Automatic Pulmonary Nodule Detection and Management System

ZHANLIN JI[1,2], SHENGNAN HAO[3], JIANHUA PANG[3], IVAN GANCHEV[2,4,5,*],
[1]Key Laboratory of Intelligent Forestry Monitoring and Information Technology,
Zhejiang A&F University,
Hangzhou,
CHINA

[2]Telecommunications Research Center (TRC),
University of Limerick,
Limerick,
IRELAND

[3]Department of Artificial Intelligence,
North China University of Science and Technology,
Tangshan,
CHINA

[4]Faculty of Mathematics and Informatics,
University of Plovdiv "Paisii Hilendarski",
Plovdiv,
BULGARIA

[5]Institute of Mathematics and Informatics,
Bulgarian Academy of Sciences (IMI–BAS),
Sofia,
BULGARIA

Corresponding Author

Abstract: - This paper presents a self-developed automatic pulmonary nodule detection and management system, built and operating on top of the IoT platform EMULSION as an effective tool for physicians and patients to conduct preliminary diagnoses of lung diseases and detect potential pulmonary-nodule-related health issues. The elaborated system architecture is described, including its overall structure, main functional modules, and their display pages. Providing a more convenient way for physicians to systematically handle and cure their patients, the designed and implemented system helps alleviate the workload of physicians while also giving patients more opportunities for follow-up treatment.

Key-Words: - biomedical signal processing, object detection, deep learning, pulmonary nodule, automatic system, IoT platform.

Received: May 8, 2024. Revised: December 9, 2024. Accepted: January 7, 2025. Published: February 26, 2025.

1 Introduction

In China, lung cancer ranks top among malignant tumors in terms of both incidence rate and mortality rate. It represents a major chronic disease that threatens the life and health of Chinese citizens. According to the China guideline for the screening and early detection of lung cancer, published by the National Cancer Center [1], the 5-year survival rate of lung cancer patients could be improved if the number of diagnostic stages increases. Typically, patients in stage I have a survival rate of 55.5%, while those in stage IV have a survival rate of only 5.3%. Therefore, improving both the early diagnosis rate and the survival rate of patients are considered important goals in the prevention and treatment of lung cancer.

Pulmonary nodules refer to focal, round, dense, ground glass, or hybrid structures of various sizes, contours, and shapes contained in lungs. Given the possibility that some pulmonary nodules may deteriorate into lung cancer in a later stage, using efficient methods to detect pulmonary nodules quickly and accurately can provide patients with timely treatment solutions and enable them to have healthier bodies with more chances of survival.

Traditional detection methods rely on physicians to observe radiographic images to determine whether pulmonary shadows are pulmonary nodules indeed and whether further medical intervention is required. With the continuous increase in the number of patients for diagnosing and the rapid increase in the number of generated lung medical images, relying solely on the individual capabilities of physicians to handle this issue is becoming increasingly inadequate. Therefore, it is imperative to use automatic systems, utilizing neural-network-based models, for assisting doctors in pulmonary nodule detection.

In [2], a computer-aided detection (CAD) system is proposed for pulmonary nodule detection in thoracic computed tomography (CT) images based on the location, shape, size, and gradient features of the nodules. In [3], a model for automatic detection of subsolid pulmonary nodules in thoracic CT images is developed based on 128 expression features extracted from context information by using a Sequential Floating Forward Selection (SFFS) and linear discriminant classification selection. In [4], an improved residual network structure, combining deep separable convolution and pre-activation, is proposed for the detection of pulmonary nodules based on Faster R-CNN with U-Net coder–decoder structure.

Building on previous research [5], a successful design and implementation of an automatic pulmonary nodule detection and management system operating on top of the IoT platform EMULSION [6] is showcased here for easy use by both physicians and patients. This paper provides a detailed introduction to the design philosophy, functions, and implementation of the system.

2 System Architecture

Pulmonary nodules, as a common focal lesion of lung diseases, are crucial for patient treatment if detected early, followed by an accurate diagnosis. Currently, existing detection methods primarily rely on physicians' visual judgment. However, in order to enhance the accuracy and efficiency of detection, there is an urgent need for automated pulmonary nodule detection and management systems. The main objective of such systems is to significantly improve the efficiency of pulmonary nodule detection by applying automation technologies, thereby assisting physicians in diagnosing pulmonary nodules in patients' lungs more accurately and quickly while also providing patients with a convenient self-check pathway. Such a self-elaborate system is described in this section, dedicated to alleviating the workload of physicians by increasing the detection speed and allowing medical teams to focus more on formulating the best treatment plans. In addition, the system aims to provide patients with faster and more reliable diagnostic services and give physicians more time for in-depth analysis and treatment planning, [7].

The front-end of the designed system consists of (i) PC front-end pages created by means of the Vue 3 UI framework [8] and (ii) WeChat mini-program interfaces employing the Taro 3.x framework [9]. The back end utilizes the traditional combination of Spring Boot [10] and MyBatis-Plus [11] based on JAVA, with the security and permission framework being Apache Shiro [12]. For storing the system- and user data, the MySQL open-source database [13] is utilized. In terms of model deployment, the Flask framework [14] is adopted, and the storage of images and key documents is managed using the FastDFS high-performance distributed file system [15]. To enhance the stability and performance of the system, Nginx [16] is used for load balancing, which also allows space for future system upgrades and expansion. The architecture of the developed system is depicted in Figure 1 (Appendix).

Different registered users access the system through different interfaces. System administrators and physicians interact with the back end via the PC front-end pages, while patients can engage with the back end through the mini-program entry point. Comprehensive services are provided on the PC end, while basic services are offered on the mini-program end to meet the differentiated needs of different users and improve efficiency. When conducting pulmonary nodule detection, the front end sends images to the Spring Boot server, which stores the original images in FastDFS and records relevant data in the MySQL server to associate images with patient and physician information, [17]. The server decides how the input images need to be processed based on their category. For CT images, the server calls the Flask server to send back the images' addresses and uses the Python language to process the CT images stored at that address. After processing, the results (i.e., the processed images) are returned to the Spring Boot server, which stores them in FastDFS and records corresponding information in the MySQL database. Subsequently, the Spring Boot server asks the Flask server to invoke the relevant pulmonary nodule detection model. After the detection is completed, the Spring Boot server saves the relevant result files and image files.

In guest mode, upon receiving new images provided by unregistered users, the server, by default only performs CT image processing and pulmonary nodule detection without data storage in order to save disk space. However, the system administrator can configure the system to store data provided/generated in guest mode to expand the dataset used for model training.

Finally, the Spring Boot server displays the detection results through the front-end interface and provides services (for downloading the result files) to users wishing to do so. This process aims to ensure efficient and accurate pulmonary nodule detection while considering data storage needs under different user modes. The overall system operation is illustrated in Figure 2 (Appendix).

3 System Functional Modules

The designed automatic pulmonary nodule detection and management system consists of a login and registration module, an image preprocessing module, a pulmonary nodule detection module, and an information management module. The following subsections present each of these modules separately.

3.1 Login and Registration Module

Users on the PC end need to log in, and if they do not have an account, they can click on the registration link in order to be registered as new users to the system. For registration with a physician identity, the system administrator must confirm this information before the registration is completed. At the WeChat mini-program end, users can choose to log in or quickly enter the system's detection interface directly as guests. If they do not have an account, they can choose to register as patients with a unique identifier, and their registration does not require confirmation by the system administrator.

3.2 Image Preprocessing Module

This module is activated if a user uploads non-CT images (i.e., in another format), for performing the relevant preprocessing operations and storing the results in the system for further processing.

3.3 Pulmonary Nodule Detection Module

This module focuses on conducting related detections of pulmonary nodules and generating detailed detection-result information. This information includes but is not limited to the presence or absence of pulmonary nodules in the images, the exact locations of pulmonary nodules, the detection confidence level, and resultant images with annotation information that will assist physicians in obtaining auxiliary support during relevant diagnostic procedures, etc. The pulmonary nodule detection sequence diagram is presented in Figure 3 (Appendix).

3.4 Information Management Module

After successfully logging in, the system administrator is directed to the administrator homepage, which includes pages for managing physician role information, patient information, and system settings. The system administrator has the authority to perform *create*, *read*, *update*, and *delete* (CRUD) operations on both physician and patient roles, including but not limited to reviewing the credentials of newly registered physicians, binding/unbinding between physicians and patient information, and enabling or disabling global image information saving features.

After a successful login, the physician is redirected to the patient information management page under their name. Patient information can be directly imported from the registration office or supplemented by physicians/patients. In this process, physicians can also query and modify some patient information but do not have the authority to delete it.

After successfully logging in, the patient is automatically redirected to the patient information page, displaying relevant patient information and showcasing the profile information of the corresponding physician at the bottom of the page. Patients have the right to modify some non-core information to ensure that the database is updated in a timely manner.

4 Modules' Display Pages

4.1 Login and Registration Module

This module provides user-login-related functionality, including login/registration for both PC and mini-program interfaces. On the login/registration page, users need to enter their account name and password to complete the back-end verification before successfully logging into the system. If the verification fails, the system displays an error message, allowing the user to change his/her password and make another attempt to log in to the system. The mini-program login interface supports guest mode, which allows direct use of a low-precision version of the detection model. Registration on the mini-program side is limited to patients, while PC-side registration allows the choice of a physician's identity. The physician accounts require administrator approval before these can be used. The login and registration interfaces are shown in Appendix in Figure 4 and Figure 5.

4.2 Image Preprocessing Module

If the images uploaded by users are in medical-specific image formats, such as DICOM, MHD, etc., the system performs relevant preprocessing operations and stores the results in the file management system while also displaying these respectively on the page. Figure 6 (Appendix) shows the image upload operation interface, whereas Figure 7 (Appendix) illustrates an uploaded original image and the corresponding image after preprocessing.

4.3 Pulmonary Nodule Detection Module

Images outputted by the image preprocessing module are inputted into the pulmonary nodule detection module, which selects the corresponding neural-network-based model depending on the user type. By default, guests and patients use the EFPN model [18], while physicians use the MFFN model [19] for pulmonary nodule detection. Administrators have the authority to modify these default configurations. The images output by the pulmonary nodule detection module are stored in the file management system, and the relevant information is returned to the Spring Boot server and recorded in the patient information table, providing data support for downloading detailed result information. The display page of this module is shown in Figure 8 (Appendix).

4.4 Information Management Module

This module is designed specifically for system administrators and physicians, providing comprehensive information management capabilities. The administrator page presents detailed information, including the work and vacation status of physicians and the number of patients handled by each of them. Administrators can perform operations such as adding, deleting, modifying, and querying physician information and, in addition, have the authority to review new physician registration accounts. Moreover, administrators can reassign the responsibilities of physicians w.r.t. patients, as well as reset system default parameters and perform other functions. The administrator's operation interface is depicted in Figure 9 (Appendix).

5 Conclusion

This paper has presented a self-developed automatic pulmonary nodule detection and management system built on top of the IoT platform EMULSION. The system architecture has been described, including its overall structure, functional modules, database schema, and model deployment. In addition, the display page styles and functionalities of the main system modules have been presented, providing readers with an intuitive system operational experience.

The designed and implemented system for automatic pulmonary nodule detection offers effective tools for physicians and patients to conduct preliminary diagnoses of lung diseases. This not only helps to alleviate the workload of physicians but also aids in the early detection of potential pulmonary-nodule related health issues. This way, the system provides a more convenient way for physicians to systematically manage and cure their patients while also supplying the patients with more options for follow-up treatment. Overall, the design goal of the presented system is to provide more convenient and efficient healthcare services for both medical professionals and patients.

References:

[1] J. He, N. Li, W. Q. Chen, N. Wu, H. B. Shen, Y. Jiang, J. Li, F. Wang, and J. H. Tian, "China guideline for the screening and early detection of lung cancer" (in Chinese) *Zhonghua Zhong Liu Za Zhi,* vol. 43, no. 3, pp. 243-268, 2021, doi: 10.3760/cma.j.cn112152-20210119-00060.

[2] T. Messay, R. C. Hardie, and S. K. Rogers, "A new computationally efficient CAD system for pulmonary nodule detection in CT imagery," *Medical Image Analysis*, vol. 14, no. 3, pp. 390-406, 2010, doi: 10.1016/j.media.2010.02.004.

[3] C. Jacobs, E. M. van Rikxoort, T. Twellmann, E. Th. Scholten, P. A. de Jong, J.-M. Kuhnigk, M. Oudkerk, H. J. de Koning, M. Prokop, C. Schaefer-Prokop, and B. van Ginneken, "Automatic detection of subsolid pulmonary nodules in thoracic computed tomography images," *Medical Image Analysis*, vol. 18, no. 2, pp. 374-384, 2014, doi: 10.1016/j.media.2013.12.001.

[4] L. Shi, H. Ma, C. Zhang, and S. Fan, "Detection method of pulmonary nodules based on improved residual structure," (in Chinese) *Journal of Computer Applications*,

vol. 40, no. 7, pp. 2110-2116, 2020, doi: 10. 11772/j.

[5] Z. Ji, Y. Wu, X. Zeng, Y. An, L. Zhao, Z. Wang, and I. Ganchev, "Lung Nodule Detection in Medical Images Based on Improved YOLOv5s," *IEEE Access*, vol. 11, pp. 76371-76387, 2023, doi: 10.1109/ACCESS.2023.3296530.

[6] I. Ganchev, Z. Ji, and M. O'Droma, "Horizontal IoT Platform EMULSION," *Electronics*, vol. 12, no. 8, pp. 1-21, 2023, doi: 10.3390/electronics12081864.

[7] Y. Gu, J. Chi, J. Liu, L. Yang, B. Zhang, D. Yu, Y. Zhao, and X. Lu, "A survey of computer-aided diagnosis of lung nodules from CT scans using deep learning," *Computers in Biology and Medicine*, vol. 137, pp. 1-27, 2021, doi: 10.1016/j.compbiomed.2021.104806.

[8] Vue 3 UI framework, [Online]. https://ui.vuestic.dev/ (Accessed Date: October 10, 2024).

[9] Taro 3.x framework, [Online]. https://docs.taro.zone/en/docs/ (Accessed Date: October 10, 2024).

[10] Spring Boot, [Online]. https://spring.io/projects/spring-boot (Accessed Date: October 10, 2024).

[11] MyBatis-Plus, [Online]. https://mybatis.plus/en/ (Accessed Date: October 10, 2024).

[12] Apache Shiro, [Online]. https://shiro.apache.org/ (Accessed Date: October 10, 2024).

[13] MySQL, [Online]. https://www.mysql.com/ (Accessed Date: October 10, 2024).

[14] Flask framework, [Online]. https://flask.palletsprojects.com/en/stable/ (Accessed Date: February 16, 2025).

[15] FastDFS, [Online]. https://github.com/happyfish100/fastdfs (Accessed Date: October 10, 2024).

[16] Nginx, [Online]. https://nginx.org/en/ (Accessed Date: October 10, 2024).

[17] X. Ma, H. Song, X. Jia, and Z. Wang, "An improved V-Net lung nodule segmentation model based on pixel threshold separation and attention mechanism," *Scientific Reports*, vol. 14, no. 1, 4743, 2024, doi: 10.1038/s41598-024-55178-3.

[18] Z. Xu, X. Zhang, H. Zhang, Y. Liu, Y. Zhan, and T. Lukasiewicz, "EFPN: effective medical image detection using feature pyramid fusion enhancement," *Computers in Biology and Medicine*, vol. 163, pp. 1-13, 2023, doi: 10.1016/j.compbiomed.2023.107149.

[19] Y. Chen, R. Xia, K. Yang, and K. Zou, "MFFN: image super-resolution via multi-level features fusion network." *The Visual Computer*, vol. 40, pp. 489-504, 2024, doi: 10.1007/s00371-023-02795-0.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed to the presented research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This publication has emanated from joint research conducted with the financial support of the National Key Research and Development Program of China under Grant No. 2017YFE0135700 and the Bulgarian National Science Fund (BNSF) under the Grant No. KP-06-IP-CHINA/1 (КП-06-ИП-КИТАЙ/1).

Conflict of Interest

The authors have no conflicts of interest to declare.

APPENDIX

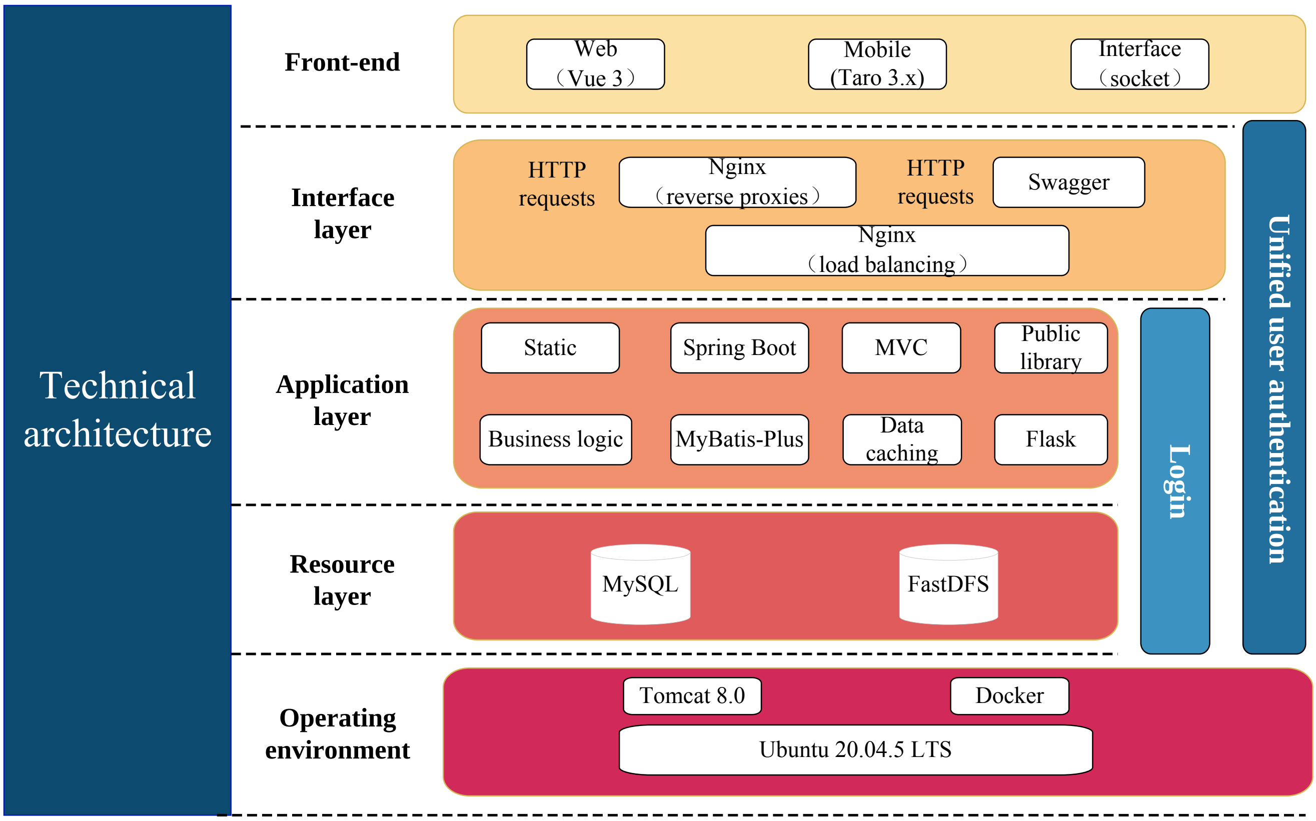

Fig. 1: The architecture of the developed system

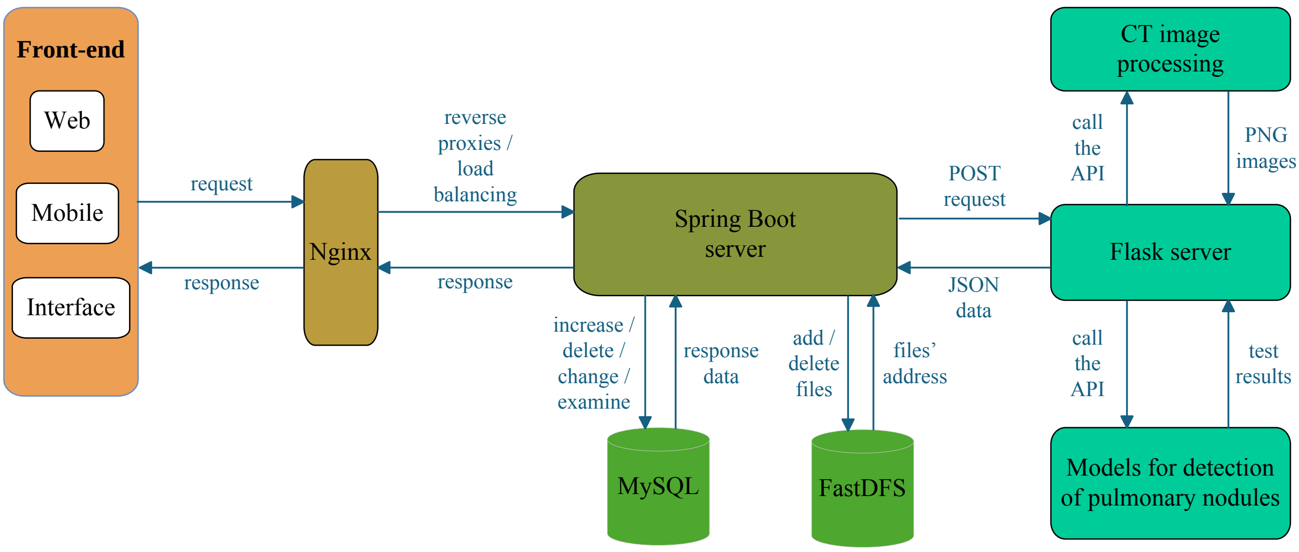

Fig. 2: The system operation diagram

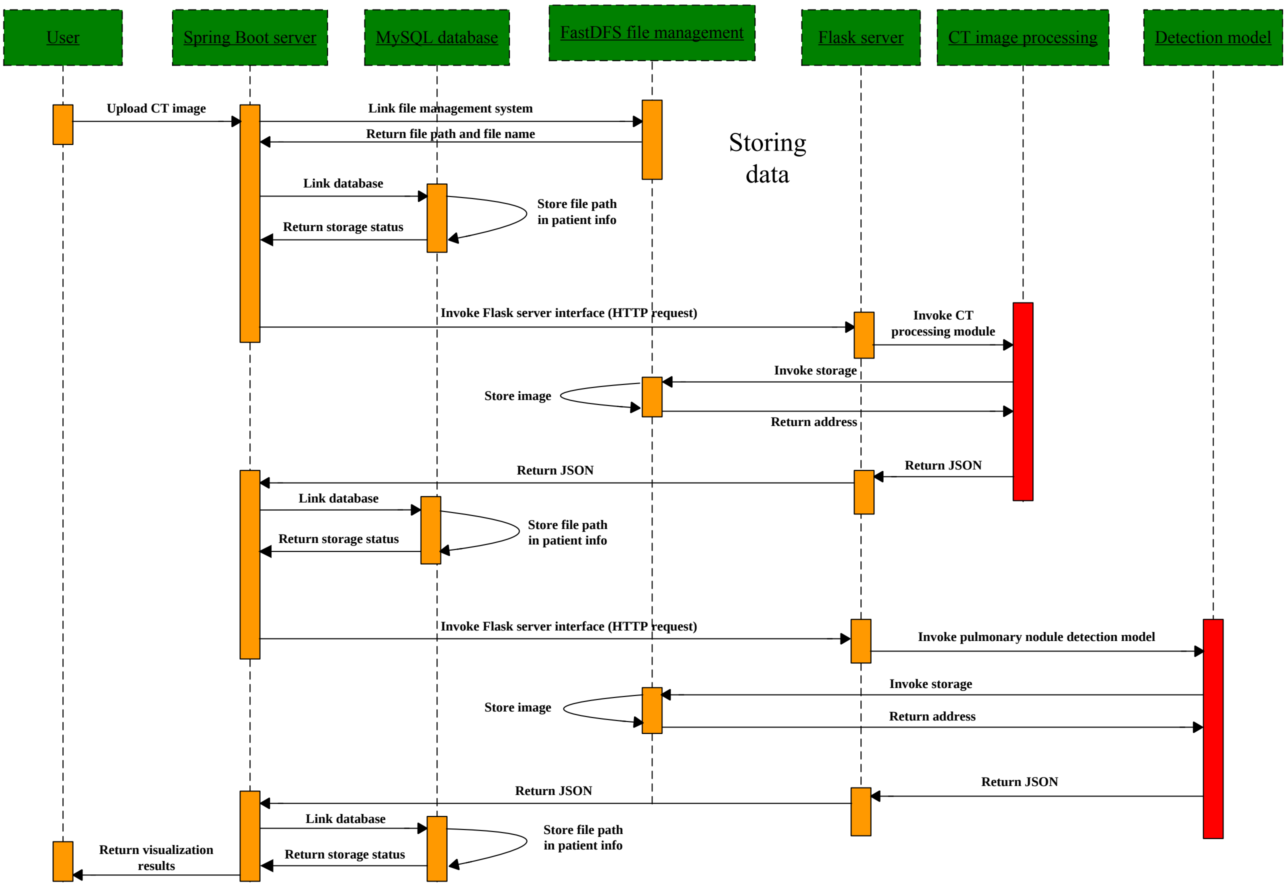

Fig. 3: The sequence diagram of the pulmonary nodule detection

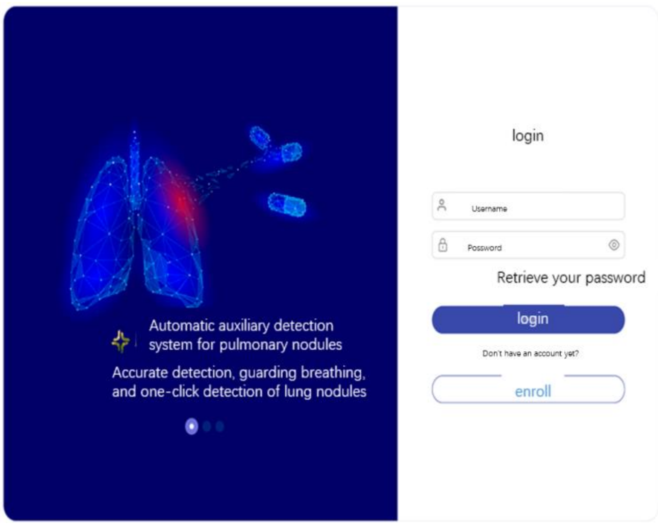

Fig. 4: The PC end's login and registration interface

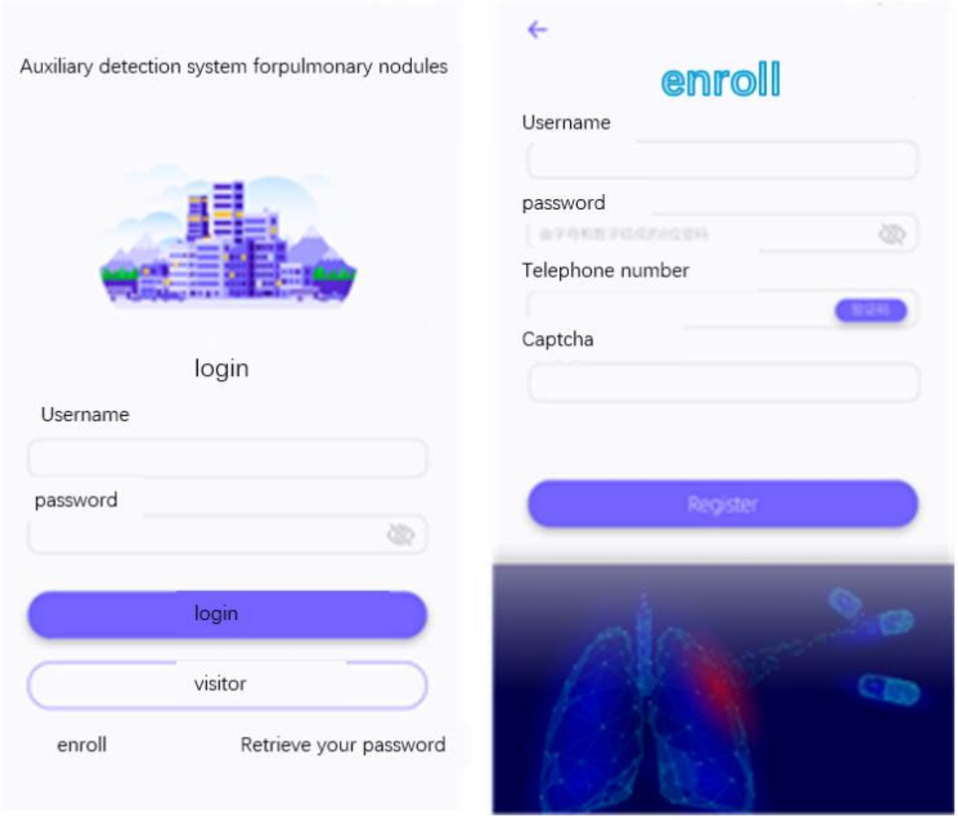

Fig. 5: The mini-program end’s login and registration: (a) the login page; (b) the registration page

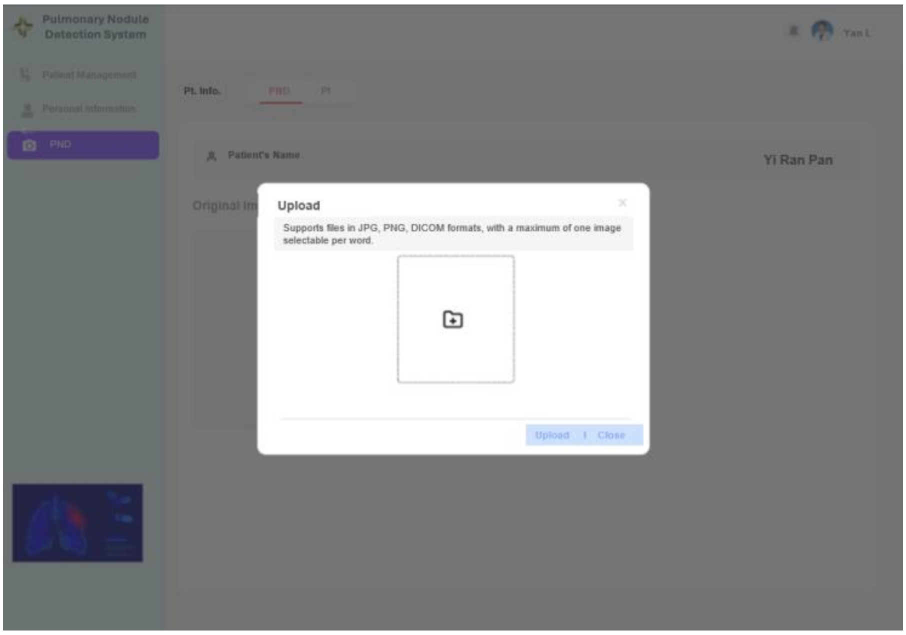

Fig. 6: Manual uploading of medical images

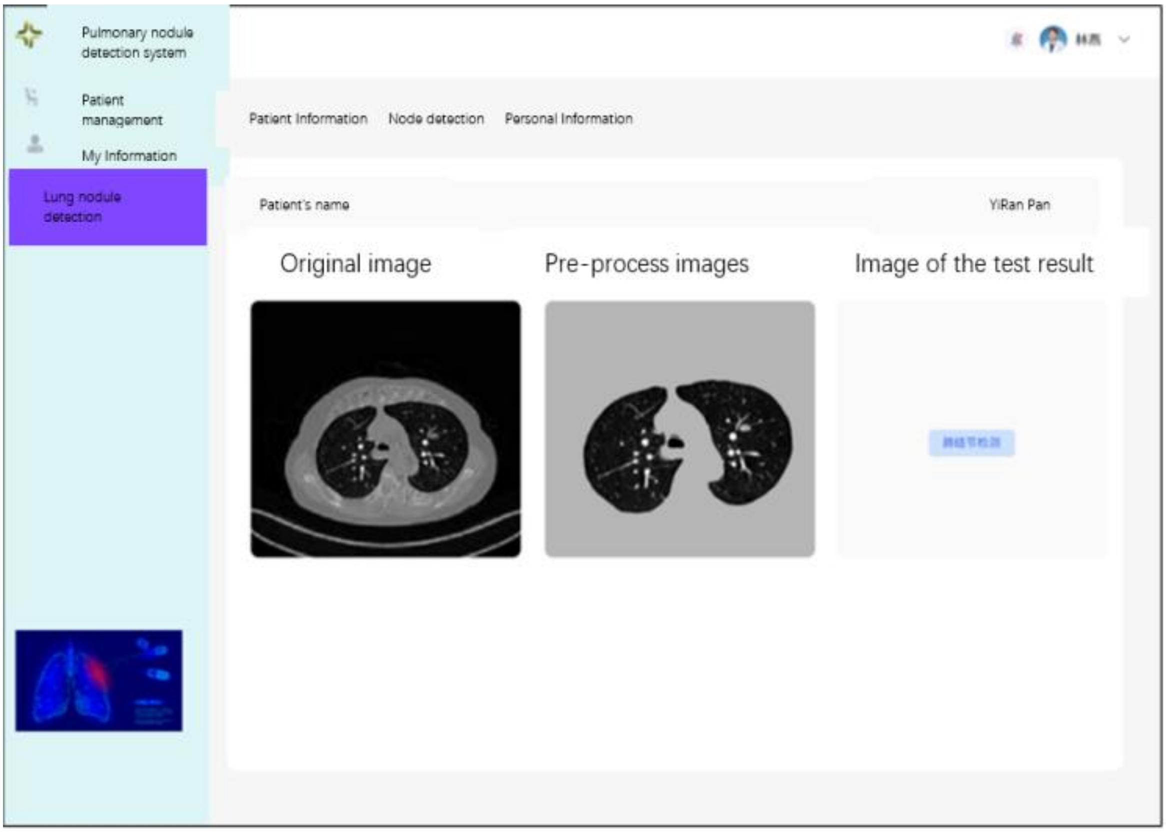

Fig. 7: A medical image preprocessing completion page

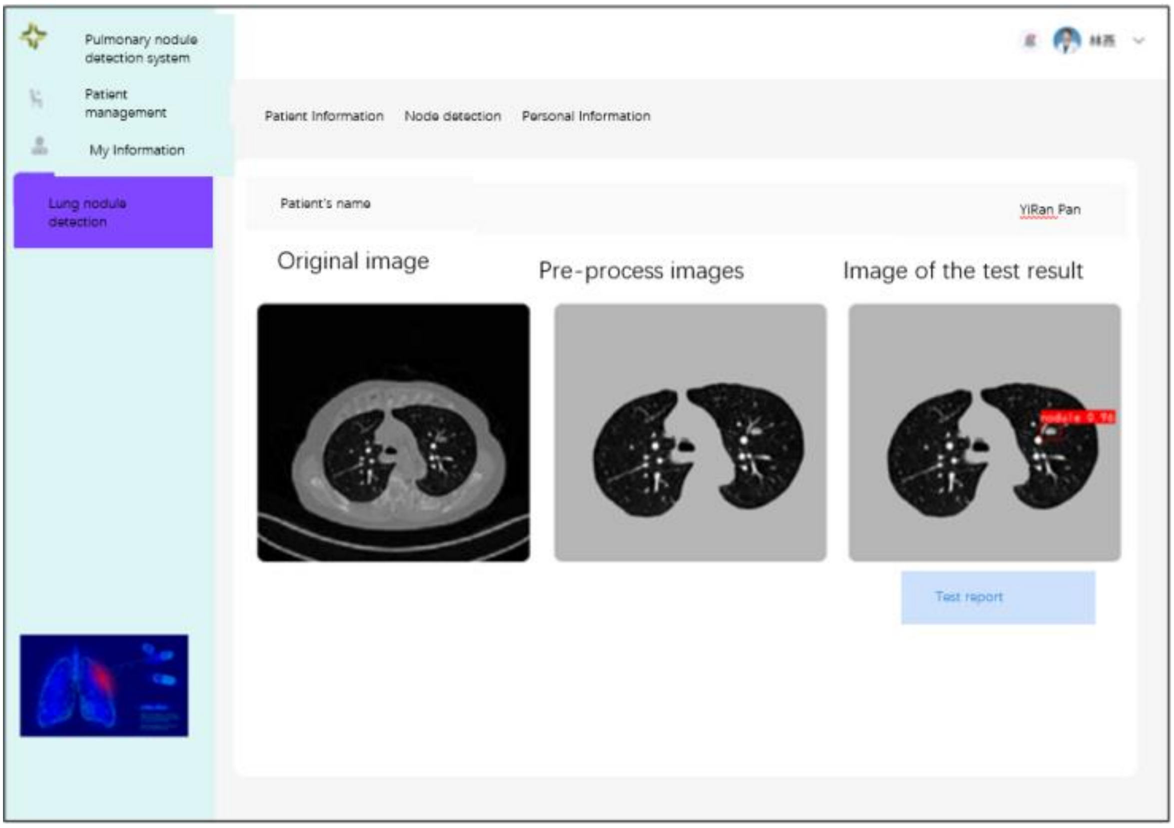

Fig. 8: The pulmonary nodule detection module's display page

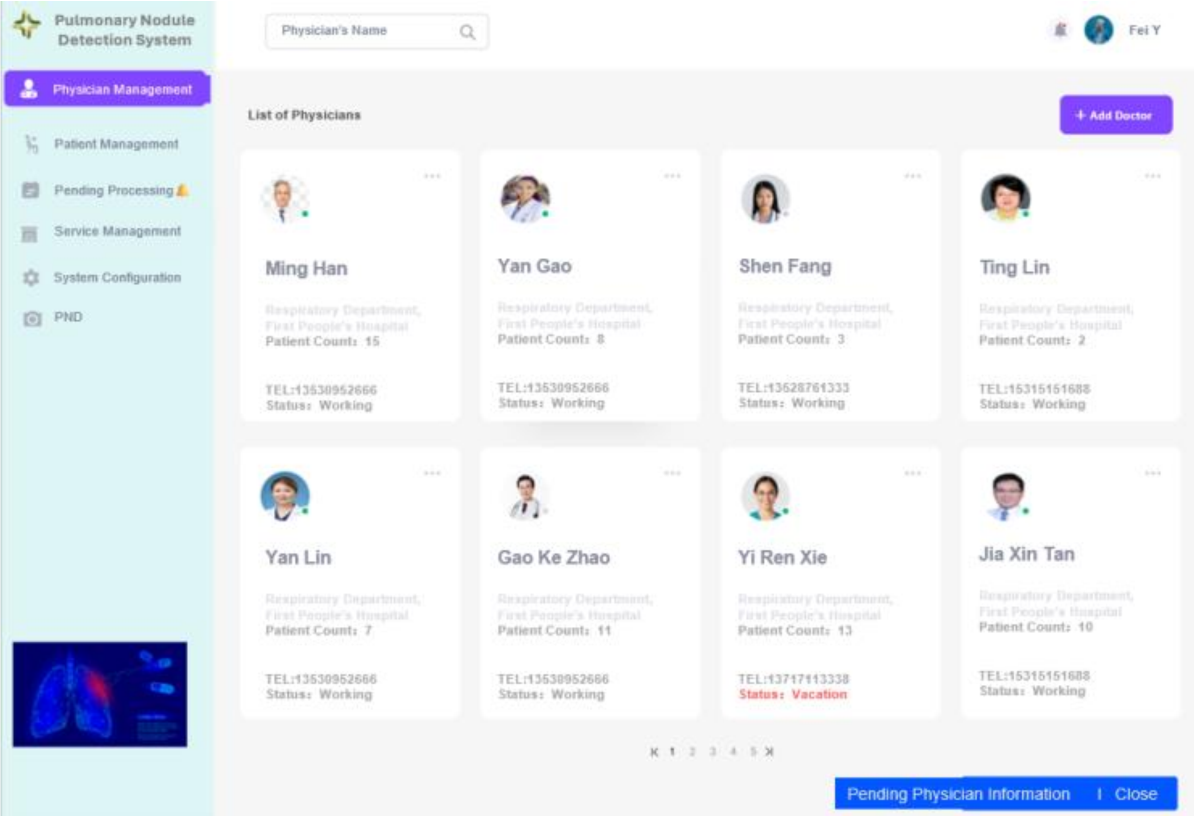

Fig. 9: The administrator’s operation interface