User Centred Design and Implementation of Useful Picture Archiving and Communication Systems for Effective Radiological Workflows in Public Health Facilities in Zambia

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Radiological workflows in public health facilities in The Republic of Zambia are performed using manual processes. With a broad spectrum of stakeholders—Physicians, Radiographers and Radiologists—involved in radiological workflows, the efficiency of health service provision is drastically reduced, subsequently compromising clinical care. While there are a number of software platforms that are used in radiological workflows, Picture Archiving and Communication System platforms are crucial as they are primarily used to store, manage and facilitate access to Medical Images. This paper outlines the user-centred design and implementation of a prototype PACS platform aimed at demonstrating the feasibility of designing and implementing a PACS platform for use in public health facilities in Zambia. The prototype PACS platform was subsequently evaluated in order to assess its perceived usefulness and ease of use. The results indicate the feasibility of implementing and deploying PACS platforms in public health facilities in Zambia and, additionally, their potential usefulness.

CCS CONCEPTS •Human-centered computing~Human computer interaction (HCI)~HCI design and evaluation methods~Usability testing•Human-centered computing~Human computer interaction (HCI)~HCI design and evaluation methods~User studies•Human-centered computing~Human computer interaction (HCI)~HCI design and evaluation methods~Laboratory experiments•Human-centered computing~Human computer interaction (HCI)~Interactive systems and tools~User interface management systems•Applied computing~Life and medical sciences~Health care information systems

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1 Introduction

The automation of radiological workflows, such as through implementation of Picture Archiving and Communication System (PACS)—software tools used to store, manage and access medical images such as X-rays—and Radiology Information System (RIS)—software tools used to manage radiological workflow processes as requests for patients to be examined, has undoubtedly proved valuable at improving the productivity and efficiency of radiology departments. Although the implementation of PACS systems often result in increased workload for some individual stakeholders—such as radiologists, gains are ultimately realised through the resultant time efficiency and enhanced image storage, access, management and transfer.

However, the lack of PACS has been identified as the critical missing element for international radiology development in resource constrained countries [7]. In The Republic of Zambia, public health facilities lack this crucial software platform and as such, radiological workflows are currently performed using manual processes. For instance, historical medical images are stored on optical discs and external hard drives. Coupled with other confounding challenges including the critical shortage of radiologists, low utilisation of technology among stakeholders and the broad spectrum of stakeholders involved in the radiological workflows, this drastically reduces the efficiency of the radiological services thereby compromising clinical care. Zulu and Phiri [14] highlighted challenges and opportunities associated with the implementation of Enterprise Medical Imaging (EMI) strategies, whose crucial infrastructure components are PACS platforms.

This paper outlines the design, implementation and subsequent evaluation for usefulness, of a prototype user-centered PACS platform aimed at demonstrating the feasibility of designing and implementing potentially cost-effective PACS platforms for use in public health facilities in Zambia.

The remainder of this paper is organised as follows: Section 2 describes relevant literature related to this work; Section 3 outlines the methodological approach employed to conduct this study; Section 4 describes and interprets the results associated with the study and, finally, Section 5 presents concluding remarks and potential future work.

2 Related Work

The challenges associated with access to radiological services in Low and Middle Income Countries (LMICs) are extensively documented in literature. Hricak et al. report that a global assessment of medical imaging revealed significant shortages of human resource and equipment in LMICs [5]. Frija et al. further emphasise seriousness of these challenges and highlight the importance of access to imaging services in LMICs due to the rise in cases of non-communicable diseases [4]. Zambia faces a challenge of not having enough radiology workers countrywide, a situation that slows down the process of delivering radiological findings to support medical diagnosis and decision making, with a recent study reporting the existence of only nine (9) Radiologists in public health facilities, servicing a population of 18 million [1].

In one of our most recent studies aimed at identifying potential ways of addressing radiological workflow challenges in public health facilities in Zambia, a SWOT analysis conducted revealed challenges and potential opportunities that exist through the use of Enterprise Medical Imaging [11]. While EMI strategies involve the

use of various technological infrastructure, PACS platforms are considered a crucial technological infrastructure. This study focused on early attempts at designing and implementing PACS platforms to be used in public health facilities in Zambia.

In the recent past, a number of Free and Open Source Software (FOSS) PACS platforms have been designed and implemented, focused on facilitating the storage of medical images. They include tools and services such as ClearCanvas [2], Dicoogle [8,9], Orthanc [6], DCM4CHEE [13] and EasyPACS [10]. While the design and implementation considerations and approaches are different, the vast majority of FOSS PACS platforms are integrated with basic features necessary to store, manage and access medical images. As part of this study, a systematic comparative analysis—outlined in Section 3.2.1—was done by focusing on crucial feature offerings.

3 Methodology

A mixed-method approach was used as the basis for conducting this research, combining the use of guided interview sessions and questionnaires.

Ethical clearance was granted by The University of Zambia Biomedical Research Ethics Committee (Reference Number: 2731-2022) and The National Health Research Authority (Reference Number: NRHA000024/10/05/2022), to conduct this study at two public health facilities—University Teaching Hospitals (UTHs) and Levy Mwanawasa University Teaching Hospital (LMUTH). In addition, formal permission was granted from the two facilities.

3.1 Medical Image Workflows

In order to understand how radiological workflows associated with medical images are conducted, a study was conducted with two (2) key stakeholders: Radiologists and Radiographers. Radiographers are technicians responsible for performing imaging examinations on patients and, subsequently producing corresponding medical images in appropriate modalities, while Radiologists are medical experts who interpret the medical images produced and report the findings.

This study was carried out at two (2) large referral hospitals in Zambia: UTHs and LMUTH. The target population for the study included all Trainee Radiologists and Radiographers at the two (2) public health facilities. Convenience sampling was used to identify potential study participants. Guided interview sessions were conducted in order to determine how medical images were stored, managed and accessed and, more importantly, the policies and procedures associated with medical imaging workflows.

3.2 Design and Implementation of Picture Archiving and Communication System Platform

3.2.1 Picture Archiving and Communication System Frameworks Feature Evaluation

An evaluation of the identified FOSS PACS Platforms—ClearCanvas [15], Dicoogle [8], DCM4CHEE [16], EasyPACS [17] and Orthanc [18] was carried out to assess the suitability and effectiveness of the platforms. The evaluation involved the assessment of the PACS platforms considering the following factors: “Base Languages”, “Extensibility”, “Extensibility Languages”, “Operating System Support”, “Database Support”, “Search Service”, “Authentication Support”, “DICOM Compliance”, “DICOM Modality Worklist”, “API Support”,”Scalability”, “Relative Adoption” and “Community Support”. Ultimately, the Dicoogle platform was chosen as the base framework to be used to implement the PACS Server.

3.2.2 Picture Archiving and Communication System Design and Implementation

Using input from the interactions with key stakeholders—outlined in Section 3.1—and the systematic comparative analysis of existing FOSS platforms—outlined in 3.2.1—an appropriate base PACS framework was identified as the basis for the design and implementation of the UTHs PACS prototype platform.

The design and implementation of the PACS platform necessitated the development of two software components: the PACS Server/Archive—responsible for the storage and retrieval of medical images—and a corresponding PACS Client—used to ingest/deposit medical images into the PACS Server. In essence the medical images are deposited into one of many storage locations integrated with the PACS Server

Radiographers would ideally use the PACS Client to ingest/deposit medical images after performing an examination with an applicable modality, while Radiologists and Physicians would primarily use the PACS server to retrieve medical images.

As stated in Section 3.2.1, the Dicoogle FOSS toolkit was used as the base platform framework for the implementation of the UTHs PACS Server. Specifically, extensive changes were made to the front-end and, additionally, the platform was modified in order to facilitate password authentication. Furthermore, the feasibility of utilising cloud storage services was explored by using Amazon Web Services [19] as a case example.

The PACS Client is a standalone thin client implemented to facilitate seamless upload of DICOM images to the appropriate storage services associated with the PACS Server. The Python Flask [20] Web framework was used to implement the PACS Client.

3.3 Prototype User Evaluation

The PACS platform, implemented as outlined in Section 3.2, was evaluated in a controlled environment in order to assess relative potential to being adopted into a typical public health facility in Zambia. Radiology Registrars from UTHs were recruited, using convenience sampling, in order to participate in the controlled study which involved interacting with the deployed PACS prototype platform and subsequently completing a questionnaire.

Participants were required to perform a series of predefined tasks which involved searching and browsing for a medical image stored in the PACS platform. Participants were then required to complete a TAM 2 based questionnaire comprising of a section to capture participants' demographics, TAM 2 construct items—TAM 2 helps explain perceived usefulness and usage intentions in terms of social influence and cognitive instrumental processes [12]—and a questionnaire item for participants to provide general comments about the PACS platform and the study in general. TAM 2 instrument comprises questionnaire items—measured on a 7-point likert scale—associated with constructors that helped in the assessment of the perceived usefulness and usage intention for the PACS platform.

4 Results and Discussion

4.1 Workflow Challenges

Guided interviews were conducted with six (6) participants—four (4) Radiographers and two (2) Trainee Radiologists. All the participants had more than four (4) years experience with radiological workflows.

Interactions with Radiographers focused on determining challenges associated with image storage and management. The results indicate that medical images are primarily stored in both analog and digital formats, with a combination of Compact Discs (CDs), External Hard Drives and storage rooms used as primary storage techniques. Interestingly enough, there was reference to Patients being used as a means to preserve medical images, possibly to ensure that medical images are available to Referring Physicians when needed. Expectedly, the main themes linked to challenges with medical image storage were largely associated with retrieval of existing medical images and storage capacity.

The interviews with Radiologists were primarily aimed at determining challenges associated with accessing medical images during the interpretation process. The main issue raised is associated with long-term preservation of medical images. For instance, [Radiologist 1] emphasised that follow-ups with patients are difficult as images are typically given to patients and will generally be unreadable, making it difficult to

determine the progression of diseases. [Radiologist 2] echoed this point by highlighting that films will frequently be discarded in order to reclaim space for recent medical images. Interestingly enough, [Radiologist 2] made mention of the importance of preservation of medical images in order to further research.

While some challenges, such as issues related to capacity, might not be directly addressed by implementing and deploying a PACS platform, issues related to retrieval and medical images would clearly be resolved with the deployment of a PACS platform. Another important point to note is that issues linked to capacity would be resolved through the implementation of proper policies and procedures and, additionally, a commitment from management in investing in the procurement of storage space required for long-term preservation.

4.2 Prototype Picture Archive and Communication System Platform

Figure 2: Screenshot of the Prototype Picture Archiving and Communication System

Figure 2 shows a search result page rendered using the final version of the PACS Server high fidelity prototype that was designed and implemented. Once successfully logged into the PACS Server, a Physician or Radiologist can search for medical images using open ended text queries corresponding to metadata linked to the medical image.

Using the content rendered on the search result page, the user can then browse to the desired medical image using the DICOM hierarchy [3], making it possible for Patient, Study, Series and Image data to be accessed. The access to specific images associated with a Study Series has a provision for users to view thumbnails of medical images.

While the basic discoverability features would be sufficient for Physician and Radiologists to use the platform, further enhancements are required to implement vital features that would enable downloading of DICOM formatted medical images and integration with other platforms used in public health facilities. Incidentally, one of the main goals for the implementation of the prototype was to use it as a probe during the refinement of requirements for the implementation of a production quality PACS platform.

4.3 Evaluation Using TAM 2 Questionnaire

4.3.1 Participants Demographics

A total of eight (8) Radiology Registrars (Trainee Radiologists) at different levels of training participated in the study. Eight participants were used due to the shortage of Radiologists in the country and, more importantly, in the study setting. Registrars at higher levels of training also had prior exposure to other training sites besides the study site. Most of the participants were females. In addition, most of the participants had “1—5 years” medical practising experience. Furthermore half of the participants had no experience using PACS platforms.

4.3.2 *TAM 2 Constructs and Participants Remarks*

The TAM 2 questionnaire items for each of the constructs described in Section 3.3 were aggregated and average score computed. Figure 3 is a radar chart that illustrates average scores for the TAM 2 constructs.

The results indicate that most of the participants highly—Strongly Agree, Moderately Agree or Somewhat Agree—rated the "Intention to Use", "Job Relevance", "Perceived Usefulness" and "Result Demonstrability". The logical explanation for this could be that participants were able to determine the obvious benefits of using a PACS platform as opposed to the manual workflows currently used. This assertion is supported by comments made by [Radiologist 1] and [Radiologist 2] during the interview sessions outlined in Table 3, in Section 3.1. The low number of responses related to "Output Quality", "Perceived Ease of Use" and "Subjective Norm" can be attributed to the basic features available through the prototype PACS platform. Additionally, the study was conducted within a short space of time, using predefined tasks, making it difficult for users to appreciate the full potential of the platform. Perhaps the most interesting results from the TAM 2 constructs are the low number of responses linked to "Voluntariness". An argument to be made is that the results suggest a need to put in place organisational policies that would require medical images to be stored and accessed through PACS platforms, once deployed.

The general comments provided by study participants mostly consisted of suggestions on how to improve the PACS platform. The general comments suggest a need to further involve experts during the refinement of requirements as the production-quality PACS platform is being designed and implemented.

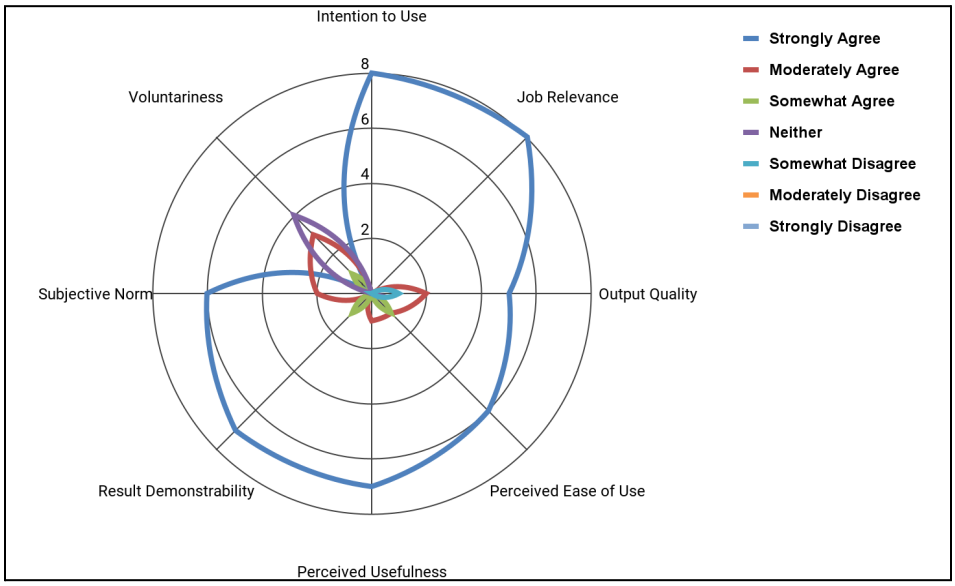

Figure 3: Spider/Radar Chart Illustrating Average Ratings for the Seven TAM 2 Constructs

5 Conclusions and Future Work

This paper outlined a study conducted to design, implement and evaluate a prototype PACS platform aimed at demonstrating the feasibility of designing and implementing potentially cost-effective PACS platforms for use in public health facilities in Zambia.

There is presently ongoing work focused on implementing production-quality PACS platforms for use in public health facilities in Zambia, with the prototype PACS platform described in this paper used as a basis to continuously refine software requirements. Additionally, efforts are being made to explore the potential of

using machine learning techniques to automatically classify medical images, once ingested into PACS platforms.

PACS platforms typically operate within a complex ecosystem of heterogeneous software platforms and as such, there is a need to comprehensively take interoperability into consideration during the development of such systems. While current efforts are confined to well-resourced public health facility settings in Zambia, there are a number of remote health facilities that might require the development of PACS platforms that can easily operate in settings with limited bandwidth; potential future work could explore the design and implementation of tools for devices associated with significantly small form factors. Potential future work could also focus on effective ways of ensuring that PACS platforms are interoperable with a wide array of software platforms used in public health facilities.

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