Int. J. Advanced Networking and Applications
Volume: 17, Issue: 03, Pages : 6933-6943 (2025) ISSN: 0975-0290
https://doi.org/10.35444/IJANA.2025.17306

A Mobile Personal Health Record System for Resource Constrained Environment

Richard Ssembatya
Department of Computer Science, Mbarara University of Science and Technology, P.O Box 1410, Mbarara – Uganda
Department of Computing and Technology, Uganda Christian University, P.O Box 4, Mukono-Uganda
Email: richssembatya@gmail.com
Justine Mukalere
Department of Computer Science, Mbarara University of Science and Technology, P.O Box 1410, Mbarara – Uganda
Department of Computing and Technology, Uganda Christian University, P.O Box 4, Mukono-Uganda
Email: jmukalere@gmail.com
Moreen Kabarungi
Department of Information Technology, Mbarara University of Science and Technology, P.O Box 1410, Mbarara – Uganda
EMAIL : moreen@must.ac.ug

ABSTRACT

While there has been an increase in the design and development of Personal Health Record (PHR) systems in the developed world, little has been done to explore the utility of these systems in the developing world. Despite the usual problems of poor infrastructure, health records for the developing world need to conform to users with different models of security and literacy than those the PHR systems where originally designed for. In this paper, we report on a PHR system distributed across mobile devices with a security model and an interface that supports the usage and concerns of low literacy users in Uganda. We show that suitably adapted PHR systems can address the needs of low-literacy and technology-constrained users in developing countries.

Keywords - Electronic Personal Health Records, Mobile Application, Push Model, Resource Constraints, Usable Security

Date of Submission: August 01, 2025 Date of Acceptance: September 30, 2025

I. INTRODUCTION

Personal Health Records (PHRs) have received considerable attention as a means by which a patient can access, use and share his or her healthcare information, thus improving the quality of healthcare. Although there is no generally agreed definition of personal health record (PHR) [17], PHRs have been described as "an electronic application through which individuals can access, manage and share their health information in a secure and confidential environment" [10]. PHRs include applications that help individuals take a more active role in their health, and therefore represent a repository for patient data. PHRs can be presented in two different formats: paper-based format or electronic format maintained by the owner of the computing device. While Electronic Health Records (EHR) systems function to serve the information needs of the healthcare professionals, PHR systems provide health- related information of an individual from a single, or multiple sources of EHR systems across networks [14].

Recently, there has been an increase in the activities that promote the adoption of PHRs in developed countries [24]. Many healthcare providers and information technology vendors have invested in PHR systems to provide quality healthcare services to their patients and customers. For example, the Department of Veterans Affairs (VA), with its approximately 25 million veterans, has invested into a Web-based PHR system called MyHealtheVet to allow US veterans obtain access to personal health information [37]. The EPIC[1] "MyChart" provides a Web-based portal that allows patients access a variety of PHR functions, including reviewing test results, medication, Allergies and scheduling appointments [52].

While there has been an increase in the design and development of PHR systems, little has been done to explore their utility in the developing world. In this paper, we report a PHR system distributed across mobile devices with a security model and an interface that supports the usage and concerns of low literacy users in Uganda.

[1] Epic is private and employee-owned company responsible for developing, installing and supporting in-house applications. Epic's leadership team includes clinicians, developers and process experts – people deeply experienced in patient care and healthcare technology.

In prior work, we proposed an Identity-Based Encryption (IBE) inspired architecture that protects patients' records on a mobile phone. Here we extend this work and develop a mobile phone-based PHR tool called M-Health App that enables secure sharing of PHRs beyond the hospital's boundaries. Using the development of M-Health App as an exemplar, we further illustrate how User-Centered Design (UCD) drove the design and testing of the application. We show that we can provide the benefits of PHR systems to address the needs of low-literacy and technology constrained users in developing countries.

The rest of the paper is organized as follows. Section 2 describes the motivation of our research. Section 3 explains the design requirements and gives a brief overview of our system. Section 4 describes the design methods and finally, conclusion and future work come in section 5.

II. MOTIVATION

Providing efficient and timely access to healthcare services in rural areas of developing countries is a difficult task. Current PHR practices in most rural areas are primarily paper-based [20, 32, 3]. Paper-based PHR systems impose many disadvantages such as incorrect recording of diagnoses, unavailability and loss of patient information, delays in accessing the information and space limitations for record-keeping [3, 32]. Additionally, due to infrastructural constraints such as intermittent power and internet connectivity, the introduction of computing technologies to automate these processes is equally challenging.

In a related study that was carried out to identify how the current healthcare system works in developing countries, it was observed that the process of using patient data is mainly paper-based. When providers see patients, paper- based forms are completed to document the encounter. Every few days, the encounter along with laboratory data is manually entered into the EHR system and then returned to the patient's record. Upon a return visit, the provider reviews the patient's record on paper using the previous encounters to guide decision making. Most EHR systems in developing countries focus on reporting aggregate statistics to the stakeholders [2].

A systematic review of EHR systems conducted as part of this research reveals a number of open research areas that must be addressed in order to meet patient's requirements particularly in developing countries;

EHR systems are online only: The majority of EHR systems require online access control decisions. Relying solely on online access control systems is limiting, particularly in developing countries where access to the servers is frequently disrupted by frequent power outages and limited bandwidth among other constraints. When the server fails or becomes unavailable, access control decisions cannot be made, making PHRs unreachable.

Provider-Centric Environment: Most EHR systems are geared towards healthcare providers. Patients have little or no access to their records. Personal Health Record systems such as Microsoft HealthVault [36], Indivo^{tm} [21], and Dossia [12] empower users with some access but the access must be online.

In addition, all the tools we found are developed with user contexts in the developed world and thus do not represent the needs of the users in developing world [50].

In order for the PHR systems to satisfy the intended users, specifically in developing countries, existing systems need to be extended on mobile phones such that records can be made available when hospital servers are offline [50]. This will reduce the need to rely on online access control authorities in the provision of personal health records.

It is interesting to note that the adoption rate of mobile technologies in developing countries is among the highest rates globally [22]. International Telecommunication Union (ITU) estimates indicate that almost four in every five people in developing countries own a mobile phone for information access, exchange and transfer [22]. The transfer and exchange of information can be used in the context of applications for health purposes [40, 41], education [41, 46, 48] and banking [6, 29].

III. DESIGN REQUIREMENTS

The design of a successful mobile phone-based PHR tool involves factors related to the technical characteristics of the device [26, 13], the use of the tool [13] and privacy issues [51]. These factors impose PHR designers with new challenges such as: design for limited output facilities (small screen sizes and font size support), design for mobility and design for a wide group of people with various levels of technology competencies. Additionally, mobile phones have less memory and processing capabilities, which are important to consider when developing secure and attractive PHRs.

In terms of interface design and usage, Jones and Marsden [24] gave practical guidelines towards an aesthetically pleasing mobile application interface: each screen node of the application should fit the mobile phone screen; the navigation of the application should be structured hierarchically and support towards backtrack and easy access to the previous screens. These requirements have been considered in the design of our PHR tool described below.

IV. SYSTEM OVERVIEW

Traditionally, access control architectures are designed to secure health records at the hospital server. When the server fails or becomes unavailable for example due to frequent power outages that are common in developing countries, access control decisions cannot be made, making health records unreachable. Building on IBE architecture, we designed a PHR system distributed across mobile devices to enables secure sharing of PHRs. Contrary to the previous approaches, our system enables patients to download and update their PHR onto the mobile phone and securely share their records with healthcare providers in an offline mode i.e. when hospital servers are offline due to unstable main electricity and/or unreliable internet connection.

To enable offline access, the developed M-health App incorporates the "pull model" where patients can periodically download and update their health records to the mobile phone with minimal user intervention.

Int. J. Advanced Networking and Applications
Volume: 17, Issue: 03, Pages : 6933-6943 (2025) ISSN: 0975-0290
https://doi.org/10.35444/IJANA.2025.17306

Once the encrypted records are downloaded to the mobile phone, the application then breaks down the records into an XML hierarchical structure such that records can be viewed\shared selectively. However, only users with a PIN that satisfies the policy will be able to decrypt. Our application has been developed using Android platform. Earlier studies indicate that Android is among the most popular open-source platform for mobile devices. The mobile application interface to the server side is implemented with Php scripts running an apache web server and storing encrypted data on MySql database. The user interface for data entry by medical practitioners is implemented using pure java.

V. PRIVACY AND SECURITY CONSIDERATIONS

Benaloh et al [7] explored the challenges of preserving a patient's privacy in electronic health record systems and argued that security of PHR systems should be enforced via encryption as well as access control. Therefore, we investigated encryption and access control approaches that are appropriate for our case in order to meet patient's requirements regarding security and privacy of their records.

Encryption is necessary in our system for protecting patient records. Our goal is to store and transmit patient's records encrypted so that no one sniffing the network can get access to the data. Different approaches have been proposed for securing data using encryption: network encryption (since part of the network is wireless) and data encryption using public key cryptography. In the next section, we discuss these approaches and choose the best option for our case.

The wired equivalent privacy (WEP) protocol currently available in most of the mobile phones provides confidentiality on wireless networks. However, previous research by Bittau et al [8] found that it is not considered to be secure against a casual eavesdropper attack. We therefore need a more secure protocol in order to enforce patient's privacy.

Traditional access control approaches such as public key cryptography (PKC) are cumbersome to apply to mobile devices that have restriction on memory and battery life. Managing keys has often been a limiting factor in real world applications [7, 33, 16, 24]. Keys need to be created and distributed to all users through the use of digital certificates. Key and Certificates have a finite lifetime and need to be renewed. All these add unnecessary complexity to our system and thus do not offer a feasible solution for our case.

```
Input: PIN, C, dklen
Output: DK

Begin
    Generate a 64-bit random number
    /* Pad the PIN*/
    DK ← SHA-1 (PIN, Salt)

/* Hash the output repeatedly for c iterations */
For (c = 0; c < 2000; c++)
   DK ← Hash (SHA-1, DK, salt)
Endfor

If (DK > dklen)
/* Shrink DK */
# of blocks to delete = (length (DK) – dklen) / block_size

     else
     /* increase DK to dklen */
     /* create extra blocks to fill in key length*/
     #of blocks added = (dklen – length (DK)) / block size

Endif
Output (DK)
End
```

Figure 1: Key generation Algorithm

VI. IDENTITY-BASED ENCRYPTION

Identity-based encryption (IBE) offers more flexibility than PKC in our case. The main advantage of IBE over other traditional methods is that any string can be used as an encryption key and thus there is no need for key management [47] [16]. The table 1 below describes the key generation algorithm.

The private key is obtained by authenticating to a trusted authority called the Private Key Generator (PKG). Furthermore, managing user accounts is easier. When a user, such as a doctor, leaves the hospital, his account can be disabled and thus no longer have access to decrypt. From a usability point of view, IBE is an ideal to our environment.

VII. DESIGN METHOD

A. User Centered Design

Mobile health or M-health represents a relatively new trend in the field of personal health records. It involves the use of mobile devices in the provision of personal health information. The convenience of data access and mobility enables patients to access their health records and promote quality healthcare. However, its ultimate success largely depends on whether the intended users find the application useful. Numerous studies have recommended user-centered design (UCD) as an approach where end-users influence the design activities in order to improve the usefulness of the application [24, 11].

Gould and Lewis [18] described three guiding principles of UCD: 1. Focus on users and tasks early and throughout the design process, 2. Measure usability empirically, and 3. Design and test usability with users in an iterative manner. In the next section, we describe how each of the three principles of UCD was applied to the design and testing of M-Health App.

B. UCD Principle 1: Focus on Users and Tasks

An interdisciplinary team was assembled to ensure that M-health App addresses the latest medical behavior and computer science standards. The team included a senor clinical officer from Allan Galpin Health Centre, who provided guidance on health-related tasks. The clinical officer also introduced us to other healthcare professionals and patients at the clinic, whom we worked with throughout the entire study. Allan Galpin Health Clinic (AGHC) is a Uganda Christian University health centre responsible for the provision of healthcare services to students and staff (and their dependents). The clinic is located within Uganda Christian University Mukono, along Bishop Tucker Road, about 33 kilometers from Uganda's capital and main city Kampala. Currently, Allan Galpin Health centre offers health-related services to over 8000 people.

C. Analyzing Patient Tasks and Requirements

Understanding patient characteristics, their requirements and the health-related tasks to be performed was our primary concern. This enabled us to understand patient's interests and needs that may impact the use and effectiveness of the application. After receiving ethical approval from the National Research Council and the Institutional review board, we recruited and interviewed 60 patients from among the patients who visit the Centre. The patient's average age was 28.9, median = 30 and range 18 –46.

Int. J. Advanced Networking and Applications
Volume: 17, Issue: 03, Pages : 6933-6943 (2025) ISSN: 0975-0290
https://doi.org/10.35444/IJANA.2025.17306

The semi-structured interview protocol contained a combination of yes/no, multiple choices and open-ended questions, that determined how often the participants visit the healthcare provider, what kind of information are they always required to provide and how would they "feel" about having their personal health records on mobile phones. Our aim was to have a clear understanding of patients' requirements towards mobile phone-based PHRs.
Similar to other situations, there is significant number of patients who provide personal information to their health service providers. Most of the patients whose personal information is collected would be concerned if their information is accessed by unauthorized users. The study further reveals that, although the majority of patients (75%) would like to have their personal health records on their mobile phone for portability, taking medication, consulting test results and personal control, they are also concerned about cases of privacy and simplicity of use. 84% of patients noted that they would communicate electronically with their healthcare providers if given the means to do so.

D. Contextual Inquiry with the Clinical Officer

We further conducted an interview with a clinical officer at Allan Galpin Health Centre. The semi-structured interview was conducted at the health centre in her office, in order to determine: how the current health record system works, what constitutes personal health records, what information goes into a patient health records and lastly, in terms of patient confidentiality, what information the patient can have on a mobile phone? This also gave the respondent an opportunity to discuss her work and her relationship with the patients. During the initial part of the interview, the clinical officer was asked to give examples of situations where she considers the current health record system unsatisfactory. These situations were then discussed in greater depth. The respondent was then asked to give concrete examples how they have been dealing with them.
Interestingly, the health centre currently uses "Clinic Master" – a client-server-based application to monitor its patients. Patients' details are captured using clinic forms and then entered by the data clerk into the clinic server. When patients come for treatment at the clinic, they only present the patient number and their details such as demographic information, clinical problems, allergies, diagnosis, previous medication, chronic problems and surgeries are displayed on the computer system.
The Clinic Master has significantly simplified the work of the healthcare professionals at the Centre and improved quality care. In addition, it has also reduced the long queues for patients. This was also witnessed by one of the patients during our interview;

"…When I came here for medication last month, I precisely took less than 6 minutes to be served. I expected to receive and hawk cheats from one room to another to convey information, but to my surprise this was not the case. After submitting my ID number at the help desk, everything fell into place. I would be told to proceed to the next step only to find my requirements assembled. How the communication was done, I don't know…."

However, the clinical officer highlighted that, although Clinic Master has been developed towards improved service delivery; its operations and functions are fully dependent on online access control authorities. When the server fails, or become unavailable due to frequent power outages in Uganda, (during this period, the country was going through 12 hour rolling power cuts) access control decisions cannot be made, making patients' health records unreachable. Under normal circumstances, this can result in patient harm. Our respondent further noted that;

"…Within this week, we have experienced internet interruptions thrice, whole days and this made patient's records unreachable…"

When asked how they have been dealing with such situations, the respondent reported that such problematic situations have forced them to keep paper-based PHRs for patients, which represents a massive fragmentation of clinical information.
We also reviewed Clinic Master with the clinical officer and the following gaps were confirmed;

1. **Paper-based PHRs**. Due to frequent power outages and unstable internet connections, the health centre keeps paper-based PHRs as an alternative to Clinic Master in the provision of personal health records.
2. **Access Control to EHRs**. Despite patients' desire to protect their medical records, Clinic Master does not adequately provide meaningful access control mechanisms to patients' records. Records on the server are not protected, and all clinic employees have access to the medical records for all patients.

E. UCD Principle 2: Empirical Measurements

1) Low-Fidelity Prototypes

In moving towards the creation of a functioning system, we engaged users in co-design. Low-fidelity paper prototypes (indicating sketches of interface elements) were used to get feedback regarding features such as the appearance of interfaces, syntax of commands, and the performance of simple tasks.
We recruited a sample of eight patients using random sampling to take part in the design. The group was then divided into two groups, each with four participants in which the researcher acted as the facilitator for each group. Figure 2 shows an example from our participatory design sessions.

Participants were briefed about the overall objectives of the session and the goal to be accomplished. They were also reminded that they were the users of the system and that is why they were designing the application. They were also asked to think about the things that they do frequently during and after visiting the doctor or any healthcare professional.
In order to stimulate the production of paper-based PHR application design, we created a story-board showing activities that patients perform when they visit the healthcare provider. The designs were then re-arranged, starting with what they would want to see first. After each session, a walk through was done in order to identify any issues and for participants to justify their choices. Each group then started developing the prototypes with the researcher as the facilitator.
Although the initial prototypes did not have all the functionality of the final product, some parts of the design were ready to be tested and could be developed and modified more quickly.

During this process, we obtained good feedback from users before we proceeded to the more expensive back-end programming activities [24, 43].

Figure 2: Few examples from our participatory design Sessions

F. High-Fidelity Prototypes

Despite the advantages of low-fedelity prototypes in predicting patients' preferences in the actual product, researchers believe that low-fedelity prototypes do not provide a good forum for user evaluation, and thus the need for a high-fedelity prototype [45, 24].

We built a number of prototypes to refine the design ideas. These prototypes incorporated an IBE architecture developed by Changyu [9] to enables secure sharing of personal health records beyond the hospital boundaries. Contrary to the previous approaches, our system enables patients to download and update their medical records securely onto the mobile phone and selectively share their records with healthcare providers in an offline mode i.e. when hospital servers are offline due to unstable main electricity and/or unreliable internet connection.

VIII. System Architecture

Figure 3 describes the inner processes of the encryption operations of our architecture. In the first step, the patient registers with the hospital and the details are sent to the hospital database. Registration enables patients to have an account with the hospital server. When a new or modified record is submitted for storage at the hospital sever, the prescription module parses the records to the encryption module where sensitive parts are selected for encryption using a 128-bit Advanced Encryption Standard (AES) session key. For efficiency purposes, our architecture uses an approach in which the records are encrypted using a 128-bit AES session key and the session key is protected using an IBE encryption scheme. The protected session key is then transferred to patient's mobile phone. Once records have been encrypted, the encrypted records can then be stored at the hospital own server and/or exported to the patient's mobile phone along with metadata, which includes the encrypted symmetric key and the associated disclosure policies.

The hash value derived from these policies is encrypted along with the session key for integrity check. The architecture is a form of public key encryption and the corresponding private keys are generated by the Private Key Generator (PKG). The PKG uses the patient's credentials (originally submitted to the hospital database) to generate the private key. For security reasons, private key is then used to protect the session key before it is delivered onto the patient's mobile phone.

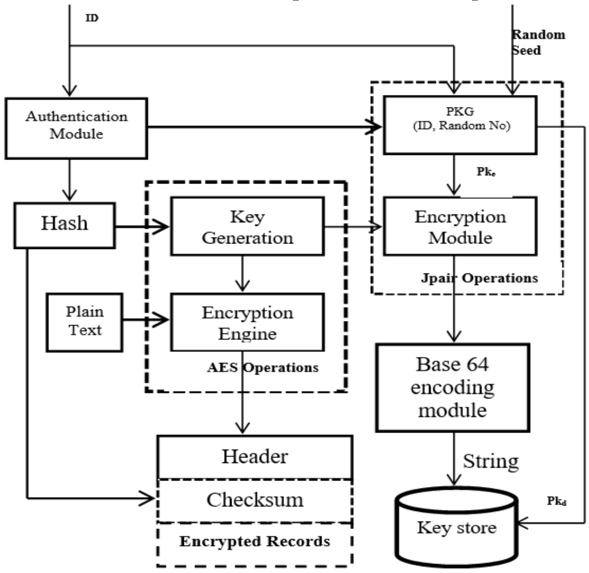

Figure 3: The Inner Processes of the Encryption Operations of our Architecture. SK represents the session key, Pk_e and Pk_d represents the public and private keys computed by the PKG

The PKG also called the key server is responsible for computing each user's private key. As long as the patient has registered with the hospital server, he/she can send a private key request to the key server in order to receive the private key. Patients obtain their private keys through the developed prototype without the need for external import or copy and paste of the private key. The only action required is to send a private key request to the PKG and the private key is then transfer and stored to the appropriate location on mobile phone.

D. System Implementation

As mentioned earlier, the IBE functions only constitute part of the proposed architecture. Our aim is to develop a usable application that protects patients' PHRs on mobile phones. To achieve this goal, the use of a programming language with capabilities of creating a graphical user-interface is necessary. J2ME fulfills this requirement and was found appropriate for the system needs. It is a Java platform for developing applications that are executed on the resource constrained devices such as feature phones. In order to provide a practical IBE solution, we made some slight modifications on "jpair" library proposed by Changyu Dong [9]. We developed a mobile phone-based application that is supported by Android features to make viewing personal health records intuitive.
Records are organized in a hierarchical data structure, allowing them to be presented in the table form. The application has a user interface for downloading and viewing personal health records. Patients are authenticated via a PIN to view and download the records. The mobile application interface to the server side is implemented with PHP scripts running an Apache web server and storing encrypted data on MySQL database.

Int. J. Advanced Networking and Applications
Volume: 17, Issue: 03, Pages : 6933-6943 (2025) ISSN: 0975-0290
https://doi.org/10.35444/IJANA.2025.17306

a. Accessing PHRs on Mobile Phone Offline

To enable offline access, the mobile phone-based application (M-Health App) incorporates the "pull model" where patients periodically download and update their health records to the mobile phone with minimal user intervention. Once the encrypted records are downloaded to the mobile phone, the M-Health App then breaks down the records into an XML hierarchical structure such that records can be viewed selectively. However, only users with a PIN that satisfies the policy will be able to decrypt.

b. Laboratory Evaluation

The concept of securing PHRs on mobile phones was explored in this study. Our application supports caching of encrypted personal health records on the mobile phone in order to protect the records from adversaries who can mount offline attacks on the device. However, patients and healthcare professionals want to view PHRs in a plaintext. Therefore, in this experiment, we investigated whether the M-Health App can be usable without interfering with the "normal" use of the device in terms of its efficiency and performance.

1) Computational Performance Evaluation

To show that our application produced acceptance standards in terms of performance, we measured the efficiency of IBE decryption on mobile phones**.** We used Huawei *IDEOS* phone, running Android OS, with 256MB of RAM and GT-I9100 Samsung, running Android OS with 1GB of RAM. Our motive was to show the abilities of different platforms. In addition, our understanding of the situation is that IDEOS phones were designed specifically for the developing countries. We conducted this experiment using a small set of medical records that contained a representation of PHRs from Allan Galpin Health Centre. The records included demographic information, allergies, prescription, lab results, chronic problems and immunization. Figure 4 summarizes the measurements conducted on the two mobile devices. The x-axis represents the structure of PHRS (bytes) and y-axis shows the time required for decryption.

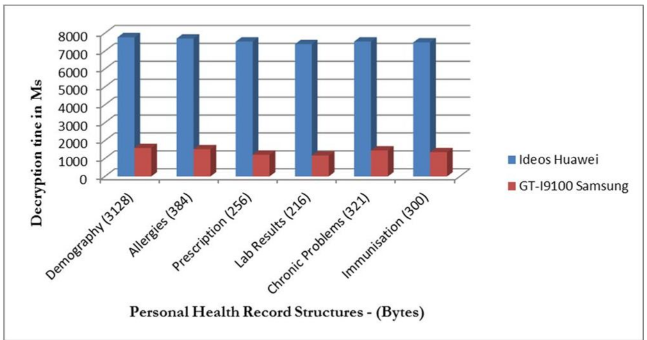

Figure 4: Decryption time (Huawei *IDEOS* and GT-I9100 Samsung)

The average decryption time of Huawei IDEOS mobile phone was 7.5 seconds while the average decryption time for GT-I9100 sum sung was 1.4 seconds. The difference in decryption time is attributed to many factors including processor and memory size, but reasonable considering IDEOS limited processing power.

2) Usability Evaluations

There are a number of studies that have proposed usability factors and how each may be measured during usability testing sessions [42, 19, 11]. These factors were measured empirically and repeatedly throughout the development process. In addition, we used several reliable and valid self-reporting measures to assess users' ratings regarding factors such as satisfaction, ease of use and efficiency as the design evolves [4]. As Rubin [44] noted, if 50% or more of the participants had difficulty in completing a task, then this feature was considered problematic and more attention was given to this particular feature.

a) Identifying the intended Tasks

There are a number of tasks (identified and agreed with the clinical officer) needed to be performed by the patients;

1. Task 1: Select the content item (M-Health_App.APK) from the website and then download it directly to the mobile device through a mobile network and the internet.
2. Task 2: Install the M-Health_App.APK directly to the personal mobile phone.
3. Task 3: Use the PIN given to you and download your medical records from the health centre server.
4. Task 4: View and share the following types of records on your mobile device with the clinical officer
   a) Demographic Information
   b) Medications
   c) Previous Lab results
   d) Allergies
   e) Immunization
   f) Emergency information
   g) Task 5: Logout the application

b) Heuristic Evaluation

This was aimed at evaluating the application for simplicity, efficiency, errors, comprehensibility and any other HCI related concerns that may discourage or stop end-users from using the application [24]. Five human computer interaction (HCI) specialist conducted the usability testing and we observed all the testing sessions. This evaluation was useful because multiple perspectives and recommendations were obtained, and several issues discussed. The feedback from this evaluation was then used to improve our application.

c) Pre-user Experience Evaluation

A pilot experiment was conducted as part of the usability test in order to find out whether the application's instructions are adequately clear and also to identify bugs that may be overlooked during the expert evaluation. Six (6) participants were recruited to take part in this phase of the evaluation. The participants were randomly picked from the health centre with the requirement of mobile phone usage experience.

Six mobile phones were provided and participants were met in groups of twos in a controlled environment. Participants were asked to accomplish a set of tasks using the application (M-Health App). Our aim was to identify any functional error/(s) and flaws that could have skipped the attention of the expert evaluators. We used observations and interviews during and after the use of the application. Observation was selected to get some information about user's reactions to the application [5]. The observation focused on user's facial expressions and behavior in general. During the test, the observations about user's gestures and behaviors were recorded and discussed during the interview. Participants were also asked to "think aloud" during the test. The whole evaluation per group including interviews took between 15 and 30 minutes.

The feedback from this evaluation was further used to improve our application. Most crucially, participants noted that, when an interrupt occurs during the use of the application, the system terminates the entirely application, prompting the user to start afresh. This prompted us to modify our prototype before the next stage of evaluation.

d) Focus Group Evaluation

Focus group evaluation was aimed at measuring learnability, efficiency and effectiveness of the application. During this type of evaluation, several quantitative usability attributes for each individual participant were measured. Out of the generic usability attributes identified in [53] and [39], we measured those that fit in the nature of our application.

1. **Effectiveness:** The percentage of tasks completed
2. **Efficiency:** Time needed to solve tasks in comparison to a pre- defined ''task completion time goal''.
3. **Learnability:** The improvement in task performance in the second trial.

We recruited a sample of 10 patients using random sampling from among patients who visits Allan Galpin health Centre. 5 participants were males and 5 females. The ages of the participants varied from 20 to 38 years, average being 28.5 years. The participants were all experienced mobile phone users and four of them had used in the past standalone mobile applications such as calendar, games etc. None of the participants had previous experience with mobile phone-based PHRs.

The participants were met in groups of twos and threes in a controlled environment and were asked to accomplish a set of tasks using the application.

Each usability test session consisted of three parts: an introduction to the scope of the session and the M-Health App, the main testing tasks, and lastly, an interview. During the introduction, the project and the M-Health App were introduced to the participants. Participants were also informed that M-Health App is a mobile application that is meant to empower them securely and usefully own their medical records.

We tested each task independently. Lewis and Rieman [31] recommended that tests that involve single service/task such as downloading records or viewing records generate reliable results than tests that combine tasks such as downloading records and then viewing records. Therefore, in each session, participants were given scenarios for a single task. The first session was driven by the following scenario.

Task 1 – Identify the M-Health_App APK: *Assume you are Mussa - a registered patient at Allan Galpin Health Clinic. Mussa's electronic health records are stored on the clinic's database server. Mussa is now required to download the M-Health_App APK from http://ictd1.cs.uct.ac.za to the mobile phone through a mobile network and the internet. Please spend the next few minutes and perform this task.*

Scenario for task 2: – Installing the APK: *Assume you are Mussa - a registered patient at Allan Galpin Health Clinic. Mussa has downloaded the M-Health_App APK to his mobile phone and is now required to install the downloaded M-Health_App to the mobile phone. Please spend the next few minutes and perform this task.*

Scenario for task 3: – Downloading the records: *Assume you are Mussa - a registered patient at* Allan Galpin Health Clinic. *Mussa's electronic health records are stored on the clinic's database server. Mussa is now required to use the M-Health App and download a copy of his personal health records from the server to his mobile phone using ucu222 as his PIN. Please spend the next few minutes using the M-Health App.*

Scenario for task 4: – Viewing the records: *Assume you are Mussa - a registered patient at Allan Galpin Health Clinic. Mussa's personal health records are stored on his mobile phone and now required to use the M-Health App to view the following sections of his personal health records using ucu222 as his PIN.*

a. Demographic Information
b. Medications
c. Previous Lab results
d. Allergies
e. Immunization

Scenario for task 5: – Log out the Application: *Assume you are Mussa - a registered patient at Allan Galpin Health Clinic. Mussa's personal health records are stored on his mobile phone and now required to use the M-Health App to log out the application. Please spend the next few minutes using the M-Health App.*

All Participants were encouraged to use the think-aloud method while performing the intended tasks. All sessions were conducted in a controlled setting in order to obtain feedback about how quickly participants can work and the number of errors committed for each task. The experiment was conducted with videotaping, but we abandoned this method for a number of reasons. First, it was not possible to aim the video recorder towards the screen and the user simultaneously. Secondly, movements by the participants made it difficult to focus the camera on the screen.

As a result, we relied on observations and screen-capturing software called Camtasia for Windows (TechSmith, free for 30 days) with video and audio capabilities loaded on the laptop and synchronized to wirelessly record how users make selections and navigate the system's features on the mobile phone. The Camtasia software enabled us view the mobile phone screen on the laptop. The recordings were automatically time stamped to facilitate tagging issues of concern and task completion time. Lewis and Rieman [31] highlighted that this approach gives a tester a machine-readable record of user actions that can be easier to summarize and access. Figure 5 (a-c) summarizes the results of the quantitative usability attributes recorded throughout the usability tests.

Int. J. Advanced Networking and Applications
Volume: 17, Issue: 03, Pages : 6933-6943 (2025) ISSN: 0975-0290
https://doi.org/10.35444/IJANA.2025.17306

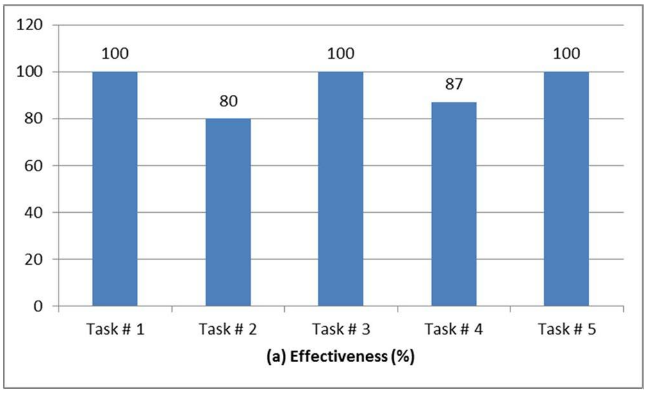

Figure 5 (a): Measurement of quantitative usability attributes. Effectiveness: the percentage of tasks completed

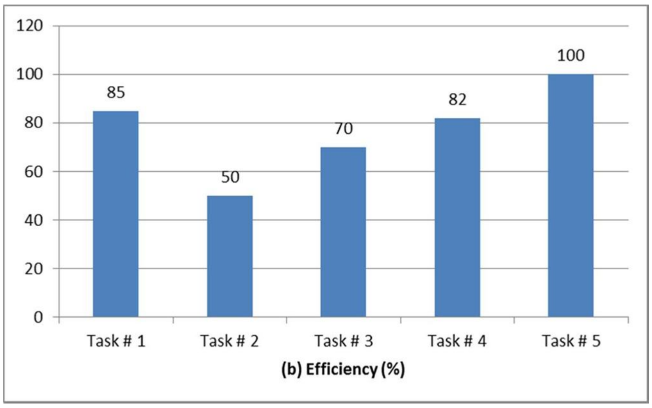

Figure 5 (b): Measurement of quantitative usability attributes. Efficiency: Time needed to solve tasks in comparison to a pre-defined "task completion time goal"

The tester's notes (taken during the session) and the laptop recordings were reviewed in conjunction with the participants to validate the findings and to elaborate the potential source of problems and errors. We also rated the significance and priority of each problem and summarized the results using the usability assessment reports. Using this process iteratively, design features were improved until requirements were met.

Three of the ten participants tested M-Health App on their own Android phone. We observed that those familiar with Android devices were able to use M-Health App with little training. Participants that were not familiar with Android phones struggled with the responsiveness of the IDEOS screen. Scrolling was not easy and the size of the characters of their records on the small screen was not clearly visible.

Participant *X:* ***"…Although the prototype is easy to learn, the mobile device keypad is hard to use. In many cases, it was hard for me to enter my PIN in one attempt. For example, whenever I could enter 'r', 't' would appear…"***

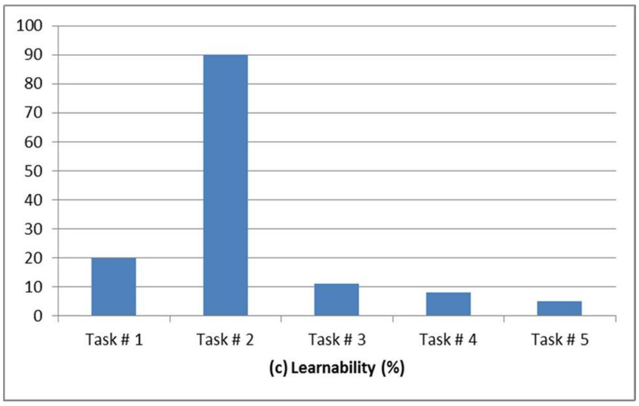

Figure 5 (c): Measurement of quantitative usability attributes. Learnability: The improvement in task performance in the second trial.

a. UCD Principle 3: Design and Test Usability with Users Iteratively

The third principle of UCD involve activities that require aplication developers to loop back to earlier stages so that development occurs in iterative cycles of assessing-designing-testing-analyzing-refining-testing-analyzing-refining-testing [18]. Thus, UCD is a way to identify users' reactions and behaviors as they interact with the application, until users find it usable and functional.

1) Field Study

Usability tests were performed both in the laboratory environment and with field studies. Field studies allow the use of mobile applications in a realistic environment and takes dynamic mobile context into consideration, which is difficult to simulate in laboratory experiments [27]. After the laboratory evaluation, the M-Health App was tested in the field to determine whether patients found the application useful, and to assess the functionality of all of its features, including records downloading and display. 15 participants tested the M-Health App in their homes and at the Allan Galpin Health Centre. In addition to user training on the use of the M-Health App, each participant was given a simple user manual describing all the features and a mobile number to call or beep for technical help. Participants were given an IDEOS U8150 Android phone containing 1GB memory card, charger and an Orange mobile sim-card loaded with 75MB of data and 2500 Uganda shillings of voice to call or beep for technical help.

The data submitted to the server was reviewed to assess utilization of the features defined by the following indices: the number of features that participants accessed, and the number of "hits" per feature. On average, the M-Health App was used daily by all participants over the 3week study period. All participants used the download feature to download their records, view your records feature to view their records and only 12 participants accessed their emergency information more than once. All error messages and interrupts were recorded by the server. For example, three recipients interrupted the normal processing of the application (during downloading records) and the interrupt occurred. Interestingly, all test users who experienced this type of interrupt continued with the normal processing\downloading of their records.

At the end of this session, we administered another reliable and valid measure called the Post-Study System Usability Questionnaire (PSSUQ) [30]. The PSSUQ was designed specifically for use at the completion of usability studies. It was used to assess the overall user satisfaction with 17 aspects of the system and the interfaces, using the same seven-point scale as the after-scenario Questionnaire (lower scores = higher satisfaction; possible range = 1-7). Table 1 shows the final PSSUQ scores (M= mean score, SD = standard deviation). Results from table 1 reveal that the test users were highly satisfied with the mean scores of 1.05 ± .09.

The feedback from the participants on electronic personal health records as well as the M-Health App was in overall positive, although three participants also gave important comment that the application should be converted into vernacular in order to allow non-English users to confidently use the application. The M-Health App was generally considered as both a nice-to-have and a need-to- have tool and participants would like to see it implemented in order to eliminate paper-based PHRs. Participants further noted that M-Health App has a positive impact in terms of increased access to health information and healthcare, improved ability to diagnose and follow-up, timelier health information and expanded access to patient's information by healthcare professionals. Interestingly, all participants expressed appreciation for the opportunity to be involved in the testing process.

Participants also appreciated the fact that M-Health App can be accessed through their personal mobile devices that they are already familiar with. They also agreed that the Government should encourage all healthcare organizations to embrace mobile health through the use of M-Health App. Participants acknowledged the need to have better mobile phones that can support M-Health App.

E. CONCLUSION

Current PHR systems in developing countries run on personal computers, yet the penetration rate of computers in developing countries is still low as compared to mobile phones. In this paper, we have presented a PHR system distributed across mobile phones. Our proposed PHR system has been tested with patients with low literacy levels in technology-constrained environments and we have established that such a system is useful in enabling patients to access their personal health records effectively. Since personal health records are constituted from sensitive data, we incorporated a security model based on an encryption mechanism that protects the records from unauthorized access beyond a hospital's security domain. We also aimed for simplicity in our user interface design in order to support low literacy users in developing countries.

We implemented a prototype system that we tested in Uganda, which is a classic case of a developing country.The results of our evaluation demonstrate that mobile phones can be used to provide efficient and secure storage of PHRs in the developing world.

A key advantage of this technology is that it would minimize the need to rely on centralized databases, which require constant power supply and internet connectivity. As noted earlier, power failures and bandwidth limitations make standard PHR implementations problematic to run in the developing world.

We applied the principles of UCD to involve patients and healthcare workers at AGHC in the design and development of our system. Based on the evaluation results, we show that participants considered our system as a nice- to-have and a need-to-have system, and majority of participants would like to see it implemented in order to eliminate the paper-based PHR systems.

All the respondents used in this study had never used or accessed their health records electronically before. They were thus excited about M-Health App, and the fact that the application was accessible through their personal devices that they are already familiar with. It is also interesting to note that; majority of participants downloaded and viewed their records at home daily, demonstrating and teaching the application to their relatives and/or children. Participants reported that they now have reasons to buy better mobile phones that can accommodate M-Health App.

Our results are based on short evaluation period. Future work will involve deploying M-health App for a long period of time, and also to convert M-Health App into a local language. We hope to document the impact of M- Health App when deployed for a long period of time, and also to identify its effect when converted into vernacular.

Table 1: Mean PSSUQ Scores after the Field Study (N=15). The PSSUQ scores range from 1-7 (lower scores = higher satisfaction).

Nos.	Items	M ± SD
1	Easy to use system	1 ± 0
2	Simple to use system	1 ± 0
3	Effectively complete tasks &scenarios	1 ± 0
4	Quickly complete tasks & scenarios	1 ± 0
5	Efficiently complete tasks & scenarios	1 ± 0
6	Comfort to use the system	1 ± 0
7	Easy to learn to use system	1 ± 0
8	Believe could become productive using system	1 ± 0
9	Error messages were clear	2.0 ± 1.5
10	Easily recover from mistakes	1 ± 0
11	Information about M-Health App was clear	1 ± 0
12	Easy to find needed information	1 ± 0
13	Easy to understand information	1 ± 0
14	Information helped complete the task	1 ± 0
15	Information was clearly organized	1 ± 0
16	Interface was pleasant	1 ± 0
17	Enjoyed using interface	1 ± 0
	PSSUQ Overall	**1.05 ± .09**

ACKNOWLEDGEMENTS

Special thanks to Allan Galpin Health Centre, Uganda Christian University and Mbarara University teaching hospital.

REFERENCES

[1]. Abras, C.; Maloney-Krichmar, D.; Preece, J. User-Centered Design. In: Bainbridge, W., editor. Encyclopedia of Human-Computer Interaction. Sage; Thousand Oaks: 2004.

[2]. Anokwa, Y. Delivering Better HIV Care in Sub-Saharan Africa Using Phone-Based Clinical Summaries and Reminders, 2010.

[3]. Anokwa, Y., Allen, C. and Parikh, T. Deploying a Medical Record System in Rural Rwanda. HCI for Community and International Development at CHI 2008, 2008.

[4]. Arean PA, et al. Recruitment and Retention of Older Minorities in Mental Health Services Research. The Gerontologist 2003; 43(1):36–44. [PubMed: 12604744].

[5]. Arhippainen, L. and Tähti, M., 2003. Empirical evaluation of user experience in two adaptive mobile application prototypes. *In*: M. Ollila and M. Rantzer, eds. *Proceedings of the 2nd international conference on mobile and ubiquitous multimedia*, 10–12 December 2003, Norrköping, Sweden. New York: ACM, 27–34. Available from: http://www.ep.liu.se/ecp/011/007/ecp011007.pdf [Accessed 23 August 2012].

[6]. Barnes, S.J., Scornavacca, E. 2004. Mobile marketing: the role of permission and acceptance. International journal of mobile communication 2: 128-139.

[7]. Benaloh, J., Chase, M., Horvitz, E. and Lauter, K. Patient controlled encryption: Ensuring privacy in medical health records, *In Proceedings of the 2009 ACM workshop on Cloud computing security*, Chicago, IL, 2009, pp. 103–114.

[8]. Bittau, A., Handley, M., Lackey, J. "The Final Nail in WEP's Coffin", The 2006 IEEE Symposium on Security and Privacy SP, pp. 386-400, 2006.

[9]. Changyu, D. (2010), "Programming with jpair", retrieved on the 21st march 2012, from https://personal.cis.strath.ac.uk/changyu.dong/jpair/intro.html.

[10]. Connecting for Health. Connecting Americans to their healthcare. Final report of the working group on policies for electronic information sharing between doctors and patients New York: Markle Foundation, 2004. [Accessed: 13th September 2011] www.connectingforhealth.org/resources/final_phwg_report1.pdf.

[11]. Dabbs AD, Myers BA, Mc Curry KR, Dunbar-Jacob J, Hawkins RP, Begey A, et al. User-centered design and interactive health technologies for patients. Comput Inform Nurs. 2009; 27(3): 175. doi:10.1097/NCN.0b013e31819f7c7c.

[12]. Dossia. Accessed [01/09/2011], from http://dossia.org.

[13]. Dunlop M, Brewster S. The challenge of mobile devices for human computer interaction. Pers Ubiquitous Comput 2002; 6(4):235–236.

[14]. ed-infomratics.org. Healthcare IT in a Nutshell. Accessed [Monday, 01 April 2013], from http://ed-informatics.org/healthcare-it-in-a-nutshell-2/emr-vs-ehr-vs-phr.

[15]. Ellis, R.D., Jankowski, T.B., and Jasper, J.E. (1998): *Participatory Design of an Internet-Based Information System for Aging Services Professionals.* The Gerontologist Journal, vol. 38, 6, pp 743-748.

[16]. Garson, K., and Adams, C., Security and privacy system architecture for an e-hospital environment. *In the Proceedings of the 7th Symposium on Identity and Trust on the Internet. ACM*, Gaithersburg, Maryland, Pp. 122 – 130, 2008.

[17]. GlobalPatientRecord. An intelligent health chart that follows you through life. Retrieved on the 13th September 2011, from http://www.globalpatientrecord.com/.

[18]. Gould JD, Lewis C. Designing for Usability: Key Principles and What Designers Think. Communications of the ACM 1985; 2(3):300–311.

[19]. Guillemette, RA. The Evaluation of Usability in Interactive Information Systems. 1995.

[20]. Hamish S F Fraser, Christian Allen, Christopher Bailey, Gerald Douglas, Sonya S Shin, and Joaquin A Blaya. Information systems for patient follow-up and chronic management of HIV and tuberculosis: a life-saving technology in resource-poor areas. J Med Internet Res, 9(4), 2007.

[21]. Indivotm .The personally controlled health record. Accessed [31/08/2011], from http://indivohealth.org/, Accessed 31/08/2011.

[22]. International Telecommunication Union (ITU) 2013. Facts and figure. Accessed [March 12, 2013], from http://www.itu.int/ITU-D/ict/facts/material/ICTFactsFigures2013.pdf

[23]. Jayaprabha, M. S., and AR Nadira Banu Kamal. "A Secure Data Self-Destructing Scheme In Cloud Computing." International Journal of Advanced Networking and Applications 8, no. 5 (2017): 14-18.

[24]. Jones, M. and Marsden, G. *Mobile Interaction Design*. John Wiley and Sons, New York, 2006.

[25]. Kaelber, D. C., Jha, A. K., Johnston, D., Middleton, B. and Bates, D. W. A research agenda for personal health records (PHRs). Journal of the American Medical Informatics Association, 15, 6 (2008), 729-736.

[26]. Kenteris M, Gavalas D, Economou D. An innovative mobile electronic tourist guide application. Personal and Ubiquitous Computing 2009; 13:103–18.

[27]. Kjeldskov J. and Stage J (2003). New techniques for usability evaluation of mobile systems. Int J Hum Comput Stud 2003, 60:599–620.

[28]. Knowles F. Patients may store health records online. Chicago Sun-Times. 2006 December 25, 2006.

[29]. Laukkanen, T., Lauronen, J. 2005. Consumer value creation in mobile banking services. International journal of mobile communications 3: 325-338.

[30]. Lewis JR. IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use. International Journal of Human-Computer Interaction 1995; 7(1):57–78.

[31]. Lewis, C., and Rieman, J. Task-centered user interface design. A Practical Introduction, 1993. Accessed [Saturday, 30 March 2013] from http://hcibib.org/tcuid/tcuid.pdf.

[32]. Luk, R., Zaharia, M., Melissa, Ho, Levine, B. and Aoki, P. ICTD for Healthcare in Ghana: Two Parallel Case Studies," Proc. ICTD, 2009.

[33]. Mani, A., Deepa, P., Dharani, M.D. and Karthiga, E., 2019. A Survey on Protected and Well Organized Entree Control for Cloud Storage. International Journal of Advanced Networking and Applications, pp.123-125.

[34]. Mayhew, DJ. The Usability Engineering Lifecycle. Morgan Kaufmann; San Francisco: 1999. p. 1-15.

[35]. Mayhew, DJ.; Mantei, MM. A Basic Framework for Cost-Justifying Usability Engineering. In: Bias, RG.; Mayhew, DJ., editors. Cost-Justifying Usability. Harcourt Brace & Company, Publishers; New York: 1994. p. 9-48.

[36]. Microsoft HealthVault. Accessed [06/04/2012], from https://account.healthvault.com/help.aspx.

[37]. My HealtheVet. The Gateway to Veteran Health and Wellness, 2007. Available at: https://www.myhealth.va.gov/index.html. Accessed Friday, 22 March 2013.

[38]. Nielsen J. Estimating the number of subjects needed for a thinking aloud test. Human-Computer Studies 1994; 41:385–397.

[39]. Nielsen, J. Usability Engineering. Morgan Kaufmann. Academic Press; New York: 1993.

[40]. Olla, P., and Tan, J. 2006. The M-health reference model: An organising framework for conceptualizing mobile health systems. International journal of healthcare information systems and informatics 1: 1 – 19.

[41]. Rashid, A. T. and Elder, L. Mobile phones and development: An analysis of IDRC-supported projects. Electronic Journal of Information Systems in Developing Countries, vol. 36, pp. 1-16, 2009.

[42]. Reed S. Who defines Usability? You do! PC Computing 1992; 5(12):220–232.

[43]. Rogers, Y., Sharp, H., and Preece, J. Interaction Design: beyond human-computer interaction. John Wiley & Sons, West Sussex, UK, 2007.

[44]. Rubin, J. Handbook of Usability Testing: How to Plan, Design, and Conduct Effective Tests. John Wiley & Sons, Inc; New York: 1994.

[45]. Rudd, J., Stern, K., Isensee, S. Low vs. high-fidelity prototyping debate, interactions, v.3 n.1, p.76-85, Jan. 1996.

[46]. Seppala, P., Alamaiki, H. 2003. Mobile learning in teacher training. Journal of computer assisted learning 19: 330-335.

[47]. Shamir, "Identity-based cryptosystems and signature schemes", In Proceedings of CRYPTO 84 on Advances in cryptology, p. 47-53. Springer-Verlag New York, Inc., 1985.

[48]. Sharples, M., Corlett, D., Westmancott, O. 2002. The design and implementation of mobile learning resources. Personal and ubiquitous computing 6: 220 - 234.

[49]. Ssembatya, R. "An Access Control Framework for Protecting Mobile Health Records: The Case Study of Developing Countries", *In the proceedings of the 9th International Network Conference (INC 2012),* Nelson Mandela Metropolitan University, South Africa, pp. 73- 82.

[50]. Ssembatya, R., Kayem, A. and Marsden, G. On the challenge of adopting standard EHR systems in developing countries. In the Proceedings of the 3rd ACM Symposium on Computing for Development, Bangalore, 2013. Doi: 10.1145/2442882.2442911.

[51]. Tang PC, Ash JS, Bates DW, et al. Personal health records: Definitions, benefits, and strategies for overcoming barriers to adoption. J Am Med Inform Assoc 2006; 13:121–6.

[52]. The EPIC "MyChart" App. The Integrated PHR. Available at: http://www.epic.com/software- phr.php. Accessed Friday, 22 March 2013.

[53]. Zhang D, Adipat B. Challenges, methodologies and issues in the usability testing of mobile applications. Int J Hum Comput Interact 18(3):293–308, 2005.

Biographies and Photographs

Richard Ssembatya is a senior lecturer, at Uganda Christian University and Mbarara University of Science and Technology. His research interest is ICT4D.

Justine Mukalere is a lecturer and researcher at Uganda Christian University and Mbarara University of Science and Technology. Her research interest is eHealth, eLearning and information systems.

Moreen Kabarungi is a lecturer at Mbarara University of Science and Technology. Her research interest is eLearning and information systems.