Fuzzy Logic Based Edge Detection Methods: A Systematic Literature Review

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Abstract: Edge detection, or the detection of the maximum limit between two regions with different properties, is one of the classic problems in the area of computer vision. The uncertainty associated with the nature of this detection, such as the characteristic fuzzy transition zone resulting from the image discretization processes, or even noise and illumination variations, justifies an approach based on fuzzy logic theory. In order to understand the state of the art in edge detection techniques using fuzzy logic-based methods, this work proposes a systematic review considering two bibliographic sources of scientific literature, Scopus and Web Of Science. In total, 34 works were selected through a systematic literature review, and their methods were summarized and reported in this research. From this analysis, it could be concluded that, in recent years, fuzzy logic has been employed in hybrid methods in order to improve the performance of existing techniques or reduce computational complexity. Studies with interval fuzzy logic of higher order have been employed for its greater flexibility in dealing with the uncertainty associated with the edge detection task.

1 INTRODUCTION

One of the most common approaches for detecting discontinuities in images is edge detection (Suresh and Srinivasa Rao, 2019). An edge is defined as the maximum boundary between two regions with different properties (Martin, 2002), i.e. the border between two objects or object faces in an image.

Edge detection represents an important task in several steps of computer vision and image processing such as (Wei et al., 2017); object detection (Yang et al., 2002); pattern recognition (Mohan et al., 2021) and others. Either because of the discretization intrinsic to the digital capture process, or because of some subsequent quantization process, the edge of the objects, or the faces of the objects, show a small smoothing around the actual boundary of the regions.

This uncertainty, among other characteristics of the images, makes it difficult to accurately determine the edge of objects, so different methods have been proposed throughout history, from methods based on partial derivatives such as Sobel (Sobel et al., 1968), Log (Marr and Hildreth, 1980) and Canny (Canny, 1986) in the 1970s and 1980s, up to methods based on convolutional neural networks in recent years (Jing et al., 2022).

Traditional methods have a number of problems, such as high sensitivity to noise, high complexity, and high consumption of time and processing. In general, these methods show very discontinuous results and false positives.

On the other hand, methods based on fuzzy logic (Zadeh, 1965) were developed in order to represent the imprecision and uncertainty of the information (Tripathi et al., 2021). In recent years, there has been increasing research on applications of fuzzy logic in several areas such as pattern recognition, neural networks, expert systems, artificial intelligence, control theory, automata, decision-making, medical diagnosis, and robotics. (Muthalagu et al., 2020; Orhei et al., 2020; Qiu et al., 2021).

In computer vision, in addition to applications in edge detection (Bustince et al., 2009; Lopez-Molina et al., 2010; Marco-Detchart et al., 2021b), fuzzy ap-
proaches have been frequent in noise reduction (Yuk-
sel and Basturk, 2012), feature extraction (Shimada
et al., 2005), classification and clustering (Koschan
and Abidi, 2005).

Considering the importance of research in edge
detection through the fuzzy theory approach, and
since, to the best of our knowledge, there are no re-
view papers devoted specifically to fuzzy methods,
a specific investigation/review of these methods is
needed.

In this sense, the main research question which is
intended to be answered is: RQF - what is the state
of the art of fuzzy edge detection methods? In order
to relate them to the rest of the literature in the area
of edge detection, the following should also be an-
wsered: RQG - what is the state of the art of edge
detection methods?

For each research question, a bibliometric analy-
sis was sought in order to provide a set of information
that would appropriately position new research activ-
ities, this being another contribution of this work, be-
sides the summarization and description of the found
methods.

This paper is organized as follows: in Section 2
(Methodology), the search terms, inclusion and exclu-
sion criteria, as well as the number of papers found
and admitted for review will be discussed. Next, in
Section 3, the results and discussion are presented for
each research question mentioned above, summariz-
ing the reviewed methods with their respective biblio-
metric analyses. Finally, in Section 4, the conclusions
are exposed.

2 METHODOLOGY

This section first introduces the concept of a system-
atric literature review and then presents the methodol-
ogy used to answer the research problems.

2.1 Systematic Literature Review

According to (Kitchenham and Charters, 2007), a sys-
tematic literature review is a form of analysis that
aims to identify, evaluate, and interpret all avail-
able relevant research on a specific research problem,
topic, or phenomenon of interest. Among the various
reasons for engaging in a systematic literature review,
the most common are:

i. Summarize the existing evidence regarding treat-
ment or technology;

ii. Identify gaps in current research with the goal of
suggesting areas for future research;

iii. Provide a set of information that appropriately po-
sitions new research activities and;

iv. Reduce, or try to eliminate research bias.

In this context, this research seeks to summarize the
existing technology regarding fuzzy edge detection
methods. For this, key good practice questions for a
quality review, found in (Tacconelli, 2010), were con-
considered.

2.2 Definition of Criteria, Search in the
Indexing Bases and Obtaining
Primary Research

In order to answer the research problems, searches
were conducted in two major bibliographic databases,
Scopus (SC) 1 and Web of Science (WS) 2. In total,
34 papers were selected by merging the results of
the searches in the two databases (21 from the SC
database and 16 from the WS database). This union,
by definition, considers the exclusion of duplicates.

The summary of all the included information and
documents that went through each exclusion step,
which will be discussed below, is shown in Table 1,
where we show for each search question, the con-
sidered inclusion terms, where ABS() refers to the
terms found in the abstract and TITLE() refers to the
terms found in the title. In the number of occurrences,
we have the total number of papers found by each
database, where inc is the number of papers found in
that search, and for each exclusion step (exc) the total
number of elected papers.

One can see in Table (1) that four exclusion steps
were considered:

i. Step one:
   a) Exclusion of papers published before the
year 2017;

ii. Step two:
   a) Elimination of those that were not written
in the English language;
   b) Deletion those that have not been pub-
lished in the computer science or related field and;
   c) Elimination papers that had a title that
demonstrated the lack of relevance of that study
to this review work.

iii. Step three:
   a) Deletion of the works flagged as portrayed
by the journal and;
   b) Analysis of the abstract, eliminating arti-
cles that were outside the scope of this review.

1 www.scopus.com
2 www.webofscience.com
iv. Step four:
a) Analysis of the methodology and exclusion of those with no validation of the proposed segmentation method.

2.3 Bibliometric Analysis

Bibliometric analysis is defined as the quantitative disclosure of the characteristics of a set of works, with the objective of managing knowledge and scientific information on a specific theme or subject (Aria and Cuccurullo, 2017). One can cite as observable parameters that are commonly analyzed from the articles and papers selected: their references, authors, number of citations, and most relevant journals.

To perform the bibliometric analysis of the papers in this research, we decided to use the bibliometrix tool through the Rstudio software (Aria and Cuccurullo, 2017). Each set of papers, which were selected in order to answer one of the problems of this research, was submitted to bibliometric analysis, evaluating the keywords, authors, affiliation, abstract, citations, and country of origin, reporting only the information relevant to the research problem.

3 RESULTS AND DISCUSSION

This section presents the results of each bibliometric analysis of each group of papers, the summary of the methods found in each set of papers, and a short discussion aiming to synthesize the obtained information.

3.1 State of the Art in Edge Detection (RQG)

In order to identify the state of the art of edge detection methods in the literature, we have chosen the papers that are summarized in Table 2. The bibliometry performed aimed to understand the frequent terms, as well as those that have gained relevance in the last 6 years.

First, the absolute numbers of citations that each work received were extracted from the metadata, to determine those with greater relevance to the research topic. In addition, the most cited papers are those that, potentially, best summarize the state of the art until that year of publication, and have a higher ratio between the number of citations and the time elapsed since publication.

In this case, the articles (Magnier et al., 2018; Kaur and Kaur, 2017; Yogesh et al., 2018) appear as the most cited, in the first three positions. Evaluating the number of citations/year, from publication to the present moment, we observe that the works (Suresh and Srinivasa Rao, 2019; Magnier et al., 2018) have the highest scores. In the case of (Suresh and Srinivasa Rao, 2019) it is the most recent work with the highest citation/year ratio.

Through the word cloud of the keywords of all the papers, if we disregard terms such as: “edge detection”, “segmentation”, “image processing” and other terms that are synonyms or homonyms to them since they are expected words considering the search terms, we find related and recurrent terms that may indicate the methods or applications that have been developed in the studied period. Figure 1 summarizes the most frequent terms found, among them, we can observe terms related to fuzzy logic, machine learning, genetic algorithms, and other classical segmentation and edge detection techniques.

Figure 1: Word clouds of key terms of RQG edge detection methods.

The occurrence of terms related to classical segmentation and edge detection techniques such as Canny, Sobel, and Watershed in the keywords may indicate a movement towards improving the performance of these techniques that have already been exhaustively studied. Further evidence of this could be found through another analysis, where the terms were considered by year. In this case, words like “edge”, “detection” and “segmentation” were the most frequent in the abstracts of the papers in the year 2020, where performance-related terms also started, which had a higher frequency in the year 2022. From these papers, it is interesting to extract especially the methods reviewed by the authors regarding the state of the art in the area of edge detection. Therefore, in the following, we will present a summary of the techniques, grouped by approach.

Gradient-Based Methods: A digital image is a discrete representation of the variation of light in the real world, so each numerical value carried by the pixel represents the intensity of light or color at that...
Table 1: Terms of inclusion and exclusion and number of selected papers.

<table>
<thead>
<tr>
<th>Research question</th>
<th>Terms of Inclusion</th>
<th>Number of occurrences</th>
<th>SCOPUS</th>
<th>WEB OF SCIENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQG</td>
<td>(ABS( edge PRE/ detection ) OR ABS(image PRE/ segmentation )) AND TITLE(survey or review)</td>
<td>inc: 768 1ª exc: 518 (i) 2ª exc: 244 (ii) 3ª exc: 15 (iii) 4ª exc: 15 (iv)</td>
<td>inc: 1,475 1ª exc: 1,038(i) 2ª exc: 248(ii) 3ª exc: 3(iii): 4ª exc: 3 (iv)</td>
<td></td>
</tr>
<tr>
<td>RQF</td>
<td>ABS (fuzzy AND ( edge PRE/ detection ) ) AND TITLE (fuzzy OR edge OR segmentation)</td>
<td>inc: 870 1ª exc: 247 (i) 2ª exc: 7 (ii) 3ª exc: 6 (iii) 4ª exc: 6(iv)</td>
<td>inc: 717 1ª exc: 224 (i) 2ª exc: 21(ii) 3ª exc: 13(iii) 4ª exc: 13(iv)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Papers in edge detection (RQG).

<table>
<thead>
<tr>
<th>Reference</th>
<th>Paper title</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Kaur and Kaur, 2017)</td>
<td>An Edge detection technique with image segmentation using Ant Colony Optimization: A review</td>
</tr>
<tr>
<td>(Castillo et al., 2017)</td>
<td>Review of Recent Type-2 Fuzzy Image Processing Applications</td>
</tr>
<tr>
<td>(Yogesh et al., 2018)</td>
<td>A comparative review of various segmentation methods and its application</td>
</tr>
<tr>
<td>(Magnier et al., 2018)</td>
<td>A review of supervised edge detection evaluation methods and an objective comparison of filtering gradient computations using hysteresis thresholds</td>
</tr>
<tr>
<td>(Magnier, 2018)</td>
<td>Edge detection: a review of dissimilarity evaluations and a proposed normalized measure</td>
</tr>
<tr>
<td>(Agrawal and Bhogal, 2019)</td>
<td>A review—Edge detection techniques in dental images</td>
</tr>
<tr>
<td>(Aggarwal et al., 2019)</td>
<td>Review of Segmentation Techniques on Multi-Dimensional Images</td>
</tr>
<tr>
<td>(Zhu and Li, 2019)</td>
<td>Survey on the image segmentation algorithms</td>
</tr>
<tr>
<td>(Suresh and Srinivasa Rao, 2019)</td>
<td>Various image segmentation algorithms: A survey</td>
</tr>
<tr>
<td>(Ghosh et al., 2020)</td>
<td>Different EDGE Detection Techniques: A Review</td>
</tr>
<tr>
<td>(Budzyn and Rzepka, 2020)</td>
<td>Review of edge detection algorithms for application in miniature dimension measurement modules</td>
</tr>
<tr>
<td>(Chakrapani et al., 2021)</td>
<td>A Survey of Sobel Edge Detection VLSI Architectures</td>
</tr>
<tr>
<td>(Isa et al., 2021)</td>
<td>Review of Edge-based Image Segmentation on Electrical Tree Classification in Cross-linked Polyethylene (XLPE) Insulation</td>
</tr>
<tr>
<td>(Mubashar et al., 2022)</td>
<td>Have We Solved Edge Detection? A Review of State-of-the-art Datasets and DNN based Techniques</td>
</tr>
<tr>
<td>(Yadav and Pandey, 2022)</td>
<td>Image Segmentation Techniques: A Survey</td>
</tr>
<tr>
<td>(Jing et al., 2022)</td>
<td>Recent advances on image edge detection: A comprehensive review</td>
</tr>
</tbody>
</table>

The contours of objects in the image can be interpreted as a transition zone between these intensities so that more intense transitions have a much greater chance of being an edge than smoother transitions. That is, given a direction in the image, the rate of change or discrete difference between pixels highlights the likely edges of the objects (Marco-Detchart et al., 2021a).

It was through this reasoning that the first edge detectors emerged (Agrawal and Bhogal, 2019). There are two approaches to gradient-based detection: first-order derivative-based, and second-order derivative-based.

The best-known gradient-based detection methods are first-order fixed operations; first-order oriented operations that use the maximum energy of the orientation; or two-direction operations.

To facilitate understanding regarding the development of the techniques throughout history, we have summarized in a timeline the publication dates of the articles describing the first version of each method described in this section, which can be seen in Figure 2. The following are some of the classical gradient-based methods and their main differences (Aggarwal et al., 2019).

The Canny Detector (Canny, 1986), to this day one of the most widely used, was proposed considering a Gaussian smoothing followed by a gradient operation and finally thresholding. In the studies in (Jing et al., 2022), we found other methods based on first-order derivatives, inspired by Canny, such as Infinite size Symmetrical Exponential Filters (D-
ISEF), a color-boundary and first-order derivative of anisotropic Gaussian (FDAG).

Sobel’s detector (Sobel et al., 1968) calculates the gradient value at each pixel position in the image using a fixed operator. In turn, Prewitt (Prewitt et al., 1970) has a similar technique to Sobel, but unlike Sobel it has no adjustment coefficients, varies by a constant value, and calculates the magnitude of the gradient with the image orientations.

The method proposed by Roberts (Roberts, 1980) first appears in the literature in 1963, as the product of his doctoral thesis. This method calculates the derivative by taking the root of the difference between diagonally adjacent pixels. It focuses on invariant properties that edges exhibit.

The LoG (Marr and Hildreth, 1980), or Gaussian Laplacian, is based on a Gaussian filtering followed by a Laplacian operation. It is based on a second-order operator, which seeks to identify the maximum and minimum points of the variation of intensities so that by finding these points that cross to zero, the edge candidates in the image are found. The Gaussian filter step is important because it is a second-order method and therefore extremely sensitive to noise.

Region Segmentation-Based Methods: Another set of methods for edge detection is based on region segmentation. In these methods, regions are segmented, such as clustering and automated thresholding methods, and edges are detected as the boundary of these regions. According to (Mubashar et al., 2022), the regions formed by the textures in high-complexity images can be used as a facilitator in the process of detecting the edges between them.

The region-based approach outperforms direct detection methods such as gradient methods. Others, such as frequency domain filtering and statistics can be classified as either region segmentation or direct edge detection methods, depending on how the detection modeling is done. These works can be found in (Jing et al., 2022; Mubashar et al., 2022).

Through the emergence of texture descriptors and other local information such as brightness gradient, texture gradient, and color gradient, the probabilistic contour (Pb) method emerged (Arbelaez et al., 2010).

Methods Based on Machine Learning and Neural Networks: Combining the Pb method with a logistic regression it was possible to develop a model for edge detection in the image (Jing et al., 2022). The method has been extended over the years, for example by bringing in the multi-scale probabilistic contouring method and a multi-scale spectral clustering.

Currently, new machine learning-based techniques have emerged, in particular those based on Convolutional Neural Networks (CNN’s). Other methods based on machine learning are presented in (Jing et al., 2022), this is the case of Holistically-nested edge detection better known as HED that was proposed to improve the performance of the convolutional neural network, inspired other methods as, Convolutional Encoder-Decoder Network (CEDN), Richer Convolutional Features (RCF), Learning to Predict Crisp Boundaries (LPCB).

In 2019, the bi-directional cascade network (BDCN) method emerges, which proposes detection at different scales. More recently, techniques such as, Fined, Edge Detection Transformer (EDTER), and Pixel Difference Networks (PiDiNet) have been proposed, to handle edge detection without the need for such a large database for model training.

Fuzzy Logic Based Methods: Since Russo (Russo, 1998) first presented a fuzzy inference system modeling to efficiently extract edges in high noise images in 1998, the application of fuzzy theory in edge detection has increased, justified by the fuzzy nature of object edges in a digital image, which makes fuzzy theory suitable for solving such problems (Russo, 1998).

As reported by (Jing et al., 2022), detectors based on joining techniques like divergence and fuzzy entropy minimization (FED) and detectors based on morphological gradient and type-2 fuzzy logic have been proposed (Type-2 Color). Hybrid techniques and fuzzy versions of neural networks have been created, improving the performance of other approaches and in some cases decreasing the computational complexity.

In the studies of (Ghosh et al., 2020) we can identify hybrid methods that use neural networks and fuzzy logic type-1, type-2, and type-3, which are extensions of fuzzy logic with more degrees of uncertainty associated, they are called Hybrid approach neuro-fuzzy-1, neuro-fuzzy-2 and neuro-fuzzy-3 (Neuro-fuzzy’s). As well as the use of fuzzy logic to improve classical methods such as Canny (C&I-TYPE2), and a hybrid method that uses Sobel, fuzzy logic type-1, and fuzzy interval system type-2 (T2FLS).

Figure 3 presents the chronology of the found fuzzy methods, through the two proposed research questions. Observe the predominance of applications of fuzzy logic type-1, type-2, and type-3 and the use of this approach in conjunction with other techniques, evidencing a clear research trend.

3.2 Fuzzy Logic-Based Edge Detection Methods (RQF)

Considering the current state of edge detection methods and the importance of fuzzy logic-based methods,
evidenced in the previous section, it was possible to perform a bibliometric analysis of these articles in order to obtain some useful information in understanding the state of the art of fuzzy logic-based methods.

It is important to emphasize that some works focused on the review of segmentation methods, in general, using fuzzy logic, were included in this review. This is justified by the fact that the process of edge detection is a method of segmentation of the boundary between two or more regions, i.e., a particular case of the segmentation area in general and, therefore, high-impact works that were not specific to edge detection but returned from consultations and went through the exclusion processes were admitted.

Table 3 summarizes the papers returned from the search, organized by publication date. In the first column, we show the reference and, next to it, the title of the work.

Next, we present the relevant results of the bibliometric analysis, with the objective of presenting the most important papers and the common terms among the papers. This may allow a better understanding of the research carried out in this area, with the help of the description of the methods, to understand the gaps in the literature regarding this theme.

By extracting the metadata of the papers, it was possible, as described in the previous chapter for general edge detection methods, to determine the most cited papers among the selected ones. The paper with the highest number of absolute citations was the paper by (Castillo et al., 2017). In the second and third positions, in absolute numbers of citations, we have the works (Kumar et al., 2019; Gonzalez et al., 2017a).

Analyzing the ratio of citations per year, we have that the three most cited papers in absolute number, are also those with the highest citations/year ratio without losing the hierarchical order. Of these works, two are about edge detection using type-2 interval fuzzy logic, and the second position is relatively recent.

Through the word cloud, it is possible to identify, disregarding obvious terms such as those used in the search, or synonyms and homonyms, the terms...
that have raised the interest of researchers in the area, when using a fuzzy treatment in solving the problem of edge detection and image segmentation. In Figure 4, one can observe terms such as: “Medical Imaging”, “Computer Circuits”, “General Type-2 fuzzy sets”, “Classical Methods” and “Sobel Operator”. This word cloud was obtained through the frequency of the terms in the keywords, which are terms chosen by the authors to describe their work, using the software R Studio.

The metrics presented in the results of these works in comparison with classical methods show that the approach plays a key role in improving the performance of classical and other existing methods.

The found methods can be divided into four classes:

i. Methods based on interval fuzzy logic of the type-\(n\) (LFIT-\(n\)) (Baghbani et al., 2019; Raheja and Kumar, 2021; Gonzalez et al., 2017a; Kaur and Kaur, 2017; Castillo et al., 2017; Gonzalez et al., 2017b);

ii. Hybrid methods (FHM), in combination with neural networks or improving the performance of classical edge detection techniques (Balabantaray et al., 2017; Kumawat and Panda, 2021; Moya-Albor et al., 2017; Dhargupta et al., 2019; Kaur and Kaur, 2017; Dorrani et al., 2020);

iii. Methods that are based on fuzzy inference systems (FISM) (Dhivya and Prakash, 2019);

iv. Methods that are based on fuzzy clustering methods (FCEM) (Flores-Vidal et al., 2018).

4 CONCLUSION

Edge detection represents an important task in several steps in computer vision, such as (Wei et al., 2017); object detection (Yang et al., 2002); pattern recognition (Mohan et al., 2021); or image retrieval (Pavithra and Sharmila, 2018).

Recently, research in this area has been gaining momentum due to its importance in several applications, such as augmented reality (Orhei et al., 2020); image colorization (Sun et al., 2019) and medical image processing (Qiu et al., 2021) among others. Because of the fuzzy nature of the edges of an object in a digital image, many methods have been developed over the years, and more recently, with the use of fuzzy theory, which has been improving and performing applications in various areas.

Considering the advancement of research in edge detection through fuzzy theory approaches, and the lack of review papers dedicated to these methods, a specific investigation of these techniques is justified.

In this sense, this work presented a review of edge detection methods in order to understand the state of the art of fuzzy edge detection methods. For this, searches were performed in two major databases, Scopus and Web Of Science, and defined the terms of inclusion and exclusion, so that of 3,830 papers that returned from the searches, only 34 went through the exclusion steps. The methods were reviewed and organized by category according to the proposed approach by the method.

Classical methods can be divided into four classes: methods based on gradient; methods based on segmentation of regions; methods based on machine learning and Neural Networks and; methods based on Fuzzy Logic that in turn, through the specific search can be divided into four subclasses; methods based on interval fuzzy logic type-\(n\); hybrid methods, in combination with neural networks or improving the performance of classical techniques for edge detection; those based on fuzzy inference systems and; based on clustering methods.

The fuzzy set theory proposed by Zadeh (Zadeh, 1965) as well as the Roberts method (Roberts, 1980) of edge detection, has its first works in the mid-1970s. Despite the nature of edge detection fitting clearly in a fuzzy theory approach, fuzzy applications in this task only appeared for the first time in the late 1990s using fuzzy inference systems, with the method of Russo (Russo, 1998).

Even after this initiative, little has been explored over the years, with the first relevant papers around the year 2012. A bibliometric analysis was also conducted, where the metadata of the documents was analyzed, in order to understand, in conjunction with the summary of the methods whether there are gaps or trends in research regarding the studied topic.

Through the analysis, it could be concluded that in recent years, from the year 2012, fuzzy logic has been employed in hybrid methods in order to improve the performance of existing techniques or reduce computational complexity. Studies with interval fuzzy logic of higher order have been employed for its greater flexibility in dealing with the uncertainty associated with the edge detection task.

As future work, a review dedicated to the performance of the methods is proposed, comparing works that used the same metrics and databases in order to evaluate the gain that these different techniques have in relation to other non-fuzzy methods. This quantitative evaluation is necessary considering the number of methods proposed in the last ten years, and the scarcity of review work in this regard.
Table 3: Works in edge detection based on fuzzy logic (RQF).

<table>
<thead>
<tr>
<th>References</th>
<th>Paper title</th>
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</thead>
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<tr>
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<td>Review of Recent Type-2 Fuzzy Image Processing Applications</td>
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<tr>
<td>(Moya-Albor et al., 2017)</td>
<td>An Edge Detection Method using a Fuzzy Ensemble Approach</td>
</tr>
<tr>
<td>(Gonzalez et al., 2017a)</td>
<td>Edge detection method based on general type-2 fuzzy logic applied to color images</td>
</tr>
<tr>
<td>(Balabantaray et al., 2017)</td>
<td>A Quantitative Performance Analysis of Edge Detectors with Hybrid Edge Detector</td>
</tr>
<tr>
<td>(Flores-Vidal et al., 2018)</td>
<td>A New Edge Detection Approach Based on Fuzzy Segments Clustering</td>
</tr>
<tr>
<td>(Bueno et al., 2018)</td>
<td>Two-phase flow bubble detection method applied to natural circulation system using fuzzy image processing</td>
</tr>
<tr>
<td>(Baghbani et al., 2019)</td>
<td>A method for image edge detection based on interval-valued fuzzy sets</td>
</tr>
<tr>
<td>(Flores-Vidal et al., 2019)</td>
<td>A new edge detection method based on global evaluation using fuzzy clustering</td>
</tr>
<tr>
<td>(Dhargupta et al., 2019)</td>
<td>Fuzzy edge detection based steganography using modified Gaussian distribution</td>
</tr>
<tr>
<td>(Bhogal and Agrawal, 2019)</td>
<td>Image Edge Detection Techniques Using Sobel, T1FLS, and IT2FLS</td>
</tr>
<tr>
<td>(Kumar et al., 2019)</td>
<td>Information hiding with adaptive steganography based on novel fuzzy edge identification</td>
</tr>
<tr>
<td>(Dhivya and Prakash, 2019)</td>
<td>Edge detection of satellite image using fuzzy logic</td>
</tr>
<tr>
<td>(Dorrani et al., 2020)</td>
<td>Image Edge Detection with Fuzzy Ant Colony Optimization Algorithm</td>
</tr>
<tr>
<td>(Kumawat and Panda, 2021)</td>
<td>A robust edge detection algorithm based on feature-based image registration (FBIR) using improved canny with fuzzy logic (ICWFL)</td>
</tr>
<tr>
<td>(Raheja and Kumar, 2021)</td>
<td>Edge detection based on type-1 fuzzy logic and guided smoothing</td>
</tr>
<tr>
<td>(Tripathi et al., 2021)</td>
<td>Edge Detection on Medical Images Using Intuitionistic Fuzzy Logic</td>
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DECLARATIONS

The authors declare that there is no financial or personal conflict directly or indirectly related to this work.

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