A New Hybrid Metaheuristic Model for Image Edge Detection

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Abstract: Image edge detection is a vital process in various applications, such as medical image analysis, computer vision, and security systems. Several models were proposed to determine image edges. However, each method has some limitations in finding the best edges, such as choosing the ideal parameters or the presence of noise. New techniques, such as nature-inspired optimization, have emerged as a promising approach in several domains. These techniques may have the potential to provide advanced capabilities to improve the image edge detection process. A metaheuristic model such as the Bat algorithm may offer appropriate parameters for the edge detection algorithm. Therefore, the primary focus of this study is to build a new hybrid model that integrates the Bat algorithm and Canny filter to enhance the output of image edge detection process. To achieve the goal of this study, the hybrid model has been applied to JPG images. Notable improvements in edge detection were observed during the application of the proposed system on the tested images compared to the traditional Canny algorithm. The improvement rate in the performance of the proposed system reached 30%. It was concluded from this study that modifying the parameters of the Canny filter using the proposed dynamic model leads to optimizing the image edge detection processes. Therefore, integrating other algorithms, such as deep learning techniques, is recommended to study the parameters and performance of edge detection operators.

1 INTRODUCTION

In the applications of computer vision and image processing, edge detection is considered an essential step in image interpretation[1]–[3]. Although traditional edge detection methods offer acceptable performance, they face some limitations. The main difficulty is identifying the correct and closed edges. For this reason, several algorithms were proposed for identifying image optimal edges [4][5].

Methods that process images to detect edges are divided into two groups: 1) The first group does not use prior knowledge about the scene or image. This type is limited to the image to be examined and is based on the local processing of neighbouring pixels. For example, the Canny operator is one of the most popular edge detection methods [4], [6]. This algorithm consists of several stages, including image smoothing, gradient calculation, non-maximal peak suppression, and hysteresis concatenation. 2) The second group uses prior knowledge about the edges of the image. The most common techniques in this field are the algorithms inspired by nature, that is called optimization algorithms. This group of techniques is used to find the optimal values of the basic parameters to increase the system's efficiency.

Traditional edge detection models provide efficient results for limited purposes. However, these methods have difficulty in dealing with noise or enhancing edges in some complex cases. For example, the effectiveness of the Canny algorithm depends on the selection of appropriate parameters, such as the upper and lower thresholds [5], [7], [8]. The Canny filter is very sensitive to the choice of these parameters, especially when the selection of these parameters is human intervention, which may lead to the loss of some essential edges of the image.[9], [10].

Optimization algorithms can analyze the problem to find optimal values for the system parameters [11], [12]. Therefore, optimization algorithms are widely used to overcome such problems. The Bat algorithm is an ideal search model inspired by the echolocation behavior of bats[13]. This algorithm is based on the principle of searching for the best solutions in a way inspired by nature. This algorithm is characterized by its ability to explore the solution space efficiently and search for optimal solutions in a way similar to nature.

This paper aims to present a new hybrid model based on the Bat algorithm and the Canny filter to enhance the image edges detection processes. The proposed model was applied to 100 different images, and the results were compared with the edges detected using the regular Canny filter. The ground truth file for each tested images and metrics such as Structural Similarity Index Measure (SSIM) and Dice Similarity Coefficient (Dic) were used to measure system efficiency.

2 MATERILAS AND METHOD

2.1 Image Dataset

The dataset contains 100 color JPG images. Each image has a corresponding image containing the real edge data (ground truth data). The images varied between natural scenes, objects, and complex backgrounds, making them suitable for testing edge detection algorithms.

2.2 The Proposed Model

The following steps were followed to implement the proposed model:

1) Upload the image and convert it to grayscale.
2) Apply a Canny filter to extract raw edges from the image. Basic Canny parameters (minimum and maximum) were determined to obtain the edges.
3) Refine edges using the Bat algorithm. The Bat algorithm determines the optimal Canny parameters (low and high threshold) that provide the best performance in edge detection.
4) Evaluate the models using SSIM and Dice metrics to measure the edge-detected performance of the proposed hybrid model compared to the Canny algorithm using ground truth data as a reference.

Figure 1 illustrates the workflow of the proposed hybrid model.

2.3 The Mechanism of Bat Algorithm

Micro bats use echolocation to find food, navigate barriers, and roost. The Bat algorithm uses this information to create its mechanism [14]. Micro bats move around an octave using brief, frequency-modulated sounds f, with pulse emission rates accelerating when homing on prey. The Bat algorithm's foundation is based on three principles.

1) All bats use echolocation in some magical way to perceive background barriers, distance, and the distinction between food and prey.
2) Bats fly randomly with velocity υ_i, frequency f, and loudness A_o to find prey. They can change the frequency and wavelength of their pulses as they come closer to their target, allowing them to change their speed appropriately.
3) We suppose that the loudness extends from a significant positive A_o to a minimal constant value A_{mi}, regardless of many conceivable fluctuations.

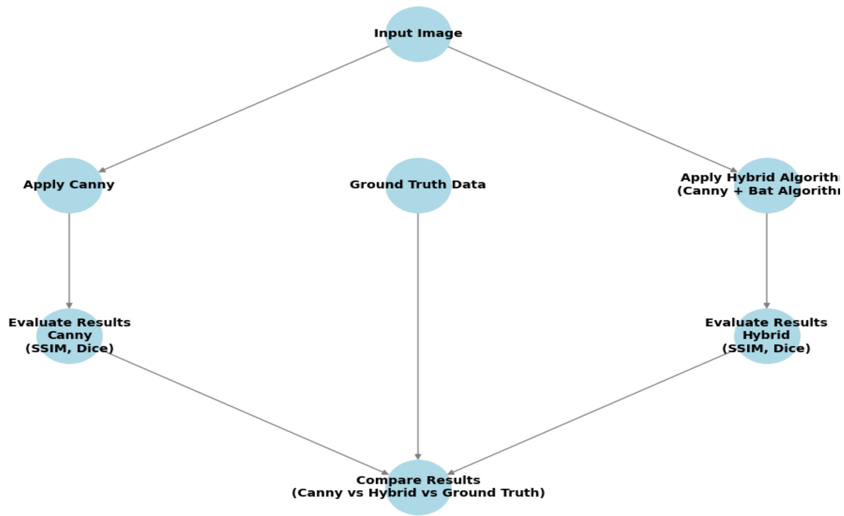

Figure 1: The proposed system diagram.

At iteration t, each bat is linked to a location x_i^t and a velocity v_i^t in a d-dimensional search or solution area. Right now, x^* is the best solution out of all the bats. As seen below, the locations x_i^t and velocities v_i^t can thus be found by translating the three rules mentioned above:

$$f_i = f_{min} + (f_{max} - f_{min})\beta, \quad (1)$$

$$v_i^t = v_i^{t-1} + (x_i^{t-1} - x^*)f_i. \quad (2)$$

$$x_i^t = x_i^{t-1} + v_i^t. \quad (3)$$

where a random vector $\beta \in [0,1]$ is selected from a uniform distribution. As was previously noted, relying on the field size of the issue relevant, we will employ either wavelengths or frequencies for implementation; $f_{min} = 0$ and $f_{min} = 1$. First, a uniformly chosen frequency from [f_{min}, f_{max}] is assigned to each bat at randomly. This makes the bat method a frequency-tuning algorithm that offers a well-balanced mix of exploitation and exploration. According to [15], [16], Loudness and pulse emission rates allow automatic management and auto-zooming into prospective solutions. A random walk with direct exploitation is used in the local search that modifies the current optimal solution in line with the equation:

$$x_{new} = x_{old} + \partial_{A^t}, \quad (4)$$

where A^t is the average loudness of all the best at this time step, and $\partial \in [-1,1]$ is a random value.

2.3.1 Differences in Loudness and Pulse Rates

To regulate exploration and exploitation stages, we must adjust loudness and pulse emission rate during iterations. If $A_{min} = 0$, loudness can be set between A_{min} and A_{max}, as loudness drops after finding prey and pulse emission increases. Assuming these things, we have:

$$A_i^{t+1} = \alpha A_i^t, \quad (5)$$

and

$$r_i^t = r_i^o\ [1 - \exp(-\gamma t)], \quad (6)$$

where α and ϒ are constants. The loudness at iteration t, initial pulse emission rate r_i^o, and cooling factor α are used to calculate the pulse emission rate at iteration t, with $0 < \alpha < 1$ and $\Upsilon > 0$. [15]–[17].

2.4 Study Evaluation Metrics

In this study, two metrics were used to analyze the quality of the proposed model. The first one is the Structural Similarity Index Measure (SSIM). This measure is used to analyze the quality of images or videos by comparing the structure of the original image with a reference image (ground truth) [18]. The SSIM is computed using the following equation:

$$SSIM(a,b) = \frac{(2\mu_a\mu_b + c_1)(2\sigma_{ab} + c_2)}{(\mu_a^2 + \mu_b^2 + c_1)(\sigma_a^2 + \sigma_b^2 + c_2)}\ , \quad (7)$$

where $\boldsymbol{\mu_a}$ and $\boldsymbol{\mu_b}$ are the average values of images a and b respectively. The contrast between images a and b is illustrated in $\boldsymbol{\mu_a}$ and $\boldsymbol{\mu_b}$ respectively. C values are constant to prevent division by zero.

The second metric is the Dice Similarity Coefficient (Dice). This metric is used in the field of image processing to evaluate the similarity between two image data, especially in the edge detection process. The mathematical representation of this measure is shown below:

$$Dice = \frac{2|A \cap B|}{|A| + |Y|}\ , \quad (8)$$

Where A and B are the set of points in the original image and ground truth image respectively. The number of similar points between the two images is represented by $A \cap B$

3 RESULTS AND DISCUSSION

Figure 2a shows the original image after converting it to grayscale format. Figure 2b shows the traditional Canny results, and Figure 2c presents the results of Canny after optimizing its parameters using the Bat algorithm. In addition, this Figure presents the ground truth image which is related to the original image as shown in Figure 2d. The comparison between Canny model and the hybrid model results was performed by studying the values of SSIM and Dice metrics based on the ground truth image as a reference for measurement. Therefore, from this Figure, one can notice that the proposed model achieved higher SSIM and Dice values compared to the traditional canny

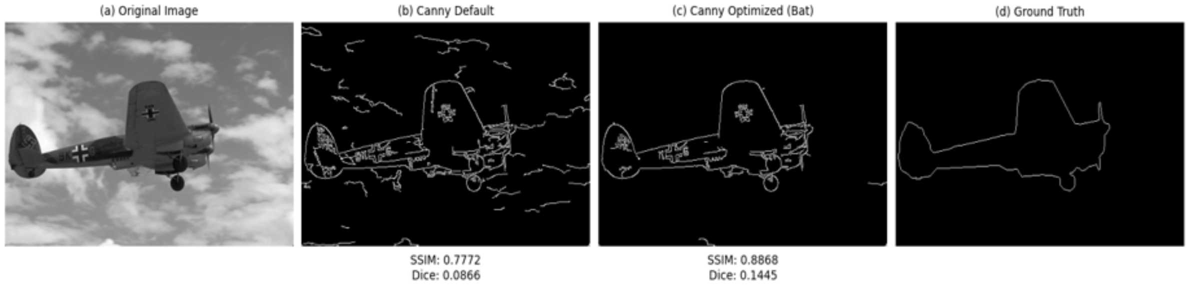

Figure 2: Enhancing image edges detection using the Bat hybrid model with Canny filter. (a) Original image (b) Canny result (c) Hybrid model result (d) Ground Truth image.

model. The hybrid model provides more accurate edges in important areas, which may improve performance in applications such as computer vision. In addition, it is clear from Fig. 2 that the hybrid model provides more accurate details than the traditional model, especially within the main regions of the image.

Table 1 provides the SSIM and Dice metrics values of Canny algorithm and the proposed hybrid model for 10 images. From this table, we can observe that the performance results of our hybrid model outperformed the canny algorithm regarding SSIM and Dice values.

Table 1: Performance analysis of the hybrid model compared to the Canny filter using SSIM and Dice metrics for 10 images.

Image no.	canny		Hybrid (canny + Bat alg.)	
	SSIM	Dice	SSIM	Dice
1	0.3447	0.0392	0.5036	0.0477
2	0.7777	0.0866	0.8868	0.1445
3	0.4374	0.0514	0.0672	0.0803
4	0.6546	0.0442	0.7562	0.0502
5	0.6448	0.0757	0.7879	0.1524
6	0.6321	0.1157	0.7967	0.1875
7	0.3442	0.0901	0.5934	0.1422
8	0.5115	0.0700	0.8538	0.2113
9	0.7582	0.1411	0.8755	0.2531
10	0.4784	0.0146	0.6851	0.0918

In all cases, the hybrid algorithm achieved higher SSIM values, indicating that the extracted edges are more similar to the ground truth image. Furthermore, the values increased in most images, indicating a reduction in the differences between the extracted edges and the real edges. In contrast, Some images showed only slight improvement (e.g. Figure 2c and 2d), which may mean that the algorithm may need to adjust some parameters to handle different types of images.

It can be said that the hybrid algorithm is better in the case of applications that require high accuracy in identifying edges. Therefore, in medical image analysis, the hybrid method can be better because it provides finer edges, which makes it easier to detect tumors or different tissues. In contrast, in image and video surveillance, the method may help improve the detection of objects or subtle movements.

Based on the experiments performed on the test images, it was found that the algorithm provided high performance and achieved high index values when applied to images with uniform backgrounds and low contrast, where the edges are clearer and less complex. Therefore, the proposed algorithm can be applied to images with blurry backgrounds such as images taken with wide aperture cameras. The algorithm can also be applied to images with objects that stand out clearly from the background such as wildlife photographs or products displayed on a uniform background, document and drawing scans – where the background is white or of a uniform color with prominent lines, and medical imaging images (such as X-rays or MRIs) especially when there is significant contrast between tissues.

Figure 3(a) shows a comparison view of SSIM values between Canny filter and the hybrid model (Canny + Bat Algorithm) across 100 images. Form this Figure, one can observe that the hybrid model achieved higher SSIM values than the traditional Canny for all tested images. This indicates that the extracted edges using the hybrid model are closely matched to the ground truth compared to the Canny filter. Therefore, these results demonstrate the efficiency of the proposed system in reducing noise and improving the detection of image edges when compared with the traditional Canny filter.

In contrast, Figure 3(b) shows accuracy edge detection result of Canny and the hybrid model using the Dice metric. From this figure, it is clear that the proposed hybrid system achieved higher Dice values than the Canny filter. This findings indicate that the hybrid system achieved more accurate edges that are close to the original image edges.

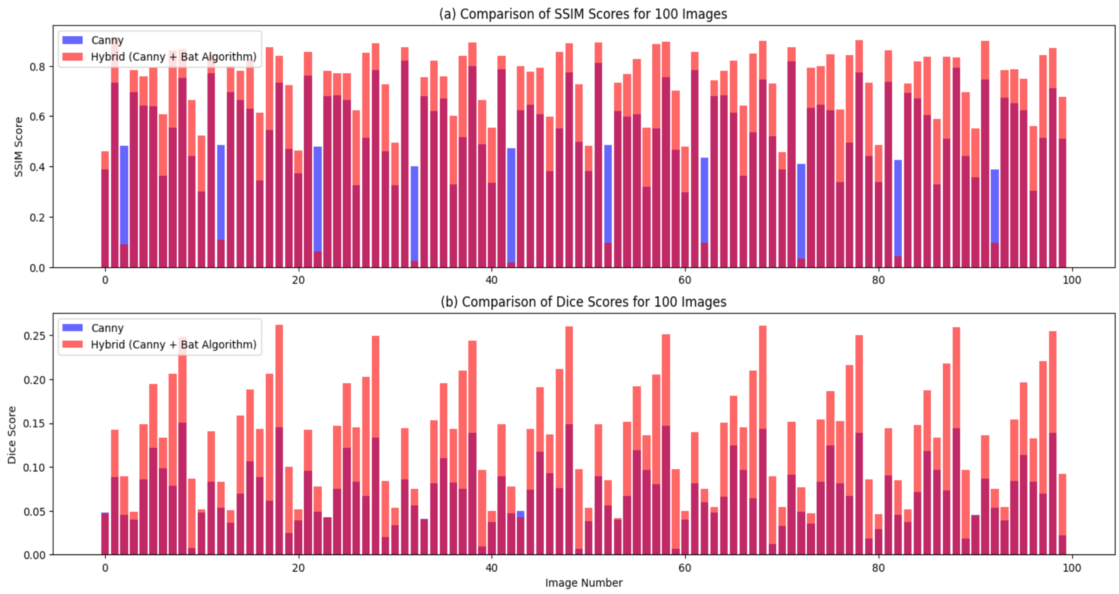

Figure 3: Evaluation metrics results. (a) SSIM values and (b) Dice values.

4 CONCLUSIONS

A hybrid model to optimize Canny parameters using the Bat algorithm to improve the image edge detection process was presented in this paper. The statistical metrics used in this study showed that the hybrid model outperformed the Canny algorithm in detecting image edges. The study confirmed that choosing the Canny filter parameters automatically contributes significantly to improving the filter efficiency compared to the fixed parameters that are pre-determined for the traditional filter operation. According to this finding, the hybrid model is useful in applications that require high accuracy such as medical computer vision or security systems. Furthermore, the proposed model of this study can be used in other applications that require more accurate edge detection, such as autonomous robotics or advanced medical data analysis. Finally, algorithms such as deep learning can be integrated to study edge detection performance.

REFERENCES

[1] M. Ali, L. Goyal, C. M. Sharma, and S. Kumar, "Edge-computing-enabled abnormal activity recognition for visual surveillance," Electronics (Switzerland), vol. 13, no. 2, 2024, [Online]. Available: https://doi.org/10.3390/electronics13020251.

[2] R. C. Gonzalez and P. Wintz, Digital Image Processing. Reading, MA, USA: Addison-Wesley, 1987.

[3] M. M. Kabir, J. R. Jim, and Z. Istenes, "Terrain detection and segmentation for autonomous vehicle navigation: A state-of-the-art systematic review," Information Fusion, vol. 113, p. 102644, Jan. 2025, [Online]. Available: https://doi.org/10.1016/j.inffus.2024.102644.

[4] Z. Xu, X. Ji, M. Wang, and X. Sun, "Edge detection algorithm of medical image based on Canny operator," in J. Phys.: Conf. Ser., vol. 1955, p. 012080, 2021, [Online]. Available: https://doi.org/10.1088/1742-6596/1955/1/012080.

[5] H. M. Zangana, A. K. Mohammed, and F. M. Mustafa, "Advancements in edge detection techniques for image enhancement: A comprehensive review," Int. J. Artif. Intell. Robot. (IJAIR), vol. 6, no. 1, pp. 29-39, 2024, [Online]. Available: https://doi.org/10.25139/ijair.v6i1.8217.

[6] N. D. Lynn, A. I. Sourav, and A. J. Santoso, "Implementation of real-time edge detection using Canny and Sobel algorithms," IOP Conf. Ser.: Mater. Sci. Eng., vol. 1096, no. 1, p. 012079, 2021, [Online]. Available: https://doi.org/10.1088/1757-899X/1096/1/012079.

[7] N. Tawfeeq and J. Harbi, "Using the Canny method with deep learning to detect and predict river water level," J. Al-Qadisiyah Comput. Sci. Math., vol. 16, no. 2, pp. 135-150, 2024, [Online]. Available: https://doi.org/10.29304/jqcsm.2024.16.21565.

[8] W. A. Sasmita, H. Mubarok, and N. Widiyasono, "Agricultural path detection systems using Canny-edge detection and Hough transform," IAES Int. J. Robot. Autom., vol. 13, no. 3, pp. 247-254, 2024, [Online]. Available: https://doi.org/10.11591/ijra.v13i3.pp247-254.

[9] T. Saini, P. S. Shiakolas, and C. McMurrough, "Evaluation of image segmentation methods for in situ quality assessment in additive manufacturing,"

Metrology, vol. 4, no. 4, pp. 598-618, 2024, [Online]. Available: https://doi.org/10.3390/metrology4040037.

[10] X. D. Sun and X. F. Sun, "An edge detection algorithm based upon the adaptive multi-directional anisotropic Gaussian filter and its applications," J. Supercomput., vol. 80, no. 11, pp. 15183-15214, Jul. 2024, [Online]. Available: https://doi.org/10.1007/s11227-024-06044-6.

[11] K. H. Choi and J. E. Ha, "An adaptive threshold for the Canny edge with actor-critic algorithm," IEEE Access, vol. 11, pp. 67058-67069, 2023, [Online]. Available: https://doi.org/10.1109/ACCESS.2023.3291593.

[12] H. Harish and A. S. Murthy, "Edge discerning using improved PSO and Canny algorithm," in Commun. Comput. Inf. Sci., pp. 192-202, 2023, [Online]. Available: https://doi.org/10.1007/978-3-031-43140-1_17.

[13] M. Shehab et al., "A comprehensive review of bat inspired algorithm: Variants, applications, and hybridization," Arch. Comput. Methods Eng., vol. 30, no. 2, pp. 765-797, Mar. 2023, [Online]. Available: https://doi.org/10.1007/s11831-022-09817-5.

[14] X. S. Yang, "A new metaheuristic bat-inspired algorithm," in Stud. Comput. Intell., pp. 65-74, Springer, 2010, [Online]. Available: https://doi.org/10.1007/978-3-642-12538-6_6.

[15] X. S. Yang, "Bat algorithm: Literature review and applications," Int. J. Bio-Inspired Comput., vol. 5, no. 3, pp. 141-149, 2013, [Online]. Available: https://doi.org/10.1504/IJBIC.2013.055093.

[16] P. Kora and S. R. Kalva, "Improved bat algorithm for the detection of myocardial infarction," SpringerPlus, vol. 4, no. 1, pp. 1-18, Dec. 2015, [Online]. Available: https://doi.org/10.1186/s40064-015-1379-7.

[17] X. S. Yang, "Bat algorithm and cuckoo search: A tutorial," in Artificial Intelligence, Evolutionary Computing and Metaheuristics, pp. 421-439, Springer, 2013, [Online]. Available: https://doi.org/10.1007/978-3-642-29694-9.

[18] Z. Wang, E. P. Simoncelli, and A. C. Bovik, "Multi-scale structural similarity for image quality assessment," in Proc. Asilomar Conf. Signals, Syst. Comput., pp. 1398-1402, 2003, [Online]. Available: https://doi.org/10.1109/ACSSC.2003.1292216.