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Integrating a Novel Eye Imaging System into Clinical Practice: An Open-Source DICOM Simulation Platform

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Abstract. Background: The integration of innovative imaging technologies into clinical workflows requires the utilization of a standardized data exchange format. The “Digital Imaging and Communications in Medicine” (DICOM) standard is widely used in healthcare to process and transfer medical images. However, no simulation environment is ready to use for development. The objective of this paper is to provide an open-source DICOM platform for integrating a novel ocular photography system into a clinical setting. Methods: After a thorough analysis of the available open-source tools, a subset was selected and aligned with the U-Eyecare Profile of Integrating the Healthcare Enterprise (IHE). Results: Orthanc served as a PACS with a modality worklist and the OHIF-Viewer for image retrieval. Minimal interfaces for the electronic health record and image modality were created. Docker-compose further integrates all components and simulates the network protocols DICOM Message Service Element and DICOMWeb. Discussion: The platform was used to develop and integrate the developed image modality and will be further utilized for teleophthalmology and processing eye images. The platform could be useful for other researchers to integrate an image modality into a clinical environment along IHE.

Keywords. DICOM standard, Ophthalmology, Health Information Interoperability

1. Introduction

Digital innovations and developments are currently disrupting the traditional healthcare system, which is centralized around large and specialized hospital centers [1]. Especially image-driven specialties such as radiology, dermatology or ophthalmology experienced multifaceted changes driven by the latest artificial intelligence (AI) developments and the heightened demand for new digital information & communication technology (ICT), which was accelerated by the Covid-19 pandemic [2].

Ophthalmology is a medical discipline that heavily depends on digital communication and imaging. There are now more chances than ever for the creation of

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effective and efficient ophthalmology diagnostic systems thanks to the innovations in telemedicine, AI and ICT [1]. According to studies, teleophthalmology, or the use of telemedicine for ophthalmic care, can significantly lessen the need for hospital eye services and expedite patient care [3]. This is especially true for diseases with high incidences, e.g., diabetic retinopathy or age-related macular degeneration, which are clinically assessed using optical coherence tomography (OCT) and fundus photography (FP) [4]. Recently, there has been a boost in applications addressing anterior segment diseases and imaging [2, 5].

Standardized image formats and communication are crucial for all medical image-based disciplines, especially in the era of big data and AI, which heavily depend on high-quality data comprising the image and subject information. The Digital Imaging and Communications in Medicine (DICOM) standard is considered the state-of-the-art approach for both, a structured image standard as well as a standard for medical image data exchange. Hereby, the DICOM Message Service Element (DIMSE) and the DICOMWeb protocols are used to exchange necessary information between actors in the healthcare environment (information providers and users) [6]. While DICOMWeb is a protocol that uses RESTful API calls to obtain and transmit DICOM data over the web, DIMSE is a low-level communication protocol used to establish a network connection and exchange data between medical imaging devices and servers. The use of DICOM is further complemented by other well-established standards, e.g., HL7-FHIR [6], which are collectively endorsed by the Integrating the Healthcare Enterprise (IHE) initiative and their best practices for standardized clinical workflows.

This work focuses on the Cornea Dome Lens Ocular Imaging System (CDL, Occyo GmbH), a technology developed for capturing high-resolution color photographs of the ocular surface at standardized eye position, focus and lighting. The device is designed to allow for a maximum level of operator independence. The system supports ophthalmologists in documenting and monitoring ocular surface problems like dry eye disease, corneal infection, or conjunctivitis over time. The goal is to establish a telemedicine platform for eye imaging and based on that to develop AI algorithms for advanced eye disease diagnosis as well as data-centric AI algorithms for advanced interpretation and diagnosis of ocular surface diseases.

Although several DICOM-based open-source solutions exist that may operate as actors in the IHE architecture, an integrated platform used out-of-the-box is currently not available. This study presents a DICOM simulation platform along IHE in the field of ophthalmology. As such, the platform might be used and adapted by vendors of novel imaging modalities for verification and validation purposes. Additionally, the platform offers the possibility of using an IHE-compliant workflow in settings without dedicated IT equipment for clinical studies in research centers or healthcare organisations.

2. Methods

For the ophthalmology domain, IHE provides the Eye Care Technical Framework which consists of a dedicated profile for the Unified Eye Care Workflow (U-EYECARE). This profile includes the description of three real-world scenarios, where we chose to focus on the “Real World Model I” [7]. This model describes a clinical scenario where organizations are utilizing a Practice Management System (PMS), an Electronic Health Record System (EHR) implementing a modality worklist (MWL), a centralized Image Archive and Image Display (e.g., a Picture Archiving and Communication System, PACS) and eye care diagnostic imaging and testing equipment (e.g., fundus cameras, slit lamps, refractive measurement devices, visual fields, etc.) as depicted in Figure 1. Thereby, each system can comprise one or multiple actors as defined in the IHE Technical framework. **PMS and EHR** are used for patient registration and appointment scheduling. While the PMS is mainly used for administrative purposes, the EHR is responsible for establishing patient records and scheduling appointments in various hospital departments. They usually communicate via HL7 messages and consists of multiple actors. The EHR implements a modality worklist (MWL) to schedule procedures for individual patients. The **Eye care imaging system** is any DICOM conform modality defined by its DICOM conformance statement. DICOM DIMSE and DICOM Web protocols might be supported by the modality. The imaging system retrieves the MWL, acquires the image and stores the image with all its metadata in the archive, i.e., a PACS system. The **Image Archive** is used to store and retrieve DICOM images and mostly acts as a service class provider and service class user. **Image Display** system is used to view the images and analyze the image data, respectively. This might also add reports, measurements, or other health-related information to the images in a standardized format.

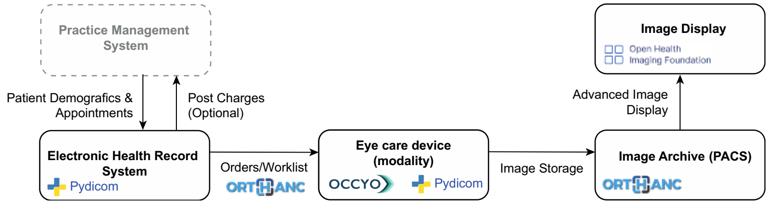

Figure 1. Workflow of the IHE Real World Model I from the U-EYECARE profile together with our selected open-source tools for the simulation platform.

According to this real-world model, we chose to align suitable open-source tools with the related systems to implement the IHE actors and transactions. The tools were further integrated into a connected environment for simulating the network. We conducted research to find open-source DICOM technologies that might be used for our platform. Our strategy involved completing a thorough online search of the available resources and considering several variables, including functionality, compatibility, documentation, and community. We considered online open-source repository websites like GitHub as well as blog posts and other articles about DICOM tools. The most suitable tools were chosen once the information had been assessed for its applicability to our platform. Finally, we chose one tool per actor and implemented the simulation platform according to the described IHE actors and related transactions.

3. Results

We collected a list of 32 suitable DICOM tools, libraries and frameworks which can be obtained from the authors upon request. Our final selection for the subsequent development of the simulation platform is stated in Table 1. We aligned the open-source components and custom-made scripts along the systems proposed by the IHE profile to simulate the Unified Eye Care Workflow (Real World Model I) as depicted in Figure 2.

The docker technology [8] was used to simulate network-connected systems in a healthcare context. Each component of the simulation platform was packaged in a docker container that might operate as a separate system on a separate machine in a real-world scenario. These containers were then organized using the tool docker-compose, which enables the linking of several docker containers into a common network and facilitates the management of all containers. This replicates the healthcare environment and enables the preconfigured simulation platform to be easily shared and executed on any docker-suitable device with very low effort.

Table 1. Overview of needed systems and related actors mapped to the selected open-source tools, libraries and frameworks utilized in the platform.

System in the Real World Model	Purpose [Actors] in the Platform	Implementation	Details
Image Archive (PACS)	Image archive [Image Manager/Image Archive], Modality Worklist Server	Orthanc Server [9]	lightweight DICOM server for medical imaging; web-based interface; DICOMWeb capability; Plugin for Modality Worklist
Image Display	Retrieve, view and annotate DICOM images [Image Display, Evidence Creator]	Open Health Imaging Foundation (OHIF) Viewer [10]	Web-based DICOM image viewer; utilized in several projects;
PMS/EHR	Creating the worklist [DSS/Order Filler]	Pydicom [11]	Arbitrary DICOM-worklist creation script
Eye care imaging system,	Providing a demo image [Acquisition Modality]	Pydicom [11]	creating DICOM images; realization of DIMSE / DICOMWeb
-	Component Encapsulation, Network simulation	Docker, docker-compose [8]	Containerization and multi-container management
-	Reverse Proxy	Nginx	Webserver with reverse proxy functionality
-	Persistence layer for Orthanc	PostgreSQL	Relational Database

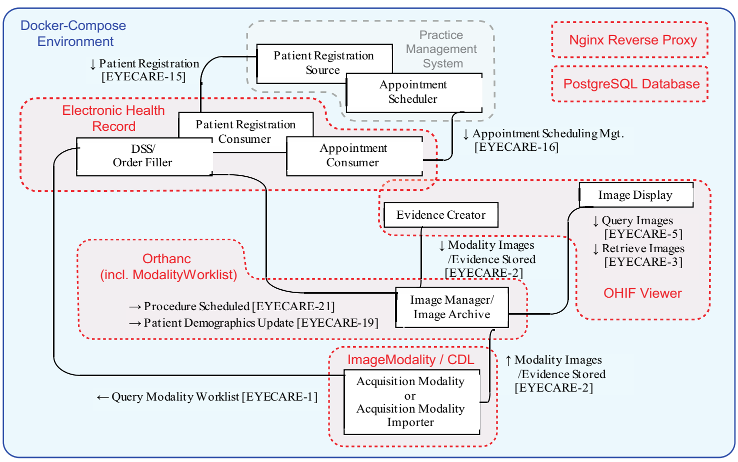

Figure 2. The alignment of our used components with the IHE profile. The needed components are encapsulated within docker containers (red boxes). Additional containers were added for a reverse proxy to enable accessibility and a database for data persistence.

The DSS/Order Filler actor was designed to simulate the worklist creation using a python script, that utilizes the Pydicom [11] library and creates a DICOM-Worklist based on user input and stored in a designated path in the configuration. It is important to note that no further EHR connection using HL7 is provided in the simulation platform yet, as the focus is set on the DICOM communication.

The Orthanc Server [9] was deployed in another container and was used to store and manage the medical images as needed for the related actor. In order to persist the data for the PACS, Orthanc connects to a PostgreSQL database that also runs in a separate container. The simple file-based worklists plugin provided by Orthanc was enabled in the configuration before initiating the environment.

The image modality was simulated by isolating the DICOM module from the CDL imaging system and feeding the module with a sample image. This approach eliminates the need for the full imaging system to be operational during the simulation. The module retrieves the available worklist from Orthanc and securely stores the associated image in Orthanc. Another container running the web-based OHIF-Viewer [10] is used to access stored images in Orthanc and provide further possibilities to annotate the images, based on the default functionalities of OHIF (simple measurements and notes). The Evidence Creator actor is also part of the OHIF-Viewer but currently only provides basic functionality, e.g., to annotate Text in an image. This actor will be the focus for future enhancement and expansion.

For the described transactions in Figure 2, we omitted EYECARE-15, EYECARE-16 and EYECARE-19, as they are supported in our simulation by just creating a new or modifying an existing Worklist. All other transactions were carried out using both DICOM DIMSE as well as the DICOMWeb Protocols.

4. Discussion

We successfully created and deployed the DICOM simulation framework for integrating a novel image modality for anterior eye segment photographs into a clinical workflow. The simulation platform simulates the IHE Unified Eye Care Workflow in accordance with the Real World Model I, which implies that the EHR implements a DICOM Modality Worklist and interfaces with a PACS.

The biggest challenge was to assure the compatibility between the various components and interaction with current systems. To overcome this, we explored several tools and ultimately relied on web-based components and open-source solutions which helped to guarantee interoperability and compatibility. Finally, we combined two popular DICOM tools, i.e., Orthanc and OHIF Viewer, and complemented these systems with custom-made python scripts based on the Pydicom library as well as the DICOM module of the imaging system. All systems were containerized using docker for integration into the DICOM simulation framework. Finally, a reverse proxy container realized with Nginx provides access to the containers outside the environment as needed for further telemedical developments. As a result, we were able to establish communication between all systems and their actors by precisely following the DICOM standard and leveraging the DIMSE and DICOMWeb protocols. The source code and instructions for deploying the simulation platform are available online [12] for interested parties.

This work is particularly aligned with the ophthalmology domain. However, the approach of adapting IHE profiles to open-source components and connecting them via a container-based environment like docker might be suitable for other profiles as well. The system's adaptability allows for easy substitution of individual components. We focused on the U-EYECARE Real World Model I, as this is the most common setting for the current intended purpose of the CDL imaging system. The integration of the DICOMWeb protocol into the imaging modality provides potential for future workflows, e.g., to connect to cloud platforms such as the Google Cloud Platform, which features DICOMWeb to store and manage images in their Cloud Healthcare API. These platforms could then be further utilized for telemedical consultation on the image data, data labeling [13] and eventually the development of novel data-centric AI pipelines [14].

The tools used in the simulation platform were selected based on initial research, but no systematic review was performed. However, it should be noted that well-established and maintained open-source tools in this field are scarce, thus it is important to highlight their accessibility and discoverability in order to guarantee adequate quality. Docker and docker-compose provide means to easily deploy the environment on any machine with just one *docker-compose.yml* file that holds all instructions. Besides some configuration files (e.g., Orthanc config), no further information is needed to utilize the environment. Docker-compose further eases the deployment by utilizing component names instead of IP addresses in the configuration, so the related IPs were dynamically assigned at runtime. Further, it is possible to integrate docker with the host network by using a reverse proxy. This allows e.g. to install Windows-based DICOM tools on the host and interact with the simulation platform. We used this feature during development, e.g. for the EHR and the demo image modality, without the need to run a further container.

The utilization of the web-based components Orthanc and OHIF-Viewer provides a perfect foundation for simulation and testing. They deliver a browser-based user interface without installing any third-party software. Open-source tools have the advantage of utilizing them as a base for future developments.

In this work, we demonstrated our platform to be a valuable tool for the design, simulation, and evaluation of DICOM-based imaging workflows. The usage of docker-compose and other open-source technologies enables the simulation platform to be easily shared and executed on any machine, making it a useful resource for the healthcare community. While the currently implemented workflow focuses on an eye-related clinical scenario, the platform's adaptability will allow us to adapt and expand this workflow for telemedical scenarios or structured data analysis workflows.

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