Network Modeling Analysis in Health Informatics and Bioinformatics (2022) 11:35
https://doi.org/10.1007/s13721-022-00376-0

REVIEW ARTICLE

Trends and challenges of image analysis in facial emotion recognition: a review

Soumya Ranjan Mohanta[1] · **Karan Veer**[1]

Received: 27 March 2022 / Revised: 27 July 2022 / Accepted: 24 August 2022 / Published online: 23 September 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Austria, part of Springer Nature 2022

Abstract
In the field of pattern recognition, facial expression recognition (FER) has a significant influence, and researchers are working hard to develop a better FER system for applications involving human–computer interaction. The facial expression provides important information for building a FER system and is often regarded as the most effective tool for quickly recognizing human emotions and intentions. Presently, a FER system is a key component of artificial intelligence and has practical uses in a variety of sectors such as psychological studies, portable mobile applications to automatically insert emotions into autistic people's assistance systems, and so on. A system encounters numerous variations of the human face, such as expression, colour, orientation, texture, posture, and so on, to detect a facial expression. It is a tough task to create a human FER system that is based on machines. Facial muscular motion and skin deformation-based algorithms are used to develop a variety of FER systems. This study offers a thorough overview of FER processes as well as a comparison of some of the efficient methods. Furthermore, this survey will aid scholars in better understanding many types of challenges in the field of emotion detection. The PRISMA model representation is also addressed in this study.

Keywords Facial expression recognition (FER) · Biomedical signal · Patch-based methods · Emotions recognition · Gabor filter · Support Vector Machine (SVM) · k-nearest neighbors (KNN) · Random Forest · Decision Tree

1 Introduction

A facial expression is a prevalent form of human communication and an important aspect of nonverbal communication (Wang and Jing-Wei 2018). Humans use facial expressions to convey their emotions and intentions which are one of the most powerful, natural, and direct ways (Sariyanidi et al. 2015). They are also the most evident and potent indicators of the emotional state of mind. Six face expressions are universal namely happy, surprise, disgust, sad, fear, and angry (Kiran and Kushal 2016).

One or several actions or positioning of the muscles underneath the epidermis of the human face cause an expression. These muscular motions are employed to communicate an individual's emotional state. For facial expression recognition, the eye is considered a crucial feature of the face. Furthermore, mouth and lip muscle movements are crucial in transmitting a person's emotional state (De and Saha 2015). A face recognition system (FRS) is a computer program that automatically recognizes or verifies a person based on a digital image or a video frame from a video source. The FRS is provided a face picture or image sequence as input and it matches the given input with face images stored in the database using the proposed methods (Ohlyan 2013) Table 1.

In a possible version of a facial expression recognition system, an input sensing device (a webcam or a basic camera) gets the input image from a person and then interacts with the computer. The emotionally expressive facial picture is created after representative features from the face area are detected, it is then pre-processed and classified into one of the emotion classes (anger, fear, surprise, gladness, neutral, or disgust) using a classifier. For the identification and categorization of images, there are many detection methods and classifier algorithms (shown in Table 1) that can be applied (Saha et al. 2013).

Feelings have a vital role in our interpersonal relationships as well as in how we utilize computers. Affective

✉ Karan Veer
veerk@nitj.ac.in

[1] Department of Instrumentation and Control Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India

Table 1 FER techniques with their algorithms

Authors	Pre-processing technique	Feature extraction technique	Classifier	Accuracy
Noh et al (2007)	Face detection	Action-based model	ID3 decision tree	73%
Bashyal et al (2008)	Image enhancement	Gabor filter (GF)	LVQ	88.86%
Zhang et al (2011)	Gabor filter	Patch-based	SVM	82.5%
Ji and Idrissi (2012)	Face acquisition	LBP, VTB, Moments	SVM	95.84%
Demir et al (2014)	Histogram Equalization	LCT	OSLEM	94.41%
Dahmane and Meunier (2014)	Face alignment	HOG	SVM	85%
Mahersia and Hamrouni (2015)	Normalization	Steerable pyramid	Bayesian neural network	95.73
Hegde et al (2016)	Resizing	GF	Euclidean distance, SVM	88.58%
Ju Jia1 et al (2016)	Not mentioned	2DPCA	Random forest	92.72%
Nivedita Chitra et al (2016)	contrast and illumination equalization, fuzzy filtering, histogram equalization	LBP	SVM	86.6%
Talele Kiran et al. (2016)	Face detection	LBP Histogram	SVM	94.77%
Islamet al.(2018)	Face detection	2DPCA	MDC	89.86%
Maryam Imani et al. (2019)	Not specified	GF	CNN	95.58%
Fan Zhang et al. (2020)	Face detection	HOG, PCA	SVM	71.4%
Zhou Ruan et al (2020)	Not mentioned	GNN	GNN	95.85%

computing is a field of computer science that emphasizes a user's emotions when interacting with computers and software. Since a person's emotional state may affect their focus, problem-solving, and decision-making abilities, the goal of affective computing is to create systems that can identify and control human emotions to improve productivity and effectiveness while working with computers (Kołakowska et al. 2014).

The identification of human emotions has a variety of uses and implementations in a variety of situations while man–machine communication is the most encouraging one among them. Other applications for emotion detection include patient monitoring, evaluating a suspect for antisocial intentions, and many more. The centre can use an emotion recognition system to analyse a consumer's response to viewing certain commodities or commercials or to get specific data or messages. The service centre can adjust its approach according to the consumer's reaction, like whether they are pleased, disappointed, or angry (De and Saha 2015; Bhattacharya 2022).

Human–computer interface (HCI), commercial goods, and medical research are the three primary categories of computer-based emotion detection applications. Human-centered systems in the field of HCI must be created in such a manner that they respond not just to user input but also to user behaviour, particularly in ubiquitous computing situations (Zeng et al. 2009). Automobile fatigue monitoring systems, entertaining systems such as gaming, human–robot interaction, and security are some examples of commercial implementations. Medical research includes clinical depression detection, pain evaluation, behavioural and neurological studies, and so on (Nuwan 2018). One can detect the emotions of autistic people (Leung et al. 2022). However, as more applications migrate to the cloud, the majority of enterprise businesses now function from a distance. Almost every enterprise firm uses the cloud as a platform. Cloud computing provides customers with a wide choice of applications based on massive resources and unlimited storage space (Ghobaei-Arani et al. 2017; Drishti et al. 2020; Shahidinejad et al. 2020).

Facial expression recognition for detecting human emotion is gaining prominence due to its expanding range of uses in human–computer interaction systems. Although various approaches to facial emotion detection, such as facial expression, speech, gesture, and stance, have been explored in journals, emotion recognition is primarily consisting of two fundamental processes involving feature extraction and classifications. The process of selecting a set of characteristics or attributes, usually independent, that collectively reflect a particular emotive face expression, is known as feature extraction. Whereas classification is the coding of emotional characteristics into a particular emotion from various emotion types such as gladness, anger, amazement, sadness, disgust, and so on. In influencing the effectiveness of a FER system, both the collection of features evaluated for extraction and the classifier is equally important. Even a decent classification algorithm cannot always get the best results when the features are poorly chosen. As a result,

picking superior characteristics or features has become a requirement for high recognition accuracy and a positive outcome. Over the last three decades, several approaches to identifying emotion using facial expressions have been formulated and applied (Saha et al. 2013).

1.1 Motivation and challenges

Facial expression recognition for detecting human emotion is gaining prominence due to its expanding range of applications. Improved and optimized human–computer interaction is required for the ubiquitous and universal usage of computing systems. There is no such standard system that is universally used for facial emotion recognition. The recent advancement in technology and the development of various algorithms and tools make the research work less complex and less time-consuming for researchers.

Many researchers have presented their studies to provide a basic idea or review on facial emotion recognition. Amreen Fathima and K Vaidehi gave a review on the recognition of facial expressions. Their review was focused on machine learning techniques. They categorized the features of facial images into geometric features, appearance features, and hybrid features. Several feature extraction techniques and classification algorithms that researchers used are discussed comparatively. They also mentioned the applications of facial recognition systems in a multitude of sectors such as health care, robotics, forensics, security, etc. (Fathima and Vaidehi 2020). Olufisayo Ekundayo and Serestina Viriri presented a review on different methods of facial expression recognition. They explained LBP, HOG, and Gabor filter texture techniques for the feature extraction process. They reviewed SVM, Adaboost, deep learning, and Hidden Markov Model. In their study, they explained the performance and limitations of various methods in a comparative manner (Ekundayo and Viriri 2019). Francesca Nonis et al. presented a literature review on traditional and deep learning techniques in the field of facial emotion recognition. They mainly discussed the strength and weaknesses of these two types of techniques (Nonis et al. 2019). Byoung Chul Kogave a brief review on facial emotion recognition. They discussed conventional methods along with deep learning techniques. They mainly explain deep learning techniques in detail. They also discussed a hybrid approach using CNN (convolutional neural network) and long short-term memory (LSTM). The datasets were also provided along with their web link (Byoung Chul Ko 2018a). Wafa Mellouk and Wahida Handouzi presented a study that was mainly focused on neural networks like CNN, and VGGNet networks in facial emotion recognition or we can say deep learning techniques (Mellouk and Handouzi 2020). Xiaoming Zhao and Shiqing Zhang divided the methodologies for extracting facial features into two groups: approaches based on geometric features and approaches based on appearance. They explained the feature extraction techniques that are used for dynamic image sequences. Various classification techniques were explained along with their performance using the JAFFE and Cohn-Kanade databases (Zhao and Zhang 2016). Table 2.

The similarities and differences (shown in Table 2) between the above-discussed reviews and this present study are discussed: Similarities: The proposed study also gives a brief overview of various feature extraction techniques and classification techniques. It discussed some popular classification techniques which yield good results in the recognition of emotion from facial expressions. So that one can get a general idea about different feature extraction techniques and classification techniques. Differences: The study shows a comparative analysis of the accuracies of various classification algorithms to provide a basic idea about the classification accuracies of the algorithms so that one can work on facial emotion recognition using these techniques to get

Table 2 Summary of the research questions-answers

Sr. No	Questions	Answers
1	What are the key steps in a facial recognition system?	In a facial recognition system, there are three key steps: preprocessing, feature extraction, and classification
2	What are the different feature extraction techniques available which can be used for the feature extraction process?	Gabor filters, Local binary pattern, Histogram of oriented gradients, Local curvelet transform, Local directional number pattern, Discrete wavelet transform, and so on
3	What are the different classification algorithms that are used to classify facial expressions?	Support vector machine, fuzzy logic, Convolutional neural networks, Multi-layer perceptrons, Decision tree, Random forest, and so on
4	What are the average efficiencies of different classification algorithms?	SVM—95.31% Fuzzy Logic–87.98% Neural Networks–91.38% Random Forest–89.16% KNN–77.71% Decision Tree–90.98%

better results. To provide the different challenges that one may face during his/her research work the paper also talks about the challenges in facial emotion recognition. It also gives an overview of the PRISMA model presentation.

Even for humans, describing a facial expression that conveys a specific emotion can be challenging. In the same facial expression, different people detect various emotions. It's significantly more challenging for AI. Emotion identification is difficult due to a variety of factors. The following are some of the most typical issues and obstacles that a face emotion detection system can encounter:

1.2 Lighting issues.

In an unrestricted environment, changing lighting and contrast are also extremely typical. Developers frequently use illumination normalization techniques to improve recognition rates.

There are also some other ideas that are not conventional. Certain experts recommend introducing an infrared or near-infrared layer to a stream of data. for example. The layer is unaffected by changes in illumination and adds recordings of changes in skin temperature that might reflect emotions (Stratou et al. 2011).

1.3 Identifying facial features

Faces are scanned for brows, eyes, noses, lips, chins, and other facial characteristics using an emotion recognition solution. This detection can be challenging in some cases because of:

- The separating distance between the characteristics. The program "remembers" the mean distance among the landmarks. It only searches within that range while looking for them. For example, it could have trouble distinguishing between eyes that are far apart.
- The dimensions of the feature. Emotion recognition software has a hard time recognizing atypical characteristics like thin or pale lips, small eyes, and so on.
- Colour of the skin. Because of a person's skin color, a solution may misclassify or misinterpret a characteristic on some occasions.

Some researchers use a part-based model that separates facial points into numerous sections depending on the actual anatomy of a face to enhance feature identification accuracy. This model then sends these sections into the network one at a time, with appropriate labels (Alina 2019).

1.4 Recognizing incomplete emotions

The majority of algorithms are designed to recognize the peak high-intensity expression while ignoring lower-intensity expressions. When examining individuals who are self-contained or persons from cultures where emotional repression is a tradition, this leads to incorrect emotion identification. By adding new labels to datasets, an algorithm may be trained to identify early indicators of emotions. To accomplish so, we'll have to include emotion intensity badges on the labels along with emotion identifiers and landmarks of facial characteristics. Implementing a peak-piloted deep network is another solution to resolving this problem. While minimizing frame changes, this network analyses peak and non-peak expressions of the same feeling (Deng et al. 2020).

1.5 Capturing the context of emotion

The same amount of information about emotions may be obtained from the environment or surroundings and body posture as from the face. However, capturing context is a time-consuming process since it needs a thorough examination of the entire image rather than just a face. Furthermore, emotions displayed through gestures have received very little attention compared to facial emotions. A video stream is split into two parts by the Context-aware neural networks (such as CACA-RNN and CAER-Net). The two parts are a face (or many faces) and the surroundings (body posture, gestures, items in the frame, etc.). A facial emotion analyser and a context analyser are the two parts of the network. Both network readings are taken into consideration in the final outcome (Aldao 2013).

1.6 Racial differences

We may struggle to recognize others' feelings, particularly if they are of a different race or have distinct cultural customs. Even the most advanced AI technologies have significant difficulty in this area. Google Photo algorithms, for example, did not detect persons with a dark complexion in 2015. The issue here is the diversity of data as well as the development team structure of researchers. The majority of publicly available databases have a huge amount of information on white males and never on females or persons of colour. Furthermore, labelling teams are usually composed of white men, who have a tendency for putting solutions to the test themselves. A more thorough study of datasets before training might be one answer to this problem. Another option is to form more diverse teams (Sohail et al. 2021).

1.7 Differences in emotional expression between cultures

Though everybody experiences the same emotions, we convey them in various ways. Many individuals in western cultures use a different set of facial and body gestures to indicate each of the seven fundamental emotions. People in Japan and China, on the other hand, are typically more restrained, expressing their feelings or emotions solely through unique eye movements. This must be considered when selecting data for training. Choose a suitable database with individuals belonging to the same culture to identify their emotions, or examine the algorithm using multiple databases (Lim 2016).

1.8 Recognizing the emotions of children

Children and infants convey emotions in different ways compared to adults. They comprehend more than they can convey vocally. Also, they respond to what they see with a variety of gestures on their face. Furthermore, the child does not control his feelings. Scientific research, on the other hand, cannot prove that these expressions of face convey feelings in newborns and pre-schoolers. Another problem arises from the fact that adults interpret children's emotions. Early studies of baby emotions, for example, suggested that anger might be shown by newborns as early as 7 months old. The reality is that babies were just scowling and at such a young age, there's no way to accurately link this expression with emotion (Guiping 2021).

The remaining part of our paper is organized as follows: Section 2 presents the design of literature review methodologies, Sect. 3 represents the key steps in a facial emotion recognition system, Sect. 4 discusses the various available datasets on the internet, and Sect. 5 discusses the different feature extraction techniques, Sect. 6 talks about the different available classifiers, Sect. 7 talks about the performance analysis parameters. The accuracy of different classification techniques is analysed in Sect. 8, and the conclusion part is presented in Sect. 9.

2 Design of literature review methodologiES

To do systematic mapping various guidelines (GRADE, SWiM, PICO, and PRISMA) are there in the literature (Sachin and Karan 2022; Gao et al. 2020; Pooja and Karan 2021; Eriksen and Frandsen 2018; Liberati et al. 2009). Grading of Recommendations Assessment, Development, and Evaluation (GRADE) is an approach used in systematic reviews for the quality rating of the evidence (Guyatt et al. 2011). GRADE norms cab be used at different stages where a researcher could begin by formulating questions in Preferred Reporting Items for Systematic Reviews (PRISMA) format. PRISMA is a set of minimum elements for evidence-based systematic reviews and meta-analyses. PRISMA is primarily intended for evaluating the impact of interventions, although it can also be used to document systematic reviews with aims other than evaluating interventions. Using PRISMA writers can improve their paper review or presentation. It may not be a tool for quality evaluation but editors and reviewers of journals can take advantage of PRISMA during a critical assessment of published systematic reviews (http 2022; Katurura and Cilliers 2018).

To carry out our research work in this paper, we have taken journals from publications like IEEE Xplore, Science Director, MDPI, and Springer. The paper also contains some journals and conferences from other sources on the internet. Apart from these, we have also taken some papers from ResearchGate. Most of the taken papers are published between 2007 and 2022. In these papers machine learning has taken the centre stage. To get these papers we used some search strings in a particular format in the search engine and for that Boolean Operators are required to link the leading terms. For example (Facial Emotion Recognition OR Machine Learning) AND (Facial Emotion Recognition OR Feature Extraction techniques OR Performance evaluation Parameters) AND (Facial Emotion Recognition OR Supervised Machine learnings OR Accuracy Analysis) AND (Facial Emotion Recognition OR Unsupervised Machine Learnings OR Accuracy) AND (Facial Emotion Recognition OR Face Detection techniques OR Preprocessing parameters) AND (Facial Emotion Recognition OR Neural Networks).

2.1 Research questions

What are the key steps in a facial recognition system?
What are the different feature extraction techniques available which can be used for the feature extraction process?
What are the different classification algorithms that are used to classify facial expressions?
What are the average efficiencies of different classification algorithms?

2.2 Selection of studies

Based on the string search approach we collected a total of 515 studies. After that, screening of the collected studies was carried out based on five elimination criteria which are mentioned below:

Eliminations of duplicate papers.
Eliminations of papers after viewing the titles and year of publication.
Eliminations of papers after viewing the abstract of the papers.
Eliminations after observing the obtained results of the papers.
Elimination after reading the complete paper.

After going through all these criteria, we found out that there were 164 duplicate items. The title and publication year criteria removed around 103 items. The 85 items were eliminated based on the abstract and 51 items were excluded based on the results. After thoroughly reading the full contents of the papers 37 items were removed. As a result of this filtering process, the total number of studies was reduced to 75. Figure 1 shows the elimination process.

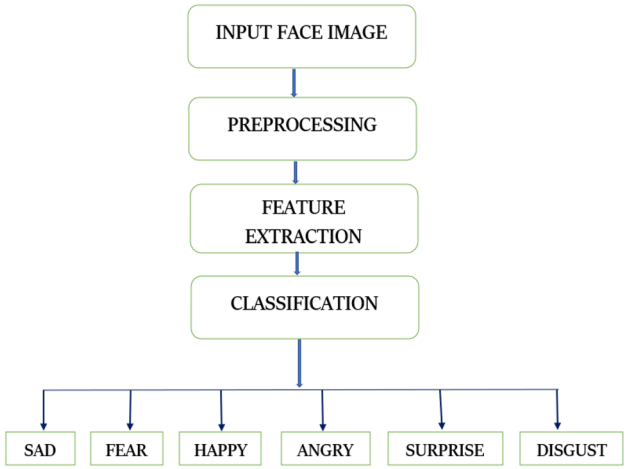

Fig. 2 Block diagram representation of FER system (Michael Revina and Sam Emmanuel 2021)

3 Facial expression recognition system

Any FER system has three main steps. These steps are very crucial steps for a FER system. For each step, various techniques are there and the selection of these techniques determines the performance of the FER system. The three key steps are (Fig. 2):

- Pre-processing
- Extraction of facial feature
- Emotion classification

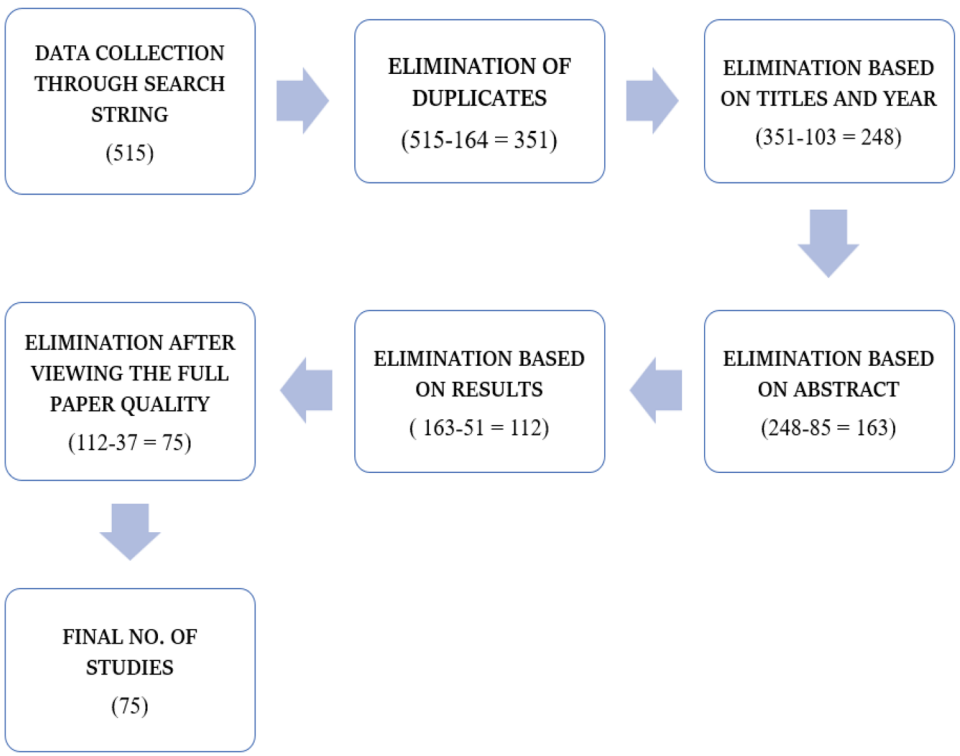

Fig. 1 PRISMA model presentation of data collection process (Katurura and Cilliers 2018)

3.1 Pre-processing

Pre-processing is a crucial aspect of facial feature extraction since it has a significant influence on the performance of the facial emotion recognition system. Various sorts of procedures, such as picture clarity and scaling, contrast adjustment, and extra enhancement processes, are used to improve the FER system's performance (Upadhyay and Kotak 2020). This step can be skipped if the dataset is already processed. If the dataset has raw images, then pre-processing is needed (Pooja et al. 2022).

3.2 Facial feature extraction

The extraction of face characteristics from pre-processed pictures is the next stage in any FER system. Face features or characteristics are extracted using a variety of techniques, including the Gabor filter, appearance-based methods, and geometry-based methods, among others. Any FER system's heart can be this step.

3.3 Emotion classification

This is the final stage in any FER system. Here, the generated features from the feature extraction process are fed to a classifier. The classifier classifies emotions into different categories like happy, sad, amazement, anger, fear, and disgust. For the classification process different classifiers like Support Vector Machine (SVM), Decision tree, K-Nearest Neighbor (KNN), Bayesian Networks, etc. are used.

4 Dataset

The first requirement to analyse or implement a facial emotion recognition system is the dataset. Various datasets are available on the internet. In this section, some datasets are briefly discussed which contain facial expression images.

- FER2013:—It consists of 28,709 no. of training samples and 3,589 no. of test samples. In this dataset neutral expression is also there along with the six basic emotions. The images are of size 48 × 48 pixel. All images are grayscale images.
- CK + 48:—A total of 981 no. of facial expression images are present here. Anger, contempt, sadness, surprise, fear, happy and disgust facial expressions are present in this dataset. The images are of size 48 × 48 pixel. All images are grayscale images.
- Facial Expression Dataset:—In this dataset, we can find six basic emotions as well as neutral expressions. There are 28,709 no. of facial expression images present for training and 7,178 no. of facial expression images are there for testing. All images are in grayscale form.
- FER Modified:—In this dataset, most of the images are taken from the FER dataset and the rest of the images are taken from google. All images are in grayscale form. In this dataset neutral expression is also there along with the six basic emotions. In total 38,983 no. of facial expression images are present. The whole dataset is divided into two subsets, namely, train and test.
- JAFFE:—Here 213 no. of facial expression images of 10 different Japanese females are present. In this dataset neutral expression is also there along with the six basic emotions.
- RAFD-DB:—It has around 30 K facial images with great diversity. The images are collected from the internet. It also has neutral expressions along with six basic emotions.
- Extended Cohn-Kanade Dataset (CK +):—This dataset includes a total of 5,876 images. Images are mainly grayscale and 640 × 490 pixels. It includes neutral and contempt expressions along with six basic emotions.

5 Feature extraction methods

Identifying and displaying relevant features of concern inside an image for subsequent processing is known as feature extraction. The transition from graphic to implicit encoding is detected by computer vision feature extraction, which is a vital phase in image processing. The classifier can then utilize this data depiction as an input. Texture feature-based techniques, edge-based methods, global and local feature-based approaches, geometric feature-based techniques, and patch-based methods are the five categories of feature extraction techniques (Michael Revina and Sam Emmanuel 2021). Every feature extraction method yields unique features. These techniques are discussed in the following subsections to provide a basic idea about these techniques.

5.1 Texture feature-based techniques

Here the features are extracted using texture descriptor. Gabor filter is an example of a texture descriptor. It utilizes magnitude and phase information for extracting features. The Gabor filter's magnitude feature restricts the amount of information regarding the facial picture's arrangement. The information regarding the entire description of the magnitude features is contained inside the phase feature (Hernandez-Matamoros et al. 2015). LBP (Local Binary Pattern) is another example texture descriptor. It is useful in the extraction of non-dynamic appearance based on features from static face images (Ji and Khalid Idrissi 2012). Weber Local Descriptor (WLD) is also a method for extracting

textural features for segmented face pictures that obtain high discriminant texture characteristics (Cossetin et al. 2016).

5.2 Edge-based methods

Here the descriptors extract features based on edge-based techniques. The followings are some examples of it. The Line Edge Map (LEM) descriptor is a facial expression descriptor that improves geometrical structural properties by employing the dynamic two-strip algorithm (Dyn2S). The gradient filter is used by the Histogram of Oriented Gradients (HOG), a window-supported feature descriptor. The edge information of the registered face pictures is used to extract the features. For example, it extracts visual features, such as curvature-shaped eyes in the case of a smiling expression (Dahmane and Meunier 2014).

5.3 Global and local feature-based approaches

Here the descriptors extract features based on global and local feature-based techniques. The followings are some examples of it. For extracting features, the Principal Component Analysis (PCA) technique is utilized. The global and low-dimensional characteristics are extracted by this. Independent Component Analysis (ICA) is a technique for extracting local features using multichannel observations. Stepwise Linear Discriminant Analysis (SWLDA) is a feature extraction approach that uses backward and forwards regression models to extract localized features. The F test values for both regression models are computed based on the class labels (Michael Revina and Sam Emmanuel 2021; Lee et al. 2005).

5.4 Geometric feature-based techniques

Here the descriptors use geometric feature-based approaches for extracting features. Many descriptors are used to extract features using geometric feature-based techniques. LCT (Local Curvelet Transform) uses the wrapping technique for extracting geometric features. Mean, entropy, and standard deviation are some examples of geometric characteristics that are extracted (Michael Revina and Sam Emmanuel 2021; Kahaki et al. 2018; Amelia Carolina Sparavigna 2019).

5.5 Patch-based methods

Here the descriptors extract features based on patch-based techniques. The followings are some examples of it. Based on the distance characteristics, facial movement features are obtained as patches. These are accomplished through the use of two processes: extracting patches and matching patches. Translation of extracted patches into distance characteristics is used to accomplish patch matching.

The textural descriptors are a more helpful feature extraction technique compared to others since they extract texture features such as those linked to appearance, which gives FER essential feature vectors. The dimensional vectors of some extracted features are large. Various dimensionality reduction techniques, including PCA, Linear Discriminant Analysis, and Whitened Principal Component Analysis, are typically used to minimize these feature vectors (Michael Revina and Sam Emmanuel 2021; Rahul and Cherian 2016). In the below-given table-1, various preprocessing techniques, feature extraction techniques, and classification techniques used by different authors are presented.

6 Classification algorIthms

In the process of classification of facial expressions from facial images, the most valued stage is the classification stage where the given facial image gets classified into one of the six basic emotions. For this classification stage, various algorithms are used. Some good results yielding algorithms are discussed in the following subsections so that one can get a brief idea about the classification algorithms and their performance in classification.

6.1 Support vector machine

Support vector machines (SVMs) are the most prominent machine learning techniques for the classification of facial expressions. They are supervised and robust in nature. They are used to solve classification as well as regression problems. Both linear and non-linear problems can be solved. In SVMs the optimum hyperplane gives the best classification result. The data points from the input are mapped into high dimensional feature space by a suitable kernel function which makes it easier to find the complicated relationship between input and output (Applications of support vector machine (SVM) learning in cancer genomics. 2018; Samantaray et al. 2022).

P.C. Vasanth and K.R. Nataraj proposed an SVM-based emotion recognition system to recognize emotion from facial expressions. They extracted the features from the eye and mouth using the Gabor filter and then they did dimension reduction of the extracted features using LBP and PCA. After that SVM classifier was used to classify the expressions (Vasanth and Nataraj 2015). Chirra Venkata Rami Reddy et al. also classified facial emotions using an SVM classifier. They improved the accuracy of recognition under varying illumination. They used Haar Wavelet Transform and Gabor wavelets to extract the global and local features,

respectively, from the images of facial expressions. Both features were merged by utilizing concatenated and weighted fusion techniques. To reduce the dimension of the extracted features they took Nonlinear PCA (NLPCA) and classified the facial expressions using an SVM classifier (Reddy et al. 2019). Muzammil Abdulrahman and Alaa Eleyan presented a method to recognize facial expressions by taking LBP and PCA in the feature extraction process and the SVM classifier was used to classify the facial expressions (Abdulrahman and Eleyan 2015).

6.2 Fuzzy logic

Fuzzy logic is a little bit different from ordinary logic. In ordinary logic, we have two truth values 0 and 1. But in fuzzy logic, we can have partial truth values like 0.7, 0.4, and so on. It can take any value between zero and one which addresses relative definitions like large, tall, and so on. It emulates the decision-making capability of humans over non-numerical information. Since it is a rule-based technique human involvement is needed to create the rules which evaluate each sample and this results in the optimum matching of feature values during classification. Thus, the rule set is responsible for the accuracy of the fuzzy system. The steps that involve in a fuzzy classification system are shown in the figure-. First, we need to give the features as input to the fuzzy system. After this, the fed inputs are fuzzified and membership functions are created. The next step is the generation of a fuzzy rule base. Based on these rules fuzzy outputs are generated by logical multiplication. After that defuzzification of those outputs takes place and the final output is obtained (Dutta et al. 2022; Cheng-JinDu 2008; Joy Sarkar et al. 2022). Figure 3 depicts the steps that are involved in a fuzzy logic-based emotion recognition system.

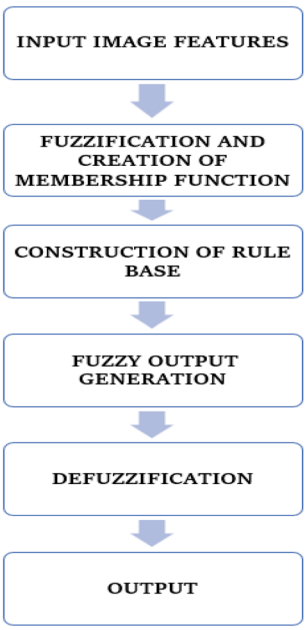

Fig. 3 Fuzzy classification system (Cheng-JinDu 2008)

Austin Nicolai and Anthony Choi developed a model for emotion recognition. They extracted the relevant points from the features like eyes, mouth, and so on. Then these points were fuzzified and the facial action strengths were determined and based on these strengths, emotions were determined (Nicolai and Choi 2015). Soumya Batra et al. proposed another fuzzy logic-based emotion recognition system. There they used AdaBoost to obtain the membership function parameters in the Fuzzy Inference System (Batra et al. 2011). Akanksha Chaturvedi and Alpika Tripathi proposed a system for emotion recognition from facial expressions using fuzzy rules. With the help of the point location method, they extracted the features from the facial images of different expressions. Then for classification, a fuzzy rule-based system was used (Chaturvedi and Tripathi 2014). Aasia Khanum et al. developed a hybrid model using Fuzzy logic (FL) and case-based reasoning (CBR) to recognize facial expressions (Khanum et al. 2009).

6.3 Random forest

The Random Forest Classifier is a collection of algorithms (which combines more than one algorithm of the same or different kinds for classifying objects). From a randomly selected portion of the training data, the random forest classifier generates a set of decision trees. It then combines the votes from several decision trees to get the test object's final class (Patel 2017). It has the benefits of speedy classification, robustness, and excellent recognition for greater dimension instances.

Yingying Wang et al. designed a system to recognize facial expressions. They extracted the features from the facial images using CNN. To classify the expressions random forest classifier was used which was composed of decision trees. For the determination of the decision trees in the random forest classifier they used a probability selection-based method instead of the traditional approach and got a better result (Wang et al. 2019). M.I.N.P Munasinghe made use of facial landmarks to obtain feature vectors. In his method, the feature vector corresponding to the neutral expression was taken as a reference and from that, the vector difference is calculated for each expression using the corresponding feature vector. Then, this calculated vector difference was taken to classify the facial expressions using a random forest classifier (Munasinghe 2018). Mustapha Kardouchi et al. used the HOG descriptor for extracting the features from the

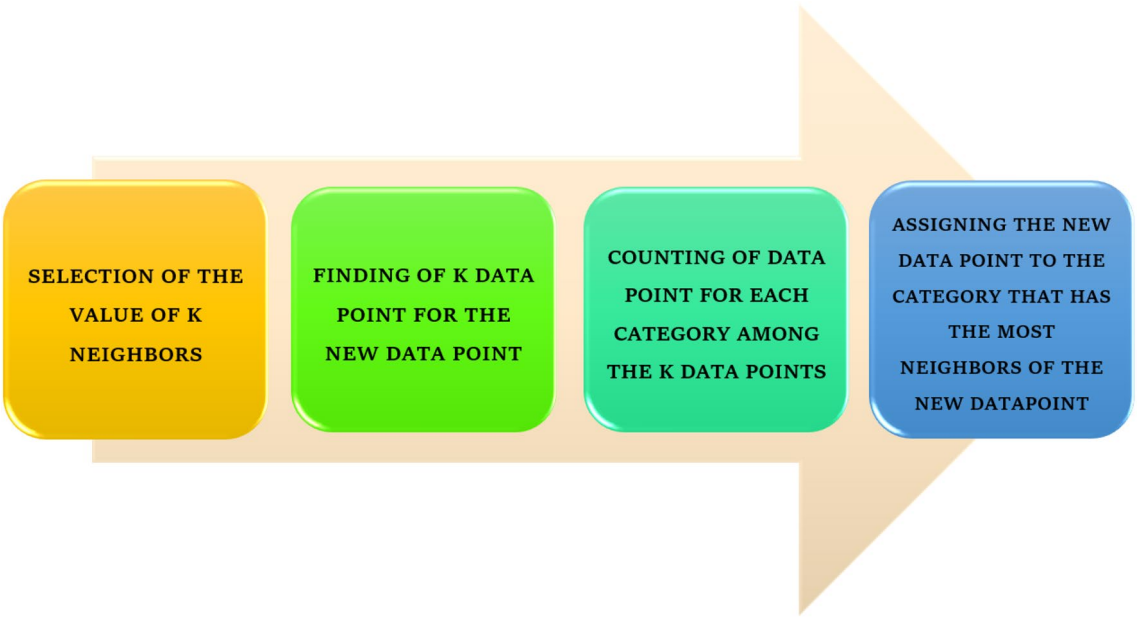

Fig. 4 Steps for KNN algorithm

images and after that, they used a random forest classifier for the classification process (Salhi et al. 2012).

6.4 K-Nearest neighbors

It is a supervised machine learning technique and it is one of the most extensively used and basic classification methods. It can also be used for regression problems (Shokrzade et al. 2021; Deng et al. 2016). The steps of the KNN algorithm are shown in Fig. 4 (Saji 2021). The value of K should be selected in such a way that the overfitting and complex model problems can be avoided. The larger value of K gives a less complex model and smoother curves that separate the classes but it may increase the computational complexity whereas a lower value may result in an overfitting and complex model. So, an optimum value of K must be chosen (Zakka 2016).

Pawel Tarnowski et al. developed a method to recognize emotion from facial expressions. They calculated six action units (AU) with the help of the Kinect device and these action units were used as features. The features were fed to a KNN classifier to carry out the classification process (Tarnowski et al. 2017).

Hivi Ismat Dino and Maiwan Bahjat Abdulrazzaq et al. presented an automatic facial expression recognition system. They took the Viola-Jones algorithm for the detection of the face. To get the features, a Histogram of Oriented Gradients was used and these extracted features were subjected to Principal Component Analysis for the dimension reduction process. After this, they fed the features to three classifiers SVM, KNN, and MLP. They compared the results and found that the SVM classifier was better (Dino and Abdulrazzaq 2019). Prashant P Thakare and Pravin S Patil used curvelet transform for emotion recognition. They derived the features using Robust Local Binary Pattern and Distinct Local Binary Pattern which were based on curvelet transform and fed them to a KNN classifier. They found that features that were derived using Robust LBP and Distinct LBP were superior to the features that were derived using Distinct LBP and GLCM. In other words, the features that were derived using Robust LBP and Distinct LBP obtained a better accuracy (Thakare and Patil 2016).

6.5 Artificial neural networks

Nowadays artificial neural networks are trending in computer vision. The neural networks imitate the human nervous system consisting of processing units known as nodes and weights which establish interconnection between nodes. Based on the configuration of the neural network there are several types of networks like multi-layer perceptron neural network, convolutional neural network and so on and they have different results while classifying objects (Cross et al. 1995; Karan and Renu 2017).

6.6 Multi-layer perceptron

A multilayer perceptron (MLP) is a type of artificial neural network that uses feed-forward learning. The input layer,

output layer, and hidden layer are the three kinds of layers found in it. The input layer receives the signal to be processed. The output layer is in charge of things like prediction and classification. MLP uses a supervised learning method known as back-propagation for training. Except for input nodes, each node is a neuron with a nonlinear activation function (https:, , en.wikipedia.org, wiki, Multilayer_perceptron. xxxx). Graph-based feature extraction is used here, and it involves two steps: identifying points in the facial picture and creating a feature vector. The emotions are recognized by the next MLP using a back propagation technique (Tanchotsrinon et al. 2011).

Maryam Pourebadi and Masume Pourebadi proposed an emotion recognition system based on a multi-layer perceptron (MLP). In their proposed method, modified facial units were used along with principal component analysis to obtain the features and MLP was taken as a classifier (Pourebadi and Pourebadi 2016). Fatma Zohra Chelali and Amar Djeradi used Gabor and discrete wavelet-based algorithms to get the features. They used a multilayer perceptron neural network and radial basis function (RBF) for the classification process and found that MLP was better than RBF (Chelali and Djeradi 2015).

6.7 Convolutional neural network

It is also a classification algorithm but here we do not need to feed the features to the network. The network itself extracts features and classifies the facial images. Convolutional neural networks (CNNs) have superior performance with image, and speech signals compared to other neural networks. In CNN, mainly three types of layers are present: convolutional layer, pooling layer, and fully connected layer. The feature extraction process takes place with the help of a convolutional layer and pooling layer whereas the classification part comprises of fully connected layer and output layer (Ghosh et al. 2020; Yamashita et al. 2018; Canal et al. 2022). We can see the basic convolutional neural network in Canal et al. (2022). In practice, there are multiple convolutional and pooling layers present. The no. of fully connected layers is also more in the case of practical applications (Phung and Rhee 2019).

Milad Mohammad Taghi Zadeh et al. proposed a deep learning-based approach to recognizing human emotions. They used Gabor filters for extracting the features from the facial images and fed those features to a convolutional neural network that classified the emotions (Zadeh et al. 2019). Jielong Tang et al. designed a model for real-time emotion recognition for classroom assessment based on a CNN. In their model, they removed the fully connected layer and combine the depth separable convolution with the remaining modules which resulted in high accuracy and robustness (Tang et al. 2019). Asad Khattak et al. introduced a deep learning approach for identifying emotions age and gender from the images of facial expressions using a CNN model (Khattak et al. 2021). Saiyed Umer et al. offered a novel facial expression recognition system. First of all, they detected the face from the facial image. To get more unique and discriminating features, they used CNN. They also augmented the facial images to improve the efficiency of the suggested system (Umer et al. 2022). To design a real-time system for emotion recognition, Prerana Kundu et al. took the help of computer vision libraries and CNN. They used facial action units to mark the changes in facial expressions (Kundu et al. 2022).

6.8 Decision tree

A decision tree gives the solutions to a problem in a graphical manner. Being a machine learning technique, it is used for classification as well as regression. However, it is generally used to solve classification problems. If we consider its structure it looks like a tree consisting of a decision node and leaf node. In the decision tree, decisions are made by a decision node having multiple branches that represents the decision rules. The outputs of the decisions are indicated by leaf nodes. The decision tree basically imitates our thinking ability when it makes a decision (An and Zhou 2022; Singh et al. 2022; Ramos et al. 2022).

Fatima Zahra Salmam et al. took the decision tree to design a recognition system to classify facial expressions. They used a geometric-based method for feature extraction from the facial images and fed those features to the decision tree classifier (Salmam et al. 2016). Carlos Orrite et al. proposed a HOG-based decision tree approach to classify facial expressions. To make the decision in each branch they used the support vector machine (Orrite et al. 2009).

Besides these above-mentioned algorithms, there are also other algorithms like Dynamic Bayesian Networks, Naïve Bayes, Hidden Markov Model, Euclidean Distance, etc. which can be used for the classification process. Figure 5 shows the usage of different classification algorithms. The pie chart was developed based on our literature review work. From the pie chart, we can see that most of the facial expression recognition approaches have used SVM and neural networks.

7 Performance analysis parameters

The performance of a proposed or designed emotion recognition model can be evaluated using five metrics that are obtained from the confusion matrix of the proposed model or methodology (Byoung Chul Ko 2018b; Jayaswal 2020).

$$Accuracy = \frac{No.\ of\ correctpredictions}{Total\ no/,\ .of\ predictions} = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

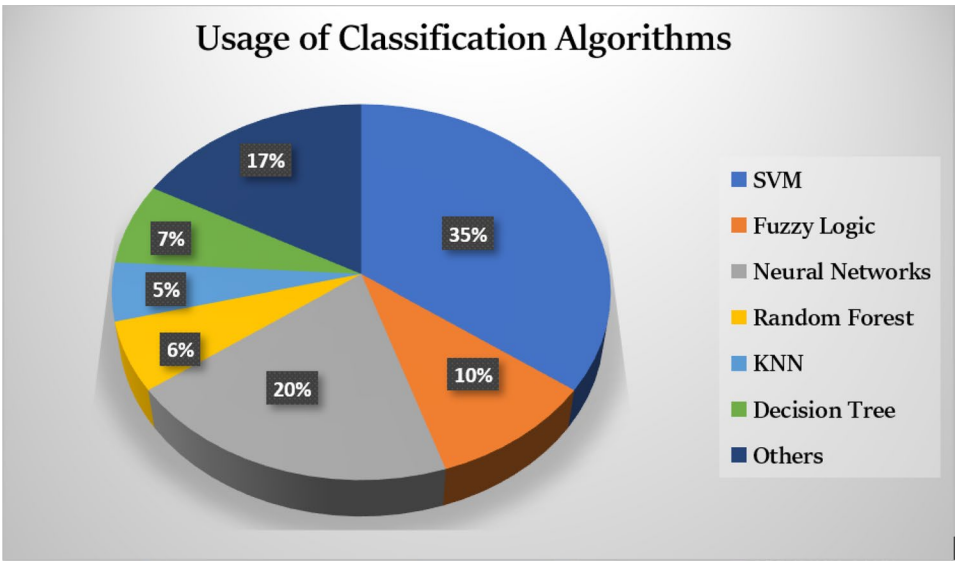

Fig. 5 Pie chart based on our literature review (Canal et al. 2022)

$$\text{Misclassification} = \frac{No.\ of\ \ incorrect\ predictions}{Total\ no.\ of\ predictions} = \frac{FP + FN}{TP + TN + FP + FN} \quad (2)$$

$$Precision = \frac{TP}{TP + FP} \quad (3)$$

$$SensitivityorRecall = \frac{TP}{TP + FN} \quad (4)$$

$$Specificity = \frac{TN}{TN + FP} \quad (5)$$

True Positive (TP) — Predicted class is positive and the actual class is also positive.

True Negative (TN) — Predicted class is negative and the actual class is also negative.

False Positive (FP) —Predicted class is positive but the actual class is negative.

False Negative (FN) — Predicted class is negative but the actual class is positive.

8 Accuracy analysis

After reviewing various papers on image-based facial emotion recognition using, we analyzed the accuracy of different classification algorithms or classifiers. Based on our analysis we generated a plot that shows the average accuracies of

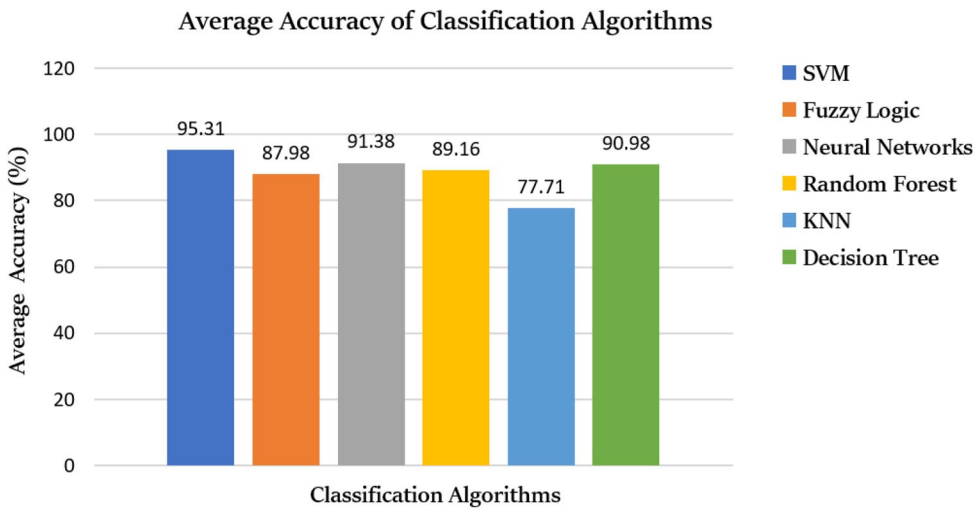

Fig. 6 Average accuracies of the above-discussed classifiers (Canal et al. 2022)

different algorithms (Fig. 6). This bar plot is showing that the SVM-based facial emotion recognition systems obtain higher accuracy than others.

9 Conclusion

For the past two decades, a large scale of research has been conducted on emotion recognition. In the last few years, it gains much more focus because of its wide range of applications. Facial emotion recognition is a very tough and challenging task (Anitha et al. 2021; Arinin 2008; Gashnikov et al. 2007; Keerti and Karan 2022; Sourav and Karan 2022; Makhortykh et al. 2019). In this study, one can see various available methods for feature extraction and classification process in an emotion recognition system. Also, various available datasets for facial expression images and performance analysis metrics are depicted. In machine learning, SVM and neural networks are the two well-loved algorithms. From Fig. 5 we can see that among all the classification algorithms SVM and neural networks are mostly used because of their excellent performance in classification problems. Based on our literature review it was found that in the classification of facial expression the SVM classifier-based facial expression recognition methodologies are more efficient. Besides SVM-based algorithms, other algorithms like neural networks and decision trees also produce very good results. So, one can try to design his/her own methodology based on these techniques to get better results. Basically, this paper represents a comparative analysis of various approaches to facial emotion recognition. There are also many challenges and problems in the facial emotion recognition process which are also discussed in this paper. They need to be overcome to improve the performance of the facial emotion recognition system. And finally, one can get the answers to the research questions that were mentioned in section- 2.1. The table-2 summarizes the answers to those research questions.

Funding None.

Declarations

Conflict of interest None.

Ethical approval Not required.

References

Abdel Ilah Salhi, Mustapha Kardouchi, and Nabil Belacel (2012) Fast and efficient face recognition system using random forest and histograms of oriented gradients. IEEE BIOSIG-Proceedings of the International Conference of Biometrics Special Interest Group (BIOSIG)

Ashim Saha, Anurag De and Nirmalya Kar. (2013) Different techniques of automatic facial expression recognition: a survey. Second Intl. Conf. on Advances in Computing, Communication and Information Technology- CCIT 2014, DOI: 10.15224/978–1–63248–051–4–25.

Aldao A (2013) The future of emotion regulation research: capturing context. Perspect Psychol Sci 8:155–172. https://doi.org/10.1177/1745691612459518

An Y, Zhou H (2022) Short term effect evaluation model of rural energy construction revitalization based on ID3 decision tree algorithm.". Energy Rep 8:1004–1012. https://doi.org/10.1016/j.egyr.2022.01.239

Anitha M, Kumar VD, Malathi S, Kumar VD, Ramakrishnan M, Kumar A, Ali R (2021) A survey on the usage of pattern recognition and image analysis methods for the lifestyle improvement on low vision and visually impaired people. Pattern Recognit Image Anal 31:24–34. https://doi.org/10.1134/S105466182101003X

Arinin VA (2008) Histogram analysis and synthesis in processing series of images: extending the concept of image similarity. Pattern Recognit Image Anal 18:588–591. https://doi.org/10.1134/S1054661808040081

Byoung Chul Ko. (2018a) A brief review of facial emotion recognition based on visual information. sensors 18(2): 421

Byoung Chul Ko (2018b) A brief review of facial emotion recognition based on visual information. Sensors. https://doi.org/10.3390/s18020401

Beliba Alina. 2019 Challenges of emotion recognition in images and videos. 24th October. https://www.apriorit.com/dev-blog/642-ai-emotion-recognition Accessed 12 March 2022

Basil S (2021) A Quick Introduction to K – Nearest Neighbor (KNN) Classification Using Python Data Science Blogathon Analytics Vidhya. https://www.analyticsvidhya.com/blog/2021/01/a-quick-introduction-tok-nearest-neighbor-knn-classification-using-python/

Bhattacharya S (2022) A survey on: facial expression recognition using various deep learning techniques. In Adv Computational Paradigms Hybrid Intell Comput 1373:619–631. https://doi.org/10.1007/978-981-16-4369-9_59

Cross SS, Harrison RF, Lee Kennedy R (1995) Introduction to neural networks. The Lancet 346:1075–1079. https://doi.org/10.1016/S0140-6736(95)91746-2

Cheng-JinDu D-W (2008) Object Classification methods. Comput vis Technol Food Quality Eval. https://doi.org/10.1016/B978-012373642-0.50007-7

Carlos Orrite, Andrés Ganán, and Grégory Rogez. (2009) Hog-based decision tree for facial expression classification. 4th Iberian Conference on Pattern Recognition and Image Analysis (ibPRIA) 5524: 176–183. https://doi.org/10.1007/978-3-642-02172-5_24

Chaturvedi A, Tripathi A (2014) Emotion recognition using fuzzy rule-based system. Int J Comput Appl 93:25–28. https://doi.org/10.5120/16260-5920

Chelali FZ, Djeradi A (2015) Face recognition using MLP and RBF neural network with Gabor and discrete wavelet transform characterization: a comparative study. Math Probl Eng. https://doi.org/10.1155/2015/523603

Chirra Venkata Rami Reddy, Uyyala Srinivasulu Reddy, and Kolli Venkata Krishna Kishore. (2019) Facial emotion recognition using NLPCA and SVM. Traitement du Signal 36: 13–22. https://doi.org/10.18280/ts.360102

Canal FZ, Müller TR, Matias JC, Scotton GG, Reis A, de Sa Junior, Eliane Pozzebon, and Antonio Carlos Sobieranski. (2022) A survey on facial emotion recognition techniques: a

state-of-the-art literature review. Inf Sci 582:593–617. https://doi.org/10.1016/j.ins.2021.10.005
Dahmane M, Meunier J (2014) Prototype-based modeling for facial expression analysis. IEEE Trans Multimed 16:1574–1584. https://doi.org/10.1109/TMM.2014.2321113
De A, Saha A (2015) A comparative study on different approaches of real time human emotion recognition based on facial expression detection. Int Conf Adv Comput Eng App. https://doi.org/10.1109/ICACEA.2015.7164792,IEEE
Deng Z, Zhu X, Cheng D, Zong M, Zhang S (2016) Efficient kNN classification algorithm for big data. Neurocomputing 195:143–148. https://doi.org/10.1016/j.neucom.2015.08.112
Dino HI, Abdulrazzaq MB (2019) Facial expression classification based on SVM, KNN and MLP classifiers. IEEE Int Conf Adv Sci Eng. https://doi.org/10.1109/ICOASE.2019.8723728
Drishti Y, Yadav S, Karan V (2020) A comprehensive assessment of brain computer interfaces: recent trends and challenges. J Neurosci Methods 346:108918
Didan Deng, Zhaokang Chen, and Bertram E. Shi. (2020) Multitask emotion recognition with incomplete labels. 15th IEEE International Conference on Automatic Face and Gesture Recognition. https://doi.org/10.1109/FG47880.2020.00131
Dutta MK, Kaur M, Sarkar RK (2022) Image quality improvement of old and distorted artworks using fuzzy logic technique. Optik. https://doi.org/10.1016/j.ijleo.2021.168252
Eriksen MB, Frandsen TF (2018) The impact of patient, intervention, comparison, outcome (PICO) as a search strategy tool on literature search quality: a systematic review. J Med Library Assoc JMLA 106:420–431. https://doi.org/10.5195/jmla.2018.345
Fatima Zahra Salmam, Abdellah Madani, and Mohamed Kissi. (2016) Facial expression recognition using decision trees. IEEE 13th International Conference on Computer Graphics, Imaging and Visualization (CGiV). https://doi.org/10.1109/CGiV.2016.33
Fathima A, Vaidehi K (2020) Review on facial expression recognition system using machine learning techniques. In Adv Decis Sci Image Proc Secur Comput vis. https://doi.org/10.1007/978-3-030-24318-0_70
Gashnikov MV, Glumov NI, Evgeny Myasnikov VV, Sergeev AV, Chernov, and M. A. Chicheva. (2007) Software environment for simulating algorithms for image analysis and processing. Pattern Recognit Image Anal 17:279–283. https://doi.org/10.1134/S1054661807020162
Gao Y, Suyun Xu, Shen Y, Liao T, Shiruo Hu, Zhou S, Chen Q (2020) Metformin and acupuncture for polycystic ovary syndrome: a protocol for a systematic review and meta-analysis. Medicine. https://doi.org/10.1097/MD.0000000000019683
Ghobaei-Arani M, Shamsi M, Rahmanian AA (2017) An efficient approach for improving virtual machine placement in cloud computing environment. J Exp Theor Artif Intell 29:1149–1171. https://doi.org/10.1080/0952813X.2017.1310308
Ghosh A, Sufian A, Sultana F, Chakrabarti A, De D (2020) Fundamental concepts of convolutional neural network. In Rec Trends Adv Artificial Intell Internet Things 172:519–567. https://doi.org/10.1007/978-3-030-32644-9_36
Guiping Yu (2021) Emotion monitoring for preschool children based on face recognition and emotion recognition algorithms. Complexity. https://doi.org/10.1155/2021/6654455
Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J, Norris S et al (2011) GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. J Clin Epidemiol 64:383–394. https://doi.org/10.1016/j.jclinepi.2010.04.026
Hela M, Kamel H (2015) Using multiple steerable filters and Bayesian regularization for facial expression recognition Engineering Applications of Artificial Intelligence 38:190–202. https://doi.org/10.1016/j.engappai.2014.11.002
Hegde G. P, Seetha M, Hegde N (2016) Kernel locality preserving symmetrical weighted fisher discriminant analysis based subspace approach for expression recognition Engineering science and technology, an international journal 19:1321–1333. https://doi.org/10.1016/j.jestch.2016.03.005
Hernandez-Matamoros A, Escamilla-Hernandez E, Bonarini A, Nakano-Miyatake M, Perez-Meana H (2015) A facial expression recognition with automatic segmentation of face regions. Int Conf Intell Software Methodol Tools Tech 532:529–540. https://doi.org/10.1007/978-3-319-22689-7_41
http://www.prisma-statement.org/
https://en.wikipedia.org/wiki/Multilayer_perceptron
Jia J, Xu Y, Zhang S, Xue X (2016) The facial expression recognition method of random forest based on improved PCA extracting feature IEEE International Conference on Signal Processing Communications and Computing (ICSPCC) 1–5. https://doi.org/10.1109/ICSPCC.2016.7753643
Joy Sarkar Md, Faruque AA, Khalil E (2022) Predicting the tearing strength of laser engraved denim garments using a fuzzy logic approach. Heliyon. https://doi.org/10.1016/j.heliyon.2022.e08740
Kevin Zakka. 2016 A complete Guide to K- Neighbors with Applications in Python and R. https://kevinzakka.github.io/2016/07/13/k-nearest-neighbor/
Kahaki SMM, Haslina Arshad Md, Nordin J, Ismail W (2018) Geometric feature descriptor and dissimilarity-based registration of remotely sensed imagery. PLoS ONE. https://doi.org/10.1371/journal.pone.0200676
Karan V, Renu V (2017) Analysis and recognition of operations using SEMG from upper arm muscles. Exp Syst 34:e12221
Katurura MC, Cilliers L (2018) Electronic health record system in the public health care sector of South Africa: a systematic literature review. African J Primary Health Care Family Med 10:1–8. https://doi.org/10.4102/phcfm.v10i1.1746
Keerti R, Karan V (2022) SEMG based recognition of hand motions for lower limb prostheses. Curr Signal Transduct Ther 17:75–81
Khanum A, Muid Mufti M, Javed Y, Zubair Shafiq M (2009) Fuzzy case-based reasoning for facial expression recognition. Fuzzy Sets Syst 160:231–250. https://doi.org/10.1016/j.fss.2008.05.022
Khattak A, Asghar MZ, Ali M, Batool U (2021) An efficient deep learning technique for facial emotion recognition. Multimed Tools App. https://doi.org/10.1007/s11042-021-11298-w Accessed 9 March 2022.
Kołakowska A, Landowska A, Szwoch M, Szwoch W, Wrobel MR (2014) Emotion recognition and its applications. In Hum-Comput Syst Inter 3:51–62. https://doi.org/10.1007/978-3-319-08491-6_5
Kundu P, Kundu P, Mallik S, Bhowmick S, Mandal P, Banerjee H, Pal SB (2022) Facial expression recognition using convoluted neural network (CNN). In Cyber Intell Info Retr 291:81–88. https://doi.org/10.1007/978-981-16-4284-5_8
Lee Y, Lee K, Pan S (2005) Local and global feature extraction for face recognition. In Int Conf Aud Vid-Based Biomet Person Auth. https://doi.org/10.1007/11527923_23
Zhang Dian T (2011) Facial expression recognition using facial movement features IEEE transactions on affective computing 2:219–229. https://doi.org/10.1109/T-AFFC.2011.13
Leung FYN, Sin J, Dawson C, Ong JH, Zhao C, Veić A, Liu F (2022) Emotion recognition across visual and auditory modalities in

autism spectrum disorder: a systematic review and meta-analysis. Dev Rev. https://doi.org/10.1016/j.dr.2021.101000

Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, Clarke M, Devereaux PJ, Kleijnen J, Moher D (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol 62:e1–e34. https://doi.org/10.1016/j.jclinepi.2009.06.006

Lim N (2016) Cultural differences in emotion: differences in emotional arousal level between the East and the West. Integr Med Res 5:105–109. https://doi.org/10.1016/j.imr.2016.03.004

Muzammil Abdulrahman and Alaa Eleyan. (2015) Facial expression recognition using support vector machines. IEEE 23nd signal processing and communications applications conference (SIU). https://doi.org/10.1109/SIU.2015.7129813

Marcelo Junior Cossetin, Alessandro Lameiras Koerich, and Julio Cesar Nievola 2016 Facial Expression Recognition Using a Pairwise Feature Selection and Classification Approach. IEEE International Joint Conference on Neural Networks (IJCNN), Vancouver. https://doi.org/10.1109/IJCNN.2016.7727879

Maryam Pourebadi, and Masume Pourebadi. 2016 MLP neural network based approach for facial expression analysis. In Proceedings of the International Conference on Image Processing, Computer Vision, and Pattern Recognition (IPCV), The Steering Committee of The World Congress in Computer Science, Computer Engineering and Applied Computing (WorldComp).

M. I. N. P. Munasinghe (2018) Facial expression recognition using facial landmarks and random forest classifier. IEEE/ACIS 17th International Conference on Computer and Information Science (ICIS). https://doi.org/10.1109/ICIS.2018.8466510

Munasinghe Nuwan. 2018 Facial Expression Recognition Using Facial Landmarks and Random Forest Classifier. 17th IEEE/ACIS International Conference on Computer and Information Science (ICIS). https://doi.org/10.1109/ICIS.2018.8466510.

Milad Mohammad Taghi Zadeh, Maryam Imani and Babak Majidi. (2019) Fast Facial emotion recognition Using Convolutional Neural Networks and Gabor Filters. IEEE 5th Conference on Knowledge Based Engineering and Innovation (KBEI). https://doi.org/10.1109/KBEI.2019.8734943

Makhortykh SA, Kulikova LI, Pankratov AN, Tetuev RK (2019) Generalized spectral-analytical method and its applications in image analysis and pattern recognition problems. Pattern Recognit Image Anal 29:621–638. https://doi.org/10.1134/S1054661819040102

Mellouk W, Handouzi W (2020) Facial emotion recognition using deep learning: review and insights. Procedia Comput Science 175:689–694. https://doi.org/10.1016/j.procs.2020.07.101

Michael Revina I, Sam Emmanuel WR (2021) A survey on human face expression recognition techniques" sciencedirect. J King Saud Univ Comput Info Sci. https://doi.org/10.1016/j.jksuci.2018.09.002

Nicolai A, Choi A (2015) Facial emotion recognition using fuzzy systems. IEEE International Conference on Syst Cybernet. https://doi.org/10.1109/SMC.2015.387

Nivedita C, Geeta N (2016) Facial expression recognition using local binary pattern and support vector machine International Journal of Innovative Research in Advanced Engineering 3:103–108.

Nonis F, Dagnes N, Marcolin F, Vezzetti E (2019) 3D Approaches and challenges in facial expression recognition algorithms—a literature review. Appl Sci. https://doi.org/10.3390/app9183904

Olufisayo Ekundayo, and Serestina Viriri. (2019) Facial expression recognition: a review of methods, performances and limitations. IEEE 2019 Conference on Information Communications Technology and Society (ICTAS). https://doi.org/10.1109/ICTAS.2019.8703619

Phung VH, Rhee EJ (2019) A high-accuracy model average ensemble of convolutional neural networks for classification of cloud image patches on small datasets. Appl Sci. https://doi.org/10.3390/app9214500

Pooja PSK, Karan V (2021) A systematic review of machine learning based gait characteristics in parkinson's disease. Mini-Rev Med Chem. https://doi.org/10.2174/1389557521666210927151553

Pooja S, Pahuja SK, Karan V (2022) "Recent approaches on classification and feature extraction of EEG signal: a review. Robotica 40:77–101

Rahul R, Cherian M (2016) Facial Expression Recognition Using PCA and Texture-Based LD.N Descriptor. In Book: Proceedings of the International Conference on Soft Computing Systems 398:113–122. https://doi.org/10.1007/978-81-322-2674-1_11

Ramos D, Faria P, Morais A, Vale Z (2022) Using decision tree to select forecasting algorithms in distinct electricity consumption context of an office building. Energy Rep 8:417–422. https://doi.org/10.1016/j.egyr.2022.01.046

Sungkyu N, Hanhoon P, Yoonjong J, Jong-Il Park (2007) Feature-adaptive motion energy analysis for facial expression recognition In International Symposium on Visual Computing 4841:452–463. https://doi.org/10.1007/978-3-540-76858-6_45

Shishir B, Ganesh K. Venayagamoorthy (2008) Recognition of facial expressions using Gabor wavelets and learning vector quantization Engineering Applications of Artificial Intelligence 21:1056–1064. https://doi.org/10.1016/j.engappai.2007.11.010

Stratou, Giota, Abhijeet Ghosh, Paul Debevec, and Louis-Philippe Morency. (2011) Effect of illumination on automatic expression recognition: a novel 3D relightable facial database. In 2011 IEEE International Conference on Automatic Face & Gesture Recognition (FG). https://doi.org/10.1109/FG.2011.5771467

Soumya B, Konda T, Kuchibhotla B 2011 Facial Expression Recognition using Fuzzy Logic. ResearchGate

Sonia O, Sunita S, Tarun A (2013) A Survey on Various Problems & Challenges in Face Recognition International Journal of Engineering Research & Technology 2:2533–2538. https://doi.org/10.17577/IJERTV2IS60850

Sariyanidi E, Gunes H, Cavallaro A (2015) Automatic analysis of facial affect: A survey of registration, representation, and recognition. IEEE Trans Pattern Anal Mach Intell 37:1113–1133. https://doi.org/10.1109/TPAMI.2014.2366127

Savan Patel. 2017 Random forest classifier https://medium.com/machine-learning-101/chapter-5-random-forest-classifier-56dc7425c3e1, May 18

Shujun Huang, Nianguang Cai, Pedro Penzuti Pacheco, Shavira Narrandes, Yang Wang, and Wayne Xu. (2018) Applications of support vector machine (SVM) learning in cancer genomics. Cancer genomics proteomics. 15: 41–51. https://doi.org/10.21873/cgp.20063

Sparavigna AC (2019) Entropy in image analysis. Entropy. https://doi.org/10.3390/e21050502

Shahidinejad A, Ghobaei-Arani M, Esmaeili L (2020) An elastic controller using colored petri nets in cloud computing environment. Clust Comput 23:1045–1071. https://doi.org/10.1007/s10586-019-02972-

Shokrzade A, Ramezani M, Tab FA, Mohammad MA (2021) A novel extreme learning machine based kNN classification method for dealing with big data. Expert Syst Appl. https://doi.org/10.1016/j.eswa.2021.115293

Sohail M, Ali G, Rashid J, Ahmad I, Almotiri SH, AlGhamdi MA, Nagra AA, Masood K (2021) Racial identity-aware facial expression recognition using deep convolutional neural networks. Appl Sci. https://doi.org/10.3390/app12010088

Samantaray S, Das SS, Sahoo A, Satapathy DP (2022) Monthly runoff prediction at Baitarani river basin by support vector machine based on salp swarm algorithm. Ain Shams Eng J. https://doi.org/10.1016/j.asej.2022.101732

Singh N, Jena S, Panigrahi CK (2022) A novel application of decision tree classifier in solar irradiance prediction. Mater Today Proc. https://doi.org/10.1016/j.matpr.2022.02.198

Sachin KS, Karan V (2022) A spider tool based qualitative analysis of machine learning for wrist pulse analysis. Network Model Anal Health Inform Bioinform. https://doi.org/10.1007/s13721-022-00361-7

Sourav M, Karan V (2022) Recent trends of human face emotion recognition using EMG signals. Recent Pat Eng. https://doi.org/10.2174/1872212116666220518122621

Tanchotsrinon C, Phimoltares S, Maneero S (2011) Facial Epression recognition using graph-based features and artificial neural networks. IEEE Int Conf Imaging Syst Tech. https://doi.org/10.1109/IST.2011.5962229

Talele Kiran, and Tuckley Kushal. 2016 "Facial Expression Classification using Support Vector Machine Based on Bidirectional Local Binary Pattern Histogram Feature Descriptor" 17th IEEE/ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD). https://doi.org/10.1109/SNPD.2016.7515888.

Thakare PP, Patil PS (2016) Facial expression recognition algorithm based on KNN classifier. Int J of Comp Sci Net 5:941–947

Tarnowski P, Kołodziej M, Majkowski A, Rak RJ (2017) Emotion recognition using facial expressions. Procedia Comput Sci 108:1175–1184. https://doi.org/10.1016/j.procs.2017.05.025

Tang J, Zhou X, Zheng J (2019) Design of Intelligent classroom facial recognition based on deep learning. In J Phys Conf Ser. https://doi.org/10.1088/1742-6596/1168/2/022043

Umer S, Rout RK, Pero C, Nappi M (2022) Facial expression recognition with trade-offs between data augmentation and deep learning features. J Ambient Intell Humaniz Comput 13:721–735. https://doi.org/10.1007/s12652-020-02845-8

Vasanth PC, Nataraj KR (2015) Facial expression recognition using SVM classifier Indonesian Journal of Electrical Engineering and Informatics (IJEEI). 3: 16–20. https://doi.org/10.11591/ijeei.v3i1.126

Viha Upadhyay, and Devangi Kotak. 2020 A Review on Different Facial Feature Extraction Methods for Face Emotions Recognition System. Fourth International Conference on Inventive Systems and Control (ICISC), IEEE. https://doi.org/10.1109/ICISC47916.2020.9171172.

Vaibhav Jayaswal "Performance Metrics: Confusion matrix, Precision, Recall, and F1 Score" Towards Data Science, 2020. https://towardsdatascience.com/performance-metrics-confusion-matrix-precisionrecall-and-f1-score-a8fe076a2262

Wang H-H, Jing-Wei Gu (2018) The applications of facial expression recognition in human-computer interaction. IEEE Int Conf Adv Manufact. https://doi.org/10.1109/AMCON.2018.8614755

Wang Y, Li Y, Song Y, Rong X (2019) Facial expression recognition based on random forest and convolutional neural network. Information. https://doi.org/10.3390/info10120375

Xu Xu, Zhou Ruan, and Lei Yang (2020) Facial expression recognition based on graph neural network 5th International Conference on Image Vision and Computing (ICIVC) 211–214. https://doi.org/10.1109/ICIVC50857.2020.9177430

Yi J, Khalid I (2012) Automatic facial expression recognition based on spatiotemporal descriptors Pattern Recognition Letters 33:1373–1380 https://doi.org/10.1016/j.patrec.2012.03.006

Yakup D, Ayşegül U, Cüneyt G (2016) A new facial expression recognition based on curvelet transform and online sequential extreme learning machine initialized with spherical clustering Neural Computing and Applications 27:131–142. https://doi.org/10.1007/s00521-014-1569-1

Yamashita R, Nishio M, Do RKG, Togashi K (2018) Convolutional neural networks: an overview and application in radiology. Insights Imaging 9:611–629. https://doi.org/10.1007/s13244-018-0639-9

Zeng Z, Pantic M, Roisman G, Huang T (2009) A Survey of affect recognition methods: audio, visual, and spontaneous expressions. IEEE Trans Pattern Anal Mach Intell 31:39–58. https://doi.org/10.1109/TPAMI.2008.52

Zhao X, Zhang S (2016) A review on facial expression recognition: feature extraction and classification. IETE Tech Rev 33:505–517. https://doi.org/10.1080/02564602.2015.1117403

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.