Integration of a Zero-footprint Cloud-based Picture Archiving and Communication System with Customizable Forms for Radiology Research and Education

Jason Hostetter, MD, Nishanth Khanna, MD, Jacob C. Mandell, MD

Rationale and Objectives: The purpose of this study was to integrate web-based forms with a zero-footprint cloud-based Picture Archiving and Communication Systems (PACS) to create a tool of potential benefit to radiology research and education.

Materials and Methods: Web-based forms were created with a front-end and back-end architecture utilizing common programming languages including Vue.js, Node.js and MongoDB, and integrated into an existing zero-footprint cloud-based PACS.

Results: The web-based forms application can be accessed in any modern internet browser on desktop or mobile devices and allows the creation of customizable forms consisting of a variety of questions types. Each form can be linked to an individual DICOM examination or a collection of DICOM examinations.

Conclusions: Several uses are demonstrated through a series of case studies, including implementation of a research platform for multi-reader multi-case (MRMC) studies and other imaging research, and creation of an online Objective Structure Clinical Examination (OSCE) and an educational case file.

Key Words: Cloud-based PACS; web-based forms; educational case file; multireader study.

INTRODUCTION

Cloud-based picture archiving and communication systems (PACSs) have been widely available for the past several years. The National Institute of Standards and Technology broadly defines cloud computing as a "model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources" (1). Such a rapidly elastic framework offers several advantages to a PACS implementation, including offloading of server considerations to the cloud provider with resultant reliable and maintenance-free performance, and ensuring broad compatibility across computing platforms and handheld devices.

The functionality of a cloud-based PACS can potentially be further enhanced by integrating web forms to allow easily customizable data collection linked to each DICOM (Digital Imaging and Communications in Medicine) examination. Web forms are commonly used in research, education, and administration. However, the integration of images into web-based forms such as Google Forms (Google Inc., Mountain View, MA) or SurveyMonkey (San Mateo, CA) is relatively primitive, and to our knowledge, there is no online form provider that supports the DICOM standard and allows standard PACS functionality. Combining a zero-footprint PACS with web-based forms may offer unique benefits to several research and educational tasks. Additionally, universal compatibility among desktop and handheld devices could facilitate studies or educational tasks tailored for mobile computing and more general applications.

Several types of research may be able to utilize the integration of web forms with a cloud-based PACS. For instance, multireader, multicase (MRMC) studies are commonly performed to evaluate the accuracy of diagnostic tests (2); however, these studies can be difficult to reliably perform (3). MRMC studies are resource-intensive to carry out, as each reading session may need to be administered in person, and data often need to be collected manually. Additionally, it may be important to evaluate the interpretation time required for a novel imaging method, as has been described in the recent literature for digital breast tomosynthesis (4,5) and novel bone

Acad Radiol 2018; ■:■■–■■

From the Department of Diagnostic Radiology and Nuclear Medicine, University of Maryland, Baltimore, Maryland (J.H., N.K.); Department of Radiology, Division of Musculoskeletal Imaging and Intervention, Brigham and Women's Hospital, Harvard Medical School, 75 Francis St, Boston, MA 02115 (J.C.M.). Received October 25, 2017; revised December 16, 2017; accepted January 15, 2018. **Address correspondence to:** J.C.M. e-mail: jmandell@bwh.harvard.edu

https://doi.org/10.1016/j.acra.2018.01.031

processing algorithms (6,7). By integrating a cloud-based PACS with web forms, much of this process can be automated, readers can be recruited without geographic restrictions, each reader can potentially increase focus on the interpretation of images rather than the recording of imaging findings, and the time required to interpret each examination can be automatically recorded. By combining the PACS and the form collection into a single window, data entry errors can potentially be avoided (such as typing in an incorrect case identification number). Management of multiple windows can be simplified by presenting both the imaging and the forms in a single web browser window, and compatibility can be extended to all modern desktop and handheld environments. In addition to MRMC studies, other types of research may also be facilitated using an integrated cloud-based system including studies requiring two or more readers to interpret the same set of examinations and make measurements or describe imaging findings pertaining to a certain disease process.

Similarly, a cloud-based PACS with web forms may offer significant benefits to education. For instance, Objective Structured Clinical Examinations (OSCEs) are commonly used to assess residents' competency during training (8). These examinations can be time-consuming to administer and to score, and a cloud-based system has potential advantages including the ability to facilitate more regular and comprehensive assessments. Specific to radiology education, such a system would allow the learner to interpret an entire cross-sectional examination rather than be shown a single key image containing the important finding, thereby more accurately simulating the actual clinical practice of radiology. Such simulation has been proposed to offer several benefits in radiology education (9–11).

Therefore, the purpose of this endeavor was to create a cloud-based system combining a zero-footprint online PACS with web forms for research and education. In this report, we describe the technical means utilized to integrate web-based forms with a cloud-based PACS. We then will highlight potential applications of this system by describing research and educational case studies with example workflows.

INTEGRATION OF FORMS WITH CLOUD-BASED PACS

Cloud-based PACS

The central component of this project is a zero-footprint cloud-based PACS offering both free and paid subscription tiers, http://pacsbin.com, which was developed by the first author (J.H.) and created with ubiquitous web technologies and based on the open-source Cornerstone library (12). Cornerstone is an HTML5 and JavaScript-based library to display interactive medical images on any modern browser that supports the HTML5 canvas element including desktop, mobile devices, and tablets. A zero-footprint viewer enables access to images on a browser without requiring installation of additional software (13). Similar types of online PACS have been previously reported in the radiology literature (14,15). This PACS was designed for image sharing and educational use rather than clinical practice, and thus all DICOM images are de-identified at the time of image upload, and only de-identified images are stored on the cloud servers. The PACS supports a full range of standard image viewing and manipulation functions including multisequence viewing with cross-localization, zoom, pan, and window and level. Annotation and image markup is also implemented, allowing linear measurements (ruler), elliptical region of interest measurements (with automatic calculation of mean and standard deviation of attenuation or signal intensity and measurement of area in square millimeters), and the ability to draw arrows with or without text annotations.

Similar to other cloud-based case files (16,17), the cloud-based PACS utilizes a front-end and a back-end approach for content management, image storage, and image display. The back-end comprises the web server and the cloud-based image storage and content management, and was created with industry-standard programming languages and cloud communication and data storage protocols. The web server was written in JavaScript using Node.js (9), an open-source server-side back-end implementation of the JavaScript programming language that is powered by Google's V8 JavaScript engine. Metadata was stored and retrieved using the open-source MongoDB document-oriented database. Cloud image storage was based on Amazon Simple Storage Service (S3) (Amazon Inc., Seattle, WA), and several image processing routines were implemented with Amazon Lambda. S3 and Lambda services are provided as part of Amazon Web Services, a widely used cloud infrastructure platform. Only de-identified data are stored on the back-end cloud servers, as all DICOM tags that contain potentially identifiable information are automatically stripped at the time of image upload. A list of the DICOM fields that are removed at the time of upload is provided in Table 1. Fields containing technical information about the scan parameters (eg, slice thickness, repetition time, echo time, number of averages, magnetic field strength) are not anonymized as these may have educational and research importance. There is currently no capability to perform pixel-level anonymization. Therefore, ultrasound images are not supported at this time, as ultrasounds typically embed patient information into the image file, and anonymization requires more sophisticated methods (18). Secondary capture images and postprocessed images are also not supported, as systems generating these images can sometimes embed patient information.

The front-end is the user interface displayed via a modern web browser on the local device. The standard HTML5 and JavaScript languages render the user interface on the end-user's device and communicate between the end-user and the web server. The PACS web page provides account and content management features to allow users to register and manage their account and to manage uploading of DICOM data.

An edge server may also be installed within an institution's network to enable direct export of DICOM images from clinical PACS to the cloud-based PACS. The edge server manages image transfer from the clinical PACS using the standard DICOM Message Service Element image transfer protocol.