Development of a Mobile Image-Based Reminder Application to Support Tuberculosis Treatment in Africa

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***Abstract*—**This paper presents the design, development and evaluation of an application prototype developed to support tuberculosis (TB) patients' treatment adherence. The system makes use of graphics and voice reminders as opposed to text messaging to encourage patients to follow their medication routine. To evaluate the effect of the prototype applications, participants were given mobile phones on which the reminder system was installed. Thirty-eight people, including TB health workers and patients from Zanzibar, Tanzania, participated in the evaluation exercises. The results indicate that the participants found the mobile image-based application is useful to support TB treatment. All participants understood and interpreted the intended meaning of every image correctly. The study findings revealed that the use of a mobile visual-based application may have potential benefit to support TB patients (both literate and illiterate) in their treatment processes.

***Keywords*—**ICT4D, mobile technology, tuberculosis, visual-based reminder.

I. Introduction

TUBERCULOSIS commonly known as TB, continues to be a major health problem in the world, particularly in developing countries. There were almost nine million infections of TB in 2012, and more than one million people die every year from TB [1]. Sub-Saharan Africa carried the greatest number of new cases with over 260 cases per 100 000 people [1].

TB can be cured if patients strictly follow a prescribed medication procedure for a minimum of six months. Patients often forget to take their medicine as recommended. As a result, the disease takes longer to be cured, require more cost and the medication may no longer be successful [1], [2]. Directly observed therapy (DOT) has been proposed as the TB medication management strategy since the 1950s. However, DOT is challenging for patients and healthcare workers, due to limited resources, operation expenses, and daily travel burden [3].

A mobile reminder system has potential to support TB patients to adhere to their treatment. Information and Communication Technology for Development (ICT4D) can play beneficial role to support the treatment of TB. ICT4D can be defined as the use of ICTs, including computers, mobile phones, satellites, wireless technologies and Internet, in the fields of socioeconomic development, international development and human rights [4]. The target of ICT4D is driven by the provision of appropriate technology solutions for the challenges faced by poor communities [5]. Its objectives may include, among others, income growth, education, health and government services delivery [5], [6].

Many studies have been carried out on appropriate mobile reminder systems using text messaging and telephone call interventions to support patients in following their treatments [7]-[9]. However, these systems do not take patients with low-literacy or illiteracy into consideration [10]. Text-based and speech-based interventions have limited use by some people. The only people who are able to read and understand that language could be able to use these interventions.

This study proposes a mobile visual-based reminder application to support the treatment of TB in Africa. Unlike text or speech, the visual application is generally free from language and literacy barriers, which may enable every patient to understand the meaning of a particular reminder. In addition, people understand and remember what they see much more readily than what they hear or read [11], [12].

The paper is organized as follows. In section two, the related works are presented. The discussion of the study context and how the mobile application was designed, developed and evaluated is described in section three. The findings of a user evaluation are presented in section four. The paper concludes with a reflection on the results and previous works.

II. Related Works

Mobile health (mHealth) refers to the use of mobile devices, such as mobile phones, tablet computers and personal digital assistants (PDAs) to support the practice of medicine and public health. At present mHealth is a rapidly growing field with potential applications for frequent use of mobile phones for healthcare services [13], [14]. The growing field of mHealth in low and middle income regions has seen an increasing number of projects targeting patients, such as those with HIV/AIDS (Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome), Malaria, Diabetes and TB. Various strategies have been proposed regarding the use of mobile phones to support patients' treatment [7], [9].

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Studies have shown how mobile reminder systems can be effective for improving patients keeping follow-up appointments [8], [15] and supporting adherence to medication [16]-[18]. Okuboyejo et al. [16] proposed an application that aids a user in remembering drug times and dosages. The system employs the use of SMS (short message service) to send automatic reminders to patients so as to enhance compliance with drug regimens. It also contains a feature that the patient could replay SMS alerts to indicate whether he has taken the pills or not. However, although the SMS technology was found helpful to support patients' treatment, some participants reported difficulty in using the service [7], [19].

Sidney et al. [20] conducted a study to support adherence to antiretroviral therapy (ARV) among HIV patients using mobile phone reminders in South India. Two mobile interventions were used: SMS and phone call. Patients received weekly SMSs and interactive calls. After four weeks of the intervention, participants were interviewed regarding the usefulness and potential of the interventions. It was found that the majority of patients were receiving SMSs rather than telephone calls [20], which were caused by the problems of the mobile network. However, the patients preferred a phone call system over SMS. It was reported that illiteracy was a major reason for patients to not prefer the text messaging intervention [20]. A similar kind of approach is presented by [21]. They developed an automated voice call system to promote adherence to iron supplements among pregnant women in a low income area of Mumbai, India. The study assessed the impact of hemoglobin (Hb) levels in the blood of pregnant woman. Participants received automated voice calls three times per week, encouraging them to take iron supplements. The study's findings show that the calls positively impacted Hb levels of pregnant women, although some participants were unreachable due to their phone numbers having gone out of service [21].

The SMS text message and phone call systems are faced by various challenges, particularly in low-resource setting countries. These challenges include mobile network, literacy and language barriers [7]-[10]. Compared to a phone call, the text message requires low operational cost and lower use of resources [22], [23]. Telephone calls need a good network connection during implementation [10], which is more challenging in the many developing countries.

This study suggests a visual-based reminder application that could be applied to support TB patients to adhere to their treatment. Picture languages enable people who speak different languages from different countries to understand one another [11], [12]. For the purpose of this research, a degree of literacy is defined as being the ability to read and write, or the ability to use language to read, write, listen, and understand.

III. Research Methodology

A. Designing Graphic Interventions

The intention of this study was to design clear, acceptable, culturally relevant graphics that would relate to the patients' experiences and environment. Previously, it was shown the challenges faced by TB patients and healthcare workers during treatment and how reminders' intervention was obtained from field study [24]. The challenges include lack of treatment resources, limited health staffs, financial support and patients fail to comply with the treatment regimens due to the forgetfulness. TB health workers and patients suggested various reminders to be included in this research (Table I). These reminders are used as interventions to support TB treatment and reduce the risks of transmission.

TABLE I
Suggested Reminder Notifications

No.	Reminder Message
1	Patient reminded to take pills
2	Patient reminded to submit his or her smear sputum to clinic for checking
3	Patient reminded to collect his or her medication for upcoming days
4	Patient reminded to go to clinic for consultation
5	Patient reminded to visit a clinic when feeling unwell
6	Patient reminded to cough in a proper manner
7	Patient reminded to take a glass of milk
8	Patient reminded to eat a healthy meal

The collected text reminders were then converted into graphics. Adobe Photoshop was used to develop the graphics. The "visual aids for communication" theory was applied during the development. This theory was adopted from [25]. Pettersson [26] defined visual aids as the conveyance of ideas and information in forms that can be read or looked upon. Perry [27] pointed out that in designing visual aids, the designer should "connect" to the viewer's existing knowledge and interest, gain the attention of the viewer, and the message must be perceived as relevant, logical and attainable [25], [27]. Eight graphics were developed (Fig. 1). After the development of graphics is completed, the graphics were passed to different people to testing. Various people participated in the graphic evaluation exercises including TB health workers, TB patients, academics and researchers as described in previous work [28]. The health workers and patients are the target users of the proposed application, but input from academics and researchers helped ensure that the graphics were understood by all. The testing criterion was to ensure that each image is understood and conveys the correct meaning of a particular reminder. The participants provide feedbacks once again. The process is repeated so that, at each evaluation stage, the graphics evolve towards the final design. Therefore, Fig. 1 shows the final graphics after users satisfied with them.

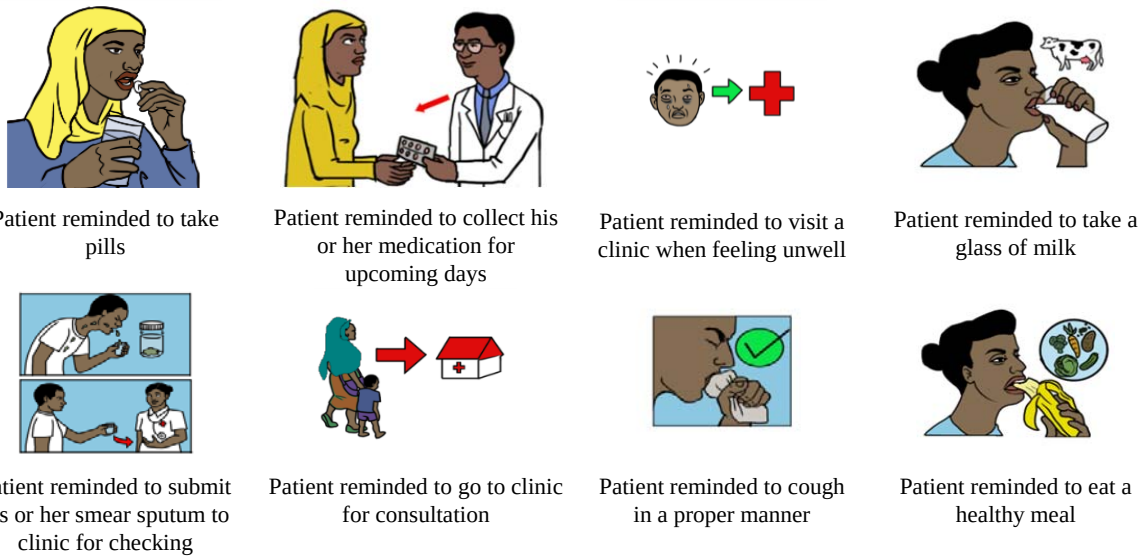

Fig. 1 The graphical reminder notification

B. Development of mHealth Prototype Application

The Android platform was used to develop the mHealth image-based prototype. The aim was to provide a user friendly system that enables patients to easily use and understand the meaning of reminder interventions. The motivation to use Android platform is that Android makes strong headway in Africa and other part of developing world. At present almost 30% of the total mobile population in Africa use Android phones [29]. Fig. 2 represents some screenshots of the prototype. The system contained the voice which tells the user in Swahili (local language) that a reminder has been triggered on his or her phone.

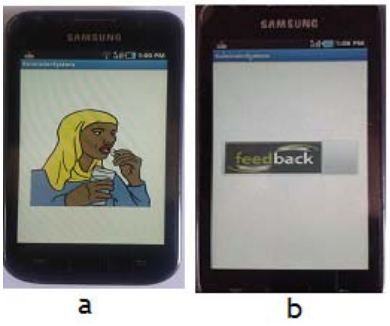

Fig. 2 Example of screenshots of the application (a) take drugs reminder message (b) medication feedback screen

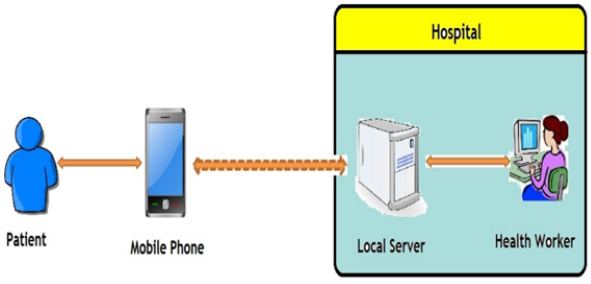

Fig. 3 System overview

Since the target communities are based on low and middle income areas, mHealth image-based system is intended to work in the most resource-constrained environments. In the proposed system, the user only has to download the system once through any network connection and the system will then work offline as illustrated in Fig. 3.

Fig. 3 shows the overview of the image-based reminders network, which contains three parts: hospital, user and network link. The hospital side involves a trained health staffs who manages the system. It also contains a database where the patients' information and the prototype application reside. The user side consists of patient and mobile phone. The network link is the communication channels in which user and database communicate through each other.

It is assumed that patients are equipped with mobile phones, which they can use to download mHealth system. Since patient information is stored at the hospital server the mobile phone communicates with the server through a network connection. The system contains eight reminder messages, (Fig. 1) which is supposed to be triggered based on the TB treatment schedule as prescribed by a health care professionals. The reminders are set to automatically activate on different days and times, which include daily, after every two days, weekly, etc, with the aim of reminding a patient to adhere to treatment.

One of the most important features that are offered by mHealth image-based application is a medication confirmation feedback. The system prompts patients to reply by pressing a button (Fig. 2 (b)) after having taken the pills. The confirmation feedback is directly sent to the local hospital database. When disconnected, a SQLite database stores the feedback offline for automatic forwarding as soon as the connection is available.

In this study, the health worker is responsible for managing the patients' information and viewing the patients' feedback report in order to track the routine of a patients' treatment process. Furthermore, the system has a feature that

automatically corrects a phone's clock. Periodically, every 30 minutes, the system checks the phone time based on the time zone of a particular area or country.

C. Experimental Design

1. Methods

A qualitative research approach was used to collect participants' feedback. This method was chosen because qualitative research consists of an investigation that: seeks to answer a question; uses a systematic procedure to answer the question; collects evidence; produces findings that were not determined in advance; and produces findings that are applicable beyond the immediate boundaries of the study [30]. Furthermore, a qualitative approach is more flexible in that is allows greater freedom of the interaction between the researcher and participant. The approach uses "open-ended" questions that allowed the researcher to ask questions in a different ways with each participant. This allowed participants to respond in their own words rather than multiple choice ("close-ended") questions as in the quantitative methods [30], [31].

Semi-structured interview, focus group and observation techniques were used to collect data. Semi-structured interviews were used to probe participants' feedback, in order to better understand their perception and understanding of the mHealth image-based reminder application. The semi-structured interviews allowed the researcher to have a thorough communication with the participant in order to collect the most accurate information [32]. This was particularly important with some of the participants being illiterate.

2. Ethical Clearance and Consent

The University of Cape Town and the Ministry of Health and Social Welfare in Zanzibar granted ethical clearance for the study. Before the experiment began, participants were briefed on the purpose of the research and were requested to complete a consent form.

3. Participants and Study Sites

A total of 38 people participated in the mHealth image-based prototype evaluation (Table II). Thirteen were male (34.2%) and 25 women (65.8%). Their median age was 26 years (range 16-55). The participants were divided into two major groups: health workers and patients. The evaluation was conducted in Zanzibar, Tanzania from July to August 2014. All patients were in home-based-care. The health workers were from different TB health sections, including Clinical officers, Health officers, Community health workers, Public health officers and Nurses.

The patients were further categorized into four groups. Group A involved eight patients, group B seven patients and group C and D involved six patients each. The patients' groups were obtained based on the treatment zone.

4. System Evaluation

The goal of evaluation was to find out whether the mHealth image-based prototype is useful, acceptable and if it meets with the TB patients' experiences and environment. The International Organization for Standardization ISO9241-11 for usability measurement was implied during the evaluation of this study to measure the usability of the prototype application [33]. The following main themes investigated: understanding of the purpose of the image-based reminder system; perception, acceptance and challenge of the system; and suggestions about system design and how it could be improved as illustrated in the results and discussions section.

The participants were given mobile phones with the mHealth image-based reminders prototype on them. The issued phones were of different models, including Samsung Galaxy Pocket (GT-S5300), Samsung Galaxy S (GT-19003) and Samsung Galaxy SIII mini (GT-18190). The majority of them were Galaxy Pocket.

The evaluation was first conducted with health workers before moving to patients. During the health workers experiment, the evaluation was conducted within a day. The reminders were set trigger for an interval of five minutes. The researcher observed the health workers and how they interacted with the application.

On the side of the patients, the reminders were set to trigger based on the TB treatment regimens as scheduled. For example, a current TB treatment timelines in Zanzibar is that every patient is asked to take pills once a day in the morning at 7am. During the trial each patient was given mobile phone for the duration of eight days. The researcher and his assistants distributed mobile phones to participants and came back after eight days for collections and getting feedback.

IV. Results and Discussions

This section describes the findings obtained from the evaluation of the mHealth image-based prototypes. The data collected in this study was manually analyzed by the researcher and where needed, Microsoft Excel software was used.

A. Mobile Phone Ownership

Since the application was developed on the smart phones (Android platform), ownership of smart phones had to be evaluated. The results are presented in Fig. 4.

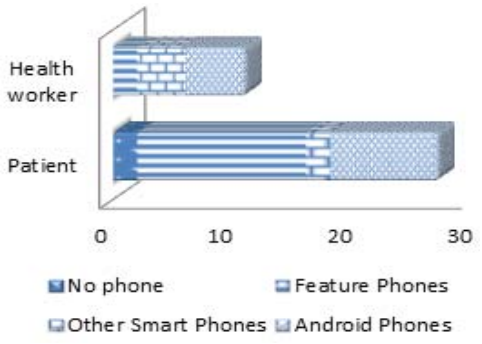

Fig. 4 Participants' mobile phones ownership

The findings showed that 52.6% (n=20) of participants had smart phones, of which 70% were Android phones (Fig. 4).

42.1% of participants had feature phones that support multimedia systems. 5.3%, (n=2) did not have mobile phones; all of whom were patients. Michael [34] noted that by the end of 2013, Android was at 78.4% of the operating system market share, making it one of the most used mobile operating systems globally, particularly in developing countries. Additionally, at a moment the price of Android phones is closer to the price of feature phones which are largely available in African countries [35].

TABLE II
CHARACTERISTICS OF PARTICIPANTS

Characteristics	Respondent distribution	N=38 (%)
Gender	Male	13 (34.2)
	Female	25 (65.8)
User group	Patients	27 (71.1)
	Health workers	11 (28.9)
Age group	16-25	8 (21.1)
	26-35	13 (34.2)
	36-45	10 (26.3)
	>=46	7 (18.4)
Education level	Can read and write	35 (92.1)
	Cannot read and write	3 (7.9)
Mobile phone ownership	Have mobile phone	36 (94.8)
	Don't have mobile phone	2 (5.2)
	Mobile owned by patient	25 (92.6)
	Mobile not owned by patient	2 (7.4)
	Mobile owned by health worker	11 (100)

B. Participants' Understanding of the Purpose of mHealth Image-Based Reminders System

The findings revealed that participants believed that the system has potentials. All participants (100%, n=38) responded that the application contains graphics that illustrated the meaning of an intended purpose. 94.8% (n=36) of participants found the system relevant to the TB patients' needs. Participants made comments such as "I found this system to be helpful in supporting my treatment regimens", "I really appreciate the system, I understood the meaning of all graphics", "The application seems to be worthwhile in helping us", and "This kind of system is what we want". However, two patients were unsure whether the proposed system could help them. It was found that these two participants are fishermen. The reason mentioned that due to their work it was difficult to carry the cell phones particularly during the raining time. Thus, they said that they were missing some reminders because the phones were far away from them. However, they mentioned that the proposed system could have benefit for those people who are close with their mobile phones. Those participants who reported understanding the purpose of the mHealth image-based system said that the application is simple to understand and contained the relevant features for TB patients. In addition, participants were asked about their opinion whether the proposed application contained simple features and if every person could be able to use the system. The findings showed that all participants (100%) found the system easy to use and everyone can simply be able to use the proposed system.

C. mHealth Image-Based Reminders System Technical Performance and Design

The majority of survey participants (97.4%) found that the reminder messages were triggered properly and thirty-seven (97.4%) participants found the voice was good and clearly understood except one healthcare worker who reported problem of sound. During the trial a participant mentioned that she had difficulty in hearing the voice. At the end of experiment it found that the phone that the participant used had its volume set too low. Furthermore, during the patients' interview sessions it was found that some participants received a reminder, and it was observed they were properly interacting with the system. However, one participant responded that he received a reminder around 9PM, which was the incorrect time. It was found that the participant had changed a phone clock when he interacted with other applications. To ensure the reminder messages trigger at the expected time, the mHealth image-based system was defined to automatically correct a phone clock every 30 min, the reminder triggered off before the phone clock was corrected. To solve this problem, the checked time interval will be reduced from 30 min to at least 10 or 5 min.

D.Analysing mHealth Image-Based Reminders System Challenges

Most of the challenges with the system were observed with the replaying of the confirmation medication feedback. It was found that although the majority of participants (84.2%, n=32) sent the take pills confirmation feedback to the server, 15.8% (n=6) participants did not frequently press the feedback button that sent the confirmation feedback report. All of them were patients. They responded that they were not seeing the feedback screen (Fig. 2 (b)). This is because the participants did not discard a "take pill reminder screen" (Fig. 2 (a)) by pressing a back key of mobile phone. The feedback screen appeared once the take drugs reminder was triggered and disposed. On the other hand, two patients (5.2%) had difficulties using the application, as they noted that short training provided on how to use the mobile phones was not enough for them to understand everything. It was found that these participants did not use mobile phones before. It can be suggested that training sessions have to be adjusted to

accommodate participants who do not have experience of the phones in order to be familiar with mobile phone before using the system. Furthermore, the feedback button will be embedded on the same screen of "take pills" reminder. That way user would see it straight away.

E. Acceptance of mHealth Image-Based Reminders System

It was evident from the analysis of participants' feedback that many participants appreciated the mHealth image-based system. Thirty-six (94.8%) participants found the application easy to use and they believed it could support the TB treatment regimens. The patients' feedback on the mHealth intervention after a trial indicated that they were pleased to receive visual reminders. However, one patient and one healthcare worker gave suggestion to improve the "feedback button" to be more visible as now proposed in section IV (D). Furthermore, most participants have expressed similar opinions about the usefulness of the image-based reminders system such as.

"I am very glad to see this system and hopefully, it will be implemented as soon as possible, I really like it, currently our patients are faced with the problem of missed taking the pills, this system is very important it might be supported them by reminding and encouraging to follow the routine of treatment"- participant X (English translation).

"This system is very useful it contained the simple and understandable graphics. This kind of system is that we want, it could promote patients to take their medication on time, and it also could help them to come to the clinic when they needed to do so. Recently, most of the patients missed to attend the clinic the major reason is forgetfulness. I hope this system has a big impact on supporting them and us (health workers) as well to achieve the adherence of TB treatment" - participant Y (English translation).

"…this system is very good, see this picture show woman cough and cover her mouth (laughing) very interesting. It was encouraged me a lot including taking pills, cough in proper manner, drink milk and so on. I like this system very much. Is it possible this system to be continuing? (she asked)… because since you gave me this phone it support remind me and I always take my medication in exactly time compared in normal days (usual care) without mobile reminder"- participant Z (English translation).

Most patient participants indicated that they would recommend the mHealth image-based reminder intervention to other patients.

F. *Most Helpful Messages*

During the individual patient interviews, participants indicated that the most helpful messages were "take pills", "proper manner to cough", and "feeling unwell". The majority of participants responded that mHealth image-based system was helpful in reminding them to take their medication. One participant stated "One day I was going to my farm and I forgot to take the pills, when I was about 500 metre from home I received a reminder. Then I returned home to take my pills" and another participant noted that "I was in my work I slept there. In the morning I received a take pill message, actually I was forgetting, the system reminded me! I really like it". Furthermore two participants indicated that they shared the educational messages ("proper manner to cough", and "feeling unwell") with family and friends to help educate them about the disease. One participant indicated "I was in public transport with my friends suddenly I received a proper manner to cough message after viewed it I show with my friends they really appreciated it and one of them said this system could be indeed educative one".

G. Discussions

This study suggests that the use of visual-based reminders to support the treatment of TB in resource-constrained environment is technically feasible. The literature highlights the use of SMS text messaging and telephone call in reminder systems has had limited use particularly in the context of literacy and language barriers. During the field trial, participants suggested that a visual-based reminder could be more applicable to support patients' treatment including semi-literates and illiterates. However, the participants were only given image-based prototype for testing. They were asked about their experiences with the use of SMSs and telephone calls. It was found that all participants who have mobile phones had used SMS and phone call services before. These participants advocated the visual applications which were felt to be feasible when compared to text and voice applications. Furthermore, SMS text messages, phone calls and Multimedia (MMS) image services require operational cost where mobile operator should be involved to operate the services. There are a number of studies reported the challenges of cost of text messages, telephone calls and MMS in supporting healthcare services [19], [36]-[38]. The proposed system is supposed to work without being connected to a mobile service provider. The system contains several reminder messages that are set to automatically trigger on different days and times based on the TB treatment regimens. The cost of MMS services is still high and not heavily adopted in the Africa continent [39]. Thus, the image-based reminders system is proposed instead of multimedia services in supporting TB treatment. Additionally, three patients among the others who lived in rural settings mentioned that mobile networks are limited in their areas. They said that the proposed system was working fine because it did not require a mobile provider as the text messages and phone calls do. At the end of experiment all mobile phones were connected to the Internet (using hospital WiFi or mobile data) by the investigator and his assistants for forwarding the feedback reports. Five participants were found to frequently use the Internet. Once the phone was connected to the Internet, it automatically synchronized the data and then forwarded to the database.

There were challenges with the use of mobile phones. The results indicated that not all participants had smart phones (Android phones) that are compatible with the prototype. At

present, the price of Android phones is close to the price of basic feature phones, which are widely available in Africa and other developing countries. The number of Android phone' users are increasing rapidly in Africa [29]. The study also found that 5% of participants did not have mobile phones. These participants did not have knowledge on how to use cell phones. It was reported that once a reminder has been triggered they could interpret the meaning of a graphic correctly, but they didn't know how to interact with the phone, such as pressing back key button, switch on the screen, etc. The study also found that there were three participants who were unable to read and write. Interestingly, two of them had mobile phones. It was found that the frequency of mobile phone use did not correlate with educational level. This study also found that visual communication may have beneficial potentials in helping TB patients to adhere to their treatment. Further study will be conducted to measure the feasibility of visual-based compared with text-based and speech-based intervention.

V. Conclusion

In this paper, the descriptions of the design, development and evaluation of the mHealth image-based reminder application were presented. The intention of this work was to answer the main research question: Can mobile image-based reminder applications support treatment compliance for tuberculosis patients including illiterate? In addressing this question, the researcher started by first looking at the previous work that is related to this research, and then used case study approaches to understand the challenges faced in treating the TB disease. The research then moved to design the graphics reminder, and followed by developing a mobile image-based reminder application. To compare with SMS text messaging and telephone call intervention, the mHealth image-based system: (1) does not have literacy and language barriers; and (2) does not require mobile operators to control the services (no operational costs). The prototype was then evaluated by different stakeholders, including TB health workers and patients. The results revealed that the use of image-based reminders may have potential for helping both literate and nonliterate TB patients to adhere to their treatment. The findings also showed that the proposed system could be used and work properly even in areas where mobile network is limited such as in remote rural areas. The study also found that the majority of participants had smart phones. To further the study, future work will consider a cross platform visual-based reminder application.

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