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Detecting Distracted Driving with Deep Learning

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Abstract. Driver distraction is the leading factor in most car crashes and near-crashes. This paper discusses the types, causes and impacts of distracted driving. A deep learning approach is then presented for the detection of such driving behaviors using images of the driver, where an enhancement has been made to a standard convolutional neural network (CNN). Experimental results on Kaggle challenge dataset have confirmed the capability of a convolutional neural network (CNN) in this complicated computer vision task and illustrated the contribution of the CNN enhancement to a better pattern recognition accuracy.

Keywords: Distraction Detection, Accident Prevention, Convolutional Neural Networks, Kaggle Challenge, Triplet Loss.

1 Introduction

Driving is a complex task and requires a number of skills such as cognitive skills, physical fitness, coordination and, most importantly, attention and concentration of the driver on the driving [1,2]. Despite of the complex nature of driving, it is common of drivers to get involved in activities that divert their full attention from driving, degrade their driving performance and even lead to fatal accidents. Typical examples of such activities include using a mobile phone, eating or drinking, using a navigation device, grooming, tuning the audio system, and/or talking to passengers, etc. In a report by the National Highway Traffic Safety Administration (NHTSA), it has been estimated that approximately 25 percent of car accidents were due to inattention of drivers [3] and around 50 percent of these accidents were caused by distraction of drivers [4,5].

With the goal of reducing car accidents and improving road safety, various computer vision based approaches have been proposed. State Farm has initiated a competition called Kaggle competition [35], which aims to distinguish distracted driving behaviours from safe driving using images captured by a single dashboard camera. This paper presents a solution to the Kaggle challenge by using the latest development in machine learning and computer vision, i.e. deep learning and a convolutional neural network (CNN).

The paper is organized as follows. Section II provides a more in-depth description of the subject of distracted driving. Section III presents the existing computer vision based approaches to the detection of distracted driving. Section IV provides a brief subject review of deep learning and CNNs as well as a detailed description of the CNN we have adopted for the Kaggle challenge. Furthermore, section IV presents the details

about the Triplet loss for the improvement in the accuracy of deep learning classification. Section V explains the Kaggle challenge, describes our experimental setup and compare the results of our two CNN models on the Kaggle images. Finally, Section VI concludes the paper and highlights some remaining challenges.

2 Distracted Driving

Distraction is a type of inattention. It has been defined by the American Automobile Association Foundation for Traffic Safety (AAAFTS) as the slow response of a driver in recognizing the information required to complete driving task safely due to some event within or outside the vehicle, which causes the shift of driver attention from the driving task [1, 4, 6]. Distraction can be categorized into four main types; visual distraction, auditory distraction, cognitive distraction and biomechanical distraction [7]. Visual distraction is the diversion of driver's visual field while looking within or outside the vehicle to observe any event, object or person [8]. Cognitive distraction is defined as diversion of thoughts from driving due to thinking about other events [9]. Auditory distraction is defined as diversion from driving due to the use of a mobile phone, communicating with other passengers or any other audio device [9]. Biomechanical distraction is diversion due to physical manipulation of objects instead of driving [10]. It is important to note that although distraction is categorized into four different types they do not occur individually but are usually linked with each other. For example, in the activity of answering an incoming call all four types of distractions can be observed: visual distraction when looking at the phone screen to interpret the phone alert and to locate the right button(s) to press; auditory distraction when hearing the alert and when being in the conversation; physical distraction when taking a hand off the wheel to press a button to receive the call; and cognitive distraction when diverting thoughts to the topic of conversation.

A research by the National Highway Traffic Safety Administration NHTSA stated thirteen different sources of distraction, which can be further categorized into technology based, no-technology based and miscellaneous sources [4]. Table 1 presents the common sources of distracted driving as identified by the NHTSA. As shown in Table 1, some technical enhancements in modern vehicles, such as the navigation system and the entrainment system, on one hand are assisting drivers in many ways but on the other hand have become sources of distraction to drivers. Furthermore, it has been predicted by Stutts et al. [11] that number of distraction-related accidents will increase with the enhancements of vehicle technologies.

Studies have been carried out to investigate the impact of distracted driving to car crashes. Stutts et al examined the Crashworthiness Data System gathered from 1995 to 1999 to identify the contribution of different distractions to accidents [11]. Glaze and Ellis focused their study on the distraction sources from within the vehicle and investigated their contributions to car accidents based on the troopers' crash record [12]. Table 2 presents a comparison of the outcomes of these two studies.

Table 1. Different Sources of Distraction in Drivers Categorized by NHSTA [4].

Type of Distraction	Source of Distraction
Technology Based Distraction	Operating radio of music devices Talking or listening on mobile phone Dialing mobile phone Adjusting climate controls Using device/object brought into vehicle Using device/controls integral to vehicle
Non-Technology Based Distraction	Eating or drinking Outside person, object or event Other occupants in vehicle Moving object in vehicle Smoking related
Miscellaneous	Other distraction Unknown distraction

Table 2. Contribution of Different Distraction Sources to Vehicle Crashes.

Distraction Type	Stutts et al. Study [11]		Glaze and Ellis's Study [12]	
	Distraction Sources	% of Crashes	Distraction Source	% of Crashes
Technology Based	Adjusting radio, cassette, CD*	11.4	Adjusting radio, cassette, CD*	6.5
	Using/dialing mobile phone*	1.5	Using/dialing mobile phone*	3.9
	Adjusting vehicle/climate controls*	2.8	Adjusting vehicle/climate controls*	3.6
	–	–	Technology device*	0.3
	–	–	Pager*	0.1
	Total	15.7		14.4
Non-Technology Based	Smoking related*	0.9	Smoking related*	2.1
	Other occupant in vehicle*	10.9	Passenger/children distraction*	8.7
	Eating or drinking*	1.7	Eating or drinking*	4.2
	Moving object ahead**	4.3	–	–
	Person, object or event**	29.4	–	–
	–	–	Grooming*	0.4
	–	–	Other personal items*	2.9
	–	–	Unrestrained pet*	0.6
	–	–	Document*	1.8
Total	47.2		20.7	
Miscellaneous	Other distraction	25.6	Other distraction inside vehicle*	26.3
	Unknown distraction	8.6	–	–
	Object brought in *	2.9	–	–
	Total	37.1		26.3

* Inside Vehicle Distraction Source

** Outside Vehicle Distraction Source

3 Previous Work

This section presents a review of the computer vision based approaches to distraction detection of drivers proposed by researchers in the literature.

Study of driver's visual behaviour has been widely carried out by researchers since 1960 [13]. Eye glance is considered a valid measure among researchers for the detection of distraction in drivers [14,15]. In the eye glance approach, the frequency and the duration of a driver's eye glances for a secondary task are taken to produce a total measure of eyes off the road [13]. Eye glance of the driver can be measured by observing the driver's eye and head movements using a video sensor. Modern computer vision systems, for example FaceLAB [16], are able to provide real-time measurement of eye glance using head tracking and eye tracking techniques. In a study by Victor et al. [17], the validity of FaceLAB data as the measure for distraction detection has been studied and confirmed. Park and Trivedi [18] also applied SVR for the classification facial features to detect the distracted eye glance in drivers. Relevant facial features were extracted using the global motion approach and colour statistical analysis. Pohl et al. [19] developed a system based on the gaze direction and head position to monitor the distraction in drivers. Instantaneous distraction level was determined and a decision maker was used to classify the distraction level in drivers. Kircher et al. [20] also used the gaze direction as the measure for distraction detection and proposed two different algorithms. Murphy-Chutorian et al. [21] proposed a distraction detection system based on the head position of driver. Localized gradient histogram approach was used to extract the relevant features and were classified using Support Vector Regressor (SVR) to detect the distraction in drivers.

In an effort to provide efficient solution for accident prevention due to distraction, different researchers have proposed distraction warning/alerts systems in the literature. A forward warning system for distraction system was proposed by Hattori et al. [22], which used the idea of checking if the driver is looking at road based on the visual information captured by an in-vehicle camera. PERLOOK is the parameter proposed by Jo et al. [23] as a measure to detect the distraction level in drivers in a similar way as the PERCLOS for drowsiness detection. PERLOOK is the percentage of time in which a driver's head is rotated or the driver is not looking at the road ahead. Higher values of PERLOOK means higher duration of distraction in driver. Nabo [24] used the SmartEye [25] software tool for the measurement of PERLOOK to detect the distraction in drivers.

Visual occlusion detection is another approach to detecting distracted driving. It assumes that safe driving does not require the driver to look at the road all the time and short intervals are allowed for performing other tasks, such as tuning the radio or adjusting climate controls. With this assumption, secondary tasks that can be performed within 2 seconds are classified as 'chunkable' and considered acceptable during driving [26, 27]. During the occluded time interval, driver can work with different control devices without getting distracted [28]. Validity of visual occlusion technique for the distraction detection is widely measured by researchers and considered promising approach for measurement of visual distraction in drivers [29-31].

4 Our Deep Learning Solution

4.1 Model A: The Baseline Convolutional Neural Network

AlexNet deep network [32], which was the winner of 2012 ImageNet challenge has been used as the baseline model (Model A) in this work. In ImageNet competition, AlexNet was trained on about 1.3 million real life images of 1000 different classes of objects and has achieved the test error rate of 15.3% [32]. Fig. 1 shows the architecture of the AlexNet network that we have modified and used for the Kaggle challenge.

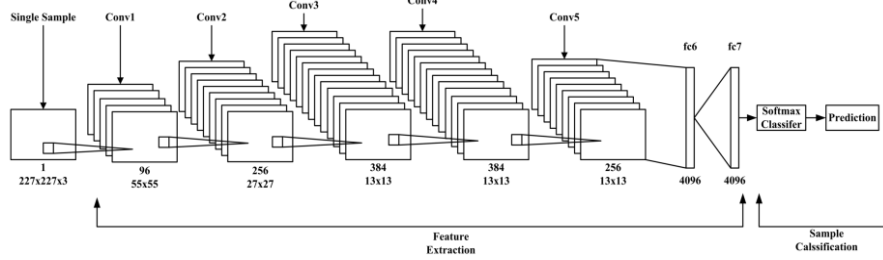


Fig. 1. Modified AlexNet Deep Learning Architecture for Kaggle Challenge.

The reason behind adopting AlexNet in this work is that AlexNet (or more precisely, the architecture of AlexNet) has demonstrated its ability to learn what to 'see' in an image for the purpose of object classification. This ability means, with appropriate training, a CNN with the same architecture as AlexNet will have the ability to recognize objects such as coke cups, phones, pets, driver's hand etc., all of which are valuable measures in classification of distracted driving.

Each input image to our AlexNet (model A) is $227 \times 227 \times 3$ as defined by the Kaggle challenge. As adopted in the ImageNet competition, the first five layers of network are convolutional layers and provide representation for local features in the images while the last layers are fully connected layers responsible for learning the key features for the given classification task. Our AlexNet extracts 4096 features at fc7 layer and creates a matrix X of the features extracted from all the training images. The dimension of feature matrix X is $m \times 4096$, where m is the number of training images in each batch. In our work, m equals 50. This extracted feature matrix is then fed into the Softmax classifier, which predicts the probabilities of the images in the input batch to the output classes. In Kaggle challenge, there are 10 classes of distracted driving. The output probability values from the Softmax classifier will be compared to the ground truth labels to calculate the following classification loss.

$$\text{logloss} = \frac{1}{N} \sum_i^N \sum_j^M y_{ij} \log(p_{ij}) \quad (2)$$

where N is the total number of images, M is the total number of classes, y_{ij} is the actual class of image and p_{ij} is the predicted class of image.

4.2 Model B: CNN Enhanced with Triplet Loss

In this work, triplet loss has been used to fine tune the model A network pre-trained with classification loss to improve the overall accuracy of the model. There are three main components in each triplet, a positive, an anchor and a negative sample as shown in Fig. 2. The aim of applying triplet loss is to minimize the distance between the anchor and the positive during the learning process and simultaneously increases distance between the anchor and the negative during the learning process to improve the classification accuracy of deep networks. Equation 2 represents the mathematical formulation of triplet loss [33].

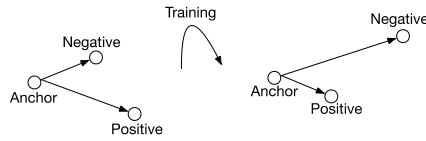


Fig. 2. Working Illustration of Triplet Loss.

$$\sum_i^N \max(0, f(x_i^a, x_i^p) - f(x_i^a, x_i^n) + \alpha) \quad (2)$$

where x_i^a represents the anchor feature vector, x_i^p the positive feature vector and x_i^n the negative feature vector; and α is the forced margin between the anchor-to-positive distance and the anchor-to-negative distance. $f(x_i^a, x_i^p)$ is the function which gives the distance between two feature vector. Triplet loss function from this equation tries to set apart the position samples from the negative samples by a minimum margin of α . The only condition at which the triplet loss will be greater than zero is when $f(x_i^a, x_i^p) + \alpha > f(x_i^a, x_i^n)$.

Random selection of triplets is a slow process and not much efficient for training the network. Triplets that actively contribute to the loss function and hence to improving the accuracy of the network are called hard triplets. Mining hard triplets is an essential step in efficient training of a CNN. Hard triplet selection can be done either offline or online. In offline approach triplets are generated offline for every few steps using the network checkpoint and argmin and argmax of the data are determined. While, in online approach triplets are generated by selecting the positive/negative exemplars from mini-batch [33] during live training. To fasten the convergence of our model B network with triplet loss, offline selection of hard triplets is implemented.

5 Experiments and Results

5.1 Dataset

The Kaggle competition provides a dataset of 80,000 2D images of drivers for data scientists (Kagglers) to classify. Each image in the dataset is captured in vehicle, some with occurrence of distracted activities such as eating, talking on phone, texting,

makeup, reaching behind, adjusting radio, or in conversation with other passengers [34]. Table 3 shows the 10 prediction classes defined by the competition.

Overall the dataset has been divided in the ratio of 90%:10% for training and testing the proposed algorithms, respectively. This means from a total of 22424 images in all the Kaggle classes, 20182 are used to train and 2242 to test the two network models.

Table 3. Prediction Classes for Kaggle Task and Number of Images in Each Class [34].

Class0	Class1	Class2	Class3	Class4	Class5	Class6	Class7	Class8	Class9
Safe Driving	Texting-Right	Talking on Phone-Right	Texting-Left	Talking on Phone-Left	Operating the Radio	Drinking	Reaching Behind	Hair and Makeup	Talking to Passenger
2489	2267	2317	2346	2326	2312	2325	2002	1911	2129

5.2 Experimental Results

This section presents the results of the experiments performed to test the classification accuracy of the two proposed deep learning models as explained in Section 4. Overall 5000 maximum iterations were allowed to train the. Fig. 3 presents the test accuracy and the test loss of both Models (A: AlexNet+Softmax and B: AlexNet+Triplet Loss) for 5000 iterations with an iteration interval of 500. It has been observed that over the number of iterations classification accuracy improved and both models converged.

Table 4. Summary of Experimental Results for Model A and Model B.

	Test Accuracy	Test Loss
Model A: AlexNet+Softmax	96.8	0.11
Model B: AlexNet+Triplet Loss	98.7	0.01

Table 4 summarize the results of both algorithms after 5000 iterations. Classification accuracy of 96.8% and 98.7% has been achieved for Model A and Model B, respectively. It is important to mention here that 100% accuracy was achieved for these algorithms when applied to training dataset.

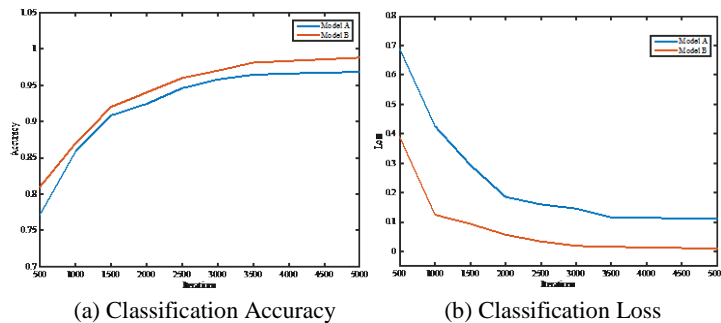


Fig. 3. Classification Accuracy and Classification Loss Plots of Model A and Model B.

5.3 Kaggle Scores

Kaggle provided 22424 images to participants for training their algorithms and asked to submit their classification probabilities for each image in form of excel sheet. Further they tested the submitted algorithms on 79,726 un-labeled images and calculated the loss score for each participant. Kaggle evaluated each submission using a multiclass logloss function as given in Equation 1.

Classification results from the Model A were submitted to Kaggle and were evaluated for the Kaggle score and rank. Table 5 shows the Kaggle submission results for Model A. The rank was determined at the time of submission out of approximately total 2000 submissions.

Table 5. Kaggle Submission Results for Model A.

	Kaggle Score	Rank
Model A: AlexNet+Softmax	1.54860	500+

6 Conclusion and Future Works

As discussed in Sections 2 and 3, majority of the existing approaches to the detection of distracted driving rely on information such as eye glance direction and head movement. To estimate such information, methods have been proposed for the extraction of relevant key features from the face/head region of the driver. However, the image data of the Kaggle challenge are provided for classification of different types of behaviors that involve whole body movements of the driver. To complete the Kaggle challenge, one has to first define the discriminative features from the entire body of the driver that the subsequent classification process can rely on. This is a challenging task as there is hardly any previous work on what are the discriminative features outside the face region. On the other hand, deep learning networks such as CNNs have provided a brand new approach to data mining and knowledge discovery, which is able to learn the discriminative features for a given classification task. The work presented in this paper confirms the above claim by conducting experiments on the Kaggle challenge using two different CNNs with promising results.

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