Machine learning for cataract classification/grading on ophthalmic imaging modalities: Survey

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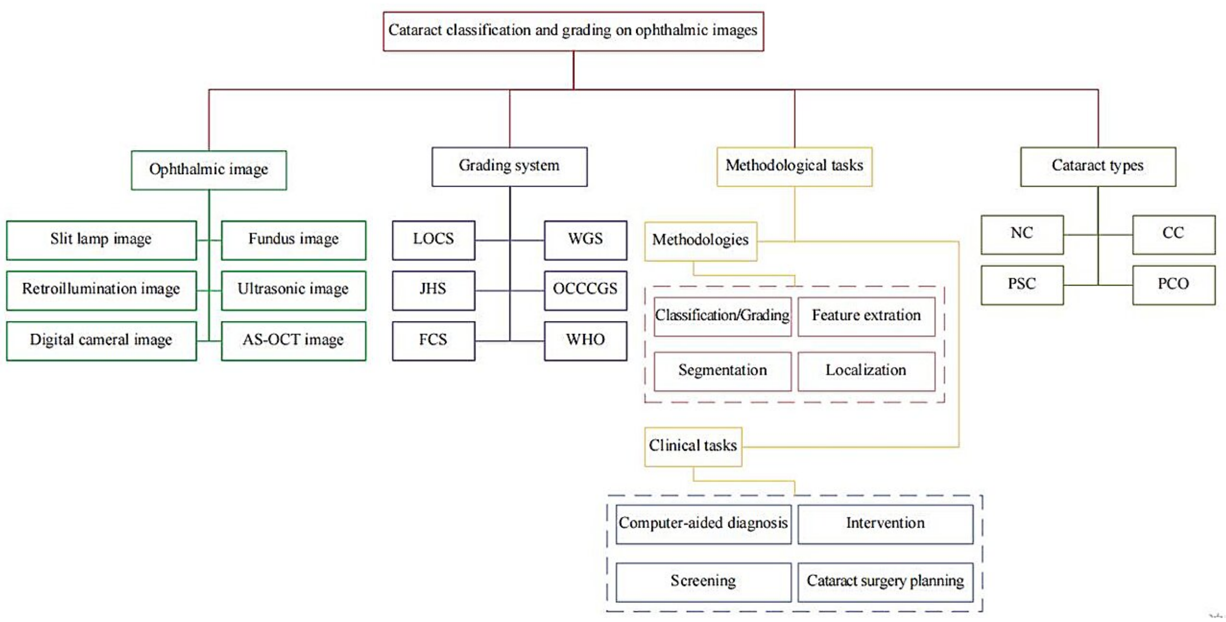

Overall organization framework of this survey. Credit: Beijing Zhongke Journal Publising Co.

According to the World Health Organization (WHO), it is estimated that approximately 2.2 billion people suffer from visual impairment. Cataracts account for about 33% of visual impairment and are the number one cause of blindness (more than 50%) worldwide. Cataract patients can improve life quality and vision through early intervention and cataract surgery, which are efficient methods to reduce the blindness ratio and cataract-blindness burden for society simultaneously.

Clinically, cataracts are the transparency loss of crystalline lens area, which occurs when the protein inside the lens clumps together. They are associated with many factors, such as developmental abnormalities, trauma, metabolic disorders, genetics, drug-induced changes, age, etc.

Genetics and aging are two of the most important factors for cataracts. Cataracts can be categorized as age-related cataract, pediatrics cataract (PC), and secondary cataract according to their causes.

Depending on the location of the crystalline lens opacity, they can be grouped into nuclear cataract (NC), cortical cataract (CC), and posterior subcapsular cataract (PSC). NC denotes the gradual clouding and the progressive hardening in the nuclear region. CC is the form of white wedged-shaped and radially oriented opacities and develops from the outside edge of the lens toward the center in a spoke-like fashion. PSC is granular opacities, and its symptom includes small breadcrumbs or sand particles, which are sprinkled beneath the lens capsule.

Over the past years, ophthalmologists have used several ophthalmic images to diagnose cataracts based on their experience and clinical training. This manual diagnosis mode is error-prone, time-consuming, subjective, and costly, which is a great challenge in developing countries or rural communities, where experienced clinicians are scarce.

To prevent cataracts early and improve the precision and efficiency of cataract diagnosis, researchers have made great efforts in developing computer-aided diagnosis (CAD) techniques for automatic cataract classification/grading on different ophthalmic images, including conventional machine learning methods and deep learning methods.

The conventional machine learning method is a combination of feature extraction and classification/grading. In the feature extraction stage, a variety of image processing methods have been proposed to obtain visual features of cataracts according to different ophthalmic images, such as density-based statistics method, density histogram method, bag-of-features (BOF) method, Gabor wavelet transform, gray level co-occurrence matrix (GLCM), Haar wavelet transform, etc.

In the classification/grading stage, strong classification methods are applied to recognize different cataract severity levels, e.g., support vector machine (SVM). Over the past 10 years, deep learning has achieved great success in various fields, including medical image analysis, which can be viewed as a representation learning approach. It can learn low-level, middle-level, and high-level feature representations from raw data in an end-to-end manner (e.g., ophthalmic images).

Various deep neural networks have been utilized to tackle cataract classification/grading tasks like convolutional neural networks (CNNs), attention-based networks, Faster-RCNN, and multilayer perceptron (MLP) neural networks.

Previous surveys had summarized cataract types, cataract classification/grading systems, and ophthalmic imaging modalities, respectively. However, none had summarized ML techniques based on ophthalmic imaging modalities for automatic cataract classification/grading systematically.

This survey is supposed to be the first survey that systematically summarizes recent advances in ML techniques for automatic cataract classification/grading. This survey mainly focuses on surveying ML techniques in cataract classification/grading, comprised of conventional ML methods and deep learning methods. The work is published in the journal *Machine Intelligence Research*.

Researchers surveyed these published papers through Web of Science (WoS), Scopus, and Google Scholar databases. To understand this survey easily, they also review ophthalmic imaging modalities, cataract grading systems, and commonly-used evaluation measures in brief. Then researchers introduce ML techniques step by step. They hope that this survey can provide a valuable summary of current research and present potential research directions for ML-based cataract classification/grading in the future.

Section 2 introduces six different eye images used for cataract classification/grading for the first time: slit lamp image, retroillumination image, ultrasonic image, fundus image, digital camera image, and anterior segment optical coherence tomography (AS-OCT) image. It also discusses their advantages and disadvantages.

To classify or grade the severity levels of cataracts (lens opacities) accurately and quantitatively, it is crucial and necessary to build standard/gold cataract classification/grading systems for clinical practice and scientific research purposes.

Section 3 briefly introduces six existing cataract classification/grading systems: Lens opacity classification system, Wisconsin grading system, Oxford clinical cataract classification and grading system, Johns Hopkins system, WHO cataract grading system, Fundus image-based cataract classification system.

Section 4 introduces ophthalmic image datasets used for cataract classification/grading, which can be grouped into private and public datasets. Private datasets include ACHIKO-NC dataset, ACHIKO-Retro dataset, CC-Cruiser dataset and Multicenter dataset. Public datasets include EyePACS dataset and HRF dataset.

Section 5 mainly investigates machine learning techniques for cataract classification/grading over the years, which comprises conventional machine learning methods and deep learning methods.

Scholars have developed state-of-the-art conventional ML methods over the years to automatically classify/grade cataract severity levels, aiming to assist clinicians in diagnosing cataracts efficiently and accurately. These methods consist of feature extraction and classification/grading.

The feature extraction methods are introduced based on ophthalmic image modalities, which include slit lamp image, retroillumination image, ultrasound images and digital camera images & AS-OCT images, fundus image. As for classification/grading, it consists of the introduction of support vector machine, linear regression, K-nearest neighbors, ensemble learning method, ranking and some other machine learning methods. Many deep learning methods are introduced in this paper, including multilayer perceptron neural networks, convolutional neural networks, recurrent neural networks, attention mechanisms and hybrid neural networks.

Section 6 introduces evaluation measures to assess the performance of cataract classification/grading. In this survey, classification denotes the cataract labels used for learning are discrete, e.g., 1, 2, 3, 4, while grading denotes cataract labels are continuous, such as 0.1, 0.5, 1.0, 1.6, and 3.3.

Although researchers have made significant development in automatic cataract classification/grading over the years, this field still has challenges.

Section 7 presents these challenges and gives possible solutions. This section consists of eight parts. The first part is the problem of lacking public cataract datasets. To this problem, it is necessary and significant to build public and standard ophthalmology image datasets based on standardized medical data collection and storage protocols.

The second part is about developing standard cataract classification/grading protocols based on new ophthalmic imaging modalities. Two possible solutions are proposed: Developing a cataract grading protocol based on clinical verification and building the mapping relationship between two ophthalmic imaging modalities.

The third part is the solutions to annotate cataract images accurately, such as semi-supervised learning, unsupervised learning and content-based image retrieval.

The fourth part is about how to classify/grade cataracts accurately for precise cataract diagnosis.

This survey provides the following research directions: clinical prior knowledge injection, multi-task learning for classification and segmentation, transfer learning, multimodality learning and image denoising.

The fifth and sixth sections are about improving the interpretability of deep learning methods and mobile cataract screening. The seventh section provides solutions to evaluate the generalization ability of machine learning methods for other eye disease classification tasks.

More information: Xiao-Qing Zhang et al, Machine Learning for Cataract Classification/Grading on Ophthalmic Imaging Modalities: A Survey, *Machine Intelligence Research* (2022). DOI: 10.1007/s11633-022-1329-0

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