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Automated retinal health diagnosis using pyramid histogram of visual words and Fisher vector techniques

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ABSTRACT

Untreated age-related macular degeneration (AMD), diabetic retinopathy (DR), and glaucoma may lead to irreversible vision loss. Hence, it is essential to have regular eye screening to detect these eye diseases at an early stage and to offer treatment where appropriate. One of the simplest, non-invasive and cost-effective techniques to screen the eyes is by using fundus photo imaging. But, the manual evaluation of fundus images is tedious and challenging. Further, the diagnosis made by ophthalmologists may be subjective. Therefore, an objective and novel algorithm using the pyramid histogram of visual words (PHOW) and Fisher vectors is proposed for the classification of fundus images into their respective eye conditions (normal, AMD, DR, and glaucoma). The proposed algorithm extracts features which are represented as words. These features are built and encoded into a Fisher vector for classification using random forest classifier. This proposed algorithm is validated with both blindfold and ten-fold cross-validation techniques. An accuracy of 90.06% is achieved with the blindfold method, and highest accuracy of 96.79% is obtained with ten-fold cross-validation. The highest classification performance of our system shows the potential of deploying it in polyclinics to assist healthcare professionals in their initial diagnosis of the eye. Our developed system can reduce the workload of ophthalmologists significantly.

1. Introduction

The world is facing an ageing population with a total number of 901 million people over the age of 60 [1], [2]. The numbers are also expected to increase to 1.4 billion in the year 2030 [2]. Due to the massive increase of elderly in the society, there is a rising concern of the challenges in an ageing society. These challenges include the economic and social burden and also a decline in the efficiency of performing their daily activities. Furthermore, according to the United Nations, the life expectancy of an individual is continually increasing because of the improved quality of life [1]. So, to cope with the longevity, it is essential for the elderly to maintain a healthy eyesight so that they can continue to contribute to the society and at the same time, enjoy a good quality of life [3].

Eye diseases namely glaucoma, age-related macular degeneration (AMD) and diabetic retinopathy (DR) are the most prevalent conditions in the elderly [4] and they may cause vision loss. Glaucoma is one of the chief causes of vision loss in the elderly (age > 40 years old) [5]. It is a disease which impairs the optic nerve of the eye because of the raised intraocular pressure in the eye [6–8]. Hence, causing damage to the optic nerve [5]. AMD is another eye condition which is a common cause of blindness in the elderly [9]. It is caused by the degeneration of the macula in the retina. The macula is responsible for maintaining sharp vision, therefore when degeneration occurs at the macula, our central vision is affected [9]. In AMD, small yellowish deposits (drusens) grow under the retina. These deposits cause leakage of blood in the retina and thus damaging it [9]. Conventionally, there are two categories of AMD – the dry and wet AMD [10]. DR, on the other hand, affects diabetic patients when high blood sugars cause changes in the blood vessel (microangiopathy) leading to decreased oxygen supply to the retinal tissue [11]. Hence, in DR, the eye tries to grow new blood vessels, but

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Table 1
Number of fundus images used.

Classes	Number of fundus images
Normal	790
AMD	531
DR	346
Glaucoma	553
Total	**2220**

they are often thin, fragile, and susceptible to blood leakage [12]. The DR can be classified into *four* stages depending on the severity [13,14]. This grading is done based on the presence of exudates, haemorrhages, cotton wool spots, microaneurysms, and neovascularisation. The first three stages are categorized as mild, moderate, and severe non-proliferative DR respectively, and the advanced stage of DR is categorized as proliferative DR.

These eye conditions are irreversible but detecting these disorders at an earlier stage will impede the progression of the diseases with proper treatment [15]. Therefore, it is of utmost importance to detect the various eye diseases early to prevent blindness. Fundus imaging is a non-invasive, safe, and economical diagnostic tool commonly adopted by ophthalmologists for diagnosis purpose. But the visual interpretation of the fundus images is subjective and laborious. In addition, it is difficult to detect the subtle microaneurysms, or exudates present in the fundus images and thus, resulting in misdiagnoses at times.

Therefore, a computer-aided diagnosis (CAD) system is proposed to aid the ophthalmologists in their diagnoses. A CAD system can also serve as a validation tool to take the second opinion for the ophthalmologists. Also, a CAD eye screening system enables hospitals to conduct a large-scale eye screening session for the elderly. Many works have been done on the automated identification of AMD [16,17]. Also, a CAD screening tool has been proposed by Acharya et al. [18] to differentiate normal, dry AMD, and wet AMD fundus images. Automated differentiation of normal and DR [19], three-class classification (normal, non-proliferative DR, proliferative DR) [13] and five-class classification (normal, mild DR, moderate DR, severe DR, proliferative DR) [20] are proposed. Also, many automated diagnoses of normal and glaucomatous eye conditions [7,8] have been proposed to diagnose glaucoma accurately.

Further, a few works have been conducted in this direction to develop the CAD algorithm for an automated diagnosis of AMD, DR, and glaucoma (refer to Table 6). The first study to categorize the various eye diseases (DR, AMD and glaucoma) as an abnormal class initiated by Acharya et al. [31]. In their work, they have decomposed the fundus images into 2-dimensional intrinsic mode functions using the bi-dimensional empirical mode decomposition technique. Later, several entropy features were extracted from the 2-dimensional intrinsic mode function and these extracted features were ranked according to their level of distinction. An accuracy of 88.63% was achieved with the support vector machine (SVM) classifier.

Both AdaSyn and particle swarm optimization(PSO) techniques were applied in the previous works by Koh et al. [33,34]. Koh et al. [33] have applied a 2-dimensional continuous wavelet transform and extracted nonlinear features from the decomposed images. After which, AdaSyn operation was applied to equalize the number of features in the *two* classes. Then, an optimization technique was employed to select highly distinctive features for classification and obtained an accuracy of 92.48%.

In another previous study, Koh et al. [34] extracted feature descriptors from pyramid histogram of oriented gradients (PHOG) and speeded up robust features (SURF). These extracted features for the normal and abnormal classes were balanced with AdaSyn. Subsequently, they used the canonical correlation analysis to fuse the features. They implemented an optimization technique to select distinct features and obtained an accuracy of 96.21% with k-nearest neighbour classifier.

The above discussed works classify two classes (normal vs abnormal). In this paper, we are proposing four class classification. Further, to the best of the authors' knowledge, this is the first work to classify *four* classes (normal, AMD, DR, and glaucoma) of eye diseases. The novelty of this study is to reliably diagnose the different eye conditions using one algorithm automatically. This four class (AMD, DR, glaucoma, and normal) identification can facilitate ophthalmologists in their diagnoses.

2. Data used

The fundus images were acquired from the Ophthalmology Department of Kasturba Medical College in Manipal, India. In this work, we have used 2220 images with a resolution of 360 × 480, and they were captured with a Zeiss FF450 plus mydriatic camera using a field of view of 50°. Table 1 shows the number of fundus images used in each class. The fundus images were taken and labelled by experienced ophthalmologists from KMC, Manipal. Also, Fig. 1 shows a typical illustration of a normal, AMD, DR, and glaucoma fundus image.

3. Methodology

Fig. 2 shows the flowchart of the proposed work. Firstly, pyramid histogram of visual words (PHOW) are extracted from the fundus images,

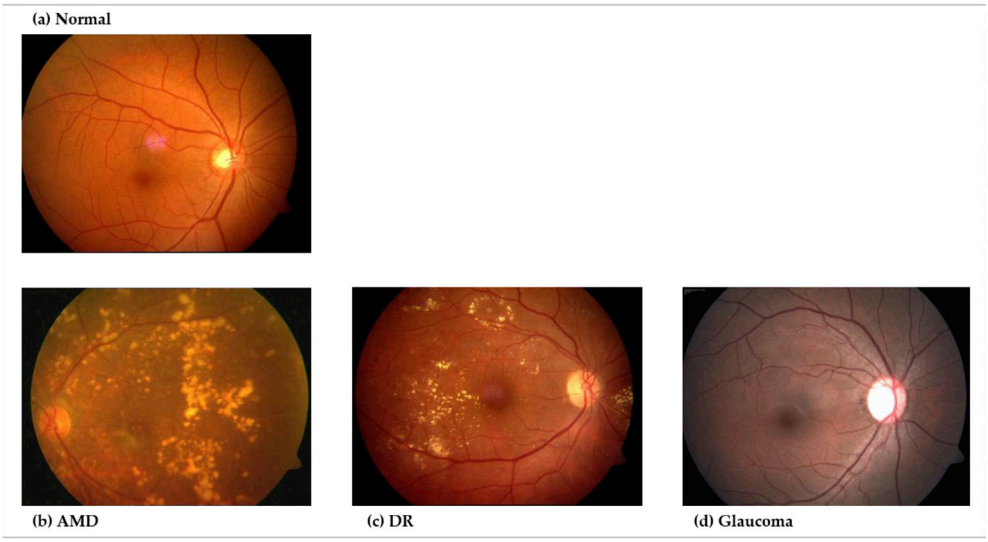

Fig. 1. Sample fundus images: (a) normal, (b) AMD, (c) DR, and (d) glaucomatous.