

# Pupill Detection Based On Computer Vision A Brief Review

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**Keywords:** Pupil detection eye tracking strabismus diagnosis iris recognition existing problems development trend

**Abstract:** Pupil detection is an important research direction in the field of computer vision and it plays a key role in many applications such as eye tracking, strabismus diagnosis and iris recognition. So far, many researchers have proposed different sorts of pupil detection methods, which have been divided into four categories in this paper, including shape features-based pupil detection, projection-based pupil detection, traditional machine learning-based pupil detection and deep learning-based pupil detection. Some specific methods have been listed in each part and elaborated. This study also analyzes the advantages and disadvantages of these methods and explains the existing problems of pupil detection, then points out the development trend of pupil detection and finally makes a summary.

## 1. Introduction:

Pupil detection means extracting the coordinates of the center of the pupil and marking the boundaries of the pupil [1]. With the development of computer vision and image processing technology, pupil detection has become a hot topic in recent years and is widely applied in various aspects [2], such as human-computer interaction, intelligent cockpit, psychological analysis, strabismus diagnosis, smart family, face recognition and so on [3-4]. Understanding processes underlying visual perception has been more and more important [5]. This paper reviews and summarizes the domestic and foreign research and divides pupil detection methods into four categories, and introduces one by one. The overall idea of the whole article is as follows:

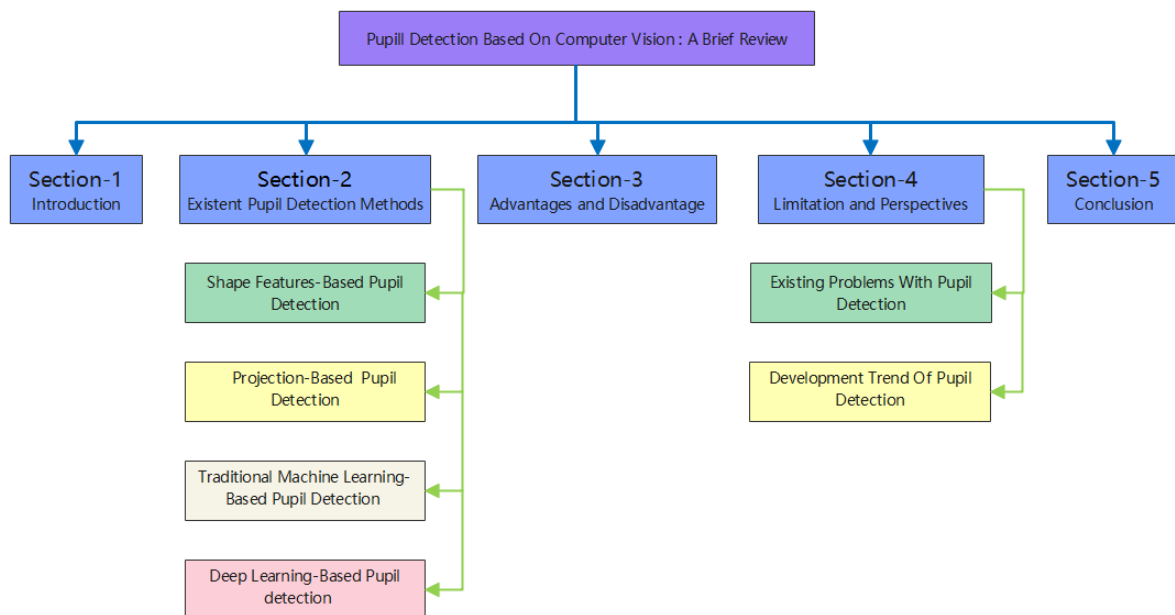


Fig.1. Abstract level diagram of this study

## 2. Existent Pupil Detection Methods

As pupil detection technology is becoming more and more mature, this paper extracts some articles from well-known international journals for researchers to study this field. This section is divided into the following sections.

### 2.1. Shape Features-Based Pupil Detection

Since the iris is round, a variety of shape-based pupil tests can be used to detect and locate the pupil based on this shape feature [6].

Hough transform is a parameter estimation technique using voting method. Its principle is to use the line-point duality of image space and Hough parameter space to detect edges first and then transfer the detection problem in image space to the parameter space [7]. Hazim G. Daway et al. [8] proposed a new method for high-precision pupil detection using Hough transform. This method first reads (R, G, B) and then determines the working area to detect the pupil boundary by many steps. It uses a variety of methods to divide the region, then uses Hough transform to detect the pupil region and optimizes the pupil region.

Snake model is a deformable parameter curve and the corresponding energy function. It aims to minimize the energy objective function and control the deformation of parameter curve. The closed curve with the minimum energy is the target contour [9]. In the development process of Snake model, many scholars put forward various improved Snake models, among which Gradient Vector Flow (GVF) model [10] expands the scope of external force of classical Snake and strengthens its attraction to the edge of concave contour of target. The accuracy of traditional Snake model is improved.

### 2.2. Projection-Based Pupil Detection

Projection is an effective method to analyze and extract image features. Firstly, the image is preprocessed and then the two-dimensional gray image is mapped to a one-dimensional sequence on the projection line along the direction perpendicular to the projection line to reduce the dimension, thus reducing the computational cost and facilitating the rapid detection of human eyes [11]. According to people's prior knowledge of eye features, the gray values of pupil and iris in the human eye region are low, while the gray values of sclera and skin are high. Therefore, compared with other areas of the face, the gray values of the human eye region vary greatly and the gray values are low [12]. Therefore, it is a feasible method to detect the human eye using projection method. The projection methods which are used to detect the human eye commonly include integral projection function, variance projection function, mixed projection function, region projection function, gradient projection function and so on [13]. Using projection function to detect human eye can not only roughly obtain the area of human eye, but also accurately locate the center of human eye. Wolfgang Fuhl et al. [14] proposed a new pupil detection, which was based on edge filtering and directed histogram function calculated by Angle integral projection. Compared with the current technology, this algorithm shows excellent robustness[15].

### 2.3. Traditional Machine Learning- Based Pupil Detection

Machine learning is a hot topic in the field of image processing. It is a general term for a class of algorithms, which trains a large amount of data to get a model and predicts or classifies the model. Boosting method and Random forest are two methods for traditional machine learning- based pupil detection[16].

Boosting method uses linear combination of weak classifiers to form strong classifiers by changing weight distribution of training data. The core of the algorithm is to assign a higher value to the failed training samples so that the algorithm can concentrate on learning the difficult training samples[17]. Wencong Zhang et al. [18] proposed a special gray AdaBoost detection, which is an adaptive pupil detection method for segmentation of eye regions by training. After getting the region of eyes, a fast radial symmetry operator is used to precisely locate the center of the pupil. XGBoosting is also a boosting method. At present, there are few literatures on the combination of pupil detection and it can become a field worth studying[19].

Random forest is an algorithm that integrates multiple decision trees through the idea of ensemble learning to obtain more accurate and stable prediction. Jullyana Fialho Pinheiro et al.[20] proposed a novel version automatic detection method based on face images. In this method, human eyes are located based on skin segmentation, directional gradient histogram and random forest.

### 2.4. Deep Learning-Based Pupil detection

Deep learning is a branch of machine learning. Compared with traditional machine learning, deep learning learns more useful features by constructing machine learning models with many hidden layers and massive training data, so as to ultimately improve the accuracy of classification or prediction. It is widely used in image processing and other fields.

Warapon Chinsatit et al. [21] proposed a pupil detection method based on convolutional neural network (CNN), which uses two CNN models. The first CNN model is used to classify the eye state and the second CNN model is used to locate the pupil center. The results show that the proposed CNN model has the potential to classify human eye state. In addition, the accuracy of this method for pupil detection is better than that of simple CNN model [22].

So far, the four kinds of methods have been introduced. The following picture is an example of the four kinds of methods, which are extracted from the paper

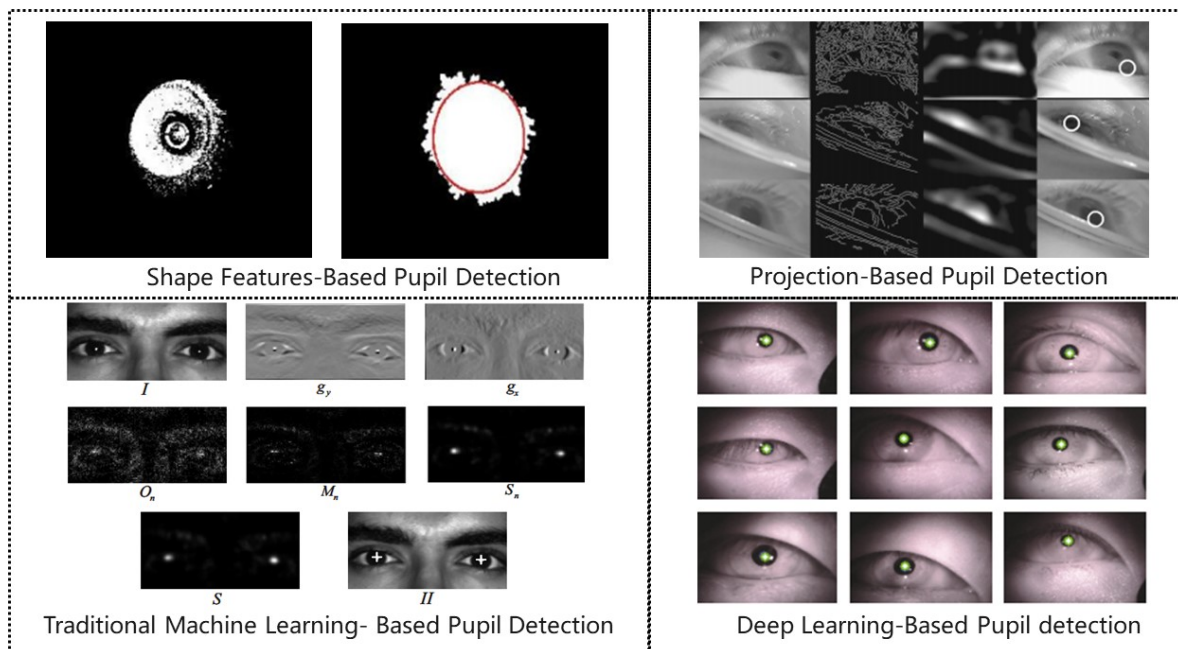


Fig.2. Images of various pupillary detection methods

### 3. Advantages and Disadvantage

The methods of pupil detection described above all have their own advantages and disadvantages.

Shape features-based pupil detection method is simple and convenient with high accuracy. However, it also has some shortcomings. For example, in Hough transform, iris cannot be covered too much by upper and lower orbits and its performance is greatly related to the threshold used in the extraction process of binary edge images since the method locates eyes from binary edge images[23]. Snake model can integrate the low-level visual attributes (edge, texture, gray level and color) of the image with people's knowledge and experience of the target to be segmented, such as the description of target shape, brightness, color experience statistics, doctor's experience, etc. In an organic way to obtain a complete expression of the region to be segmented. However, the Snake model is sensitive to the initial position and is prone to fall into local extreme values[9]. It cannot converge to the deeply depressed part of the contour and does not have the function of automatic topology transformation[24].

The projection-based pupil detection method has the advantages of simple principle, convenient operation and fast calculation, but it is prone to the interference of hair, shadow, eyelashes, eyebrows and other noises as well as the influence of light changes, and the accuracy of eye detection is low.

Traditional machine learning- based pupil detection method and pupil detection method based on the deep learning needs to collect a large number of samples used for training classifier, sometimes also need extremely time-consuming data acquisition and manual annotation[21], but with its high accuracy and strong robustness, the characteristics of all kinds of target detection in contains pupil detection applications has obtained the success. The traditional machine learning- based pupil detection is suitable for low-dimensional data, and when the data dimension is high, the computational complexity of the algorithm will be increased.

The table below summarizes the pros and cons of these pupil tests.

Table1. advantages and disadvantages of various methods

Classification of methods	advantages	disadvantages
Shape features-based pupil detection	Easy and convenient High accuracy	High contrast images are required
Projection-based pupil detection	Simple principle small amount of calculation	Low accuracy Susceptible to interference
Traditional machine learning-based pupil detection	High accuracy Strong robustness	Not suitable for higher-dimensional data and requires manual annotation of the data set
Deep learning-based pupil detection	High accuracy Strong robustness	Data dependence, training time consuming

#### 4. Limitation and Perspectives

At present, based on the research on pupil detection at home and abroad, many techniques have been very mature, but there are still some problems. One of them is the problem of occlusion[25]. For example, when wearing glasses, the edge of glasses will cause great interference to the extraction of the edge of the eye and the pupil will become unclear. At the same time, eyebrows, eyelashes, nostrils and other colors are similar to the pupil, so how to effectively distinguish the eye from these areas has become an important problem restricting the development of eye detection. Time-varying factors (such as age, makeup, facial state change, etc.) are also important factors affecting pupil recognition[26]. In practical application, there is a certain time difference between the pupil to be identified and the human eye in the database. However, it is also an important aspect of pupil detection research to eliminate the influence of age change factor to the greatest extent if it can be applied to pupil detection. In addition, makeup and fatigue are also common. Makeup is mainly manifested in the change of skin color, eyebrow shape and eye circumference, and decoration is mainly the addition of external objects such as glasses. In most identification methods, some idea of how to eliminate these factors is also involved, but it is not the focus of research. In fatigue state, the size of pupil closure is different from that of normal eyes under normal circumstances. The different sizes of the eyes in the images also make detection difficult.

Pupil detection is still a challenging core and difficult problem at present. Future research can be carried out from the following aspects.

Since each method has advantages and disadvantages, mixing more than two methods enables the disadvantages of one method to be compensated for by the advantages of the other, resulting in a more

accurate and robust pupil detection system. Static image-based pupil detection is no longer the hotspot of applications, but dynamic image-based pupil detection will become the hotspot in the future.

In view of the current shortcomings of convolutional neural network-guided evolutionary parameter eye modeling with high computational complexity and low efficiency, an appropriate optimization algorithm or strategy is designed to improve the running efficiency of the algorithm.

In the near infrared environment, the accuracy of pupil center localization and eye fine modeling algorithm is not enough in visible light and other unconstrained conditions, which will be solved gradually.

## 5. Conclusion

This paper provides a comprehensive review of pupil detection, which has been widely used in various fields including human-computer interaction, iris detection, disease diagnosis and so on. This paper first introduces the background of pupil detection, and describes four kinds of pupil detection methods, and then introduces their advantages and disadvantages and points out the existing problems of pupil detection, and finally expounds the development trend of pupil detection. All in all, this study will be a good source of information for relevant researchers.

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