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Transforming Tele-Ophthalmology: Utilizing Cloud Computing for Remote Eye Care

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Abstract. Background: Tele-ophthalmology is gaining recognition for its role in improving eye care accessibility via cloud-based solutions. The Google Cloud Platform (GCP) Healthcare API enables secure and efficient management of medical image data such as high-resolution ophthalmic images. Objectives: This study investigates cloud-based solutions' effectiveness in tele-ophthalmology, with a focus on GCP's role in data management, annotation, and integration for a novel imaging device. Methods: Leveraging the Integrating the Healthcare Enterprise (IHE) Eye Care profile, the cloud platform was utilized as a PACS and integrated with the Open Health Imaging Foundation (OHIF) Viewer for image display and annotation capabilities for ophthalmic images. Results: The setup of a GCP DICOM storage and the OHIF Viewer facilitated remote image data analytics. Prolonged loading times and relatively large individual image file sizes indicated system challenges. Conclusion: Cloud platforms have the potential to ease distributed data analytics, as needed for efficient tele-ophthalmology scenarios in research and clinical practice, by providing scalable and secure image management solutions.

Keywords. Telemedicine, Ophthalmology, Cloud Computing.

1. Introduction

The advent of telemedicine has revolutionarily transformed healthcare delivery, making medical expertise accessible even in remotest areas. In ophthalmology, the impact is particularly pronounced, given the visual nature of the specialty and the technical advances in imaging technologies. Tele-ophthalmology has emerged as a critical tool for providing eye care services [1].

The demand for tele-ophthalmology services is driven by several factors: an aging global population with an increased prevalence of eye diseases, the shortage of ophthalmologists in rural and underserved areas, and the ongoing advancements in digital imaging and communication technologies [2,3]. Despite these advancements, current tele-ophthalmology practices continue to face regulatory and technological limitations. Practical issues such as reimbursement and acceptability remain significant

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barriers. On the technological front, limitations include a lack of operator independence, challenges in device interoperability, and the need for both efficient and accurate image annotation and analysis, which are critical for effective ophthalmic diagnosis [2,4].

To address these rising issues in ocular diagnostics, especially in anterior segment imaging, Occyo (Innsbruck, Austria) has developed an imaging technology designed to take standardized high-resolution photographs of the visible ocular surface in an operator-independent way, applicable to telemedical use [5,6]. Employing such devices in a location-independent manner and sharing them with remote ophthalmologic experts for detailed examination, it has the potential to shape the future of ophthalmologic diagnostics [4]. However, the challenge lies not only in image acquisition, but also in the efficient transmission, storage, and analysis of the high-resolution image data. Therefore, standards like DICOM (Digital Imaging and Communications in Medicine) [7] and best practices like IHE (Integrating the Healthcare Enterprise) [8] are used to facilitate the seamless exchange and management of medical images and related information to use case scenarios.

In recent years, cloud services have emerged as a pivotal resource in the healthcare sector, offering scalable, secure, and efficient solutions for managing and processing vast amounts of medical data [9]. These services are increasingly valued also in telemedicine for their ability to manage and process medical data efficiently, offering essential features like scalability, security, and efficiency. Despite their potential, the practical implementation of cloud services, particularly in the domain of teleophthalmology together with specific solutions like the Google Cloud Platform (GCP), remains underexplored [10]. This study aims to bridge this gap by analyzing how cloud-based solutions can significantly enhance tele-ophthalmology and provide a prototype on utilizing the GCP for telemedical applications.

2. Methods

The concept for the prototype is based on the principles of the Integrating the Healthcare Enterprise (IHE) Eye Care technical framework [11]. This approach involves leveraging the GCP as a Picture Archiving and Communication System (PACS) and utilizing the Open Health Imaging Foundation (OHIF) Viewer as the ophthalmic expert's primary tool for viewing and analyzing images. Occyo's anterior eye photography device is used as the imaging modality within this workflow. The core idea behind this methodology is to test and evaluate a system designed for storing all data efficiently and securely within the GCP and provide means for adding related information like annotations. Building upon this foundation, the proposed workflow is designed to support telemedical routine eye care needs, facilitating the capture of high-resolution eye images during patient visits. The intention is to enable remote ophthalmology experts to precisely review and analyze these images, thereby paving the way for the creation of structured reports with support of the system. This envisioned process aims to bridge the gap in eye care accessibility, offering a glimpse into the potential for remote diagnostics and treatment planning that combines expert analysis with the convenience and efficiency of tele-ophthalmology. An overview of the proposed prototype is depicted in Fig. 1 which is based on the previously published DICOM Simulation Platform [7].

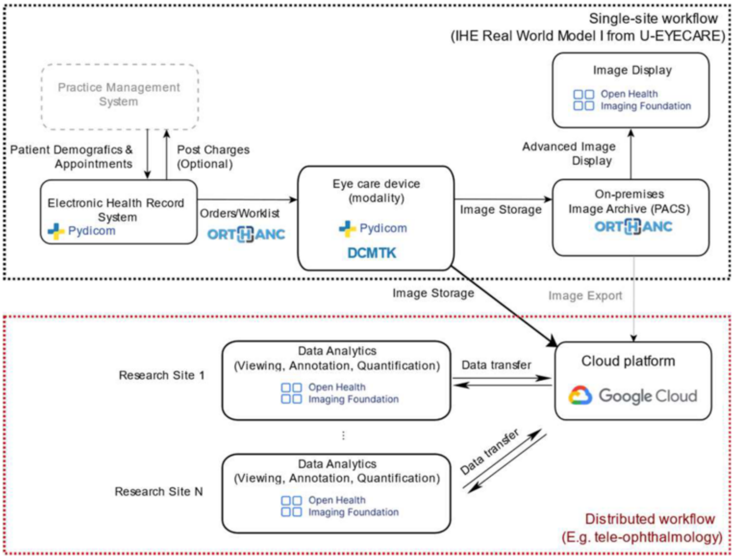

Figure 1. The workflow of the IHE Real World Model I from the U-EYECARE profile together with our DICOM simulation platform was expanded to enable the integration with a cloud platform, e.g., GCP.

The GCP offers a healthcare API for providing flexible, accessible and secure data stores such as DICOM or HL7 FHIR [12]. Further, the GCP is certified against several standards as outlined in Google Cloud's compliance offerings for the healthcare and life sciences industries within the European Union [13]. Beyond regulatory compliance the healthcare API offers data location control, and de-identification capabilities, ensuring utmost security and privacy adherence. We configured a DICOM store within GCP to accommodate the high-resolution ophthalmic images through DICOMweb. This web-based protocol facilitated seamless communication between our imaging modality and the GCP DICOM store. It allowed for the direct uploading of ophthalmic images from various locations, bypassing the limitations of traditional DICOM DIMSE networking. Strategies for optimal data transfer and memory optimization were analyzed. Further the imaging modality was integrated to utilize DICOMweb protocols, ensuring a streamlined process for transmitting images to the cloud. In parallel, we deployed an instance of the OHIF Viewer in the cloud [14], a well-established, open-source, web-based platform designed for DICOM. Known for its exceptional flexibility and seamless compatibility with DICOMweb, the viewer was configured to interface directly with the GCP DICOM store. This integration was pivotal in enabling relevant stakeholders to remotely access and analyze trial patient images.

Using this infrastructure, the OHIF Viewer provides the possibility to enhance its functionality. Individual so-called modes can be created in the OHIF Viewer, that offer a complete tailored functionality collection for the anterior segment photography use case. Each mode can load individual implemented extensions, e.g., an extension for annotating regions of interest (ROIs) within images to mark pathologies like lesions on the ocular surface and monitor them over time. Also, an extension within the OHIF Viewer is equipped with the capability to store annotations as DICOM structured reports which are exported to the GCP DICOM Store. These extensions will permit the input of general metadata, such as image quality assessments, and specialized scores like the

Efron grading for evaluating eye redness [15]. The integration ensures that all annotated information, along with crucial metadata, is cohesively maintained with the original imaging files, which is essential for maintaining the integrity and utility of the annotations and assessments in ongoing and future analyses.

This prototype is focused on the use case for data sharing for clinical research trials and involves using the platform to capture eye images and enable professionals to annotate and rate these images remotely. The ability to annotate and score images within the OHIF Viewer is anticipated to facilitate a more structured and comprehensive analysis, essential for research purposes.

3. Results

The prototype has successfully implemented a seamless integration of a GCP DICOM storage, which is specifically tailored to the management of high-resolution ophthalmic images. Problems arose due to the file size of these images, which initially exceeded acceptable waiting times when retrieving and displaying them in OHIF viewer with the default configuration. To tackle the challenge of large image file sizes and slow loading times in our tele-ophthalmology system, we applied JPEG2000 lossless compression, effectively reducing the average image size from 50 MB to ~30 MB per DICOM image. Additionally, we identified that the OHIF Viewer's simultaneous loading of images caused significant delays. By implementing a sequential loading strategy, we considerably improved the system's efficiency; where previously loading a single image from a set of five could take about 60 seconds with a 20 Mbit/s internet connection, the new approach allows the first image to be accessible in just 12 seconds. This enhancement, coupled with DICOMWeb's efficient and secure image transfer capabilities, has markedly optimized our tele-ophthalmology workflows. The successful integration of the OHIF viewer with our GCP DICOM storage has enabled a user-friendly interface for medical professionals to access, analyze, and annotate patient images remotely. Customizable through extensions, this setup enhances data sharing and analysis in research studies and lays the groundwork for future integration of machine learning and AI algorithms. These developments are crucial for advancing diagnostic capabilities and underscore our commitment to evolving a sophisticated, automated tele-ophthalmology solution.

4. Discussion

This study analyzes the potential of cloud-based solutions, particularly the GCP for teleophthalmology use cases. Hereby, we investigated the integration of the GCP into clinical workflows which potentially could be a step forward in increasing efficient and safe teleophthalmology practices. Hereby, modern cloud platforms are utilizing the DICOMWeb standard. In contrast, most medical imaging devices use the DICOM DIMSE protocol for data communication and transfer. Fulfilling this prerequisite is key for making an imaging device ready for web-based medical imaging and the interoperability with cloud platforms to be used in telemedicine use-cases.

In addition, DICOMweb protocols enhance tele-ophthalmology by streamlining image management and enabling remote analysis through compatible DICOM Viewers such as the OHIF Viewer. The decision to use the OHIF Viewer as the DICOM viewer met all requirements, as it offers extensive flexibility for expansion and customization as well as easy connectivity with the GCP [16]. The development of a specific ophthalmic device-related extension in the OHIF Viewer, i.e. a mode, is especially promising, enabling customizable annotations and assessments, such as eye redness [15]. The ability for remote annotation and scoring of images within the OHIF Viewer and being synchronized with the GCP data storage backend may impact ophthalmic research by fostering collaborative multi-site studies.

Information communication and usability challenges associated with file size and loading time emerged unexpectedly throughout implementation. The functionality to generate and display DICOM thumbnails is typically supported by known PACS systems, but this feature is currently not provided by the GCP. While lossless compression represents a viable strategy to mitigate the issue of large file sizes, it inadvertently results in thumbnails being loaded at full-size quality, thus not effectively reducing loading times for initial image previews.

The importance of addressing general bottlenecks cannot be overstated; reliance on cloud services like GCP necessitates fast and reliable internet connectivity and introduces increased complexity in integration, alongside persistent concerns related to data security. Furthermore, the effective management and maintenance of cloud-based platform demands the expertise of cloud specialists to ensure the smooth and secure functioning of the services. For research and education this is highlighting the need for a strategic approach to resource allocation and skills development within the context of cloud computing.

Looking ahead, the planned integration of artificial intelligence (AI) based tools into this platform is an exciting development. Previous studies have shown the efficacy of AI in medical imaging, particularly in fields necessitating detailed image interpretation, like ophthalmology [17,18]. Integration with the GCP, as proposed in this work, offers the possibilities to further utilize Google's machine learning frameworks and build machine learning tools based on the data ingested using the same platform. As the OHIF viewer supports the incorporation of such tools, the platform's capabilities can be greatly enhanced with innovative functions. This integration ensures a seamless user experience, empowering medical professionals with advanced tools for analysis and diagnosis directly within their clinical and research workflows.

In conclusion, this research demonstrates that the GCP provides a robust foundation for integration within a tele-ophthalmology setting, taking into account certain challenges for an effective and efficient integration. The successful but somewhat problematic deployment indicates a promising direction for future developments in this field, potentially leading to more accessible, efficient, and comprehensive eye care worldwide. Continued development and research are essential to overcome current limitations and fully realize the potential of tele-ophthalmology. Our next steps will be to use this presented platform for the purpose of analyzing and annotating clinical trial data.

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