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Article

Development of a Mobile Application for The Identification of Medicinal Plant Raw Materials Using Artificial Intelligence

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Abstract: This article discusses the development of a mobile application for automated identification of medicinal plants and quality assessment of medicinal plant materials using artificial intelligence and computer vision. This research is relevant due to the need to implement objective digital control methods in the procurement and processing of raw materials and the digitalization of the pharmaceutical industry. Neural network architectures for plant image recognition are analyzed, including MobileNet, EfficientNet, and YOLO family models. A functional architecture of the mobile application is proposed that enables field recognition of medicinal plants, analysis of the morphological purity of raw materials, and the automatic generation of quality control protocols. The development of a training set and the implementation of a mobile solution based on TensorFlow Lite are considered. The development could contribute to the automation of plant identification, increased accuracy of pharmacognostic analysis, and the development of digital technologies in the pharmaceutical industry.

Keywords: Medicinal Plant Materials, Pharmacognosy, Resource Science of Medicinal Plants, Computer Vision, Artificial Intelligence, Neural Networks, Mobile Applications, Digitalization of Pharmaceuticals

1. Introduction

Pharmacognosy is a fundamental discipline in pharmaceutical education and plays a key role in ensuring the quality of medicinal plant materials used in the production of drugs. The primary objectives of pharmacognosy are the study of the morphological, anatomical, and chemical properties of medicinal plants, as well as the development of scientifically valid methods for their identification and quality control of plant materials. The quality of medicinal plant materials is largely determined by their correct identification and compliance with pharmacopoeial documentation. Errors in identifying plant species can lead to the use of substandard or even toxic materials, posing a potential health hazard to patients[1,2]. Traditional methods of pharmacognostic analysis are based on visual assessment of plant morphological characteristics, microscopic examination of tissues, and organoleptic analysis of raw materials. Despite the high efficiency of these methods, they are characterized by a certain degree of subjectivity and require highly qualified specialists.

Recent years have seen the active development of digital technologies, including artificial intelligence and computer vision methods, opening up new possibilities for automating biological analysis processes. Modern deep learning algorithms can recognize complex visual structures, analyze plant morphological features, and classify images with a high degree of accuracy. The use of these technologies in pharmacognosy can significantly improve the objectivity of medicinal plant identification and standardize quality control procedures for plant materials. The development of digital solutions in the pharmaceutical industry is also driven by the state priorities of the Republic of Uzbekistan in implementing modern information technologies. In accordance with the Decree of the President of the Republic of Uzbekistan dated October 14, 2024, No. PP-358 "On Approval of the Strategy for the Development of Artificial Intelligence Technologies until 2030," one of the key areas of state policy is the implementation of artificial intelligence technologies in scientific research, medical practice, and process control systems[3,4,5]. The strategy envisages the development of applied solutions based on machine learning, the creation of intelligent information systems, and the expansion of the use of computer data analysis technologies in various sectors of the economy. This issue takes on additional significance in the context of the implementation of Presidential Decree No. PP-4996 of February 17, 2021, "On measures for the further development of the pharmaceutical industry of the Republic of Uzbekistan in 2021– 2025," which identifies priority tasks for improving the quality of medicines, developing the raw material base of medicinal plants, and implementing modern pharmaceutical quality control technologies. One important focus of this program is improving the procurement and processing system for medicinal plant materials, as well as introducing innovative methods for their analysis[6,7].

Furthermore, the development of a digital infrastructure for scientific and production processes is consistent with the objectives set out in the Decree of the President of the Republic of Uzbekistan dated July 17, 2017, No. PP-3137 "On measures for the further development of information technology and communications," aimed at developing the digital economy and expanding the use of modern information technologies in various economic sectors. In this context, the use of artificial intelligence and computer vision technologies for the analysis of medicinal plant materials represents a promising area for the development of pharmacognostic research[8,9,10]. The development of mobile applications based on digital learning algorithms enables the creation of portable systems for plant identification and quality assessment of plant materials. These systems can be used directly at the source, during the primary processing stages, and in field practice to optimize resource research on medicinal plant materials (MPM). Thus, the development of a mobile application for the automated identification of medicinal plants and quality assessment of MPM represents a pressing scientific and practical challenge consistent with the current trends in the development of pharmaceutical science and digital technologies. The aim of this study is to develop a concept of a mobile application for automated identification of medicinal plants and analysis of the quality of medicinal plant materials based on computer vision technologies and artificial intelligence methods[11,12].

2. Methodology

This study employs artificial intelligence and computer vision techniques to automate the identification of medicinal plants and the quality assessment of plant raw materials.

In the first stage, a dataset of medicinal plant images was collected and preprocessed through normalization, noise reduction, and image resizing to ensure consistency and improve model performance.

In the second stage, convolutional neural network (CNN) architectures, including MobileNet and EfficientNet, were utilized for image classification. The models were trained and optimized to achieve a balance between accuracy and computational efficiency.

In the third stage, object detection algorithms from the YOLO family were applied to identify and classify morphological components of plant raw materials. This enabled the automatic estimation of the proportion of different plant parts within a sample.

In the fourth stage, the trained models were integrated into a mobile application using TensorFlow Lite, allowing real-time, on-device inference without requiring constant internet connectivity.

To enhance the reliability of the results, model outputs were evaluated based on confidence scores, and additional image acquisition was recommended in cases of low prediction confidence.

3. Results and Discussion

An analytical review of modern computer vision technologies: The problem of automatic plant identification from images is actively researched in the field of computer vision. Deep learning methods based on convolutional neural networks are the primary tools for solving such problems.

Classic neural network architectures such as VGG, ResNet, and Inception demonstrate high image classification accuracy. However, their use in mobile applications is limited by significant computational requirements and large model sizes.

To address this problem, specialized neural network architectures optimized for mobile devices have been developed. One of the most well-known models is MobileNet, which uses depthwise separable convolutions. This approach significantly reduces the number of model parameters and accelerates computation. Another promising architecture is EfficientNet, based on the principle of scaling the neural network along several parameters: depth, width, and resolution of input images[13,14,15]. This architecture enables high accuracy with a relatively small model size. In addition to image classification, object detection methods play an important role. In analyzing crushed medicinal plant material, it is necessary to identify different plant fragments and determine their percentages. Algorithms from the YOLO (You Only Look Once) family, which provide high-speed image processing, are widely used to solve such problems[16,17].

Modern research also considers the use of transformer architectures, such as the Vision Transformer, which allow the analysis of global dependencies between different parts of an image. However, these models require significant computational resources and are currently of limited use in mobile systems.

Mobile application architecture and technical implementation principles: The mobile application under development is designed for professional use in the procurement, primary processing, and incoming inspection of medicinal plant materials. The primary users include medicinal plant collectors, procurement center specialists, pharmaceutical company employees, and workers in analytical and testing laboratories. Unlike general-purpose mobile solutions, the proposed system is designed to address specialized pharmacognostic and resource science tasks related to plant identification, assessment of the morphological purity of raw materials, and digital recording of inspection results. The application's architecture is modular, ensuring system flexibility, scalability, and ease of adaptation to various practical application scenarios. Each module performs an independent function, but together they form a unified intelligent decision support system for pharmacognostic and resource science analysis[18,19]. The central element of the system is the plant identification module, designed for automated species recognition of medicinal plants based on digital images obtained from a mobile device camera. This module is based on a neural network computer vision model pre-trained on a set of verified

images of medicinal plants. The training set should include images of plants in various phenological phases, including vegetation, budding, flowering, fruiting, and partial wilting, as the morphological characteristics of the same species can vary significantly depending on the season and growing conditions.

This module begins with capturing an image with a smartphone camera. It then undergoes pre-processing, including size normalization, brightness, contrast, and color balance adjustments, as well as visual noise suppression. The image is then fed to a classification model, which identifies diagnostically significant features of the object and generates a probabilistic assessment of its membership in one of the species represented in the application database. The module's output should include not only the name of the most likely species but also a confidence score for the model, expressed as a percentage. In pharmaceutical applications, it is crucial that the system not provide a definitive decision without specifying its level of confidence. If the confidence level is insufficient, the system should initiate a repeat analysis and prompt the user to take an additional image from a different angle or under different lighting. This approach improves the reliability of digital identification and minimizes the risk of erroneous procurement of raw materials. An additional function of the identification module could be to detect signs of plant pathology, including mechanical damage, traces of phytopathogenic infestation, surface contamination, partial desiccation, and the presence of morphological abnormalities indicating the object's poor suitability for procurement. In the future, this module could be expanded into a multi-class system capable of not only identifying a plant but also assessing its commercial suitability based on a combination of morphological characteristics.

The second key element of the architecture is the medicinal plant raw material quality analysis module. Its purpose is to automatically assess the morphological purity of the raw material, especially when the test subject is not a whole plant, but crushed or partially processed plant fragments. In pharmacognostic practice, it is essential that the raw material meet pharmacopoeial requirements for the content of certain plant parts and acceptable levels of impurities. For example, an excessive amount of stem fragments is unacceptable in a leaf raw material sample, while a significant proportion of foreign inclusions or mechanical impurities is unacceptable in a flower raw material sample. Therefore, the quality analysis module must automatically recognize the morphological elements of the sample and determine their quantitative ratio. Technically, this function can be implemented using object detection models capable of localizing individual fragments of the raw material in an image and classifying them by type. The system must distinguish between leaves, stems, roots, flowers, fruits, seeds, as well as foreign inclusions of non-plant or biological origin. After detection and classification of objects, the percentage content of each fragment type within the analyzed sample is calculated. The practical value of this module lies in its ability to standardize the initial assessment of plant

materials and reduce the dependence of results on the subjective visual perception of the specialist. Furthermore, the use of automated analysis speeds up the inspection process and ensures the preservation of a digital trace of the completed examination. In a more complex configuration, the module can be supplemented with microstructural feature analysis. When using macrolenses or mobile microscopic attachments, the system can recognize trichomes, the shape of vascular elements, crystalline inclusions, epidermal features, and other anatomical and diagnostic features traditionally used in pharmacognosy to confirm the authenticity of raw materials[20].

A significant component of the application's structure is the information and reference module, which serves as an internal pharmacognostic and resource science database, providing intellectual support for the user when interpreting the results of the automated analysis. This module includes pharmacopoeial descriptions of medicinal plants, information on their botanical features, microscopic characteristics, acceptable and unacceptable impurities, as well as photographs of plants at various stages of development. Structurally, the database must contain several interconnected blocks of information. The first block includes taxonomic information: the Latin and Russian names of the species, family, plant parts used, distribution, and raw material value. The second block contains a morphological description of the plant and its diagnostic features. The third block covers pharmacopoeial requirements for raw material quality, including authenticity criteria, purity indicators, acceptable impurities, and storage requirements. The fourth block consists of multimedia materials containing reference images of whole plants, plant organs, microscopic sections, and typical impurities. The importance of the information and reference module lies in the fact that the mobile application, in this case, not only performs automated recognition but also becomes a digital reference tool for professional work and training. The user can compare the results of the automatic analysis with the regulatory description, manually check the diagnostic features, and, if necessary, conduct additional expert verification. This is especially important in cases where the system demonstrates a borderline level of confidence or when the plant being studied has morphologically similar lookalike species. In the future, this module may be supplemented with interactive diagrams, anatomical atlases, three-dimensional models of morphological structures, and an educational section designed to train specialists in the field of pharmacognosy and quality control of plant materials.

A special place in the mobile application architecture is occupied by the documentation and digital traceability module, which records the circumstances of raw material procurement and analysis. Its primary function is to generate a digital batch passport for medicinal plant materials, including resource, time, visual, and analytical data. During operation, the module automatically saves the coordinates of the collection site, the date and time of collection, environmental characteristics,

photographs of the object, and the results of the analysis. With the appropriate permissions, the device can also record altitude, weather parameters, and, when integrated with external services, information on temperature, humidity, and other environmental conditions at the time of collection. All of this data is of practical importance, as growing and procurement conditions directly impact the quality of plant materials and their chemical composition. The digital batch passport generated by the system can be used as an element of a raw material traceability system. This is particularly important for the pharmaceutical industry, as supply chain transparency and documented confirmation of the raw material source are essential factors in ensuring quality and regulatory compliance. The documentation module should also generate a report on the analysis performed. Such a report can include information about the test object, a sample image, automatic identification results, the model confidence factor, detected impurities, the analysis date, and the user ID of the user who performed the procedure. As a result, the mobile application becomes not just a recognition tool, but a fully-fledged tool for digitally recording pharmacognostic control results. All of these modules function not in isolation, but within a unified architectural logic. Thus, after photographing a plant, the identification module determines the suspected species, then the information and reference module provides a reference description and pharmacopoeial information, after which the documentation module stores the results along with metadata. Similarly, when analyzing raw materials, the system can first detect fragments, then compare the obtained results with regulatory purity criteria and automatically generate a conclusion on the sample's compliance or non-compliance with established requirements. This modular organization makes the system suitable for both field conditions and laboratory practice. It allows for the consistent expansion of the application's functionality without changing its basic structure, adding new recognition models, new types of raw materials, and new analytical scenarios. The technical implementation of a mobile application should be based on the principles of reliability, scalability, autonomy, and interpretability. Since the proposed solution is intended for professional use in environments with potential internet connection limitations, the system architecture must accommodate both standalone operation of the main functions and the ability to synchronize data with remote services when a network is available.

Developing a mobile application is a multi-stage process that begins with domain analysis. This stage involves studying the specifics of pharmacognostic analysis, requirements for identifying medicinal plant materials, common errors in visual diagnostics, and regulatory provisions governing raw material quality control. This stage results in the formalization of application requirements and the definition of a list of functions required by various user categories. The next stage involves designing the system architecture. This stage involves defining the composition of functional modules, developing user interaction scenarios, designing the database

structure, and modeling the data flow between the user interface, image analysis modules, and the results storage subsystem. It is at this stage that the logical model of the application is formed, defining the principles of interaction between all its components. Following the design, the user interface is developed. For a pharmaceutical mobile app, it's especially important to ensure easy navigation, clear screen forms, minimal unnecessary user interactions, and clear presentation of analysis results. The interface must be adapted to practical conditions, including field work, bright lighting, limited decision-making time, and the need for rapid recording of results. The next step is software implementation, which includes developing the client and server components, integrating image processing modules, setting up interaction with a local or remote database, and implementing mechanisms for saving and exporting results. The final stage is testing.

The client side of the application is intended for direct user interaction with the system and is implemented as a mobile Android application. The choice of the Android platform is обусловлен its wide distribution, the availability of devices in different price segments, and the convenience of deploying application solutions in industrial, laboratory, and educational environments. The use of the Kotlin programming language makes it possible to create a modern, stable, and maintainable client-side application. On the client side, functions must be implemented for capturing images using the device’s camera, displaying data entry and data viewing screens, launching local image analysis, accessing reference information, saving the history of inspections, as well as generating reports and exporting data. An important task of the client side is the preprocessing of images before they are passed to the machine learning model. This includes resizing the image, cropping the region of interest, adjusting sharpness, reducing noise, and verifying that the image quality is sufficient. The higher the quality of preprocessing, the greater the robustness and accuracy of subsequent analysis. In addition, the client side must provide local data storage, which is particularly important when operating outside areas with stable internet connectivity. For this purpose, a built-in database can be used to store the history of analyses, images, user notes, and metadata until the moment of subsequent synchronization. The server side of the application performs the functions of centralized data storage, management of reference materials, accumulation of analytical information, and updating of software components. Its implementation in Python using the Django framework is a rational choice, since this technology stack provides sufficient flexibility, scalability, and development convenience.

On the server side, full image databases, reference pharmacopeial descriptions, versions of trained models, user activity logs, and report archives can be stored. The server can also be used for the centralized updating of reference materials and the distribution of new versions of machine learning models to client devices. When an internet connection is available, the server side can perform

additional functions that are not accessible in offline mode. For example, this may include cloud verification of ambiguous cases, aggregated analysis of recognition statistics, remote expert evaluation of disputed samples, as well as collaborative expansion of the training dataset with newly verified images. Thus, the server side is not strictly required for the basic operation of the system; however, it significantly expands its capabilities in industrial, laboratory, or educational environments.

Interaction between the client and server components is carried out through network APIs that enable the transfer of structured data between the mobile device and the remote server. Through the API, analysis results, sample images, requests for reference information, model updates, and service data related to authorization and synchronization can be transmitted. The organization of data exchange must take into account the requirements of security, integrity, and confidentiality of information. Since the application may be used in professional environments, it is particularly important to prevent the loss of inspection results, corruption of metadata, and unauthorized access to information about raw material batches. Therefore, the system must provide mechanisms for user authorization, encrypted connections, and data backup. An important principle is the asynchronous nature of data exchange: the application should continue performing its key functions even in the temporary absence of a network connection, storing all data locally and transmitting it to the server after connectivity is restored. This approach ensures the stability and reliability of the system under real operating conditions.

One of the key requirements for the developed system is the ability to perform inference directly on the mobile device without mandatory access to a remote server. Such a solution is particularly important when the application is used in field conditions where access to data networks may be limited or completely unavailable. To implement this capability, on-device machine learning technologies are employed. A pre-trained neural network model is converted into a lightweight format suitable for mobile deployment. After optimization, including parameter quantization and reduction of computational load, the model can be integrated into the mobile application and executed locally on the smartphone's processor or neural accelerator. The use of TensorFlow Lite enables efficient deployment of computer vision models on mobile devices. In practice, this reduces system response time, decreases dependence on network infrastructure, and improves the confidentiality of processed data, since images do not necessarily need to be transmitted to external servers. However, local model execution imposes certain limitations: the model size, computational complexity, and energy consumption must be balanced with the hardware capabilities of the target devices. Therefore, when designing the application, it is necessary to select model architectures that provide an optimal balance between accuracy and performance.

For practical use in the fields of pharmacognosy and medicinal plant raw material resource studies, high model accuracy alone is not sufficient. The system must also be interpretable and reliable. This means that the application should not only provide the recognition result but also indicate the level of confidence, highlight possible limitations of the analysis, and in certain cases request additional confirmation. From a technical perspective, this is implemented through confidence thresholds of the model. If the probability of assigning an image to a particular class falls below a predefined threshold, the application should not automatically generate a final conclusion. Instead, the user may be prompted to repeat the image capture, select an alternative analysis mode, or submit the case for expert review. For plant species that are potentially hazardous from a toxicological perspective, a double- verification mode can be implemented, in which the system requires additional confirmation through an alternative image, a microscopic characteristic, or comparison with reference materials. Such an approach is particularly important for practical applications in the pharmaceutical industry, where the cost of error can be extremely high.

The technical architecture of the application should also be designed with future development in mind. As training data accumulate, the system can be expanded by incorporating new plant species, additional categories of raw materials, and new analytical scenarios. A modular architecture also allows for the future integration of additional data sources, including portable microscopes, spectrometric devices, humidity sensors, and other external modules. Thus, the technical implementation of the mobile application should not only address the current task of automated identification and quality assessment of plant raw materials but also provide a foundation for the development of a broader digital ecosystem for pharmacognostic quality control.

4. Conclusion

The conducted analysis shows that the current level of development of artificial intelligence, computer vision, and mobile computing technologies creates real prerequisites for the development of applied solutions in the field of pharmacognosy and quality control of medicinal plant raw materials. The use of neural network algorithms within mobile applications makes it possible to move from predominantly subjective visual assessment to a more standardized, reproducible, and technologically supported approach to the identification of plant objects and the analysis of raw materials. The development of a mobile application for the automated identification of medicinal plants and the assessment of the quality of medicinal plant raw materials has not only scientific but also clear practical significance. Such systems can be used directly at raw material harvesting sites, during the stages of primary processing, as well as in educational fieldwork and industrial practice. This is particularly important in conditions where rapid decision- making, recognition accuracy, and documented recording of inspection results become essential for ensuring the quality of pharmaceutical products. The proposed

approach contributes to increasing the objectivity of harmacognostic analysis, reducing the risk of errors in the identification of medicinal plants, standardizing procedures for primary quality control, and expanding the possibilities for digital traceability of the origin of raw materials. Another significant advantage is the ability to integrate several functional components within a single system: plant species recognition, analysis of the morphological purity of samples, use of reference pharmacopeial information, and automatic generation of a digital passport for each batch of raw materials. This direction becomes especially important in the context of the digitalization of the pharmaceutical industry and the introduction of intelligent technologies into the practice of drug quality control. The creation of verified image databases of medicinal plants, the development of adapted machine learning models, and the design of mobile decision-support tools can be considered an important stage in the modernization of pharmacognostic analysis and in improving the efficiency of the use of plant raw materials. Future research prospects are associated with expanding training datasets by including a larger number of pharmacopeially significant plant species, improving algorithms for recognizing morphological and anatomical features, and integrating mobile applications with portable analytical instruments, including spectrometric systems. The combination of morphological image analysis with data on the chemical composition of raw materials will increase the reliability of identification, expand the analytical capabilities of the system, and bring it closer to the format of a comprehensive digital platform for the quality control of medicinal plant raw materials.

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