Performance evaluation of unpreprocessed and pre-processed ultrasound images of carotid artery using CNN algorithm

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Abstract. Detection of plaques is an important task especially those which are prone to rupture and may dislocate to some other body parts. Also early detection reduces the risk of cardiac and cerebrovascular anomalies. Due to its wide availability and low cost, ultrasound images of carotid artery has the ability and potential to gain the preference over other resources for plaque detection and analysis in medical practice. However, the difficulty caused in automated techniques to identify plaques is significantly due to image noise, plaque size and the complex appearance of tissues comprising a plaque. So, in this paper, we have addressed this problem by using deep learning techniques such as CNN algorithm. Here we will build a CNN (Convolutional Neural Network) that will extract features from the dataset of images thereby giving detailed information which will help the clinicians to identify the abnormalities and constituents of different plaques in an image and report the image as “normal” or “abnormal”. In this paper we have used approximately 1000 images (JPG format) of 100 cases to process and has validated the proposed convolutional neural network (CNN). The process of cross-validation with the clinical assessment showed a correlation of about 0.75 for the detection of plaque. This results indicate the potential of deep learning techniques in medical fields, here, automatic detection of anomalies in carotid ultrasound images.

1. Introduction
Myocardial infarction and strokes, also referred to as Cardiovascular or cerebrovascular events, are the major causes of increased death rates in today’s world. These events occur when plaques in artery or vein suddenly rupture or get dislocated to other essential body part such as heart or brain. This rupture or dislocation to other artery or vein obstructs the flow of blood to the brain or heart thereby causing strokes. An early and accurate detection of individuals especially people who are vulnerable to cardiovascular events or at high risk of stroke would help doctors for therapeutic measures, diet modifications that is preventive measures and surgical measures that can be applied apriori to the individuals diagnosed with any of these fatal events.
The identification of anomalies in individuals who are at high-risk is usually carried out by using risk prediction calculators. This risk prediction calculators concatenates generic factors of risks such as smoking, family history, Blood pressure (BP), age, BMI (Body Mass Index) and diabetes. However, these predictions calculated by risk prediction calculators do not provide information detailing out the absence or presence of plaque and atherosclerotic plaque types specific to patient’s condition, thereby resulting in inefficient estimations of plaques in patients, whereas in contrast, in today’s era of advanced medicine, with developed technology the analysis of images having plaque in it holds the potential to provide necessary and detailed features about the plaques thereby giving better results in identifying patients more accurately who are at risk of plaque rupture.

Therefore, development of computational techniques that is capable of automatically and objectively identifying the plaques from image datasets becomes very important. But due to highly complex nature of different types of tissues present in a plaque and also due to its small size in an image data still makes it a challenging task. So far majority of the techniques used for computation for detecting a plaque have been developed for MRI. The MRI images provide good quality and highresolution plaque images. However, MRI scans are costly and has some limitations in scanning which makes its use in everyday clinical practice limited. Hence these MRI images are largely used for scientific purposes, whereas Bmode ultrasound images have several advantages over MRI images in terms of use, low cost and wide availability. So, due to these benefits B-mode ultrasound images are used on a wide scale by clinicians for the examination of atherosclerosis in the carotid artery.

As illustrated below the ultrasound image of a carotid artery that bifurcates into two further arteries, typically this image has low resolution displaying reverberation, artifacts, noise and shadowing. These features of the image make the detection of plaques tedious and inconsistent even for a well experienced and an expert clinician. Therefore, it becomes necessary to develop an intelligent technique which is user-independent, robust and can alayse the presence and nature of plaque in a short span of time.

![Figure 1. Example of carotid ultrasound image showing plaques, incorporated with reverberations and noise.](image-url)
2. Literature Survey
Artificial Intelligence is a technique used to obtain a predictive outcome using existing knowledge without requiring any explicit coding for the particular application [1]. It applies the concept of using computer codes to analyse existing data to “make sense of” or find pattern in the seemingly chaotic data set in a predictive manner [2]. The objective of machine learning is not to mimic human conscious decision making but rather to enable the code to by itself without any human interference to be able to recognize and categorize data on basis of pattern they exhibit. Thus, significantly reducing man-power required for the task of categorization. Computational learning theory is a means of validating and evaluating the predictive capabilities of a machine learning algorithm statistically. Machine learning in all fundamental sense seems to resemble the characteristics of data mining and prediction algorithms [2,3].

Multiple studies have been conducted and papers have been published on how to establish and train a machine learning algorithm to customised advertising for very user. Some other popular applications for machine learning include, data mining, anomaly detection especially in medical applications, fraud detection and customizing news feeds [4-6].

In this paper, we have investigated an AI approach, precisely deep learning methods for addressing the task of automatic detection of plaque and also calculating the accuracy of CNN in detecting plaque in a given ultrasound image of a carotid artery. In the proposed technique we built a CNN network that is capable of extracting image features automatically from a given set of data for training. The proposed architecture was trained and validation accuracy was calculated using a total of 1000 and more ultrasound images of carotid artery in jpg format acquired from clinical practice. Also we investigate a comparison between raw ultrasound images passed into the CNN layer and segmented ultrasound images of carotid artery passed into the CNN layer. The techniques used for segmentation in this paper are thresholding and watershed.

3. Methods
3.1. Deep Learning
Deep learning can be defined as a branch of machine learning in AI (Artifical Intelligence) that has layers or networks which are capable of learning unsupervised from data that are unlabelled or unstructured. Deep learning has the ability to build multiple networks that helps in encoding several and variable level of abstractions, each layer contributes to the prediction power for the features in a given data. In case of image processing or image analysis, deep learning can be used for image classification, object recognition. It also helps extracting statistical informations such as intensity profiles of a given image, edges/shapes in an image. So for anomaly detection in an image or for classification of images this subset/branch of AI (Artificial Intelligence) can help extract distinct and new features that will combine both local and global details of a plaque in an image.

3.2. Plaque CNN Architecture
CNN and its kinds are types of deep learning architectures. In figure 2 the CNN architecture uses convolutional filters that is kernels of different sizes, say 3x3 or 5x5. The convolutional filters are used at each layer for extracting features from the given image datasets provided for training a network. The architecture proposed in this paper consists of convolutional layers that are four in number and three Fully Connected layers along with Relu functions followed by a softmax function that calculates the probabilities distribution of each target class over ‘n’ different classes. Here the kernel size for all the four convolutional layers was 3x3. For calculation of loss function we used cross-entropy method and Adam method was used for optimization. Also, the batch size used in this paper is of more than 1000 for training.
4. Evaluation

4.1. Datasets
The proposed technique was evaluated for plaque detection in a carotid artery and the performance evaluation was achieved based on 1000 plus images (JPG format) obtained from the SRM hospital of SRM university, Chennai, India. These images from the training dataset were fed into the CNN network and the accuracy results were obtained after 50 epochs.

4.2. Raw Images
After the proposed deep learning approach (CNN) was trained on the unmodified ultrasound images (normal and clot) of carotid artery, the accuracy obtained was 79.75 % after 50 epochs as shown in table 1 and figure 3.
Figure 3. Output image analysis of raw images fed into CNN network.

Table 1. Accuracy table of CNN trained on raw ultrasound images of carotid artery.

| Epoch | Accuracy(%) | Time(s) |
|-------|-------------|---------|
| 1     | 54.84       | 9.720   |
| 2     | 67.62       | 8.593   |
| 3     | 55.26       | 2.415   |
| 4     | 64.08       | 8.417   |
| 5     | 41.06       | 8.518   |
| ...   | ...         | ...     |
| 49    | 72.45       | 8.344   |
| 50    | 79.75       | 8.233   |
4.3. Segmented images

4.3.1 Thresholding method – This method separates or partitions an image into background and foreground. The grayscale image is converted into a binary image, by doing this objects in an image are isolated. The thresholded image of an ultrasound image of a carotid artery with a plaque is represented in figure 4. The accuracy of 75.88% was achieved after 50 epochs as shown in figure 5 and table II represents the accuracy results.

![Inverted binary thresholding is performed on a denoised input image.](image)

**Figure 4.** Inverted binary thresholding is performed on a denoised input image.

| Epoch | Accuracy (%) | Time(s) |
|-------|--------------|---------|
| 1     | 33.26        | 5.762   |
| 2     | 36.21        | 5.699   |
| 3     | 49.25        | 5.517   |
| 4     | 41.26        | 5.518   |
| 5     | 37.79        | 5.480   |
| 49    | -            | -       |
| 50    | 75.88        | 5.516   |

**Table 2.** Accuracy table of CNN trained on thresholded images of carotid artery.
4.3.2 Watershed Method – Watershed by name itself describes the pattern of water shedding off from a topographic map, and then getting divided into various streams. Similarly, this method considers an image as a topographic map, where each point with high pixel values represents its altitude and locates the lines which run along the boundary of ridges. The watershed image of a carotid artery with a plaque is represented in figure 6. The accuracy of 76.07% was achieved after 50 epochs as shown in figure 7 and table III represents the accuracy results.

| Epoch | Accuracy (%) | Time(s) |
|-------|--------------|---------|
| 1     | 41.09        | 5.651   |
| 2     | 59.05        | 5.637   |
| 3     | 62.05        | 5.674   |
| 4     | 62.74        | 5.595   |
| 5     | 62.93        | 5.620   |
| 6     | 50.25        | 5.538   |

Figure 5. Output image analysis of raw images fed into CNN network.
Figure 6. Watershed image of a denoised input images.
5. Conclusion
We obtained an accuracy of 79.75% with raw images, accuracy of 75.88% with thresholded images and accuracy of 76.07% with watershed images from the dataset of images that was used to train proposed technique in classifying the given input image as ‘normal’ or ‘clot’.
Here, we can conclude that the accuracy was highest among all three different trials of learning of proposed technique (CNN) which was 79.75%. The accuracy can be boosted by removing the texts, markings and other noises in the image. CNN learns more efficiently when fed with unmodified images as it selects features on its own and operates accordingly. Segmented images when fed into the CNN network gave slightly less accuracy when compared to raw images fed into the CNN network.

6. References
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