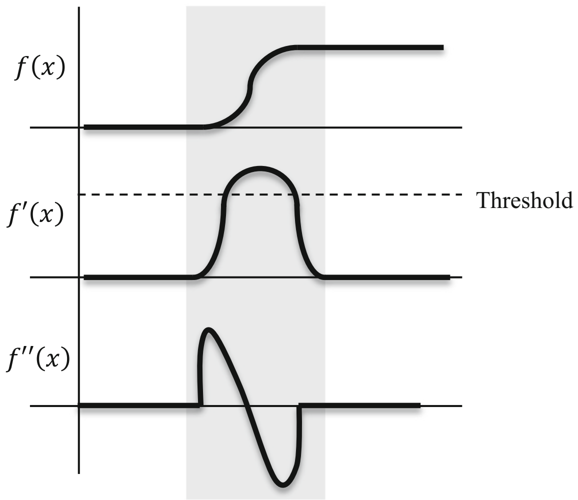

Fig. 6. Methods of the first and second derivatives for edge detection.

- Method of Canny: This algorithm for the identification of contours was developed in 1986 by John F. Canny, it presents better results than those previously explained methods, although the computational complexity is higher [21]. This algorithm is based on three basic criteria:
  - Detection: It avoids the elimination of relevant edges, as well as the generation of false edges that can harm the final result.
  - Location: It stipulates that the distance between the real position of the edge and the generated one, must be reduced.
  - Unique answer: Express that the algorithm must return an edge pixel for each true pixel, that is, there must not be groups of pixels where only one must exist.

3 Cellular Automata Design

In this work, the experiments were done with grayscale input images and an initially determined neighborhood with a 3×3 size, that is, Moore neighborhood, which travels the whole image pixel by pixel and determines if the pixel in evaluation, according to the configuration that its neighbors have (transition rules) is defined as edge. When this edge is identified, it changes its current value (by 1 or 0) and the automaton advances to the next position. The input values (initials), are provided by the image and having that data, the automaton can start to iterate all over the image. For fixed value limits, the conditions apply in which transition rules can only be designated to non-limit cells.

When talking about a Moore neighborhood and gray scale images, it is said that: (i) there is a neighborhood of fixed size of 3×3, described by Eq. (3), and, (ii) a pixel within the image you can take discrete values between 0 and 255, that is, 256 intensity values. Conceptually, the salt and pepper noise is scattered randomly over the whole image, affecting it with the maximum (white) and minimum (black) values, which, for this case, would be represented by $min = 0$ y $max = 255$. Then, when describing in a mathematical way the proposed rule for the cellular automaton, we have that the value of the pixel in evaluation in the next iteration $(C^{t+1}(i,j))$ can take two values depending of the current status $(C^{t}(i,j))$ (see Eq. (6)).

$$C^{t+1}(i,j) = \begin{cases} C^{t}(i,j), \ if\ min < C^{t}(i,j) < max \\ Cn^{t}(i,j), \ if\ C^{t}(i,j) = min\ or\ C^{t}(i,j) = max \end{cases} \quad (6)$$

Where, $C^{t+1}(i,j)$ is the value that the pixel will take in the next iteration, $C^{t}(i,j)$ is the current value of the pixel, $Cn^{t}(i,j)$ is the value that the noisy pixel will take.

$$Cn^{t}(i,j) = \begin{cases} C(2n+1)2{-}1, \ if\ \forall\, C^{t}(i,j) \in N, C^{t}(i,j) \neq min\ or\ C^{t}(i,j) \neq max\, and\, N = \emptyset \\ avg(C^{t}(i,j)), \ if\ \forall\, C^{t}(i,j) \in N, \exists C^{t}(i,j) \neq min\, or\, \exists C^{t}(i,j) \neq max \end{cases} \quad (7)$$

Where, N is the neighborhood in the current iteration y $C(2n+1)2{-}1$ indicates that the neighborhood will be expanded by $n = 2$.

Applying Eq. (6), the primary focus of this methodology is divided into two broad strands. The first one avoids acting on those pixels that are not considered noisy, which decreases the operations carried out by the algorithm and, consequently, the computational cost. The second one examines whether the affected pixel has the value of 255 (maximum or white) or 0 (minimum or black), in the affirmative case, the sub-rule described in Eq. (7) is applied, which specifies that all the minimum and maximum values will be eliminated to calculate an average of the rest and thus obtain the new value of the cell in case the Moore neighborhood lacks information, that is, that it only has maximum or minimum values in its configuration, it will adapt and it will be extended in $n = 2$ (see Fig. 5 for Moore extended neighborhood) and the cell state will be the average with the additional information excluding the maximum and minimum values. To conclude, the cellular automaton is evaluated a finite number of times depending on the value of the noise immersed in the image, in this way, if the noise level is equal to n, the cellular automaton will iterate $(n/10) + 1$ times. Upon completion of this process, the image will be ready for the edge detection process.

As explained above, when working with a 3×3 neighborhood with cells (pixels) that can take intensity values from 0 to 255, there are 256^8 possible patterns or rules that the neighborhood can have (this without considering the value of the central pixel). However, they can be reduced considerably by applying the concept of rotational symmetry. It is said that a flat figure has rotational symmetry when a center (called the center of rotation) can be found so that if the whole figure is rotated at a certain angle (greater than or equal to 0° and less than 360°), the rotated figure matches the original figure. The number of times that the rotated image can be matched with an original figure is called the order of the rotation [22].

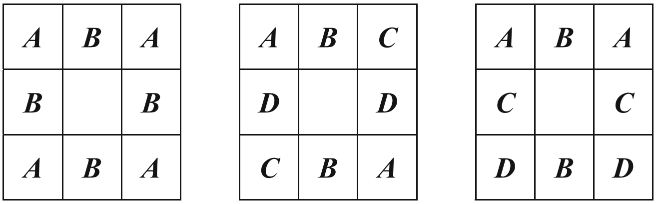

Fig. 7. Patterns of a neighborhood of 3×3 that remains invariant with a rotation of $\pm 90°$, 180° and mirror-like symmetry [4].

Considering the above and applying the concept of a Moore neighborhood, it is possible to affirm that the same rule can be discarded if the image is rotated and the pattern remains the same, reducing the number of rules by approximately 5 times its size [4, 5]; to identify the number of different resulting patterns after the elimination of equivalent symmetric pairs, it is possible to apply the enumeration method described by Pólya-Burnside [23], for all G that is a set of permutations of a set A, so that the number of equivalence classes is: