1. **Project Description**

Nowadays, technology is an everyday part of people’s lives and plays a huge role in our development as a human race. Humans spend the majority of their time interacting with various devices such as computers, smartphones, etc. Research shows, most people’s work involves working on a computer. However, when compared with human communication, interaction with currently available software interfaces is non – verbal and primitive. If computers have the ability to determine human emotions through facial expression recognition then human – computer interaction (HCI) would be significantly improved[1]. The communication between a man and machine is becoming one of the fastest – growing fields and advancements there would consequently benefit human – robotic interaction (HRI) and many other fields.

Facial expressions play an significant role in human communication[1-5]. Studies have shown human emotions expressed through facial expressions contribute 55% to emotion expression as opposed to 35% for the vocal part and only 7% for the verbal part [2]. This would imply that facial expressions play the major part in homosapiens communication. Before diving in it’s essential to make the distinction between facial expression recognition and emotion recognition. Humans express emotions in multiple ways through facial expressions, emotion of voice, body language, whereas facial expression recognition is solely based on visual information which is what this project will focus on [2].

Humans have the ability to interpret facial expressions in a situation with little effort. Attempting to develop an automated systems that will have that ability is a rather difficult task that presents a few challenges. In order to achieve humanlike results a system must be able to detect an image segment as a face, extract all the information regarding the facial expression that the face is trying to express and finally classify the expressions in emotion categories[2-5]. With the current advancements in technology and the various existing techniques available for solving this problem, a system that can accurately guess human emotions in laboratory conditions has been developed with accuracy up to around 97%, however when tested in an unconstrained real-time environment it doesn’t perform as well with accuracy as low as 50% [4]. Analysis of facial expressions can be incredibly challenging in a real-time environment due to constantly occuring small transient changes. The main three challenges that arise in an unconstrained real-world environment are illumination variation, head pose and subject dependence[4]. Different illumination levels can directly affect the accuracy of face feature extraction. In a controlled environment under laboratory conditions the head pose of a subject is usually frontal. Yet, in a real – world environment due to a subject transient movements of head, sometimes a frontal view might not be available, thus presenting a great challenge. Subject – dependence is to do with the fact a FER system can only recognize pre – trained faces. To overcome this challenge, a huge dataset and a reliable classifier would be required[4].

As mentioned above, developing a facial expression recognition system (FER) has three main parts: preprocessing, feature extraction and image classification[2-5]. Preprocessing is a process which can substantially improve the performance of a FER system by applying different cropping and scaling techniques to the images and preparing the data for feature extraction[5]. Feature extraction is a process which dimensionally reduces an initially large, raw data to a more manageable dataset by combining different features, while accurately and completely representing the original dataset[6, 7]. After the necessary features are extracted then images can be classified by emotions at the last stage[5].

The possibilities for application of FER in various areas are endless. As mentioned above, the main areas which could be drastically improved by an effective FER system are HCI and in particular HRI. Having the ability to determine people’s emotions would enable an HRI systems to simulate a more natural and friendly interaction with humans, thus improving almost every industry and occupation where computers are used. For example, they can be used in a healthcare to detect humans’ mental states through facial expression analysis[8, 9]. By being able to distinguish between the different healthy emotional states such as happiness, satisfaction and unhealthy emotinal states (anger, sadness, frustation) robots can improve the quality of life. In addition, FER could drastically help mentally ill patients by exploring their behavioural patterns. Researchers McClure et al.[10] and Coleman et al.[11] have successfully shown that by investigating emotional conflicts, which appear on the patients’ expressions some mental diseases such as anxiety or autism can be diagnosed. Furthermore, study has shown people are more likely to trust machine than another person [12]. This opens up a great application of FER in automated counceling systems. Fatigue detection is another area which could significantly benefit by a FER system [13]. According to NHTSA organization statistics, the main factor for road accidents is driver fatigue[13]. With the ability to read human emotions vehicles would be able to prevent the that alerting the drivers. In a similar way, FER can help prevent accidents at the workplace by monitoring employees fatigue levels especially for machine operators. Another area where FER could be applied is teaching[14]. Currently automated tutoring systems are becoming increasingly popular allowing anyone with computer access to learn from the comfort of their own home. An automated tutoring system with FER would be able to adapt individually to every student and determine how well they’re responding to the material. This would allow the system to make decisions and adjustments which would make the process seem less artificial, more pleasant, thus making it a more effective learning process on an individual level. Computer graphics is an area which is already largely benefitting from efficient FER systems. The modelling of a human face by precisely parameterizing the geometry of the face and muscle motions is done by FER systems[15]. Newer technologies such as Augmented Reality (AR) and Virtual Reality (VR) also apply effective FER systems to achieve a more natural, effortless communication with humans. Other areas where FER can be applied are automated surveillance systems[48], behaviour prediciton[47], lie detection[28], music/lighting for mood, etc.

1. **Related Work**

As mentioned above, HCI is an increasingly growing field that attracts a lot of people. Currently existing techniques achieve very high results in lab – controlled environment with accuracy above 95%. However, due to the challenges discussed earlier, in an unconstrained real-world environment FER systems achieve around 50% accuracy. One of the most studied topics in computer vision is face detection and more recently facial expression recognition. As a result, a large number of algorithms have been developed to overcome various challenges such as illumination variation, pose, occlusion and others. For the three stages in a FER system: preprocessing, feature extraction and image classification I’ll discuss the most popular and effective techniques used today for each part along with performance comparison.

1. Preprocessing

In image processing it’s quite common nowadays to work with large datasets, meaning the majority of the images will have different graphical properties. The model trained on such data will most likely suffer in performance[16]. In order to overcome that challenge different preprocessing techniques are applied to the data. Preprocessing is a process which prepares the data for feature extraction and can majorly improve performance of FER[17]. Image preprocessing in this case involves different cropping, scaling, contrast adjustment techniques to improve the data[5]. In almost all cases, for an accurate FER system various preprocessing techniques must be applied to the data as large disparities between image parameters such as illumination levels, contrast, size can drastically decrease the performance, hence why preprocessing is a key stage. The most popular preprocessing methods implemented for this part are Normalization[18], Locatization[19, 20], Region of Interest (ROI)[21]. Normalization is the most pupular technique, which can be used for reduction of illumination variation in different images and reduction of face image variation, thus providing more clarity to the images. Moreover, normalization is used for extraction of different features such as eyes, mouth, which helps develop a more robust FER system when it comes to personality differences. In addition to normalization, localization is another preprocessing method that can be applied[19,20]. Localization is used for detecting faces within an image and isolating them in face images. Its main purpose is spot the location and size of the face image. ROI are samples of data, isolated for a particular purpose. In image processing, ROI segmentation is an important method for identifiying the different parts of a face such as mouth, nose, eyebrows[21, 26]. Another less popular image processing technique is Histogram Equalization[19,20], which is used for adjusting the contrast in images. Histogram the graphical representation of the color value distribution of an image[22]. This method uses the image’s histogram to spread out the most frequent intensity values. This means local areas with low contrast gain a higher contrast. This technique is useful for images with similar tonal distribution in the background and foreground such as x-ray images[22]. In FER preprocessing, ROI is the most popular technique used as it precisely detects all the different face parts that people use to express emotions[21,26].

1. Feature Extraction

**Feature Extraction** is the most important, second step in designing a FER system. Being so common to work with huge datasets in present days, they usually contain thousands of features and if the number of features is bigger to the number of observations in the dataset, then highly likely the model would suffer from overfitting[6,7,24]. Overfitting refers to a dataset that has been modelled more than necessary to the point where it actually degrades the performance of the machine learning model. As a result the model would only learn to perform well on the dataset that it’s been trained on. To overcome this obstacle, it’s vital to apply regularization or dimensionality reduction techniques – feature extraction[24]. Other than overfitting risk reduction, feature extraction is especially useful where the images are large in size and a more compact feature representation, stripped of any redundant information, is required for further processing. This also necessitates less computing power and respectively speed up in training[24]. During this stage, the graphical data of an image is depicted as implicit numerical data describing the texture properties[5], which is then given as input to the classification algorithm. Feature extraction techniques are divided into five types[5].

With texture feature based algorithms[20, 22, 33, 34, 35, 37] all extracted features are based on properties defining the texture of an image. Textures are one of the most important characteristics of an image used to classify and recognize objects and find similarities between images. Scale Invariant Feature Transform (SIFT)[22, 34] has proved to be a very powerful technique for object detection/recognition, however SIFT might not be optimal for analyzing face images[23]. Keypoints-Preserving-SIFT (KPSIFT) includes all the initial keypoints as features and Partial-Descriptor-SIFT (PDSIFT) for which all keypoints detected at large scale and near face boundaries are described by a partial descriptor prove to be more efficient than the original SIFT[23]. Gabor filters are orientation-sensitive, linear filters used for edge and texture analysis that can extract local features in frequency and spatial domain[25-27]. Local Binary Patterns ( LBP) is a simple, efficient and robust local discriptor that has proven to do well in various domains such as texture analysis, facial expression recognition, and facial recognition[29]. LBP represents pixels as binary numbers by thresholding the neighbouring pixels and it’s most important property is its robustness to monotonic gray – scale changes such as illumination variations[30]. Combined with its computational simplicity, LBP is one of the more popular feature extraction techniques used in FER systems[20,22]. For multi resolution approaches, LBP is combined with Three Orthanogal Planes (TOP) method[31]. Weighted Project Based LBP (WPBLBP)[35] is an extended LBP extraction that’s based on instructive regions for which the LBP is extracted. After that, depending on the importance of the instructive region the extracted features are weighted. Gaugasian Laguere (GL) wavelets have powerful frequency extraction capabilities for extracting features of facial expressions[16]. In comparison to Gabor filters , GL uses a single filter instead of multiple ones[5], which means Gabor Filters require significantly more computational power. In addition, Vertical Time Backward (VTB)method extracts the shape related features of facial components. This makes it really effective on spatiotemporal planes. Spatiotemporal derivatives are usually contained in images produced by catadioptric sensors, which contain a significant amount of radial distortion and variantion in inherent scale[32]. Weber Local Descriptor (WLD) is another texture-based feature extraction technique, which consists of differential excitation component and orientantion component, that contains abundant local information[33]. In most cases, WLD uses Supervised Descent Method (SDM) to estimate the distance between various components of the face[5]. WLD performs better than LBP while still being as computationally efficient as LBP. As mentioned, SIFT is a sparse descripor, whereas WLD is a dense descriptor computed for every pixel and depends on the magnitude of the centre pixel’s intensity[34]. Last but not least, Discrete Contourlet Transform (DCT)[36] method is a combination of a multiscaled Laplacian pyramid and multi – directional filter banks. Compared to one-dimensional transforms such as Fourier and wavelet DCT is a two-dimensional feature extraction method that can capture geometrical structures of an image that are key to visual information. Using multidirectional filter banks with DCT multiresolutional and directional image representation controur segments, hence the name contourlet transform[36].

Edge – based feature extraction methods[38 - 43] are used for object recognition where colour or texture cannot be used as a cue for recognition. Instead, the distinctive features of such objects are edges and geometric locations between them. As mentioned above, one of the biggest challenges when it comes to image retrieval is illumination variation. Compared to texture – based feature extraction methods, techniques that use edge information instead are partially illumination – invariant and also require less memory, which makes them a preferred choice in some cases. Line Edge Map (LEM)[39] can be used to construct a compact face feature for face coding and recognition. Based on the analysis[40] two types of facial features are extracted – discriminitive and non – discriminitive. GPU based Active Shape Model (GASM)[41, 42] is a popular statistical model for object localization based on the famous Snake algorithm. Compared to CPU, the graphics – processing unit allows for substantially bigger facial feature extractions in video or image sequences. In fact, the acceleration improvement is so significant GPU reported a 48 times performance boost compared to CPU implementation[41]. Main advatange of the ASM compared to other feature extraction algorithms is the model can only deform in ways learnt from the training set, meaning it can deform considerably and maintain specifity to the object intended for representation at the same time. Histogram of Oriented Gradients (HOG)[43] are an efficient descriptor for object detection and recognition. They are generaly used in computer vision, pattern recognition and image processing for detecting and recognizing graphic objects such as faces. HOGs are especially efficient in detecting faces with occlusions, pose and illumination variation, because of the robust feature set, in which face features are extracted in a regular grid.

A different approach combines techniques for extracting global and local features. Principal Component Analysis (PCA) [44, 49] is a common method used in statistical pattern recognition and signal processing invented back in 1901. PCA extracts global and low – dimensional features about a pattern in an image. The pattern often contains redundant information. In order to get rid of that redundancy, while still preserving the key descriptive information, the pattern is matched to a feature vector. As a result, the extracted features are used to discriminate between input patterns in an image. In comparison, Independent Component Analysis (ICA)[45, 46, 49] is a novel statistical technique in machine learning and signal processing used to extract local features by using multi channel observations. ICA aims to find linear projections of data features that maximize their mutual independence. Stepwise Linear Discriminant Analysis (SWLDA)[50] is another efficient technique for extracting localized features. SWLDA employs forward and backward regression models to extract a small set of features. During forward regression, the most correlated features are isolated on the basis of defined class labels or F-test values, while the least significant are removed from the regression model during backward regression. The main advantages of SWLDA over other techniques are its computational simplicity, predictive ability and its performance doesn’t suffer from illumination variation.

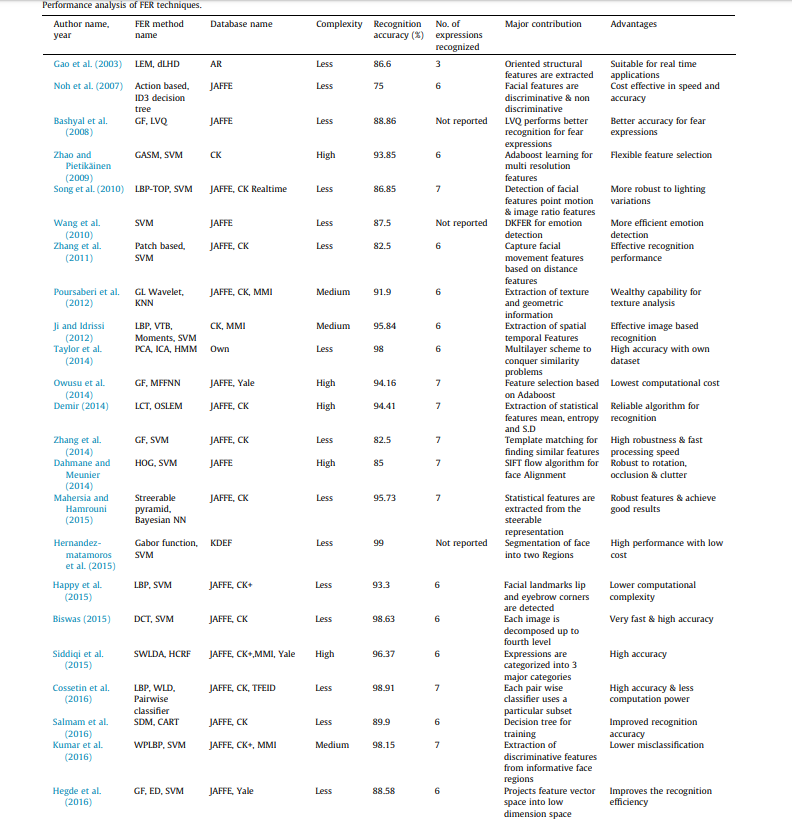
The first techniques used for feature extraction in facial expression recognition were geometry – based[19, 51, 52]. This means the extracted features we were based around the shape of the face and its parts – mouth, eyebrows, nose, rather than describing the texture of the face. Most geometric – based techniques employ Active Appearance Model (AAM) or variations of it to localize and track a dense set of facial points[51]. The locations of these facial points are combined in various ways to extract the shape of the face and monitor the movement of facial features as the expression develops. Mainly because of that, these methods perform better on a dataset comprised of videos or image sequences rather than inidividual images. Local Curvelet Transform (LCT)[19] is an effective feature extraction method that achieves localization in frequency and time domain. Some of the points and lines on a face can be better extracted than wavelet transform which deals with point singularities[52]. One disadvantage of LCT is that the features extracted are usually quite large and other dimensionality reduction techniques must be applied to overcome this issue[19, 52]. Patch – based feature extraction techniques are less used for facial expression recognition that extract patches of the image. After that, the patches are classified to a specific class and the whole image si classified based on the inidividual patches. This approach is useful where the image architype is too complex[53].

[20, 22, 33, 34, 35, 37] have shown that when it comes to designing a FER system, for the feature extraction stage texture - based techniques yield best results, since apprearance based extracted features have more significance than others. More recently developed similar techniques are Discrete Wavelet Transform (DWT)[54], Local Directional Number (LDN) Pattern[55] , Local Directional Ternary Pattern (LDTP)[56] and KL-transform Extended LBP (KELBP)[57]. It’s also important to note that in recent years, various dimensionality reduction techniques are applied to features that have high dimensional vectors. In addition, to better determine the significance of the features algorithms such as Adaptive Boosting (AdaBoost) and similarity scores.

1. Image Classification

**Image Classification** is the final stage in a FER system where the output of the feature extraction process is fed as an input to a classification algorithm or classifier and during this stage expressions are categorized as emotions such as happiness, sadness, anger, fear, etc. Similar to feature extraction stage, because of the fastest development and interest of FER in computer vision, a lot of different classifiers have been developed over the years. A distance based classifier is Euclidean distance metric[58]. The training and datasets for one subject consist of images with different expressions shown. When the model has to classify a certain image Euclidean distance is calculated between the points on the test image and the points on the training images for the same subject extracted during feature extraction. The expression shown on the test image is classied as the expression shown on the training image, for which the minimum Euclidean distance is found. Euclidean distance is more suitable for static images due to its ambiguity for real – time or robust images[58]. Another distance – based classifier is Minimum Distance Classifier (MDC) [59]. Although its classification accuracy is usually lower than more complex classifiers such as Convolutional Neural Networks (CNN) or Support Vector Machine (SVM), MDC is still used in various areas of pattern recognition due to its computational simplicity and fast execution time. With MDC, an unknown pattern is classified to a category to which the nearest prototype to the pattern belongs[59, 60]. K – Nearest Neighbours (KNN) classifier[16, 61, 62] is another simple, distance – based algorithm that classifies objects based on nearest training examples in the feature space. The object is classified by a majority vote on its neighbours, meaning the objects is assigned to most common class among its k nearest neighbours (k – positive integer, k > 0), so if k = 1, then the object is simply classified to the class of that nearest neighbour. After this stage, images are converted to vectors of fixed length with real numbers and a distance – based algorithm such as MDC or Euclidean distance is used to classify the whole image[61,62]. KNN can be defined as lazy learning or instance – based learning in which the function is only calculated locally and evaluation is postponed until classification. In this way, KNN can be used to determine the significance on the k – nearest neighbours of an object by weighing their contribution. Common factors for why all distance – based algorithms are applied for classification is simplicity, speed, and ease of understanding. A more complex classification technique is Hidden Markov Model (HMM). HMMs are probilistic models which consist of two random processes – Markov Chain comprised of a number of countable states, and a second process that defines the output transitions and corresponding emissions[50, 63]. HMMs are often used in speech recognition and more recently for FER in image sequences as well, since they can model temporal dependencies[50]. Support Vector Machine (SVM) [21, 64, 65] is a technique that combines related supervised methods used for classification and regression. SVMs use machine learning techniques which use hypothesis space of linear functions in high dimensional feature space to maximize prediction accuracy[64]. In fact, they are one of the most efficent classification techniques for dimensionally large data[21]. SVM systems are computationally complex, but perform as well as sophisticated neural networks, delivering high accuracy in FER systems, hence why they’re really popular classification technique for pattern recognition based problems and regression – based applications. For real – world FER systems Extreme Learning Machine (ELM)[66 - 68] is feed – forward neural network technique classification technique with only one hidden layer of nodes originating from the study of single hidden layer feedforward neural networks[66]. Unlike convential neural networks, with ELM there’s no need of tuning the hidden layer for weight adjustment, which makes them substantially faster and greatly reduces processing time for the data. In comparison to SVM, LBP, KNN, Extreme Machine Learning is an efficient classification method for real – world FER systems where the data is noisy and imperfect with a lot of constant transient changes. In addition, Online Sequential Extreme Learning Machine (OSELM)[68] originates from ELM, capable of learning the data one-by-one or chunk-by-chunk with fixed or varied length, with a Recursive Least Squares (RLS) algorithm constantly updating the output weights for each chunk. The main advantage of OSELM is that it can provide better generalization performance at a much greater learning speed compared to other classification techniques. A popular rule - based classfier used for FER is ID3 Decision Tree (DT)[69]. ID3 builds a decision tree from a fixed set of examples, which is later on used to classify other data. From the decision tree predefined rules are extracted to produce competent rules[5]. Compared to other algorithms, ID3 is robust to noise and has an easily interpretable tree structure ( if-then-else), meaning it can be extended to multiple output values. Learning Vector Quantization (LVQ)[70] is an supervised , prototype – based, artificial neutral network (ANN) algorithm that supports both two – class and multi – class classification problems. Compared to KNN, LVQ allows for choosing how many training instances to hang onto and learns exactly what those instances are supposed to look like, rather than having to hold onto all training instances. Last but not least, probably the most used technique in image processing and in particular FER are neural networks. Other than the ones already discussed above, the most popular ones for FER are Bayesian neural network, Deep Neural (DNN), Network, Arfiticial Neural Network (ANN) and Convolutional Neural network (CNN). The main problem with image classification is to find useful features from the feature extraction stage and this exactly what neural networks are great at as they can automatically create and select the most important useful features along with having the ability to learn extremely complex classification models. Some types of neural networks are also able to extract useful features invariant to transformation such as transformation, transposition, scaling, relocation etc.

Table 1. taken from [5]



Literature review summarized at table 1 shows that the datasets used for FER systems are JAFFE, CK/+, MUG , TFEID, Yale, AR, MMI, KDEF, MUG. The facial expressions recognized are usually 6 – happiness, sadness, anger, disgust, suprise, neutral, however it can be observed with LEM only 3 faciale expressions are recognized and some FER systems can recognized 7 expressions successfully with contempt as well. It can be seen that accuracy performance is outstandingly high in lab – controlled environment with ROI segmentation at preprocessing stage and Gabor function for feature extraction with SVM classifier giving best results 99%[26].

1. **Project Specification**

The goal of this project is to design, document, build and test a program that does real - time FER. Human faces must be detected on a streaming webcam in real – time and then their facial expressions must be recognized and classified. The program should support at least 6 emotions: happiness, sadness, anger, disgust, surprise, neutral. The facial expressions should be classified for every frame.

1. **Project Plan**

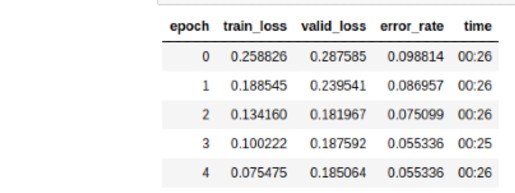
The project has two parts – developing the FER implementation and then using that implementation in an app/website whose only purpose would be to provide the wrapping streaming webcam. The main objective of this project is the FER system. During implementation of it I’ll try to develop my own model which could potentially perform better than most existing models. For the FER implementation the plan goes as follows:

1. Data Collection – in order to ensure a robust and reliable FER system data collection is an important step. Main requirements for the data is to have enough of it and in order to ensure robustness the training data should have different head poses, illumination variation, scale, occlusion, etc. There’s plenty datasets available specifically for FER as mentioned above. I’ve decided to use and currently have access to JAFFE, TFEID, CK, CK+, Yale, KDEF & AKDEF, and Oulu\_Casia. This brings me to the next step.
2. Data sorting and gardening – during this step data from all the datasets mentioned above will have to be extracted and sorted according to the emotions shown. During the gardening process the data will be prepared for the next stage - preprocessing.
3. Preprocessing – I would be applying different techniques to the data in order to normalize it and make it more similar. This would ensure substantially better performance of the program as a whole.
4. Developing and training different ResNet and CNN models and comparing their accuracy in order to determine which type of model woula d work best for FER

Once the FER system is developed next stage is to develop website/app

1. Develop app/website with a streaming webcam,
2. Detect human faces which can then be fed to the developed FER system
3. Success

As of now I’ve successfully managed with a fraction of the data to train and test a model. The model I used is resnet50 a residual neural network that is pre – trained with normalization applied to the data in advance to ensure better results. ResNet50 is a 50-layer residual network. Residual network is similar to deep convolutional neural networks except the network learns residuals instead of features at each level. A residual can be represented as subtraction of feature learned from input of that layer. ResNet uses skip connections to propagate information over layers allowing for building deeper networks. Skip connections allow the network to understand global features.

Picture 1.

As it can be observed on Picture 1. the accuracy I managed to achieve was 95% or ~0.055 error rate. This leads me to believe that developing a deep convolutional neural network model for FER would be the most appropriate solution.

1. **Summary of technology proposals**
2. Development Methodology

For development methodology I propose the traditional waterfall development method. The waterfall method is a rigid, linear model that consists of sequential phases (requirements, design, implementation, verification, maintenance) each of which focuses on distinct objectives. In order to proceed to the next phase, the previous one must be 100% completed. In comparison to agile development, there’s usually no going back to modify the direction or the project. That would not be a problem for this project, since the project requirements and objectives are clearly outlined, hence why the waterfall method is the chosen one.

1. Design

After literature review and performance comparison, I’ve decided the best approach would be to develop a deep convolutional neural network model. Because of its popularity in image processing and its ability to learn highly complex models I believe it would be the most appropiate way to go. In addition, using the pre – trained ResNet50 model during prototype development yields 95% accuracy, which proves deep CNN models can give very good results for FER. The reason why CNNs are the preferred choice for image processing is the feature extraction stage, which as mentioned above is the most significant stage of developing a FER system. Feature extraction is in a way performed automatically with CNN and no special algorithms have to be applied in order to extract useful features. CNN extracts features by constructing its own feature map using filters represented by 3x3 matrices. This is done by the convolution layers of a CNN, in which the network effectively uses adjacent pixel information to efficiently downsample an image, which preserves spatial information about features and that’s the key thing about CNN. The preservation of spatial information compared to a pixel vector algorithm for example means CNN will perform much better during the classification stage.

1. Implementation

As for implementation, the FER system will be developed with FastAI library built on top of PyTorch. The model developed will be trained on Google Cloud Platform in order to exploit the GPU on it and expedite the training process. For face detection in real time - OpenCV (Open source computer vison). As for the wrapper functionality, I’ll be using the Ionic Framework with Nodejs and Cordova.

1. Testing

To test the performance of the model developed, cross – validation will be done with the data split in 10 equal chunks.

1. Evaluation

Performance of the model will be evaluated by checking how accurately the model classifies each image according to one of the 6 emotions.

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