DIGITAL DECISION MAKING WITH ARTIFICIAL INTELIGENCE: A CNN BASED PREDICTION OF MALOCCLUSION USING DEEP LEARNING IN DENTISTRY

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ABSTRACT: In every medical and allied sector, treatment planning, management and chair side efficiency is very crucial where decision making comes to scenario. In this current digital era, computer assisted decision making is slowly replacing the manual process supporting the medical / dental fields for effective and efficient utilization of computer resources and technologies. Artificial Intelligence and virtual reality in health care has been giving successful outcomes where few of the manual procedures has been made completely automated. Now- a – days Artificial intelligence is predominantly used in almost all the medical applications for disease detection, identification, diagnosis, pre & post treatment planning, patient management, computer assisted surgeries and many more. The current paper focusses on the dentistry – which focusses on oral diseases. Proper tooth alignment is very important when concerned with aesthetics and beautiful smile. Generally people will face the problem of irregularities on the teeth and jaws which spoils the aesthetics of the face during smile. The problem of misalignment is common now a days and there are treatments to correct the alignment where the specialization in dentistry, orthodontics comes in to scenario. In the current paper, malocclusion problem from orthodontics is addressed using Artificial Intelligence, deep learning model named Convolutional neural networks (CNN). The problem of Periodontitis related to gum disease depends on bacterial accumulation that may also occurs because of malocclusion. Therefore the current paper focuses on detection / classification of malocclusion. The input dataset is the RGB images of the patients' tooth suffering from malocclusion and normally aligned tooth images. CNN is used to classify normal images from malocclusion images and encouraging results are obtained with the prediction accuracy of 98.95 %. Therefore deep learning technologies can be used for prediction of malocclusion, to design aligners during correction of tooth alignment, in prediction of whether tooth extraction is necessary or not thereby supporting orthodontists in effective decision making and proper treatment planning.

KEYWORDS: Orthodontics, Malalignment, Malocclusion, CNN, Deep learning, Decision making, Dentistry, Artificial Intelligence, Computer assisted tool, facial orthopedics, smile designing, tooth alignment

1. INTRODUCTION:

Dentistry, an oral medicine which deals with identifying and treating tooth related issues. As we all know dental pain is next to the labor pain and which needs expensive treatments if not identified and diagnosed at the earlier stages, becomes severe and damages complete tooth and supporting structures resulting in permanent tooth loss. Therefore, at most attention is essential to detect, diagnose, treat and manage oral diseases. According to the world health organization's recent oral disease health report 2022, the percentage of people suffering from oral diseases are more and it is alarming the nation to take further steps to control and create awareness on oral care and hygiene [1]. The most prevailing dental diseases in most of the patients who suffers from oral pain are oral cavities / caries, gum diseases like gingivitis and periodontitis, alveolar bone loss and oral cancers where the most contributing risk factor is their life style and food habits. There are many studies which proved that the most affected people who suffers from dental diseases are lacking awareness and good oral hygiene habits. The dental treatment expenses are proved to be most contributing expenditure in the survey worldwide when compared to the other expenses [2]. The people are not very serious on the oral problems until they are exposed to serious impact and pain. By the time they responds and wish to have a dental visit, the impact of the disease might be increased. Therefore dental awareness programme is recommended in every cluster of people to get insight of the serious impacts of the oral health on the overall health [3]. Oral health has an impact on our overall health. Many studies have proved oral health is associated with cardio vascular disease, respiratory disease, preterm births and low weight births during pregnancy, diabetes, cancer and other systemic diseases [4][5]. Consumption of high sugar intakes, tobacco, alcohol and other commercial determinants also leads to oral problems [6]. Oral health has a direct impact on the quality of life in toddlers and infants. Caries, orthodontic developmental issues, periodontal issues has more impact on the child health. Consumption of high sugar beverages and foods, lack of proper oral hygiene, malocclusions during tooth development are the few factors that provokes oral diseases [7]. There are many oral diseases that affects human tooth and the current paper focus is on malocclusion which is the most common case seen in orthodontics.

Occlusion refers to alignment of tooth when jaws are closed. Malocclusion refers to mal alignment of tooth position in to the arch when they approach. Intra and inter arch relationship with tooth decides the occlusal status. This particular problem comes under orthodontics which deals with diagnosis, prevention and management of mal-alignment. Malalignment of tooth occurs due to many factors like heredity / genetic influences resulting in disproportion of teeth and jaw size, Achondroplasia resulting in short limbs and mid face deficiency, dental development issues like Anodontia, Oligodontia, hypodontia, differences in tooth size and shape or deformities and disturbances in embryologic development like flat nasal bridge, thin upper lip like fetal alcohol syndrome, Treacher Collins syndrome, Crouzon's syndrome, molding and birth injuries, nature of food, trauma, thumb and finger sucking habits in toddlers, bruxism and other environmental influences. When the tooth is too large causing crowding, results in mal-alignment reflecting the quality of life and also there are different types of occlusion and different authors has suggested different measures of finding malocclusion angles [8][9]. There

are studies where temporomandibular disorders shows symptoms and signs in children with severe malocclusion [10]. In normal people having malocclusion will find the symptoms like difficulty during chewing, speech impairment, mouth breathing – breathe through mouth rather than nose, repeated biting of inner cheeks / tongue, tooth impaction, caries and gum related diseases and especially from aesthetics point of view it will have a serious impact on the self-esteem. Malocclusions also has an impact on the face outlook when the upper and lower arch are not in sync with tooth and each other.

Dentists identify malocclusion based on the type and severity. There are 3 main classifications and other sub classification levels. Class I, II and III are the main category of classification. In class I malocclusion, teeth is crowded but upper and lower molars are in sync with each other. In class II malocclusion, upper teeth and jaw overlaps with lower teeth and jaw and suffers from overbite. In class III malocclusion, lower teeth overlaps with upper teeth and suffers from under bite [11]. The treatment for the problem depends upon the severity level starting from tooth extractions, aligning tooth with aligners, braces and also surgery if necessary. As malocclusion problem has profound impact on many things on our quality of life, at most importance is to be given in identifying the problem at the early stages so that the severity of the disease can be reduced as it progresses with age and growth.

The role of Artificial Intelligence in dentistry is very crucial and is being used in many successful applications focusing multi-disciplinary areas [12]. Voice controlled and touch sensitive AI equipment in dental chairs replaced the manual process that clinicians are expected to do. AI is being used in assisting surgeries and in tracking supporting the dental surgeon with higher accuracy. It is also used as a supporting tool in dental implantalogy [13]. Bio printing technology, an application of AI is gaining more attention in regeneration of tissues that are lost during traumas and pathology [14]. In Oral medicine, AI can be used for dental lesions identification and classification of malignant and nonmalignant dental cases [15]. AI is being used in identifying very tiny things in radiology which cannot be sometimes detected by human eye especially apical foramen, very thin fracture lines and helps doctors for effective treatment planning and patient care [16][17]. In forensics, dental age estimation which is very crucial for extracting useful information from leftovers' in crimes are done using AI technologies [18]. There are successful researches made earlier where AI was used in dentistry on different applications like staging the development of lower third molar [19], predicting mandibular morphology [20] and many more as discussed above. Therefore the current paper focusses on the application of Artificial Intelligence subset, deep learning - convolutional neural network to identify whether a person is having malocclusion or not from the dental image. As the basic function of an orthodontist is to identify the presence of malocclusion and to categorize it based on severity, the present work focusses on identification of malocclusion which helps an orthodontist as a computer aided decision support system.

2. LITERATURE REVIEW

Classification of malocclusion was done by Idriss Tafala et al., using convolutional neural networks with different activation functions and 3 models were built having different convolutional layers and obtained their performance metrics with 57.5% accuracy on model 1,

60% accuracy on model 2 and 89.9% accuracy on model 3. 339 cephalometric images of patients' who came for orthodontic treatment are considered for the classification of class I, II & III malocclusion. Data augmentation and preprocessing techniques are implemented, Adam optimizer and softmax loss function was used. Thus the paper focused on automatic classification model supporting orthodontists during decision making [21].

To identify and locate malocclusions and to validate the application of CNN model in localizing cross bite, over bite, spacing, crowding etc., "You only look once" fully convolutional model was used on Tensor flow framework considering 700 input images. The researchers have proved the model can be considered to localize malocclusions after evaluating performance metrics with an accuracy of 99.79% [22].

The time duration for orthodontic treatments are more in general when compared to other dental procedures. The authors of this paper proposed an interface which accepts user inputs of age, gender, race, clinical results like over jet, overbite, crowding etc., based on which the time duration for the treatment will be predicted. 9 machine learning algorithms are used for predictions and compared. Bagging and Ada Boost algorithms have ended up with good predictions on comparison with other methods [23].

As dental problems burdening the global population and it has more association with the overall health, at most attention has to be paid to oral health as the consequences of dental issues are more severe in terms of both expense and health. Dental issues are more related to systemic diseases [24] also. Therefore the authors of the paper has implemented computer programming strategies to diagnose the presence of gum related periodontal problems.

Cephalometric landmarks identification is very important in ortho cases. Many works are already done on this area using pattern based and knowledge based detection techniques. The authors of this paper used line based and point based detection modules to identify cephalometric landmarks. The line detection module implements edge detection, contour segmentation, segment joining and reference line detection techniques followed by landmark localizations. The model achieved a success rate of 95.9% in identifying landmarks with a minimum deviation of 1.1 mm [25].

840 cephalograms are used as input in this paper to automate the prediction of orthognathic surgery is required or not for malocclusal and dental dysmorphosis patients. The convolutional neural network model was implemented to distinguish whether surgery needed or not and obtained a classification accuracy of 95.4%. During feature extraction, ResNet34 was used as backbone of convolutional layer [26].

An automated dental monitoring system has been in use which was driven by Artificial intelligence to know the oral health status. This article reviews the impact of automated remote monitoring system on the need of dental visits. In their work, authors reviewed many articles and concluded that the number of in - office visits are reduced after using the automated systems reducing the time consumption and both dentists and patients have been benefited [27].

128 * 128 sized 454 dental images were taken for the classification of malocclusion. They implemented cut – out method and CNN model to classify. The input images are subjected

to data augmentation / pre- processing technique followed by CNN model development, hyper parameter tuning, and then imposing cut – out method and obtained satisfying results [28].

3. PROPOSED METHODOLOGY

Development of advanced technologies is gearing up research studies accelerating the implementation of Artificial Intelligence and its subsets in the health care. In dentistry, there are many applications of AI which ended up with satisfying results for classifying, predicting disease and segmenting dental images based on region of interest. Machine and deep learning has been used for caries identification, clear aligners designing in orthodontics, gum disease detection and diagnosis, lesions detection, implantalogy, root extractions, alveolar bone loss prediction and many more [29]. In this current paper, deep learning – Convolutional neural network is used to distinguish images from presence and absence of malocclusion. There are many studies involving Artificial intelligence, fuzzy systems and neural networks for the disease predictions and classifications where the model is trained to detect the target label and back propagation has been used to make the system learn better to achieve the desired performance [30]. Any Orthodontic treatment mainly requires the classification of malocclusion. Based on the classification stage, further treatment plan will be planned. Therefore the proposed method implemented in this paper helps an Orthodontist as decision making aid during treatment planning. The present work is performed in following steps:

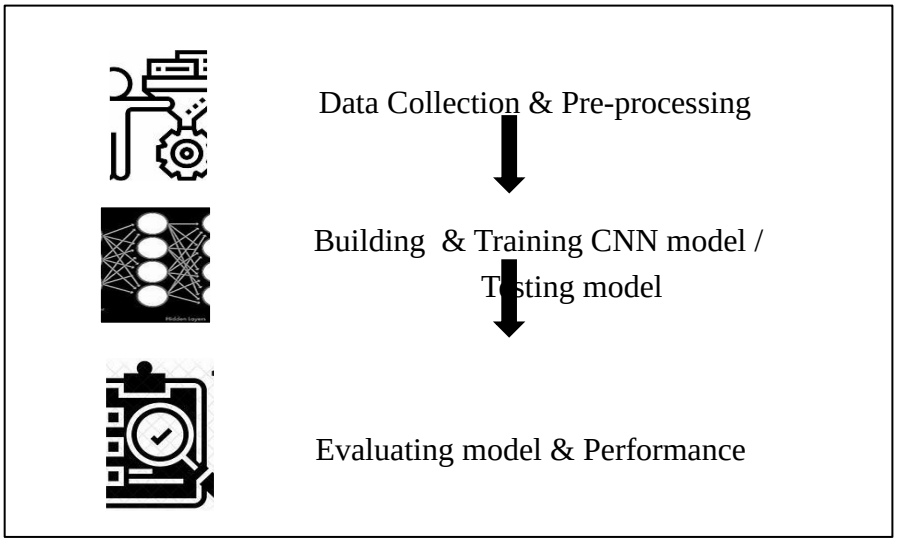


Fig 1: Proposed model Work flow

The present CNN model was built using Google Colab, Python 3 Google Compute Engine backend (GPU) on Tensor flow frame work version 2.9.2 using Python 3.8.10 version as programming language. CV2 Version 4.6.0, a library for image processing is used in the current paper for computer vision operations on images. A total of 2574 dental colored images of 256 *256 *3 are considered for the current work which includes images of 2 classes: Normal and malocclusal tooth. The total images are splitted in to train, validation and test and CNN model was developed and implemented for classification.

3.1 Data Collection & Pre-processing

For the current study, 2574 images are taken as user inputs belonging to two classes: Malocclusion and Normal. During pre-processing, the images are confined to uniform size and subjected to data augmentation with following operations: rotation_range=15, width_shift_range=0.2, height_shift_range=0.2, shear_range=0.2, zoom_range=0.2, horizontal_flip=True, fill_mode='constant'. The augmented 256 * 256, RGB images are separated in to two different folders differentiating image with malocclusion from normal image. 1360 images of malocclusion and 1214 normal images are considered for the current study as shown in the Figure 2 and Table 1 below. Now the images are ready to further proceed with the implementation of CNN model.

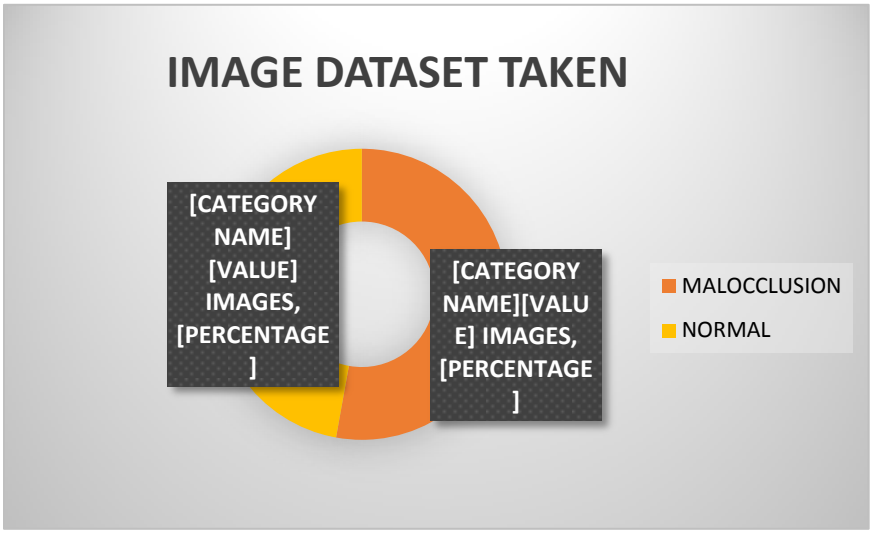


Figure 2: Image Dataset taken for the current study

Table 1: Image Dataset taken for the study

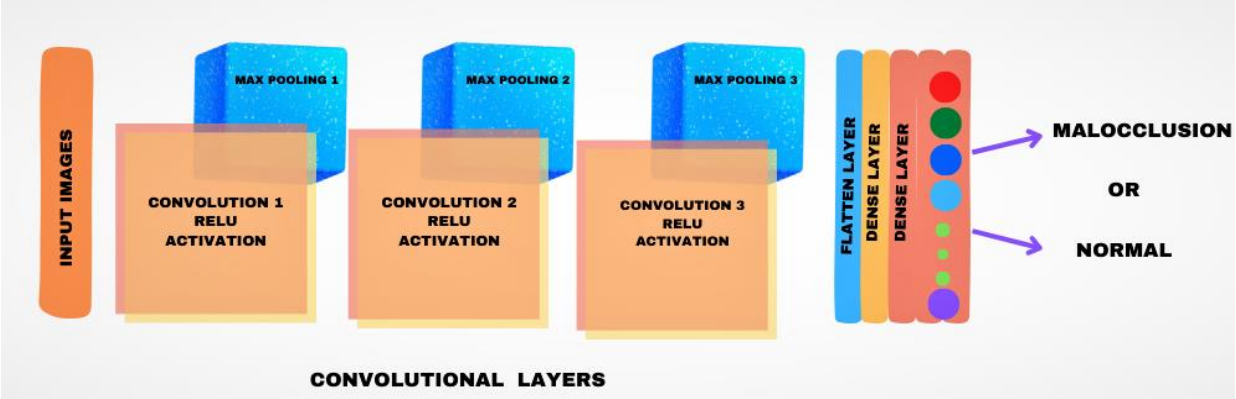
CATEGORY	NUMBER OF IMAGES TAKEN FOR THE STUDY
Normal Healthy Images Without Malocclusion	1214
Images With Malocclusion	1360
Total	2574

3.2 Building CNN model for training and testing

The present CNN model is built on Tensor flow framework version 2.9.2. Before training the model, images are segregated in to two folders where 1 folder holds images without malocclusion (normal), and the other holding images containing malocclusion. Image dataset is loaded and splitted to train, validation and test depending on the number of images available and keeping in the mind batch size, a sequential model is built. The model used “ReLu” activation function in convolutional layers, “sigmoid” at the dense layer/last layer with “RMSprop” as

optimizer. Loss function "Binary cross entropy" and accuracy are considered as performance metrics during training and compiled the sequential model. CNN gives appreciable results in various image classification problems and it has been proved in many research studies [31] [32] [33]. The majority of computations are done in convolutional layers performing multiple iterations making use of filters to check the presence of a particular feature. In pooling layer, the complexity of the model is reduced by reducing the parameters and in fully connected layers, actual image classification is done based on the features extracted from the previous layers [34]. This is the reason CNN model as shown in Figure 3 below was chosen for this classification problem.

Figure 3: CNN Model



3.3 Evaluating model & Performance

The CNN model is evaluated to obtain the performance metrics. The performance of a model is measured using the following parameters [35]:

3.3.1 Accuracy

It is the ratio of the number of correctly classified data to the total number of data considered.

$$\text{Accuracy} = (TP + TN) / (TP + TN + FP + FN) \quad (1)$$

TP: TRUE POSITIVE - Model correctly predicts the positive class

TN: TRUE NEGATIVE - Model correctly predicts the negative class

FP: FALSE POSITIVE - Model incorrectly predicts the positive class

FN: FALSE NEGATIVE - Model incorrectly predicts the negative class

3.3.2 Precision

It tells us what amount of data is predicted as positive are predicted correctly.

$$\text{Precision} = TP / (TP + FP) \quad (2)$$

3.3.3 Recall

It provides the completeness of the model. Higher recall indicates lower false negatives, while lower recall indicates higher false negatives.

$$\text{Recall} = TP / (TP + FN) \quad (3)$$

3.3.4 F1 – Score

It is the harmonic mean of precision and recall

$$F1 - \text{Score} = \text{F1-Score} = 2 \times ((\text{Recall} \times \text{Precision}) / (\text{Recall} + \text{Precision})) \quad (4)$$

The above metrics are obtained during evaluation of the proposed model as follows: Precision: 1.0, recall: 0.9836065769195557, Accuracy: 0.9921875 and the details of the model performance is discussed elaborately in results section of the current paper.

4. RESULTS & DISCUSSION

CNN, the most popular deep learning model for image classification is used in the current paper for classifying image with malocclusion from the normal image without malocclusion. In the current study, 2574 images are taken as input image set out of which 1360 are images with malocclusion and 1214 are normal images. When the model gets trained and runs for 20 epochs, the training accuracy of 100 % and the validation accuracy of 99.8 % is obtained. The details of Training loss, training accuracy, validation loss and validation accuracy during model training is depicted in the table 2 below

Table 2: Training Vs. Validation Accuracy and Loss during Training of CNN model

TRAINING LOSS	VALIDATION LOSS	TRAINING ACCURACY	VALIDATION ACCURACY
0.89	0.55	0.69	0.67
0.44	0.28	0.82	0.87
0.2	0.44	0.91	0.84
0.16	0.03	0.94	0.99
0.09	0.03	0.96	0.99
0.11	0.08	0.98	0.97
0.06	0.02	0.98	0.99
0	0	0.99	1
0.12	0.01	0.97	0.99
0.04	0	0.99	0.99
0	0	1	0.99
0.12	0.02	0.98	0.99
0	0.01	1	0.99
0.17	0.03	0.98	0.98
0	0	0.99	1
0	0	1	1

0.08	**0.04**	**0.98**	**0.98**
0	**0**	**1**	**0.99**
0	**0**	**1**	**0.99**
0	**0.01**	**1**	**0.99**

From the above table 2, it is clearly observed that as epochs are increasing, as the model gets trained, loss is decreasing and accuracy is increasing yielding better results. The following figures Figure 4 and Figure 5 depicts Training accuracy versus validation accuracy and training loss versus validation loss during model training.

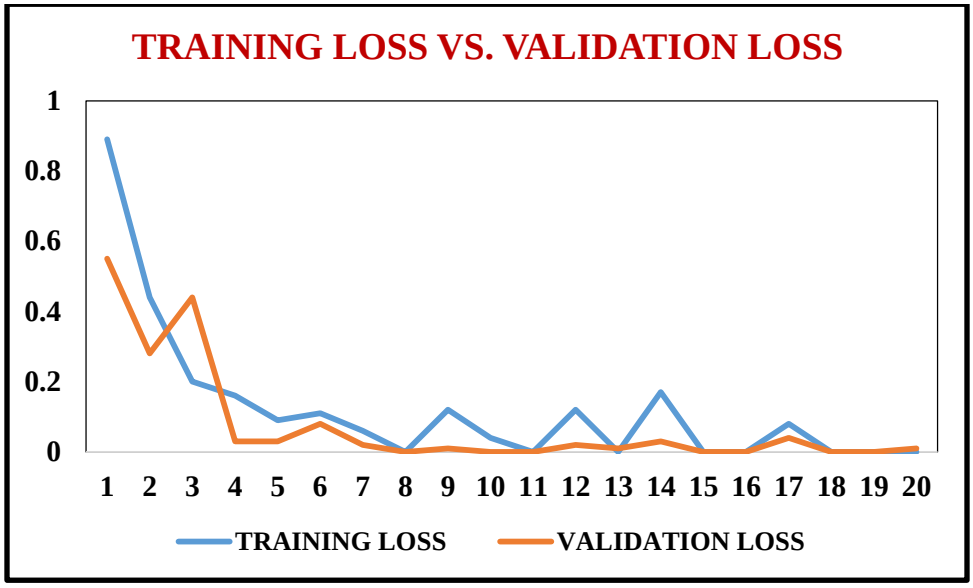


Figure 4: Training Vs. Validation Loss

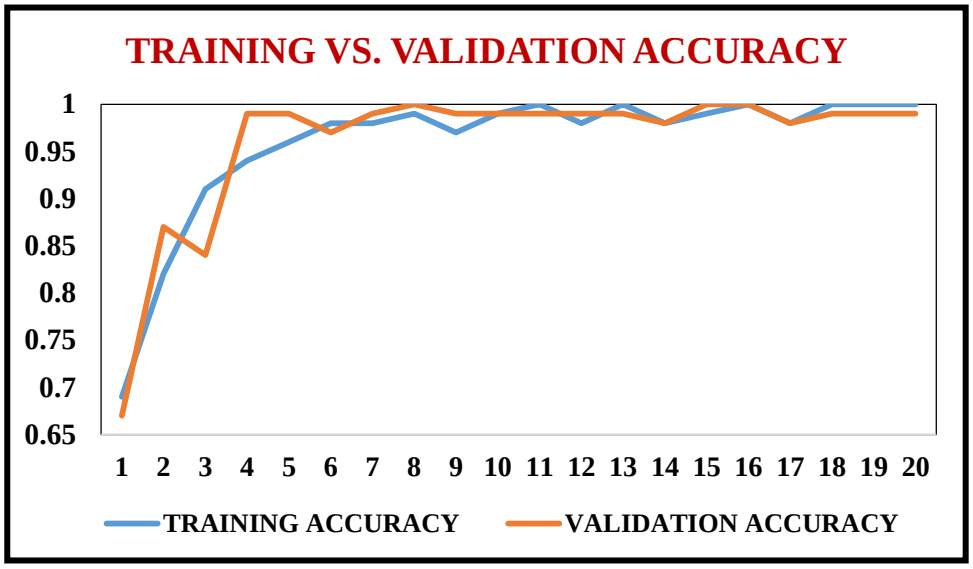


Figure 5: Training Vs. Validation Accuracy

From the above figures 4 and 5, it is clearly understood that as the number of epochs are increasing, the loss is getting decreased and the accuracy is getting increasing in both training and validation reflecting that the model has given better results. At the same time when the model is tested on unknown new image, it predicted correctly. Thus the performance metrics obtained is represented in Table 3 as follows:

METRIC	VALUE OBTAINED DURING PREDICTION
Precision	1.0
Recall	0.9836065
Accuracy	0.9921875

Table 3: Prediction Results

From the above results, it is proved that the precision is 1.0 proving that the number of correct predictions is 100%, recall is 0.98 indicating the false predictions is very less and the prediction accuracy is 99.2 % indicating the model has given better prediction results. The model is tested with new images that is the images which are not used for training and validation process as Figure 6 and 7 given below which is an ideal example for 2 classes considered for the study.

Figure 6: Test image 1
Output: Predicted class is malocclusion

Figure 7: Test image 2
Output: Predicted class is normal

Figure 8: Test image 3

Output: Predicted class is malocclusion

Figure 9: Test image 4

Output: Predicted class is normal

When an image with malocclusion was given as input, the model predicted it right and when a normal image without malocclusion was tested, it predicted it right as shown in Figures 6, 7, 8 and 9 above. Thus the present model prediction has given appreciable results and further the work can be extended with variations and different classes of malocclusions. Any Orthodontic treatment begins with the analysis of tooth and its alignment. Based on the alignment of tooth structure, the deviations from ideal alignment are assessed by the dentist and treatment is planned. As the basic step is categorizing whether a tooth structure is properly aligned or not, the classification problem was resolved using CNN model. As the model could correctly classifies with appreciable accuracy, further this work can be extended with more quantity of images to generalize the model and also can be extended with the implementation of Transfer learning techniques to further analyze the study in detail.

5. CONCLUSION & FUTURE WORK

The current study focusses on the classification problem using deep learning's CNN model. 2574 dental images are considered as image dataset for the current study belonging to 2 categories malocclusion and normal. The model was trained and differentiated the 2 categories and given prediction accuracy of 99.2 % with better performance. The trend seen in the graphs represented in the Figures 4 & 5 clearly shows the performance of the model. With increase in epochs, as training progresses, the loss value is decreasing and the accuracy is increasing in connect with both training and validation. Thus the present model can be a better solution for classifying normal image from image with malocclusion. Lot of further work can be done in this area towards contribution of research in Periodontics and Orthodontics implementing Artificial Intelligence and its subsets machine and deep learning techniques. The authors have planned to extend work further by increasing the size of image dataset generalizing the model as well the performance can be further studied by comparing with other models like VGG16, VGG19, Alex Net and etc., implementing Transfer learning. Also, in future, authors planned to work with different classes of malocclusion images for classification problem thereby the developed models can be used as a supporting aid for upcoming dentists as a decision making tool. Also authors planned to work further on Periodontitis in detail exploring different causes of gum disease that relates malocclusion. The early detection / prediction of the problem can reduce many dental complications therefore more work can be planned in this area to contribute for dentistry.

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