Research Article

Artificial-Based Pulse Learning Web Application Intelligence Using Convolutional Neural Networks

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Abstract: Studying pulse waveforms in healthcare is crucial as they aid in diagnosing and treating chronic diseases. However, the limited data on pulse waveforms makes it challenging for health education to teach this topic effectively. Practitioners of Traditional Chinese Medicine (TCM) require a significant amount of time to obtain pulse wave data accurately. Additionally, the pulse wave data collected by TCM practitioners exhibit various forms and characteristics. This study aims to integrate web-based pulse waveform learning with Artificial Intelligence (AI) using Convolutional Neural Network (CNN) to enhance effectiveness and efficiency. Pulse waveform data were obtained from Traditional Chinese Pulse Diagnosis and were redrawn to achieve diverse and accurate results. A total of 400 images were generated for each of the five types of pulse waveforms to improve data quality. The redrawn data were then tested to ensure accuracy. Once validated, a comparison of deep learning models using three CNN architectures—VGG16, VGG19, and ResNet50—was conducted, with VGG19 achieving the highest accuracy among the models. Consequently, the VGG19 model was implemented into a web-based pulse waveform learning application using JavaScript, HTML5, and TensorFlow. The results demonstrate that the VGG19 model outperformed other architectures in terms of accuracy. The successful integration of the VGG19 model into the web-based application shows that AI can be used to create an interactive learning platform for pulse waveform education. This study proves that the collaboration between web-based pulse waveform learning and AI can serve as an interactive educational tool for the future.

Keywords: convolutional neural network, pulse waveform, web application, artificial intelligence, interactive learning

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1. Introduction

In the human body, pulse rate is crucial as it serves as an indicator of the heart's ability to pump blood. Pulse rate is defined as the wave that can be felt in the arterial blood vessels due to the heart pumping blood into the vessels [1]. The waveform of the pulse is characterized by systolic and diastolic phases. Systolic and diastolic pressures are components of the peak and trough of the waveform [2]. In traditional Chinese medicine (TCM), knowledge of pulse waveforms holds significant importance. TCM practitioners require years of education and experience to accurately assess the pulse [3]. Numerous qualities of the pulse have been documented in ancient Chinese medical literature. The medical text Nei Jing describes over 30 types, and Mai Jing documents 24 pulse qualities, while 28 of the most commonly used pulse qualities in clinical practice are derived from the Chinese medical texts Bin Hu Mai Xue and Zhen Jia Zheng Yan [4]. Traditional Chinese pulse diagnosis (TCPD) has classified pulse waveforms into five categories: moderate, smooth, taut, hollow, and unsmooth [5]. Figure 1 is a Five Pulse Wave Patterns Classified by TCPD.

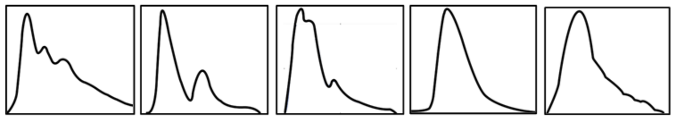

Figure 1. The Five Pulse Wave Patterns Classified by TCPD

Moderate, smooth, and taut waveforms are characterized by a smooth and sharp upward movement, a short peak, followed by a rapid and descending downward movement. The reflected wave resembles the initial wave but with a lower amplitude, depicting the pulse of a young and healthy individual [6]. The hollow pulse waveform on the surface is softer than the hollow pulse itself; the hollow pulse can only be felt at intermediate and shallow levels. The unsmooth pulse waveform has a high amplitude and significant notches on the descending branch, with the amplitude of the unsmooth wave being much higher, forming a broad and blunt peak [7].

In the field of healthcare, understanding pulse waveforms is essential because they possess random and unstable properties [8]. The significant differences in the stability of pulse waveforms are due to the varying number of harmonics present in the pulse waves [9]. This variability makes it challenging for healthcare education to study pulse waveforms effectively. Additionally, the limited data on pulse waveforms further complicates the understanding of these waves due to the scarcity of educational material on the subject.

Studying different types of pulse waveforms is essential for improving the accuracy and feasibility of pulse diagnosis [10]. Pulse waveforms can also aid in diagnosing and treating chronic diseases [11]. Research indicates that a deep understanding of the characteristics and patterns of pulse waveforms can provide valuable information for diagnosis and for planning more precise and effective treatment strategies. Therefore, integrating knowledge of pulse waveforms into medical practice can yield significant benefits for patients, enabling more accurate diagnoses and more personalized and targeted therapeutic approaches.

The study of pulse waveforms is important in the medical field because it provides valuable insights into an individual's cardiovascular health. Although there are explanations for the different characteristics of pulse waveforms, clinically studying these waveforms can be a challenging task [12]. This difficulty arises due to individual variations in the shape and nature of pulse waves, as well as the influence of factors such as age, gender, physical condition, and specific diseases [13].

Artificial intelligence (AI) is defined as the capability of digital machines to perform tasks that are typically carried out by humans [14]. AI has been utilized in various applications, including natural language processing, image recognition, and disease diagnosis [15]. Consequently, AI technology can be employed to enhance the interpretation of pulse waveforms.

Convolutional neural networks (CNNs) are a significant advancement in artificial intelligence. In deep learning, CNNs have made rapid progress in image classification tasks due to increased computational power, large datasets, and improved algorithms [16].

The application of artificial intelligence technology, particularly Convolutional Neural Networks (CNNs), in the study of pulse waveforms, holds great potential for addressing the challenges associated with understanding pulse waveforms. By using CNN algorithms, systems can learn the complex characteristics of pulse waveforms and provide insights into different types of pulse waves. Thus, the integration of AI technology in predicting pulse waveform types can support effective and efficient learning.

In recent decades, significant research has been conducted to automate and objectify pulse wave diagnosis, where sophisticated data acquisition methods and feature extraction are combined with artificial intelligence technologies. Recent studies have employed Convolutional Neural Networks (CNNs) for classifying pulse wave patterns [17]. However, there has been no implementation of such research in the form of a web-based learning application, and there is a lack of updated CNN architectures. Therefore, the researchers aim to develop an interactive and efficient pulse wave learning website, based on training results from pulse wave image datasets using CNN models.

Therefore, pulse wave comprehension is hindered due to the limitations of pulse wave learning media. This research aims to develop a web application based on artificial intelligence with Convolutional Neural Network (CNN) algorithms to predict the types of pulse waves through image depiction and uploading. It is expected that with this technology, health education will become more accessible in learning the types of pulse waves, thereby enhancing understanding of disease diagnosis through pulse waves.

2. Conceptual Framework

This study involves the development of an artificial intelligence-based web application for pulse wave learning media, which encompasses the following factors: The system is constructed to facilitate pulse wave learning. The main components of this website include pulse wave depiction, uploading of pulse wave images, and the implementation of the CNN algorithm for predicting the type of pulse wave. The researchers utilize JavaScript and HTML5. JavaScript and HTML5 are effectively used to develop visually appealing web applications with interactive interfaces [18].

In Figure 2, the architecture of the web application for predicting the type of pulse wave is depicted. The process begins with training and testing three CNN architectures, followed by comparing the accuracy of each result and selecting the highest accuracy. From this model outcome, the model is downloaded and saved onto the server. Subsequently, every image prediction processing is conducted on the client side using TensorFlow.

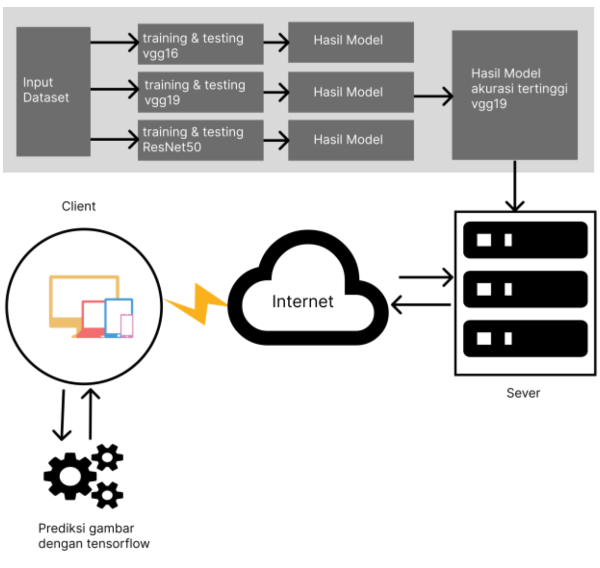

Figure 2. The infrastructure of the web application

The selection of the CNN model is based on a deep neural network with multiple layers, including convolutional layers, non-linearities, pooling, and fully connected layers, as well as outstanding performance in deep learning tasks, particularly image classification and natural language processing.

2.1 Data Set Description

The prediction process for pulse wave images involves collecting and categorizing the types of pulse wave patterns into five groups, namely moderate, hollow, taut, smooth, and unsmooth. These pulse wave types will serve as the key for classification into pulse wave categories within the web application.

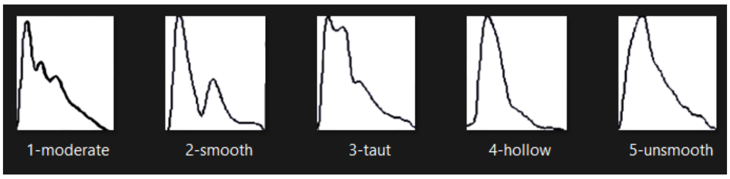

Figure 3. Image dataset acquisition

The researchers utilized images of five pulse wave patterns from Traditional Chinese Pulse Diagnosis (TCPD). Figure 3 shows the results of image acquisition with re-rendering. However, these images were deemed insufficient to train the desired model. Therefore, the researchers manually re-rendered the five types of pulse wave patterns using Photoshop software. Each type of pulse wave pattern was represented in the form of images, with one type consisting of 400 images, except for the unsmooth pulse wave type which included an additional two images, resulting in a total of 2002 images for all five pulse wave types. Subsequently, these images were processed to enhance data quality. The preprocessing stage is crucial to ensure that the data is ready for use in developing the appropriate Deep Learning model.

2.2 Data Preprocessing

During the data preprocessing stage, the dataset obtained previously was divided into three parts: training, testing, and validation, with a proportion of 60:20:20. This division resulted in a total of 1200 images for training, 401 images for testing, and 401 images for validation.

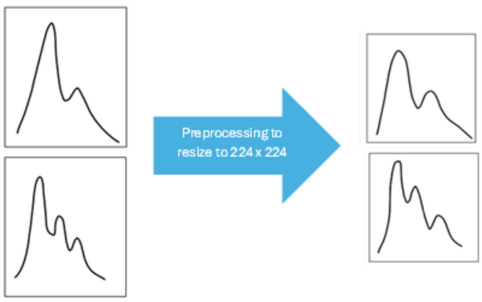

Figure 4. Preprocessing

After dividing the dataset, the researchers proceeded with improving the quality and quantity of the pulse wave images. Previously, manually creating images resulted in different original sizes, thus requiring resolution rescaling to ensure that all images have the same size, namely 224x224 pixels as shown in Figure 4. The primary goal of this preprocessing step is to make the model's classification of pulse wave types more accurate.

2.3 *Comparison of Deep Learning CNN Models*

The next step involves comparing the existing architectures in Convolutional Neural Networks (CNN). This stage aims to classify pulse wave images and compare three types of architectures in CNN. In this architectural comparison, the researchers will utilize three CNN architectures: VGG16, VGG19, and ResNet50, known for their accurate classification of images (Mascarenhas & Agarwal, 2021).

Additional GlobalAveragePooling2D and Dense layers were added to adapt the model to the dataset and improve accuracy. The inclusion of these layers aims to fine-tune the model for more accurate predictions. The researchers also utilized weights from the ImageNet dataset to leverage pre-trained weights for image classification. The training results are saved in an HDF5 file format. HDF5 format exhibits self-describing properties, allowing metadata to be stored in global attributes or variables [20]. Subsequently, the model is converted to JavaScript format using the TensorFlow framework.

2.4 *Web Application Development*

The researchers designed a website-based system consisting of two main features: prediction through drawing on canvas and prediction through image upload. The system also incorporates various information regarding pulse wave patterns and an interactive user interface. The system flow of the web application can be seen in Figure 5.

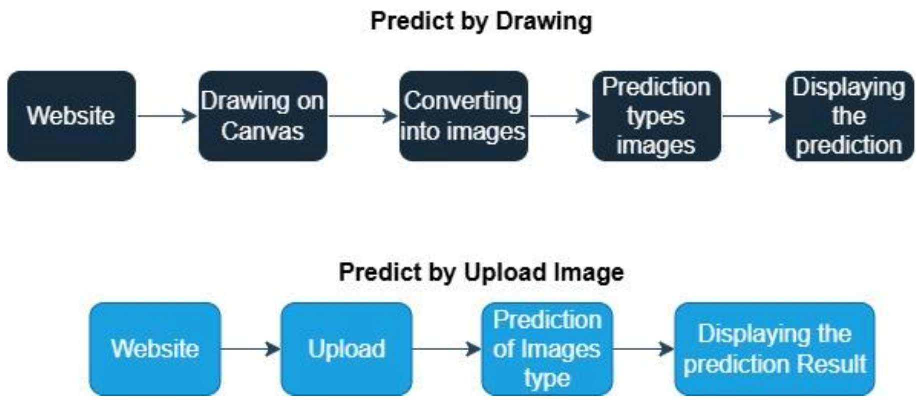

Figure 5. The flow of the web application system

In the development of this web-based learning application for pulse wave analysis, HTML5, CSS, and JavaScript are utilized as libraries and programming languages. HyperText Markup Language (HTML) serves as the browser's interpreter, rendering text, images, and videos into web pages for user viewing. HTML underwent updates, culminating in HTML5 by 2015 [21]. HTML5 offers enhanced support, including multimedia, image rendering, and local data storage [22]. In web development, HTML5 facilitates the creation of high-quality web applications [23]. Therefore, choosing HTML5 as the markup language for web application development is apt, given its capability to support more complex multimedia utilization compared to earlier HTML versions.

In using HTML5 as the markup language for developing the pulse wave learning web application, researchers also employ CSS. Cascading Style Sheets (CSS) are utilized to manage components and enhance the appearance to be visually appealing when viewed by users. While HTML5 interprets text, images, and videos into web pages, CSS is necessary to create an attractive layout and ensure organized components. In web application development, CSS can express the visual design of the website through HTML tags, with its usage constrained by the web browser platform ecosystem [24]. The utilization of CSS in web application development is aimed at enhancing or altering colors, fonts, and layouts to make them more appealing [25]. The utilization of CSS is crucial in creating an appealing appearance for web application pages, thereby stimulating user interest in utilizing the web application.

In addition to using HTML5 and CSS as the foundation for creating web pages, JavaScript also plays a crucial role as a programming language in developing pulse wave learning web applications. In web application development, JavaScript is utilized to create text animations, slide presentations, and responsive web pages, thereby enhancing user experience and perfecting web design (Shoikhedbrod, 2023). JavaScript has revolutionized the construction of web pages by making them interactive and dynamic, thus contributing to improving user engagement. JavaScript can be used to convert images and text into program-readable instructions [26]. Therefore, JavaScript can be employed to convert canvas into an image, and from that image, JavaScript can further convert it into a Uniform Resource Locator (URL). With this URL data, image prediction can be performed with the assistance of TensorFlow. TensorFlow is defined as a machine learning system that uses data flow graphs to determine operations and computations [27]. The utilization of HTML5, CSS, and JavaScript in the development of pulse wave learning web applications not only enhances the interactivity and responsiveness of web pages but also leads to better user experiences and more refined designs.

The web application provides two methods for predicting the type of pulse wave: drawing through the canvas and uploading images. The utilization of these two input methods is aimed at enhancing understanding in identifying types of pulse waves. The classification data results are stored in TensorFlow to be utilized within the pulse wave prediction web application. TensorFlow can be employed for the analysis and modeling of convolutional neural network data [28]. TensorFlow can be directly utilized within the JavaScript environment, such as in website development, to perform predictions on images directly in the web browser. This conversion process enables models trained with TensorFlow to be used directly in web applications without relying on other servers or backends, thereby enhancing flexibility and efficiency in implementing deep learning models in web environments.

3. Result and Discussion

In this section, the researcher elaborates on the development of a web application for pulse wave learning using Convolutional Neural Networks (CNN). The discussion begins with data collection and preprocessing, followed by a comparison of three CNN architectures to identify the highest percentage results for predicting pulse wave types. The study concludes by presenting the results of the web application designed for pulse wave learning methods.

The researcher conducted a comparison of three CNN architectures VGG16, VGG19, and ResNet50 using the same dataset. As explained in the method, the primary objective of this comparison is to select the architecture with high accuracy for utilization in the pulse wave type prediction web learning application.

In this experiment, the researcher conducted a comparison of three architectures with the same dataset and the addition of identical layers. The comparison results for the three architectures can be seen in Table 1.

Table 1. Comparison results of CNN architectures

Model Architecture	Loss Accuracy	Accuracy
VGG16	2.90%	98.50%
VGG19	1.12%	99.08%
ResNet50	2.67%	97.83%

In Table 1, it can be observed that all three architectures exhibit high accuracy and low accuracy loss, with a difference of 1% - 3% between architectures. However, due to the necessity of selecting one architecture for use in the web-based pulse wave learning application, the researcher opted for the VGG19 architecture. The VGG19 architecture demonstrates the highest accuracy, specifically 99.08%, making it highly effective for use in the pulse wave type prediction system.

After selecting the architecture to be used, the researcher proceeded with the development of the web application. The model results were converted into TensorFlow for integration into the web application. The web application was built using JavaScript and HTML5. The converted model results were placed into a single folder, eliminating the need for an external server for model access. However, internet connectivity is still required for sending and reading image data using TensorFlow. Figure 6 illustrates the features available in the pulse wave learning web application.

Figure 6. Navbar Page

The main feature of this web application is the "Pulse Predictor" section. As shown in Figure 7, it displays the Pulse Predictor page. On this page, there are four main buttons: "Select Image", "Canvas", "Predict", "Clear", and "Save Predictions", each serving its function. Users are prompted to input data, with two types of input available: users can make predictions using uploaded images. The "Select Image" button is used to upload images, allowing users to upload images stored on their internal files. The second input method is through drawing pulse waveforms on the display. Users will click the "Canvas" button to start drawing pulse waveforms on the display area. This input method enables users to practice drawing pulse waveforms, and if users do not have pulse waveform images, they can draw them directly on the web page.

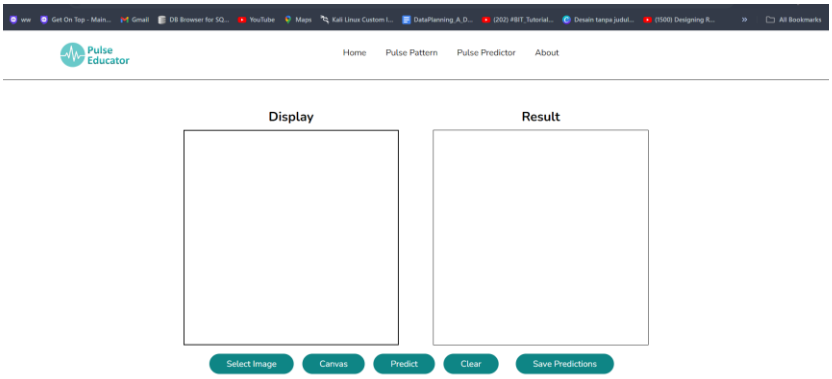

Figure 7. Display of Pulse Wave Type Prediction Page

In Figure 8, we see the display of the prediction results for the type of pulse waveform. Users click the "Predict" button each time they want to make a prediction, and the process remains the same regardless of the input. The prediction results are shown in the "Result" section, with a table containing the columns "Pulse" and "Prediction". "Pulse" indicates the type of pulse waveform, while "Prediction" shows the predicted result. There is a "Save Prediction" button, which is used to save the prediction data in either *.xlsx format or directly into an Excel worksheet. This allows users to view the prediction history they have made previously. However, if the user reloads the web application page, the previous data will be lost because the prediction data storage function is temporary. Therefore, users need to remember to save the data before reloading.

Additionally, users can click the "Clear" button to clear both the display and result sections, allowing them to draw or upload images again.

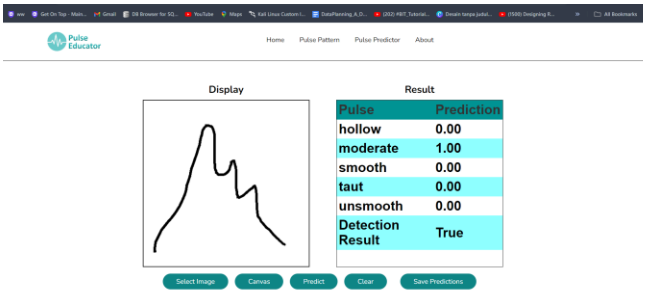

Figure 8. Display of Pulse Wave Type Prediction Results

In Figure 8, we observe the web application's display after making a prediction. On the left side of the web page, there is the display area used for input, either through drawing or uploading images. Different input methods provide users with a more varied learning experience in studying pulse waveforms. On the right side of the web page, there is the result section, which shows the predicted pulse waveform types. In this section, there are pulse waveform types, prediction results, and detection results. The pulse waveform types section displays the five predicted types of pulse waveforms, providing users with information about the input pulse waveform image. By showing the prediction results as numbers, users can assess the magnitude of the prediction. At the bottom is the detection result, indicating whether the detection result falls into the True or False category, allowing users to see the similarity between the predicted pulse waveforms.

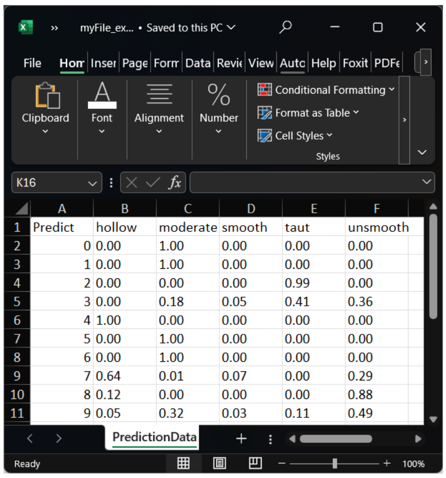

Figure 9. Download Prediction Data Results

In Figure 9, we see the result of downloading predictions in Excel format. It can be observed that the data displays the results of each prediction, showing the prediction data and prediction numbers. By using the Excel format, users can view their prediction history and process the data for other purposes.

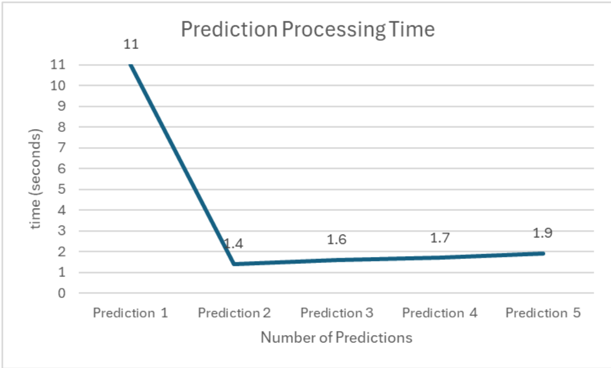

Figure 10. Prediction Time Test Results for Pulse Wave Type Images

The processing time for image prediction carried out by TensorFlow varies when initiated for the first time in the web application. The processing time for image prediction varies because the web application is initializing the first conversion into an image. As seen in Figure 10, the prediction results were obtained five times, with the processing time for Prediction 1 showing 11 seconds, while Predictions 2 to 5 experienced acceleration in prediction time, ranging from 1 to 2 seconds. This comparison result indicates that the system requires a long processing time only when the web application is first started, while subsequent processing will be faster, with a difference of only 1 second for each pulse waveform prediction image. This can occur because the system needs to download image data when initially predicting, so subsequent predictions simply use the downloaded data from earlier predictions.

In Figure 11, we see the home page, where users can view information about the pulse wave type prediction web application. Before accessing its main features, users can briefly understand the functionality of this web application. There is also a "start" button used to navigate to the pulse predictor page, allowing users to directly access its main features.

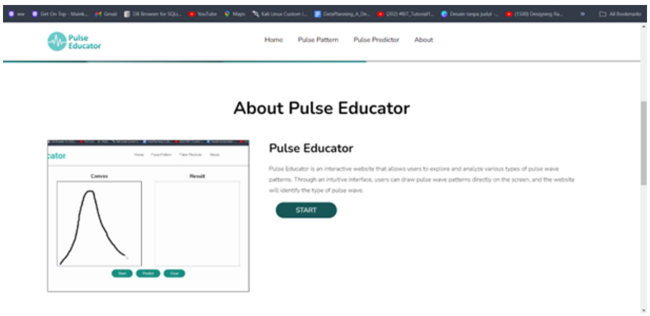

Figure 11. The introduction page display of the web application

In Figure 12, a brief overview of the five types of pulse waveforms is provided. On this page, users can view images of each type of pulse waveform along with a brief explanation. The brief explanation of each type of pulse waveform can be found in Table 2.

Table 2. List of explanations for each type of pulse waveform

Waveform Types	**Definition**	**References**
Hollow	A pulse waveform that is "hollow" occurs due to significant blood loss, resulting in a decrease in blood volume.	[29]
Moderate	The moderate type of pulse waveform is associated with high systolic pressure and pulse rate, as well as the pulse wave velocity in patients with hypertension.	[30]
Taut	Pulse waveform type tethered has greater peripheral resistance compared to slow waveforms, possibly due to strong blood vessel contractions.	[31]
Smooth	The Smooth pulse waveform type has high accuracy, low rigidity, and low breadth, and can be interpreted as a single generalization of combined beat sequence techniques with time-dependent phases.	[32]
Unsmooth	The non-smooth pulse waveform type has a smaller W1 amplitude, more NA waves, and a more curved and blunt shape with high amplitude, indicating lower vascular elasticity and greater stiffness.	[7]

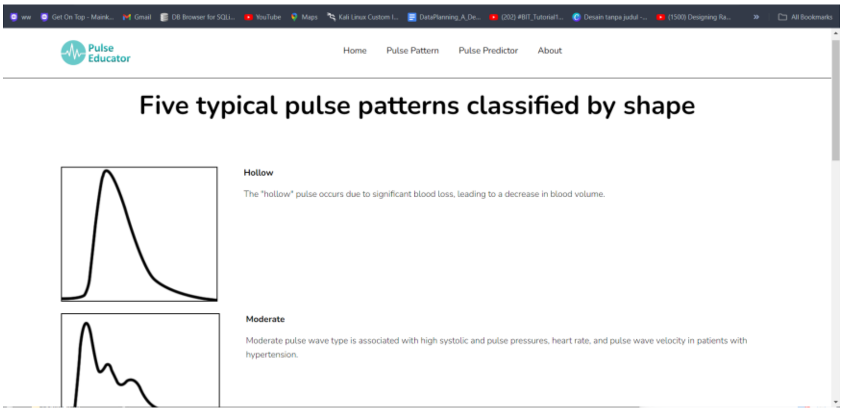

Figure 12. The Display of Materials on The Five Types of Pulse Waveforms

The last feature is the "About" page, where users are presented with a summary of information about the application creator, namely the researcher themselves, and can view the portfolio of the web application creator.

In accessing the pulse wave learning web application, users require Docker to access the web application. The researcher has uploaded the Docker application link at https://hub.docker.com/r/tiumy/pulse-educator so that users can directly use the web application through the Docker server without having to install it on other applications.

4. Conclusion

This research successfully demonstrates the potential of using artificial intelligence technology with CNN algorithms in classifying types of pulse waveforms. By comparing CNN architectures including VGG16, VGG19, and ResNet50, the researcher successfully utilized the VGG19 architecture with an accuracy of 99.08% for classifying types of pulse waveforms. The researcher successfully developed a web application from the trained dataset using VGG19 into a website using JavaScript and HTML5 and utilized TensorFlow as the framework for pulse wave prediction. By displaying the prediction results of pulse waveform types using drawing and image upload, and additional features such as information about the web application, materials about pulse waveforms, and developer information, this web application becomes interactive as a pulse wave learning medium. Suggestions for further research include utilizing other learning methods in pulse wave-type learning.

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