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Eye-DR: Mobile Application for Diabetic Retinopathy Screening

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ABSTRACT

The development of smartphone-based healthcare applications especially in medical diagnosis has become more appreciated as the pandemic COVID-19 happened. Diabetic Retinopathy (DR) is a condition that affects the small blood vessels in the retina as a result of prolonged impact of diabetes which may lead to complete loss of vision as it is the predominant cause of visual impairment among working-age individuals [1]. The evolution of portable ophthalmoscopes allows for smartphone cameras to be used as a medium for retinal imaging, especially in rural areas where healthcare services are limited. Therefore, utilizing the development of portable ophthalmoscopes has given the rural area of East Malaysia more opportunities to enhance healthcare services to reach more patients in the outskirts of Malaysia. Hence, the Eye-DR mobile application is designed to offer a third opinion to medical officers on DR diagnosis. The research is focused on the development of the user interface (UI) and user experience (UX) of a smartphone-based application for DR screening that will utilize a deep learning model. It is essential to identify the UI/UX building process of the smartphone-based app for medical disease diagnosis in order to develop a mobile app that can diagnose DR for any given retinal image. The study will also revolve around the design process of building a mobile application using Flutter and utilizing cloud computing (Google Firebase) for the model to work while reducing the application storage memory on the phone.

1. Introduction

The prevalence of diabetes worldwide has significantly risen due to changes in human behaviour and lifestyle during the past century. In 2021, it is reported in the Diabetes Atlas 10th Edition, it is estimated that there is an increase of 74 million people of age 20 to 79 who are diagnosed with

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diabetes [2]. Type 1 diabetes frequently develops in children and young adults while type 2 diabetes is the most common type which accounts for over 90% of all diabetes worldwide. It is caused by a combination of genetic predisposition, especially in specific ethnic groups, and environmental and behavioural variables such as a lack of physical activity, excessive consumption of high-calorie food, and obesity. Diabetes is correlated to multiple repercussions including cardiovascular heart disease, and microvascular medical conditions such as diabetic kidney disease, retinopathy, and peripheral neuropathy [3].

Diabetic Retinopathy (DR) is asymptomatic, as there is no apparent symptom noticed before blindness. This complication is considered a major complication occurring among patients diagnosed with diabetes mellitus. Clinically, DR is characterised as a microvascular condition characterised by retinal capillary injury resulting in secondary visual impairment [4]. Due to the disease's asymptomatic nature until advanced stages, it is believed that routine screening examinations can prevent up to 90% of vision loss [5]. Research has demonstrated that implementing a methodical process of regular screening and monitoring for DR is an economically efficient approach in decreasing the occurrence of blindness and visual impairment in individuals with diabetes mellitus [6,7]. Therefore, annual eye screening is crucial for diabetic patients to hinder the advancement of DR and avoid blindness [8]. Additionally, regular follow-ups enable timely interventions and effective management of DR.

The smartphone has become an essential tool as technology has drastically transformed all aspects of people's lives, including work, communication, and entertainment [9]. More smartphone-based healthcare services have been introduced by technologists to assist consumers in managing their health. Physicians utilise smartphones and mobile applications for several purposes in clinical practice, including communication, clinical decision-making, drug compendium access, medical education and training, health record maintenance, time management, and patient monitoring [9]. There is an increasing demand for portable medical care [10], especially among rural healthcare consumers who are considered a hard-to-reach patient population [11]. In Malaysia, the differences in population density between East Malaysia and Peninsular Malaysia are preventing the government from providing healthcare services to rural communities [12] as East Malaysia is more rural with difficult-to-navigate terrain making it more challenging to develop proper infrastructure to accommodate medical needs [13]. Currently, the medical officers will travel to the remote areas of East Malaysia to attend to the villagers and patients, while transporting enormous and cumbersome medical equipment. Hence, there is a demand for additional healthcare services and facilities to cater to the patients residing in rural areas of Malaysia. The advancement of portable ophthalmoscopes [14] has facilitated the concept of delivering medical services directly to communities, with medical professionals visiting various villages to conduct rudimentary health examinations.

However, the medical personnel on these visits lack the training necessary to provide a diagnosis for diabetic retinopathy to patients [15]. Thus, the digitalization of the screening process is crucial for medical officers in managing DR cases in rural areas. Thus, the main objectives of this work are to design and develop a mobile application for DR screening which focuses on user interface (UI) design (front-end), user experience (UX), and user data storage (back-end) that will incorporates an artificial intelligence (AI) classification model and cloud computing as a database. Various tools are identified and utilised for this purpose. The purpose of the proposed mobile app is to serve as a supplementary assessment tool while allowing ophthalmologists to review the generated reports for any potential inaccuracies made by the mobile application. Hence, the purpose of Eye-DR is to serve as a supplementary assessment tool for medical officials in the field, while allowing ophthalmologists to review the generated reports for any potential errors made by the mobile application.

2. Methodology
2.1 Software

Flutter SDK is a set of development and debugging tools for cross-platform mobile apps. NoSQL (Not Only SQL) is a distributed database consisting of the collection of key-value pairs, documents, graph databases, or wide column stores. Currently, Firebase is one of the platforms that uses No SQL database. Matlab is a computing platform that is built for engineering applications where it is used to train the deep learning model.

The programming languages used in the research are Dart, Matlab, and Python. Dart is an open-source and general-proposed programming language that can be used for mobile app development. Dart is needed to develop Android or iOS apps by utilizing Flutter software. Matlab language is used in the Matlab software that expresses matrix and array directly, making it easier to be used for developing deep learning models. Due to the complex nature of Matlab programming language, Python is required to integrate the Matlab model with the mobile app.

2.2 Convolutional Neural Network (CNN)

The CNN model is first trained using Matlab and is transferred to a Python environment to allow the model to interact with different programming languages that are used to build the Android and iOS versions of the app. Then, after training in Matlab, the model is exported to a Python savedmodel format and retrained using the training dataset. The model is then converted to TensorFlow Lite format.

For training and testing purposes, this research utilises the EyePACS dataset [16], which was downloaded from the Kaggle database. The photos were evaluated by a clinician who assigned a score ranging from 0 to 4 to indicate the existence of DR. A grade of 0 refers to No DR, 1 refers to Mild NPDR, 2 refers to Moderate NPDR, 3 refers to Severe NPDR, and 4 refers to PDR. The disparity in camera models and types utilised to capture the images in the dataset influences the visual characteristics of the left and right eyes, respectively. The images potentially contain noise, as evidenced by out-of-focus, underexposed, and overexposed portions. The dataset comprises separate folders for training data with 35,126 images and testing data with 1,754 images.

2.3 Cloud Computing: Google Firebase

The Google Firebase is employed in this project for a cloud-hosted database [17]. It is a free account that provides up to 5GB of storage and users can upgrade the capacity by subscribing accordingly. The trained model was uploaded to Google Firebase which is limited to 40MB memory storage. By utilizing the Firebase platform, it is secure and easier to integrate multiple platforms into a system with complete application testing services. For example, the testing services that assist the user in improving their application are Firebase Test Lab, App Distribution and Performance Monitoring.

2.4 Mobile Application Development

In this work, the mobile application is developed using Flutter software which enables the construction of native cross-platform (iOS and Android) applications using a single programming language and codebase [18]. Fig. 1 illustrates the block diagram for an integral part of the designed mobile app process for fully functional automated DR diagnosis. There are three integral parts in this proposed design: front-end, back-end, and API(s) of mobile app development. The front-end is the client-side of mobile apps, and the user can interact directly. The back end is known as the server-side of mobile apps, and it organizes and stores data. Application Programming Interface (API) is a software intermediary that allows two apps to communicate.

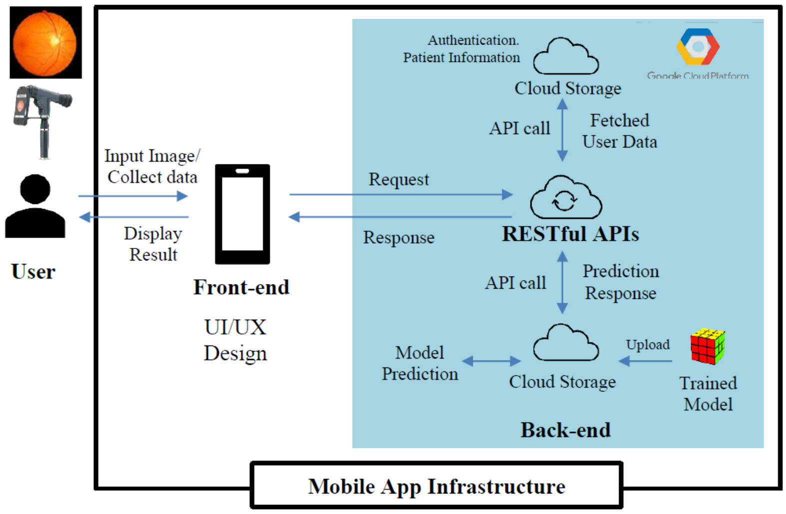

Fig. 1. Overview of the project

The proposed design can utilize Google Cloud Platform (GCP) services. There are two main back-end infrastructure sections: store user data and automated diagnosis. The data from patients' information, diagnosis and health reports can be stored and retrieved in Google Cloud Storage. The second section is to deploy the trained machine learning model into Google Cloud Storage. Then, the AI Platform Prediction is used to handle cloud computing resources for running the model and allowing any app to request a model prediction. It is a container for the versions of the machine learning model. Hence, the input images captured by the user will be predicted in this stage.

Fig. 2 illustrates the mobile application infrastructure that was developed. As initial work, this work focuses on the user interface design (front-end) and user data storage (back-end). Based on Fig. 2, Flutter is utilized as the hybrid front-end development with the benefits of the hybrid app mentioned in the literature review section. Flutter is an open-source mobile UI framework created by Google and released in May 2017. This software enables developers to develop a native mobile app using only one codebase. Flutter contains two important parts: SDK (Software Development Kit) and a framework. SDK is a set of tools to assist developers in developing applications, which includes services and tools to compile the code into native machine code. In addition, the framework is a collection of reusable UI elements such as buttons, text inputs, and sliders that developers can personalize into their interface design.

Firebase offers hosted back-end services like a real-time database, cloud storage, authentication, crash reporting, machine learning, remote setup, and hosting for static files. The Firebase features utilized in this project are Firebase Authentication, Cloud Firestore and Cloud Storage. Firebase Authentication offers ready-made UI libraries, simple SDKs, and back-end services to authenticate users for this project. Cloud Firestore is a scalable, flexible database from Firebase and Google Cloud for mobile applications development to store and sync data for the client- and server-side development. This feature is used explicitly for patient information data. Other than that, Cloud Storage is used to store and serve user-generated material, such as images or videos. The retinal image uploaded by the user will be stored in Cloud Storage.

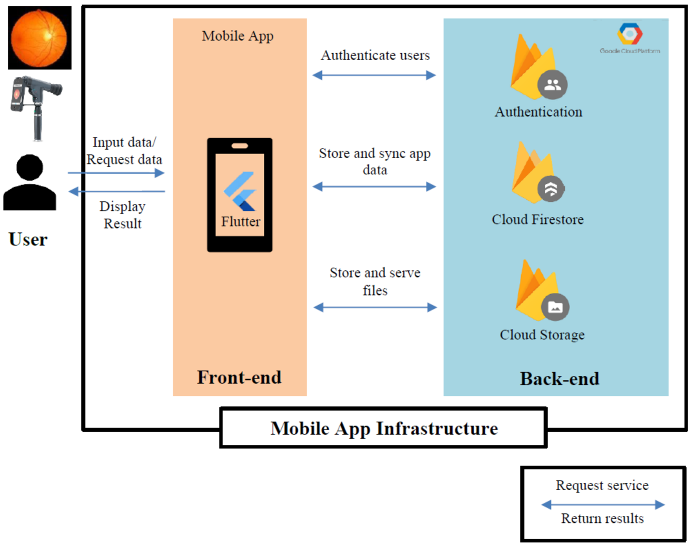

Fig. 2. Overview of the mobile application infrastructure

3. Results

The main objective of this paper is the design and development of the mobile application named Eye-DR. Eye-DR is an app that performs DR screening using fundus retinal images that incorporates Flutter to develop the UI features, cloud computing using Google Cloud Platform for the data storage and CNN for the AI model.

Table 1
User functions

Main Module	Function name	Description
Login Module	Sign Up	Users can register to the system.
	Login / Sign In	Users must log in to use the system.
	Logout	Session out from the system.
Home Module	Home	Users can access every feature from the homepage.
	Profile	View and edit his/her information.
	Complaint	If users having issues using the system, they can just send a message to the admin by using this function. The message will be shown to the admin by email.
	Settings	The settings of the app such as language, mode, privacy policy, contact us, and logout.
	Privacy and Policy	Privacy and policy of the app will be shown in this function.
Eye Scan Module	Patient Details	Users can add new patient information for diagnosis.
	Retinal Scan	Users can scan the retinal images after inputting patient details.
	Results	Users can view and share the diagnosis report.
	View Patients History	Users can view previous eye scans.

The initial design of the Eye-DR app consists of a Splash screen, Onboarding screens, Authentication screens, and four main screens. The main screen consists of Home, Eye Scan, Profile, and Settings screens. The app can be switched back and forth between English and Malay language according to the user. The app also contains light and dark modes by toggling on the switch in the Settings screen. Table 1 above shows the main user functions of the Eye-DR application.

Figure 3 shows the flowchart to navigate through the application based on the user functions in Table 1. The UI and UX of the app are constructed starting from the login module, home module, and eye scan module. The login module allows new users to create an account or return users to reset their password. Upon successful login, users are brought to the home screen where users are given options to either click on the eye scan or settings. The eye scan module works by registering the patient's details, capturing the patient's retinal image, scanning the image, and obtaining the diagnosis report. The settings screen includes features such as switching language, and mode, view the privacy policy, contact us information, and logout button. Based on the flowchart, a system for the application is created for both Android users and Apple users.

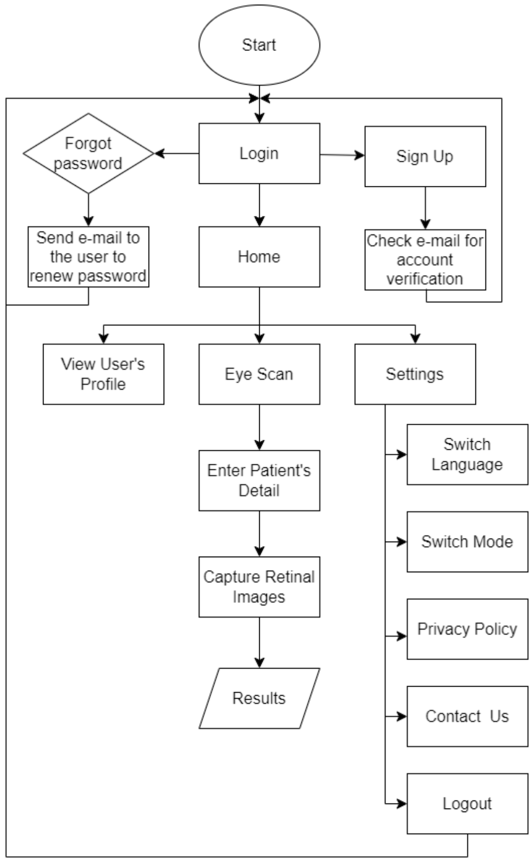

Fig. 3. Navigation flowchart through the application

The application concept depicted in Fig. 4 is elucidated by referencing Fig. 3. The Eye-DR application must adhere to the design principles, prioritising simplicity, ease of navigation, fast loading times, and reliable internet access to ensure user satisfaction.

Upon clicking on the application, the user is directed to the splash screen where the Eye-DR logo is displayed. The on-boarding screens offer a glimpse into the anticipated functionality of the application. Next, the user is directed to the login module where they are presented with the choices to either log in, create a new account, or recover a forgotten password. After logging in, the user is directed to a screen that contains all the primary features. The eye scan module enables the user to register each patient, collect their retinal scans, input them into the classification model, and generate the patient's report. Users can access the patient's screening history. If required, the user can access and observe their profile. It is imperative that the mobile application supports bilingual functionality and offers two display modes: light mode and dark mode. The light mode uses the hues of pink, cream, and light grey to establish the overall colour scheme, whereas the dark mode employs the shades of green, dark grey, and black, as depicted in Fig. 4. In addition, the application is optimized to minimise loading time and UI clutter. The mobile application size optimization methods that were implemented include extracting large files, language configuration APKs, screen density configuration APKs and code shrinking and obfuscation.

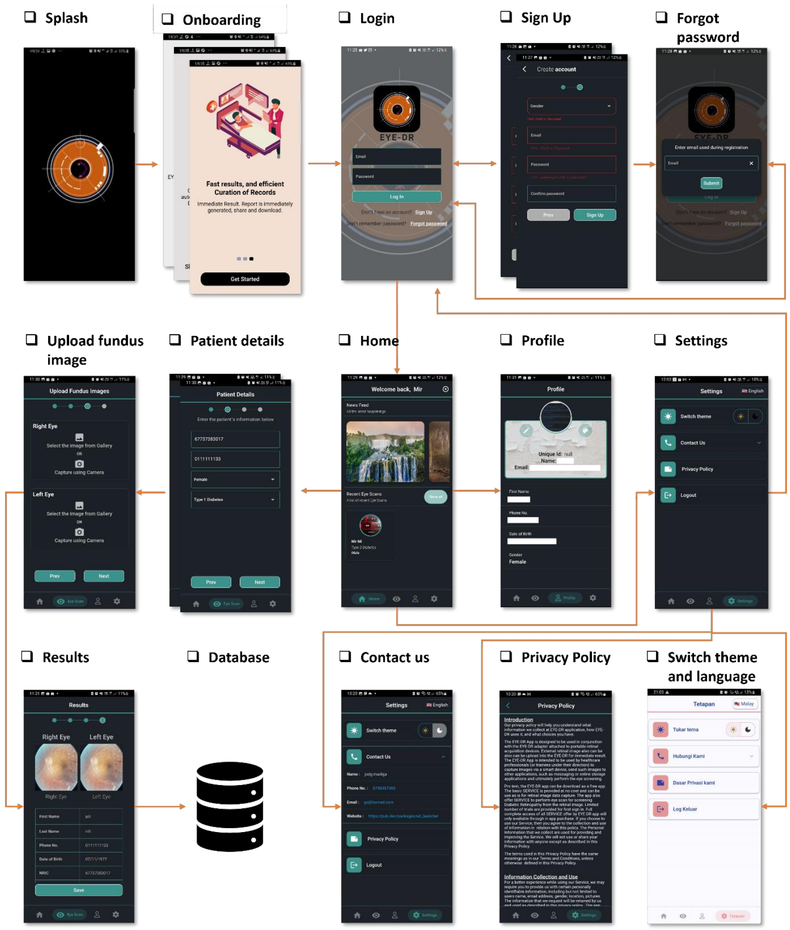

Fig. 4. Eye-DR application concept design

The Eye-DR mobile application was officially launched to the Google Play Store on the 15th of March 2023, after it successfully passed the User Acceptance Testing (UAT). The internal testing was performed by members of the team. We conducted a series of testing for the application during the pre-launch of Eye-DR. The application has no issues found in terms of stability, performance, security, and trust. In accessibility, there are a few warnings as the application was not built to target the disabled. The installation report is shown in Table 2. After that, a pilot survey is conducted to get user's opinions on the Eye-DR application design and usability which is further reported in Section 4.

Table 2
Installation report

No.	Information	Details
i	Type of testing	Closed Testing
ii.	Released date	14th March 2023
iii.	Available on	18,500+ devices
iv.	App download size	19.1MB
v.	Percentage of install for the test	100% (This means none of the testers had issues downloading the app).
vi.	Target SDK	31
vii.	API levels	21+(from Android 5.0 is covered)
viii.	Native platforms	arm64-v8a, armeabi-v7a, x86_64

4. Discussions

A survey was prepared to collect feedback from professionals of different backgrounds on the UI/UX design of the Eye-DR mobile application. With this survey, we aim to identify issues with the design of our mobile app.

Based on the survey, most of them have not heard about smartphone-based retinal image diagnosis. One of the questions is if the Eye-DR application is easy, good, and functional to use. Most of the users answered that the application design is functional and usable. The users are asked to rate the look and feel of the application. 12 users responded that the design is very good. On the question about the cohesiveness of the app, all the users answered with good, very good, and excellent. The comments and suggestions for the Eye-DR application are issues with the button's alignment, usage of relevant images and less text but more graphics. They also suggested that to include historical information to track patient health status, improve the quality of photos, and auto-send the report to patient email for their record.

During the development of Eye-DR design, there are several challenges faced by the developers that have to be addressed. The issues include model and mobile application integration, and the limitation of using Google Firebase to host the deep learning model and quantization process.

There is a challenge of integrating between two different platforms. As the model was originally trained in Matlab, the model has to be exported to the Python platform. The model then had to be converted to the tflite format as it is smaller and more efficient for mobile application usage. When the programming languages used are different, hence, there is a need for an API. The API reads the JSON file of the model; therefore, the model has to be populated with its metadata using Tensorflow Metadata Writer API. The tflite model is then uploaded to Google Firebase.

However, there is a limitation to using Google Firebase as the model hosting service. The limited model storage set by Google to 40MB has proven to be a major setback for the deep learning model. It is noted that the tflite format requires less memory compared to the saved model format upon conversion to the tflite format. To tackle this issue, one can consider utilizing the Google Cloud Storage to trigger creating a Virtual Machine (VM) instance where the user will be billed for the VM, use a different deployment platform with larger storage, develop a simpler model which leads to less memory, or bundle the model locally with the app. Any of these solutions will provide users with more flexibility in deploying their deep learning models.

To reduce the memory storage for the model, the quantization process is necessary, however, considering the complex structure of the model, this is a challenge. Hence, the quantization and pruning techniques are performed to reduce the unnecessary weights. Theoretically, the quantization technique will affect the model performance by ±5% while reducing the memory by approximately 50 to 75%. Another technique that is applied to the model is removing the later layers of the model and retraining the model. By removing the layers, we managed to reduce the storage by 20 Mb.

Several challenges need to be overcome before the Eye-DR can be implemented in real-life applications [19]. The image quality captured using a portable ophthalmoscope through a smartphone camera is poor when captured by users who are not trained to use the ophthalmoscope [20]. The images captured were blurry, contained noises, and were hindered by movements. Next, the integration process between the two platforms hindered the application interpretation of the images. Hence, image standardization is necessary before it is fed to the model.

If these challenges can be overcome, there is no doubt that expanding the features of Eye-DR to diagnose other retinal diseases as well as patients' self-monitoring systems is within reach. There is a demand for a lightweight but complex model as the complexity of the model will enhance the model's performance in real life. Other than that, a new approach for image acquisition is recommended, as the current portable ophthalmoscope has a small field of view. Also, more research is needed to understand the integration process between the model and the mobile application. By overcoming these challenges, an upgraded and more comprehensive mobile application with a high-performing model to classify DR can be produced.

5. Conclusion

In conclusion, this paper has focused on the primary goal of designing and developing the UI/UX of the mobile application, Eye-DR. The UI/UX developed for the application serves the purpose of performing diabetic retinopathy (DR) screening based on the retinal images captured that had utilized the usage of Flutter for UI features, Google Cloud Platform for the database, and CNN for the AI deep learning model.

Eye-DR will act as a secondary opinion for the medical officer with no training to diagnose DR. This application is hoped to ease the medical officer without the need to carry bulky machines to rural areas, especially in East Malaysia. The Eye-DR is targeted to be used by both Android and Apple users as the app uses the same database for both versions. It is noted that the application still needs to be improved in terms of model performance and image acquisition for model input. Therefore, additional enhancements will be implemented before Eye-DR is made available to the public.

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