Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Recognizing Objects in Complex Scenes: A Recent Systematic Review

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ABSTRACT

This systematic review provides a comprehensive examination of recent advancements in object recognition within complex scenes, focusing on addressing challenges such as clutter, occlusion, and diverse environmental conditions. Leveraging the PRISMA framework, the study meticulously analysed a diverse range of literature from esteemed sources, employing advanced search methods on Scopus and WoS databases to identify and analyse primary research studies (n = 25). The review encompasses three key themes: Theme 1 concentrates on Image Noise Identification and Removal Techniques, while Theme 2 delves into Image Classification and Recognition under Noise. Additionally, Theme 3 explores Innovative Models and Approaches for Noise-Robust Image Analysis. Despite the progress achieved, contemporary recognition systems struggle with real-world complexities such as varied scales, lighting variations, and different viewpoints. The synthesis of findings emphasizes the necessity for innovative strategies that capitalize on contextual cues and harness the potential of deep learning to enhance precision in object recognition within intricate visual environments. The insights gleaned from this synthesis are poised to guide future research directions, informing the development of more resilient algorithms capable of navigating challenges and catalysing advancements in the field of object recognition.

Keywords:
Object; recognition; image processing; machine learning; complex scene

1. Introduction

The ability to recognize objects within complex scenes [1-6] is a fundamental aspect of human cognition and a longstanding challenge in computer vision in most previous studies. In our increasingly data-driven world, where visual information is abundant and diverse, the development of robust and efficient algorithms for object recognition holds paramount importance across various domains from previous research, including robotics, autonomous systems, healthcare, security, and beyond [7-13]. Objects in natural scenes exhibit substantial variability in appearance, scale, orientation, occlusion, and context, presenting formidable hurdles for accurate recognition. The human visual system effortlessly tackles these challenges, demonstrating an innate capacity to

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https://doi.org/10.37934/araset.61.2.208226

identify objects amidst intricate backgrounds, variations in lighting, and diverse environmental conditions.

Replicating this cognitive accomplishment in machines has been a central focus of exploration in the fields of computer vision and artificial intelligence. Traditional approaches to object recognition heavily relied on handcrafted features and predefined models, facing limitations in handling the intricacies of real-world scenes. However, the field experienced a profound shift with the introduction of deep learning, specifically convolutional neural networks (CNNs). This advancement revolutionized object recognition performance by automating the extraction of hierarchical features from raw data which used on existing studies [14-16]. Deep learning models excel in learning intricate patterns and representations, offering promising avenues for addressing the complexities inherent in scene understanding. Despite significant progress, challenges persist in recognizing objects within complex scenes. Factors such as insufficient labeled data, domain shifts, adversarial attacks, and robustness to real-world variations pose persistent hurdles. Additionally, the ethical considerations regarding privacy, biases, and societal implications of object recognition technologies warrant critical attention.

The objective of this article is to examine the latest methodologies, progress, and difficulties associated with the identification of objects in intricate scenes. We delve into the evolution of object recognition techniques, the role of deep learning architectures, recent breakthroughs, and explore avenues for future research. Furthermore, we analyze the implications of object recognition in various applications and underscore the importance of developing robust, ethical, and interpretable models for addressing real-world complexities. Through this comprehensive exploration, our article endeavors to contribute to the broader discourse on advancing object recognition capabilities, fostering innovation, and guiding the development of responsible and impactful technologies for complex scene understanding.

2. Literature Review

In diving into the realm of spotting things in tricky settings, we need to cover a bunch of angles. One big thing to look at is how well methods for detecting 3D objects hold up in wild scenes, especially when it comes to self-driving situations. We want to get into the nitty-gritty of the challenges these methods face, like dealing with funky lighting, bad weather, faraway or tiny objects, and the pressing need for solid and spot-on detection in those kinds of situations [17]. Another avenue to stroll down is checking out how copying the way living things see things could help us pick out features and recognize stuff in complicated scenes. We're talking about getting inspiration from how living eyes and brains work [18].

Understanding and making sense of the environment is crucial when it comes to recognizing objects with limited examples, as highlighted in the concept of contextual cueing and scene context semantics for few-shot learning in object recognition [19]. In real-world scenarios, multiple object tracking (MOT) plays a significant role, helping to handle challenges such as occlusion, similar appearances, and difficulties in detecting small objects. This is particularly important in applications like autonomous driving [20]. Achieving high accuracy and real-time recognition of traffic signs is essential in intelligent transportation systems. To address this, a suggested two-stage approach involves using a lightweight superclass detector and a refinement classifier. This approach relies on prior knowledge of sign locations and sizes, emphasizing the importance of efficient recognition in critical situations [21].

Tracking several objects at once is crucial when dealing with intricate scenes, especially when factors like occlusion, similar appearances, and the challenges of detecting small objects come into play. The application of Multiple Object Tracking (MOT) extends to real-time tracking of multiple objects, with notable relevance in practical scenarios such as autonomous driving [22]. Keeping an eye on multiple objects simultaneously becomes quite important when handling complex scenes. This is especially true when you consider factors like objects hiding behind others, similar looks, and the difficulty of spotting small items. Multiple Object Tracking (MOT) proves its significance in scenarios that require tracking multiple objects in real-time, with practical applications like autonomous driving being particularly noteworthy [23].

Recognizing traffic signs plays a crucial role in making transportation systems smarter. To enhance this process, a proposed two-stage approach suggests combining a lightweight superclass detector with a refinement classifier. This method leverages information about the locations and sizes of signs to create a probability distribution model. To achieve this, Inception and Channel Attention are introduced, aiming to generate multi-scale receptive fields and dynamically adjust channel features [24]. Researchers have extensively explored the impact of scene context on object recognition. For example, a study conducted and published in Frontiers in Psychology revealed that scene context, such as a semantically consistent background, greatly aids in the detection and recognition of objects within natural scenes [25].

Moreover, researchers have delved into the relationship between scene and object processing through different approaches. One such method is the scene-object congruity paradigm, which assesses how contextual processing influences object recognition [26]. Another paper delves into the phenomenon of visual crowding, wherein peripheral object recognition is hindered by surrounding objects in computer-generated real-world scenarios. The results reveal instances of crowding affecting features, object components, and entire objects, underscoring its pivotal role as a constraint on conscious visual perception [27].

In general, blending these methods can enhance the identification of objects in intricate surroundings. Conducting a thorough review of existing literature on these methods can shed light on the latest advancements and possible avenues for future research.

3. Methodology

3.1 Identification

Three key phases in the systematic review process were utilized to select a substantial volume of relevant publications for this study. Initially, keywords were selected, and related terms were sought using thesauri, dictionaries, encyclopedias, and prior research. Search strings for Scopus and WoS were then developed (refer to Table 1), incorporating all relevant keywords. A total of 1600 publications pertinent to the present study were successfully gathered from both databases during the initial stage of the systematic review process.

Table 1
The search string

Scopus	TITLE ((recogni* OR detect OR classifi* OR identif* OR cluster* OR predict*) AND (object OR image OR item OR piece) AND ("complex scenes" OR noise OR overlap OR flip OR blur)) AND (LIMIT-TO (PUBYEAR , 2023)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))
World of Science	TI=(recogni* OR detect OR classifi* OR identif* OR cluster* OR predict*) AND (object OR image) AND ("complex scenes" OR noise OR overlap OR blur)

3.2 Screening

The initial step in the screening process involves a meticulous examination of the pool of potentially pertinent research materials to identify content that aligns with the predetermined research questions. Common criteria employed in this phase include filtering research items based on the categorization of recognizing objects in complex scenes. During this stage, any duplicates among the gathered papers are systematically eliminated. A total of 1536 publications were excluded during the initial screening phase, while the subsequent phase evaluated 64 papers according to distinct inclusion and exclusion criteria established for this study (refer to Table 2). The primary criterion for selection was the literature (research papers), as it serves as the principal source of practical recommendations, encompassing reviews, meta-syntheses, meta-analyses, books, book series, chapters, and conference proceedings not covered in the latest study. Furthermore, the review exclusively focused on English-language publications from the year 2023. Importantly, it should be emphasized that no publications were rejected solely based on duplication criteria.

Table 2
The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2023	< 2023
Literature type	Journal (article)	Conference, book, review
Publication stage	Final	In press

3.3 Eligibility

During the eligibility assessment phase, a collection of 50 articles was gathered. Rigorous examination was conducted on the titles and crucial content of each article to ensure alignment with the inclusion criteria, in accordance with the present research objectives. Subsequently, 25 reports were eliminated from consideration, as they did not meet the criteria of being strictly scientific articles based on empirical evidence. Therefore, 25 articles are retained for further review, as indicated in Figure 1.

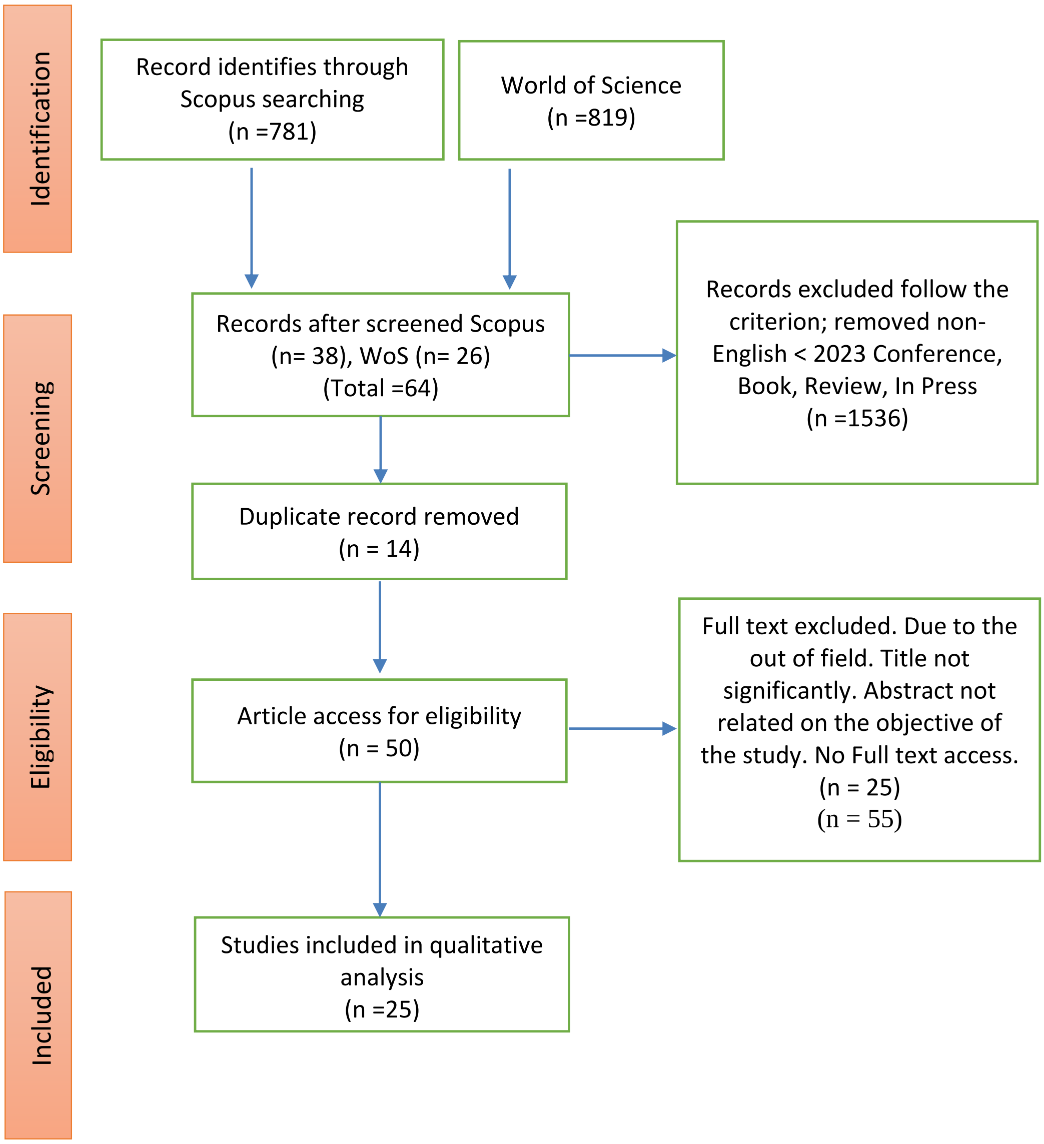


Fig. 1. Flow diagram of the proposed searching study [28]

3.4 Data Abstraction and Analysis

An integrative analysis served as a key assessment approach in this research, focusing on the examination and synthesis of various research designs, particularly quantitative methods. The objective of this proficient investigation was to pinpoint pertinent topics and subtopics. The initial phase of data collection marked the commencement of theme development. Figure 1 illustrates how the authors meticulously scrutinized a compilation of 25 publications, extracting assertions and materials pertinent to the study's themes. Subsequently, the authors assessed prevailing studies concerning the recognition of objects in intricate scenes. The investigation delves into the methodologies and research findings across all studies. Collaborating with co-authors, the authors formulated themes grounded in the study's contextual evidence. A log meticulously documented analyses, perspectives, puzzles, and other relevant thoughts during the data interpretation process. Ultimately, a comparative analysis was conducted to identify any inconsistencies in theme development. Any conceptual discrepancies were discussed among the authors, and the resulting themes underwent refinement to ensure coherence. Two experts in image processing, cognitive computation and artificial intelligence, conducted the analysis selection, verifying the validity of identified issues. The expert review phase established the domain validity, ensuring clarity, significance, and appropriateness for each subtheme.

4. Results

Numerous studies have made noteworthy contributions in these domains, collectively advancing techniques for noise identification and removal, noise-resistant image classification, and novel approaches for robust image analysis.

4.1 Theme 1: Image Noise Identification and Removal Techniques

Four different types of noise filters are proposed based on modifying linear cellular automata (LCA), offering efficient noise reduction at various levels of noise density. These filters leverage the asynchronous operation of the LCA model, which enhances computational efficiency [29]. In the field of image segmentation (Figure 2), a method called kernel fuzzy clustering (KFPKL) stands out for its ability to handle noise, uncertainty, and complex structures in images. It has shown superior performance on both synthetic image datasets and brain MRI datasets [30]. Additionally, improved filters for synthetic aperture radar (SAR) noise, including an enhanced Lee sigma filter, outperform standard filters, achieving impressive levels of noise reduction on virtual SAR datasets [31].

In the domain of deep learning, a two-stage approach to denoising images achieves excellent accuracy across different types of noise [32]. Another method, the PFLWCM-CIM algorithm, uses fuzzy clustering to segment noisy images, incorporating image patches and a special metric called correntropy induced metric (CIM) [33]. Furthermore, a novel approach to fuzzy clustering for image segmentation, the PFLWCM-CIM algorithm, focuses on using image patches instead of individual pixels, which helps preserve local image details. It also introduces a new metric that combines image patches and CIM [34]. Moreover, a new type of neural network, the Gaussian-Noise Convolutional Neural Network (GN-CNN), is introduced for identifying noise variations in scanning electron microscope (SEM) images [35]. For removing salt-and-pepper noise, the supervised hierarchical clustering filter (SHCF) shows promising results, especially on images with many black and white pixels [36]. Lastly, an adaptive neurofuzzy estimation method is used to predict denoising performance in color images by analyzing speckle noise distribution, highlighting the effectiveness of the ALOHA filter [37]. Table 3 presents the previous research findings for Theme 1.

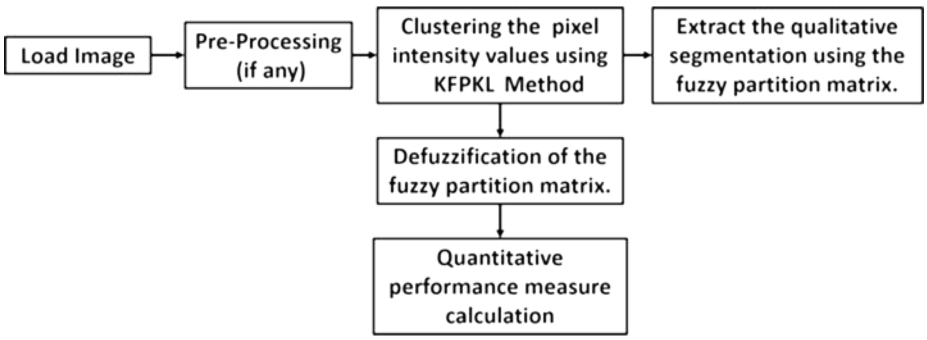


Fig. 2. Process of image segmentation [30]

Table 3
The research article findings based on the proposed searching criterion: Theme 1

Authors	Title	Year	Journal	Methodology	Findings and advantages
Jeelani *et al.,* [29]	Linear cellular automata-based impulse noise identification and filtration of degraded images	2023	Signal, Image and Video Processing	This paper presents and evaluates four filters designed for impulse noise, incorporating adaptations of linear cellular automata (LCA). Each filter utilizes a flexible neighbourhood to achieve effective noise reduction across various levels of noise density.	The suggested filters are computationally efficient because the LCA model operates asynchronously. Objective assessments of the suggested filters involve the utilization of metrics like peak signal-to-noise ratio and the structural similarity index (SSIM).
Khatri *et al.,* [30]	A noise robust kernel fuzzy clustering based on picture fuzzy sets and KL divergence measure for MRI image segmentation	2023	Applied Intelligence	This work presents KFPKL, a clustering algorithm that addresses noise, ambiguity, and non-linear patterns in images. KFPKL manages data ambiguity using image fuzzy sets, while an optimization problem includes a KL divergence term to reduce noise influence in segmentation. The kernel distance measure is used to detect nonlinear features in pictures.	The study employed two publicly available brain MRI datasets as well as several synthetic picture datasets. In contrast to cutting-edge methods, the proposed remedy surpasses them concerning average segmentation accuracy and dice score.
Parhad *et al.,* [31]	Speckle noise reduction in sar images using improved filtering and supervised classification	2023	Multimedia Tools and Applications	Research sought to enhance Synthetic Aperture Radar (SAR) image processing by tackling speckle noise and refining classification accuracy. Emphasizing SAR's pivotal role in Earth surface analysis, the paper introduced a novel method employing local statistics, evaluated filters, and stressed the importance of sliding window size in noise reduction.	In MATLAB, the Extended Lee-sigma filter beat other filters while evaluating a virtual SAR dataset. The suggested model outperformed previous models, with a PSNR of 65.72 and an SSIM of 99.92%, proving its usefulness in SAR image processing. The study also noted the WC-ISSA classification methodology's high potential.
Denić *et al.,* [32]	Adaptive neuro fuzzy estimation of the most influential speckle noise distributions in color images for denoising performance prediction	2023	Multimedia Tools and Applications	This study explores speckle noise in images to predict denoising effectiveness, using diverse spectral range reference values. It delves deeper into digital image attributes beyond conventional theoretical definitions, offering valuable insights. 2D spectrum noise analysis enhances filters. The goal is to identify crucial speckle noise distributions for	The objective of the research is to identify optimal speckle noise distributions that enhance denoising performance. This involves utilizing clean images and evaluating various metrics such as PSNR, NCD, and FSIMc. Finally, the study reveals distinct disciplines in speckle noise distributions and the ALOHA filter as a key component in forecasting

Table 3. Continued
The research article findings based on the proposed searching criterion: Theme 1

Authors	Title	Year	Journal	Methodology	Findings and advantages
				denoising. Evaluation, featuring PSNR, NCD, and FSIMc, underscores the ALOHA filter's significance in predicting denoising efficacy.	denoising performance increases.
Ahmed *et al.,* [34]	Deep Learning-based noise type classification and removal for drone image restoration	2023	Arabian Journal for Science and Engineering	Recent advancements in deep learning have spurred image noise categorization and denoising research. Existing methods, such as single-stage denoising autoencoder (DAE) and two-stage approaches, exhibit limitations. This paper presents a two-stage multi-type denoising system achieving high accuracy (98.2% to 100%) across four noise types. The methodology involves robust denoising algorithms ensuring effective restoration across diverse noise types, adaptable to various domains without prior noise type knowledge.	The paper presents a novel two-stage method for multi-type picture denoising, attaining high per-class classification accuracy (98.2% to 100%). The combined technique exhibits promising PSNR and SSIM values, suggesting its effectiveness in restoring high-quality images. Its adaptability allows implementation across various domains without prior noise type knowledge, enhancing multi-type picture denoising systems compared to existing methods.
Amalaman And Eick [33]	SHCF: A supervised hierarchical clustering approach to remove high density salt and pepper noise from black and white content digital images	2023	Multimedia Tools and Applications	The paper presents the Supervised Hierarchical Clustering Filter (SHCF), a method to identify healthy pixels from noisy ones in photos with salt and pepper noises (SPN). SHCF labels pixels, creates a SHC-tree, removes 100% purity clusters, designates smaller clusters as outliers, and replaces corrupt pixels. Evaluation includes photos with SPN and conventional test photos.	In the paper, it's found that SHCF excels by 16% in handling high-density noise, particularly in images with numerous black and white pixels. Its innovative pixel replacement approach ensures reliable and consistent restoration results. These findings highlight SHCF's effectiveness in removing salt-and-pepper noise, especially in high-density scenarios.
Gao *et al.,* [35]	Patch-based fuzzy local weighted c-means clustering algorithm with correntropy induced metric for noise image segmentation	2023	International Journal of Fuzzy Systems	The paper presents PFLWCM-CIM, an innovative approach for fuzzy clustering in image segmentation. It enhances noise resistance by clustering picture patches instead of pixels, employing a distinct distance measure based on image patches	The PFLWCM-CIM algorithm outperforms standard methods in picture segmentation under high noise, preserving local geometry with efficient image patch clustering. Its novel distance measure enhances noise resistance, and local weights ensure

Table 3. Continued
The research article findings based on the proposed searching criterion: Theme 1

Authors	Title	Year	Journal	Methodology	Findings and advantages
				and CIM. Local weights combine spatial and pixel relationships for improved similarity representation.	thorough pixel similarity representation, making it a top-tier solution for noisy picture segmentation.
Orazaev *et al.,* [36]	Neural network system for recognizing images affected by random-valued impulse noise	2023	Applied Sciences (Switzerland)	This paper presents a three-step process to address random-valued impulse noise in images. It incorporates a pixel detector, adaptive median filter for noise removal, and a neural network for image recognition, trained on the CIFAR10 dataset. Findings indicate a notable decrease in quality and accuracy beyond 10% noise levels. The research emphasizes the neural network's effectiveness in mitigating random-valued impulse noise, enhancing.	In the paper, our method reduces random-valued impulse noise in CIFAR10 images, enhancing recognition accuracy. It highlights the importance of thorough cleaning, especially above 10% noise levels, to prevent degradation. The neural network system effectively corrects damaged pixels, surpassing existing noise-cleaning techniques, showcasing the practical benefits of our three-stage approach for processing such images.
Swee *et al.,* [37]	Deep convolutional neural network for SEM image noise variance classification	2023	Engineering Letters	The paper introduces a new approach to denoise Scanning Electron Microscopy (SEM) images by employing a deep learning algorithm to detect noise variance. It utilized 1200 SEM images split into training, validation, and testing sets. The method employed a Gaussian-Noise Convolutional Neural Network (GN-CNN) with encoder, convolutional, attention, decoder, and decision layers to classify noise variance.	The paper demonstrates the system's proficiency in categorizing noise fluctuations in SEM images. GN-CNN surpasses other deep learning models and human-eye assessment, showcasing precise noise variance categorization. It proposes an effective method for denoising SEM images, enhancing their utility in industrial, medical, and research settings. The findings suggest potential for improved SEM image quality and analysis.

4.2 Theme 2: Image Classification and Recognition under Noise

This study introduces a new way to classify hyperspectral images that's better than older methods. It adds a special module to handle noise and cleans up the images using a special framework. The result is a more accurate way to tell things apart in real-world datasets [38]. When it comes to spotting breast cancer, using a method based on Muduli *et al*.'s [39] work gives impressive results: 93.2% accuracy in telling benign from malignant lesions. This suggests that using single-slice DBT could be even better than mammograms for screening [40]. Another study suggests a new method for spotting kidney problems by dealing with noisy labels. By doing this, it can beat other methods in spotting glomerular lesions, which could be helpful for diagnosing kidney issues [41]. In the world of intelligent transport systems, a new way to fuse audio and visual features is helping to classify vehicles more accurately, even in bad weather [42].

There's also progress in radar technology. A new method helps radar systems work better by reducing noise in the data they collect [43]. This could make radar systems cheaper and more effective. In medicine, a new system can clean up blurry X-ray images without needing to take the X-rays again. This could make diagnosing medical issues faster and easier [44]. In the field of brain-inspired machine learning, researchers are finding that connections in the brain can help improve how machines recognize things, especially in noisy conditions [45]. For studying yeast growth, a new algorithm called BABY helps measure how fast individual cells grow, which could give insights into how microbes work [46]. And finally, a new method using deep learning (Figure 3) can tell apart normal and noisy QR codes, helping to improve information retrieval [47]. Table 4 shows the previous research findings for Theme 2.

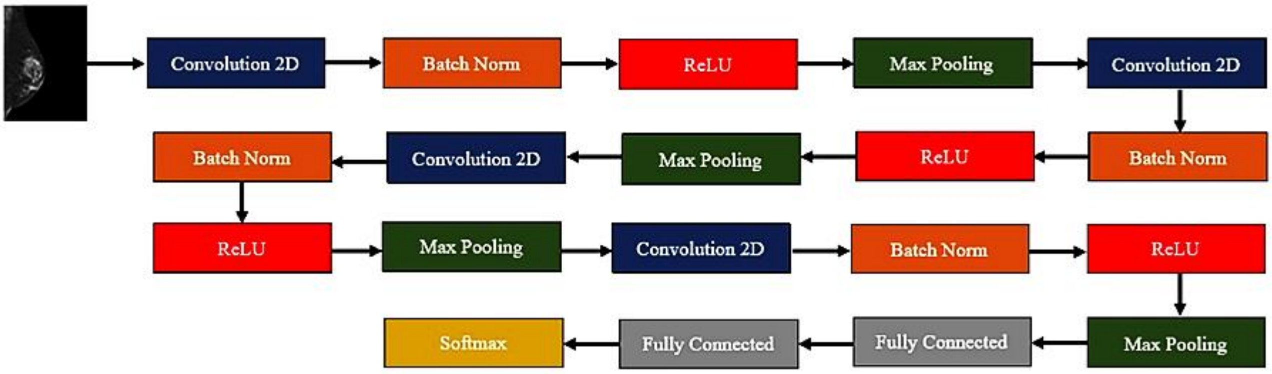


Fig. 3. Outline of the developed deep learning [40]

Table 4
The research article findings based on the proposed searching criterion: Theme 2

Authors	Title	Year	Journal	Methodology	Findings and advantages
Gong *et al.,* [38]	A CNN with noise inclined module and denoise framework for hyperspectral image classification	2023	IET Image Processing	The paper introduces a novel deep learning structure for hyperspectral image classification, incorporating a noise-oriented module and denoising framework. Addressing intra-class variance and overlap, it adopts a physical noise model for spectral signature. The noise-oriented module identifies and eliminates physical noise in objects via the denoising framework, enhancing CNN performance.	Experiments are carried out on two regularly used real-world datasets, and the results demonstrate the efficacy of the suggested strategy. The model has enhanced performance in identifying noise and removing the physical noise.
Mendes *et al.,* [40]	Avoiding tissue overlap in 2D images: Single-slice DBT classification using convolutional neural networks	2023	Tomography	The paper aimed to create a deep learning model, following proposed model, to classify lesions as benign or malignant from specific slices. It used to modify	The paper reports a 93.2% accuracy on the test set, with 92% sensitivity, 94% specificity, 94% precision, 94% F1-score, and 0.86 Cohen's kappa. These

Table 4. Continued

The research article findings based on the proposed searching criterion: Theme 2

Authors	Title	Year	Journal	Methodology	Findings and advantages
				fully connected layers and regularization. Nine slices from each of 77 DBT volumes were taken, augmented thrice to yield 2772 training images, and validated twice.	findings indicate that single-slice DBT has potential to rival advanced studies, hinting at its advantages over mammography with further data, augmentation techniques, and transfer learning.
Li *et al.,* [41]	Glomerular Lesion recognition based on pathology images with annotation noise via noisy label learning	2023	IEEE Access	This study introduces a novel method for addressing label noise in glomerular datasets. By employing a noisy label discriminator, contrastive learning, and consistency regularization, the model achieves robust supervision, pathology feature extraction, and lesion recognition from pathology images. Large-scale datasets from 870 renal disease cases were utilized, incorporating PAS, MT, and PASM staining.	The paper demonstrates the model's enhanced ability to detect glomerular lesions, achieving notable f1-scores: 25% surpass 85%, 43.75% exceed 80%, and 75% attain 70% or higher. Further tests validate each module's effectiveness. The noisy label learning method accurately identifies diverse glomerular lesions, paving the way for a computer-aided renal pathology evaluation system.
Zhao *et al.,* [42]	Vehicle classification based on audio-visual feature fusion with low-quality images and noise	2023	Journal of Intelligent and Fuzzy Systems	The paper introduces the Urban Road Vehicle Audio-visual (URVAV) dataset for challenging environments. It proposes LVINet, a CNN model for categorizing low-quality vehicle images. By employing a spatial channel attention-based audio-visual feature fusion method, it enhances accuracy by integrating auditory and visual features, improving vehicle characteristic depiction.	The results of the experiments indicate that LVINet attains a classification accuracy of 93.62%, employing fewer parameters than currently established CNN models. Moreover, the suggested fusion strategy for audio-visual features contributes to an increased accuracy of 7.02% compared to solely utilizing audio features and 4.33% compared to solely using visual features.
Erdogan and Guney [43]	Object classification on noise-reduced and augmented micro-doppler radar spectrograms	2023	Neural Computing and Applications	Introducing a technique to minimize noise in micro-Doppler radar datasets. This method involves taking the average of class spectrograms in RadEch micro-Doppler radar datasets and eliminating pixels from each sample. The Augmented RadEch dataset incorporates a combination of conventional and learning-	The paper categorizes raw, enhanced, and noise-reduced spectrograms by employing a 5-layer convolutional neural network, specifically VGG-16 and VGG-19. A comparison with current state-of-the-art investigations indicates a superior performance in classifying noise-reduced spectrograms compared to existing approaches.

Table 4. Continued
The research article findings based on the proposed searching criterion: Theme 2

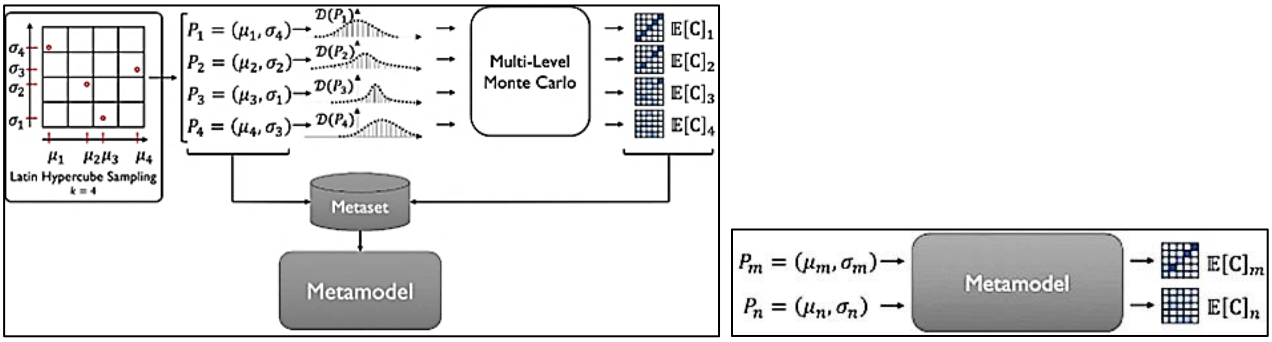
Authors	Title	Year	Journal	Methodology	Findings and advantages
				based strategies, with the latter leveraging Generative Adversarial Networks.	
Chiu and Wei [44]	Integrating DeblurGAN and CNN to improve the accuracy of motion blur X-Ray image classification	2023	Journal of Nuclear Science and Technology	This study employs DeblurGAN and a CNN to enhance motion-blurred clinical X-ray image categorization accuracy, reducing the necessity for X-ray retakes. The DeblurGAN model demonstrates effectiveness in medical X-ray image deblurring, aiding InceptionV3 in error identification. This approach may enhance diagnostic efficiency for various medical images with motion blur, such as MRI and CT scans.	The findings indicate that the motion blur group achieved a classification accuracy of 87%, whereas the deblurred group showed an accuracy of 91%. This suggests that the approach not only enhances accuracy in classification but also brings the deblurred group images back to the original image group's level of 92%.
Alamia *et al.,* [45]	On the role of feedback in image recognition under noise and adversarial attacks: A predictive coding perspective	2023	Neural Networks	In the paper, deep convolutional networks (CNNs) replicate visual processing using Predictive Coding (PC) dynamics for image reconstruction or categorization. Results demonstrate superior accuracy compared to forward networks. Hyperparameters governing recurrent dynamics are modified to assess predictive feedback's functional advantages across experiments.	The paper delves into how different model depths (3-layer CNN, ResNet18, and EfficientNetB0) respond to noise (CIFAR100-C). It finds that as noise levels rise, especially in deeper layers, the network increasingly depends on top-down predictions. This highlights the importance of feedback linkages in sensory systems, contributing to our understanding in neuroscience.
Pietsch *et al.,* [46]	Determining growth rates from bright-field images of budding cells through identifying overlaps	2023	eLife	Birth Annotator for Budding Yeast, a method employing a convolutional neural network to derive single-cell growth rates from label-free images. Employing size-based cell separation and recognizing bud necks, BABY tracks cells, forms lineages, and predicts growth rates using machine learning based on volume change rates. Find details in the paper.	The paper explores a method and a microfluidic device, finding that bud growth is likely size-then-timer-controlled. Changes in Sfp1 nuclear concentration precede growth rate changes. Real-time growth rate control enables BABY to gain insights by estimating single-cell growth rates and fitness.

Table 4. Continued
The research article findings based on the proposed searching criterion: Theme 2

Authors	Title	Year	Journal	Methodology	Findings and advantages
Waziry *et al.,* [47]	Performance comparison of machine learning driven approaches for classification of complex noises in quick response code images	2023	Heliyon	The paper introduces a straightforward deep learning framework to distinguish between clear and distorted QR codes, categorizing the noise type. Two phases are outlined: creating an 80,000-image dataset with seven noise types and training CNN, seventeen pre-trained deep learning models, and two classical algorithms (Naïve Bayes, Decision Tree) on this dataset.	XceptionNet scored the highest accuracy (87.48%) and kappa (85.7%). The suggested CNN, despite fewer layers, competes closely with top models at 86.75% accuracy. However, all models face difficulty categorizing photos with Gaussian and Localvar noises.

4.3 Theme 3: Innovative Models and Approaches for Noise-Robust Image Analysis

Machine learning models can struggle with noisy data, leading to degraded performance. To tackle this, researchers use metalearning (Figure 4), a method that predicts how different types of noise affect model accuracy. This study digs into how noise affects performance for different categories, using advanced simulation techniques. They found that metalearning accurately predicts how well a model will perform based on the type of noise it encounters [48]. In image processing, fuzzy clustering algorithms like C-means often struggle with noisy images. A new method improves this by combining different types of information to better segment noisy images, outperforming other methods [49].



(a) (b)

Fig. 4. The process for training and evaluating of the metamodels (a) Training process (b) Evaluation process [48]

For image classification, traditional deep learning models can be sensitive to noise, while spiking neural networks (SNNs) are more robust. A new kind of neural network, the Spiking Quantum Neural Network (SQNN), blends classical and quantum computing to handle noisy images better than other models [50]. There's also a new theory for recognizing objects in blurry images without having to first unblur them. This theory, developed using advanced mathematical techniques, outperforms traditional methods [51]. In hyperspectral image classification, a new method combines different techniques to improve accuracy, especially in noisy environments. This could be useful for tasks like remote sensing [52]. Lastly, a new model excels at identifying the source of digital images in social media networks, achieving impressive accuracy rates [53]. The research article findings based on the proposed search criteria are listed in Table 5.

Table 5
The research article findings based on the proposed searching criterion: Theme 3

Authors	Title	Year	Journal	Methodology	Findings and advantages
De *et al.,* [48]	Metamodelling of noise to image classification performance	2023	IEEE Access	The paper outlines a methodology comprising two key steps. Firstly, employing multi-level Monte Carlo simulations to assess established convolutional neural networks' performance with varied input noise levels. Secondly, utilizing metalearning techniques with Latin Hypercube Sampling to predict classification performance per class based on input noise distribution parameters.	The paper examines the impact of rising noise levels on diverse input data categories. Findings indicate metalearning effectively forecasts class performance amid noise level variations, with larger metasamples enhancing prediction accuracy. This research sets the groundwork for recommending robust classifiers in noisy settings, aiding future investigations.
Flusser *et al.,* [51]	Blur invariants for image recognition	2023	International Journal of Computer Vision	Blur impedes object recognition in photos. Restoration methods employ deblurring or deep learning with training set augmentation. This paper introduces blur invariants, a novel technique for fuzzy photo characterization, eliminating the need for deblurring or data augmentation. Unlike prior methods, it doesn't rely on prior blur type knowledge.	Orthogonal projection operators create Fourier invariants, ensuring stability. A universal substitution method facilitates seamless generation and application of coupled invariants for blur and spatial transformations. Experimental comparisons employing convolutional neural networks highlight the advantages outlined in the paper.
Wu *et al.,* [49]	Full-parameter adaptive fuzzy clustering for noise image segmentation based on non-local and local spatial information	2023	Computer Vision and Image Understanding	The paper recommends improving noisy image segmentation by combining local fuzzy factors with non-local full-parameter adaptive spatial data. It introduces smoothness and creates an adaptive matching function to determine smoothing parameters, search term window, and neighborhood window. This integration reduces noise interference and segmentation ambiguity, leading to enhanced overall accuracy.	The suggested technique beats most existing fuzzy clustering-based algorithms in a variety of evaluation metrics and visual impacts, as evidenced by segmentation studies on synthetic noise and color images.

Table 5. Continued
The research article findings based on the proposed searching criterion: Theme 3

Authors	Title	Year	Journal	Methodology	Findings and advantages
Konar *et al.,* [50	A shallow hybrid classical–quantum spiking feedforward neural network for noise-robust image classification	2023	Applied Soft Computing	The paper introduces SQNN, a hybrid classical-quantum spiking feedforward neural network for robust picture classification in noisy and adversarial environments. SQNN's spatial-temporal capabilities enable accurate interpretation of noisy test photos, replacing less effective techniques like STDP and Spike-Prop with variational quantum circuit training, using the PennyLane Quantum Simulator for testing and benchmarking.	Through experimental evaluations on unseen test images with added noise from ImageNet, CIFAR10, MNIST, KMNIST, and FashionMNIST datasets, the novel SQNN model outperforms Random Quantum Neural Networks (RQNN), feedforward SNN (SFNN), ResNet-18 networks, and AlexNet.
Chen *et al.,* [52]	Noise robust hyperspectral image classification with MNF-based edge preserving features	2023	Image Analysis and Stereology	This study enhances edge-preserving features (EPFs) in hyperspectral image (HSI) classification. It employs minimal noise fraction (MNF) to reduce data cube dimensionality, outperforming principal component analysis (PCA). The methodology in THE PAPER leverages MNF for improved preservation of HSI data cube fine properties, surpassing PCA-EPFs.	Experimental results show that the suggested technique outperforms PCA-based EPFs in noisy situations containing shot noise and Gaussian white noise. Furthermore, MNF+EPFs beat PCA+EPFs in most testing scenarios, even without noise in HSI data cubes, making them ideal for remote sensing.
Rana *et al.,* [53]	SNRCN2: Steganalysis noise residuals based CNN for source social network identification of digital images	2023	Pattern Recognition Letters	The CNN proposed in the paper identifies social media artifacts by analyzing noise residuals through steganalysis techniques. It filters input images with 30 SRM filters to obtain these residuals. A fully connected layer within an efficient CNN is utilized to extract and categorize social media network-related features.	The suggested model excels, surpassing current methods on VISION and Forchheim datasets, achieving 99.53% and 100% image-level accuracy. Merging similar class photos enhances model resilience, as seen in the pooled dataset's positive outcomes, reinforcing the proposed model's efficacy, as referenced in the paper.

5. Conclusions

The discoveries within three main themes highlight some exciting advancements in image processing and analysis. Theme 1 introduces us to remarkable filters like the Extended Lee-sigma filter and the SHCF. These filters excel in tasks such as SAR image processing by effectively reducing high-density noise. Moreover, the PFLWCM-CIM algorithm stands out as a significant innovation for picture segmentation in noisy environments. In Theme 2, progress in image classification and recognition is evident, with models like LVINet and single-slice DBT demonstrating impressive accuracy. This progress holds promise for enhancing medical imaging diagnoses. Lastly, Theme 3 focuses on new models and approaches that improve image analysis in noisy conditions. Techniques such as metalearning for predicting class performance and the SQNN model surpassing established networks across diverse datasets are noteworthy advancements. These findings collectively push the boundaries of image processing, offering promising solutions for real-world applications.

In conclusion, the field of object recognition in complex scenes is continuously evolving due to advancements in deep learning, biomimetic techniques, contextual cueing, and scene context semantics. Despite significant progress, challenges persist, such as detecting 3D objects in adverse conditions and learning with limited examples. However, innovative methods like biomimetic visual transformation and contextual cueing show potential in overcoming these challenges. Moreover, prioritizing ethical considerations regarding privacy, biases, and societal impacts is crucial for responsible technology development and deployment. Looking ahead, concerted efforts towards creating interpretable, robust, and ethically sound models will be essential for unlocking the full potential of object recognition across various domains. Through continued research and collaboration, we can address these challenges and drive the field towards more impactful and socially conscious advancements.

Acknowledgement
This work was supported by funding by the Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme (FRGS/1/2023/ICT02/UMT/03/2).

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