Deep neural networks in medical image classification

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Abstract

Medical imaging is one of the most important applications of artificial intelligence in the field of medicine. Despite the currently observed spectacular successes of artificial neural networks in natural language processing and image analysis, there are still difficult challenges that need to be addressed for the implementation of artificial intelligence in routine medical diagnostics.

The aim of the study was to address the problem of classifying breast cancer based on histopathological and cytological images. Scientific literature provides a rich base of solutions for this problem, indicating deep neural networks as the current best approach. However, if we take a closer look at the proposed models, we will notice that they are often trained and tested on a dataset of images from a single medical center. The conducted tests have shown that models trained in this manner, using deep neural networks, are unable to acquire the necessary generalization capabilities to be applied to classify images from different medical centers. Despite the procedures for image acquisition being somewhat standardized, human and technical factors result in significant differences among images in practice. These differences involve several crucial characteristics. Unfortunately, it is also not possible to construct a sufficiently rich and diverse dataset of histopathological or cytological images of breast tumors that would enable the models to generalize knowledge to a level allowing them to be applied to images from different medical centers. Publicly available image datasets for breast tumors are small, too homogeneous (usually representing only a few dozen patients), and insufficient in quantity.

The research conducted in the dissertation focused on developing a model capable of classifying breast tumors based on histopathological and cytological images from medical centers that were not included in the training dataset. To accomplish this project, medical images from the BreakHis dataset from Brazil and images from the University Hospital in Zielona Góra were used. The experiments demonstrated that, to a certain level of image normalization, knowledge transfer occurs, enabling the construction of a generalized and effective classification system.

The developed approach consists of four main solutions. Firstly, the images were standardized using a hybrid segmentation method designed specifically for this purpose. Two U-Net neural networks were proposed for this step, with one responsible for semantic segmentation of the images and the other for the localization of individual cell nuclei centroids. The watershed method merged information

obtained from neural networks to perform the segmentation of individual instances of cell nuclei.

Another solution proposed in the dissertation was the fusion of manual features with deep features to increase the robustness of image description against intra-class heterogeneity. This aimed to enable the constructed model to acquire generalization capabilities beyond images from a single medical center. For this purpose, an automated system was developed for extracting manual features based on cell nuclei segmentation. A hybrid segmentation method, developed for image standardization, was used for this task. The deep feature extraction system was based on a heterogeneous ensemble of deep neural networks. The members of this ensemble were individually fine-tuned using the same set of images. Ultimately, rich sets of deep features were extracted from intermediate layers of the deep neural networks, which were combined into a single set along with the manual features.

As a result, a very large set of features for describing images was created. This set needed to be reduced to relevant features for breast cancer classification. Therefore, in the next research step, multiple well-known feature selection methods were tested. Unfortunately, due to the large size of the feature vector and a relatively large number of samples, standard dimensionality reduction methods proved to be extremely time and computationally expensive. As a result, a new solution for feature selection was developed. The developed method is based on stochastic search. Initially, the optimal number of features distribution is sought based on a representative subset of images. This allows for a significant reduction of the search space during the actual feature selection phase, resulting in faster and improved feature selection results.

The final component of the developed system is the top-level classifier, which receives the set of features determined by the developed feature selection method as input. This classifier is implemented using a L2 regularized regression model. This model was chosen after conducting numerous experiments to compare the effectiveness of different machine learning techniques.

Considering that one of the key issues addressed in the dissertation was the verification of the effectiveness of the proposed system built on medical data from a different research center than the test data, comprehensive studies were conducted. As a result of the experiments, it was demonstrated that the proposed method achieves an average image classification accuracy of 79%, which translates to an average precision score for individual patients exceeding 90%.

The main achievements of the doctoral dissertation include:

- The development of a hybrid segmentation method for cytological and histopathological image segmentation, aimed at image standardization and manual feature extraction of cell nuclei.
- The development of a feature extraction system for image description using the fusion of manual features with deep features obtained from a heterogeneous ensemble of deep neural networks.

- The development of a stochastic feature selection method from a feature set that includes both deep features and manually extracted features.
- Conducting comprehensive research to verify the effectiveness of the developed methods on real images, sourced from the BreakHis dataset and the University Hospital in Zielona Góra.

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