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Targeting Morbidity in Unreached Communities Using Portable Health Clinic System

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SUMMARY This study looks at how an e-Health System can reduce morbidity (poor health) in unreached communities. The e-Health system combines affordable sensors and Body Area Networking technology with mobile health concepts and is called a Portable Health Clinic. The health clinic is portable because all the medical devices fit inside a briefcase and are carried to unreached communities by a healthcare assistants. Patient morbidity is diagnosed using software stratification algorithm and categorized according to triage color-coding scheme within the briefcase. Morbid patients are connected to remote doctor in a telemedicine call center using the mobile network coverage. Electronic Health Records (EHR) are used for the medical consultancy and e-Prescription is generated. The effectiveness of the portable health clinic system to target morbidity was tested on 8690 patients in rural and urban areas of Bangladesh during September 2012 to January 2013. There were two phases to the experiment: the first phase identified the intensity of morbidity and the second phase re-examined the morbid patients, two months later. The experiment results show a decrease in patients to identify as morbid among those who participated in telemedicine process.
key words: *Portable Health Clinic, e-Health, Electronic Health Records (EHR), Telemedicine, e-Prescription, Clinical Decision Support System (CDSS)*

1. Introduction

One billion people are unreached in terms of accessing to quality healthcare services [1]. About four thousand children die of diarrhea in a day, one pregnant mother dies every 90 seconds. These scenarios can be dramatically changed if we can simply convey a few simple medical tips to the target community. Most of the unreached people are from rural areas in developing countries [2]. Healthcare services do not exist there for two major reasons: (1) Doctors do not want to stay in the village as they do not find their livelihood requirements fulfilled; (2) Quality hospitals/clinics cannot sustain without stable income. The health-workers do not attend the patients regularly. More than 35% of the health workers were found absent during their working hours in health service centers [3].

Mobile health has increased access to healthcare and health-related information for many unreached communities. Health consultancy over mobile phones is popular in developing countries such as Bangladesh and provides an alternative solution for partial healthcare delivery [4]. Mobile health has brought many benefits to people especially to the remote female patients. Female patients can consult with a remote male doctor anonymously to discuss private diseases. Subscribers can call at any time of the day from anywhere in the country. A remote doctor can prescribe Over The Counter (OTC) medicine, interpret clinical records and also introduce a hospital or doctor near the patients' residence. However, there are gaps in mobile helath services that undermined its usefulness. There is no Patient ID and Electronic Health Records (EHRs) are not maintained for future use; the patient is not tested against a diagnostic process; remote doctors have no EHR or e-Prescriptions to refer to; and Call Detail Record (CDR) data is difficult to analyze for morbidity [5].

Remote patient monitoring (RPM) has increased access to healthcare and decreased healthcare delivery costs through the use of wireless sensors, diagnosis application software and online databases. RPM enables a patient with a chronic disease to maintain independence, prevent complications, and minimize personal costs [5]. Key features of RPM, such as remote monitoring and trend analysis of physiological parameters, enable early detection of deterioration, increase medical care efficiency, and allow healthcare providers to allocate more time to remotely educate and communicate with patients [6]. However, RPM sensors and devices are expensive and beyond the reach of low-income families and hence not feasible for the unreached population [7].

This research targets morbidity (poor health) in unreached communities using mobile health architecture (pervasive, low cost, and easy to use) and filling the medical gaps with affordable RPM technology (sensors, devices, diagnostic tools and a database). In addition, the research solution should be sustainable with input from local resources.

In this study, we introduce a focused comprehensive e-Health system called the Portable Health Clinic (PHC) and test its suitability on sample populations in Bangladesh. In Sect. 2, we describe the PHC architecture and introduce a business model for a female health worker. We outline which health sensors are used and how morbidity can be automatically defined by the system. We discuss the PHC op-

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eration and telemedicine procedure. We allude to PHC data structure and Clinical Decision Support System (CDSS) work. In Sect. 3, we test the PHC on 8,690 rural and urban subjects. We show the results of PHC tests that demonstrate a decrease in morbidity after two months. In Sect. 4, we conclude that the PHC can be used as a tool to rapidly target morbidity in any unreached community or compromised environment.

2. Portable Health Clinic Concept and Architecture

The Portable Health Clinic (PHC) system was designed by Kyushu University and Grameen Communication's Global Communication Center (GCC) to be an affordable e-Health system solution for low-income subjects in unreached communities [8]–[10]. The back-end of the system consists of data servers and a medical call center. Front-end has the instances of portable briefcase consisting of medical sensors and measuring equipments. The front-end communicates with the back-end using mobile network coverage and Internet (see Fig. 1).

The PHC back-end comprises GramHealth software applications, database, and medical call center. GramHealth software application processes patient EHR and doctor e-Prescriptions and stores them in a database. Doctors at the medical call center access GramHealth data cloud through the Internet or have a copy of the database in the call center server. Upon receiving a multimedia call from a patient, the doctor can find that patient's previous EHR record and can create and send an e-Prescription. This saves time and effort as the doctor does not need to question the patients about their personal profile (basic attributes and medical history) but can focus on the immediate health inquiry [11].

The PHC front-end consists of a briefcase containing medical sensor devices developed with international information standards, data transmission system with mobile network, easy-to-use data management application, telemedicine by Skype connection, and local Electronic health record preservation [12]. The PHC briefcase is meant to be low cost and portable. It is envisioned to cost less than US$300 (an amount an entrepreneur can borrow from micro-finance institutions such as Grameen Bank in Bangladesh) and can be carried by a female healthcare assistants. The PHC briefcase will be owned and operated by a village healthcare assistants. This will be a sustainable business model as the healthcare assistants can build a professional relationship with her local clientele.

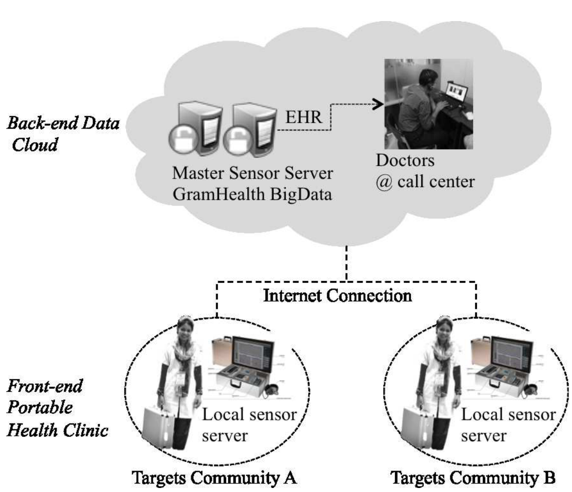

Fig. 1 Portable Health Clinic system architecture: back end data center and front ends health monitoring system.

2.1 Portable Health Clinic System Components

The Portable Health Clinic is intended to be robust in terms of accuracy and reliable in identifying the intensity of morbidity. The PHC components consist of the following advanced sensor technologies and unique automatic decision-making tools.

Briefcase sensors and materials: The healthcare assistants's briefcase is comprised of sensors based on international information standards that use either standard transmission or a 'Body Area Network' (BAN) interface on the sensor (Table 1). The briefcase also includes a tablet, or a notebook PC, consumable goods such as urine tester tapes and blood sugar cubes, a battery unit and dry cells, a measure, a barcode scanner, paper for writing and printing. The total weight of the case is about 10 kg including the weight of the briefcase [13].

Sensor System Architecture: Different sensors are used during a health check-up. A local sensor server (within the briefcase) receives and stores patient data via wireless-LAN and synchronizes its cache with the master sensor server when the Internet connection is available. The master sensor server in the back-end data cloud stores all sensor data and provides data to the Personal Health Record Server and doctors in the call center (see Fig. 1). The interface of the local sensor server is the same of that of the master sensor server. Therefore, sensor boxes can directly connect to the master sensor server by changing the configuration address [8].

Morbidity Stratification Algorithm: Morbidity is identified using a triage stratification algorithm. Local sensor data of each health check-up item is compared against risk

Table 1 Sensors and equipments for a typical Portable Health Clinic.

Sensor	Maker	Product Code	Trans-mission	Weight (gms)
Weight Scale	A&D	UC-321PBT	BAN	2500
Blood Pressure	A&D	UC-321PBT	BAN	300
Pulse Oxymeter	OXiM	S-101	BAN	60
Blood Glucose	Terumo	MEDIS AFEFIT	Felica	50
Body Temperature	Terumo	W520DZ	Felica	27
FeliCa Reader	Sony	PaSoRi	USB	35
Mobile Printer	HP	OfficeJet 100	Bluetooth	2500
Mobile Scanner	Fujitsu	FI-S1100	USB	350
Web Camera	Logicool	HD	N/A	Built-in

Table 2 Triage categories are based on medical recommendations.

	Safe *(Preventive)*⟸ ····················· ⟹**Risky***(Morbidity)*			
	Green (Healthy)	**Yellow** (Caution)	**Orange** (Affected)	**Red** (Emergency)
Blood Pressure, Systolic (BP) [mmHg]	BP<140	140≤BP <160	160 ≤BP<180	BP≥180
Blood Pressure, Diastolic (BP) [mmHg]	BP<90	90≤BP <100	100 ≤BP<110	BP≥110
Blood Sugar, Fasting (BS) [mg/dl]	BS<100	100≤BS <126	126 ≤BS<200	BS≥200
Postprandial Blood Sugar (PBS) [mg/dl]	PBS<140	140≤BS <200	200 ≤PBS<300	PBS≥300
Urine test	-	+-	+,++,+++	
···	···	···	···	···
SpO2 (S)[%]	S≥96	93≤S <96	90≤S<93	S<90

stratification matrix based on international diagnostic standards (WHO) and the results are categorized into one of four grades: green (healthy), yellow (caution), orange (affected), and red (emergency). The triage risk stratification is parameterized against a "B-logic" (Bangladesh logic) and an example of the categories is shown in Table 2. The individual health condition can be enhanced by integrating results of a questionnaire into the 4 degrees by the worst color of all health check-up items.

Booklet for Health Guidance: An 11-page booklet is provided to educate all subjects about the disadvantages of obesity, smoking, and chronic diseases such as hypertension, diabetes, and kidney disease.

Tele-medicine and tele-prescription: The healthcare assistants sets up a telemedicine session for orange and red subjects using pervasive mobile network coverage to connect the patient to the medical call center at the back-end. In the call center, male and female doctors are available to provide telemedicine. Doctors access the electronic results of the subject health check-up and provide advice regarding the disease and a tele-prescription for the patient to access medicine via the network.

2.2 Portable Health Clinic System in Operation

The Portable Health Clinic system is devised to be scalable and can serve a large queue of patients with minimum administration in the shortest period of time. The most sustainable process identified includes: a group checking methodology, a triage to classify the patients according the medical risk, and remote consultancy with a doctor only for those who need it. The general process involves five steps.

Registration: A patient registers his/her vital information such as name, age, sex, location and disease complaints. A data entry operator inputs the data into GramHealth DB. A patient ID is given to the patient. The patient pays for service in advance.

Health Check-up: A healthcare assistant carries out the patient's physical check-up (body temperature, weight, height, BMI, waist, hip, blood test, urine test) and data are automatically sent to GramHealth server via the local sensor server. The sensor server grades the patient according to the color-coded risk stratification: green (healthy), yellow (caution), orange (affected) and red (emergency). The "green" patients are given the health checkup results. The "yellow" marked patients are given a health guidance booklet. The "orange" and "red" marked patients consult with a call center doctor.

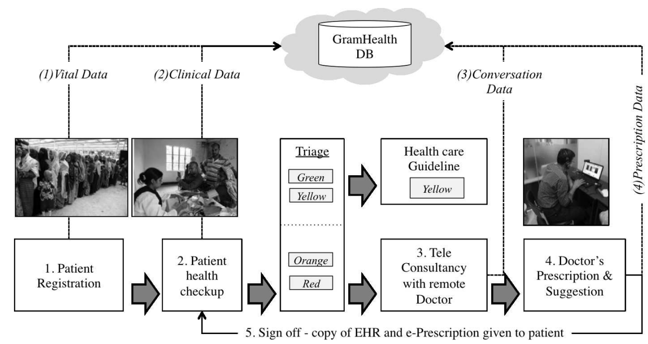

Fig. 2 Experimental environment with Portable Clinic and GramHealth systems and the 4 steps methodology to efficiently carry out group health check up in remote areas.

Telehealth Consultancy: Color coded "orange" and "red" marked patients talk to a remote doctor for further investigations of their disease and explanation of their medical records. Telehealth consultancy is over voice and video. The audio record is archived in GramHealth DB.

Prescription and Suggestion: The remote doctor identifies the disease after checking the clinical data, discussing with the patient for their symptom analysis and his/her past health records, if any. The doctor then fills up the prescription and a technical assistant helps the doctor to insert the necessary information into the database and sends it to the healthcare assistants.

Sign off: The healthcare assistants prints and gives a copy of the EHR and prescription to the patient and schedules a follow-up health check-up within two months.

2.3 Portable Health Clinic Data

The portable health clinic is a learning platform for users of the system (healthcare assistantss and doctors) and distant parties interested in preventative methods and morbidity types (virtual health teams and researchers). The GramHealth DB collects data from four different sources of which each provides rich data that can be used to analyze underlying factors contributing to morbidity (Fig. 2). PHC data are captured in various formats and includes the following:

Registration data have personal data and inquiry data. Personal data (Name, Age, Sex, Address, Check-up date) are

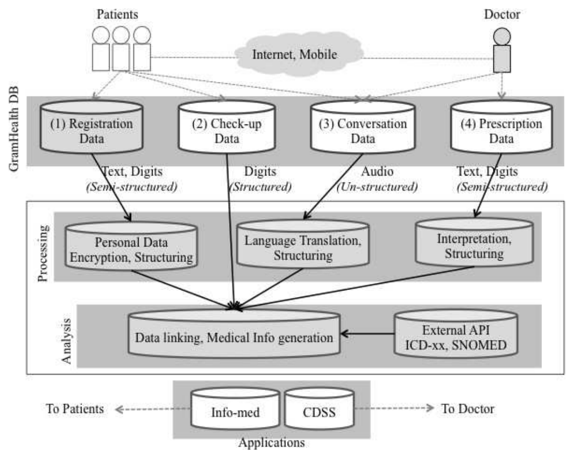

Fig. 3 GramHealth DB to produce medical knowledge for the healthcare assistantss and doctors.

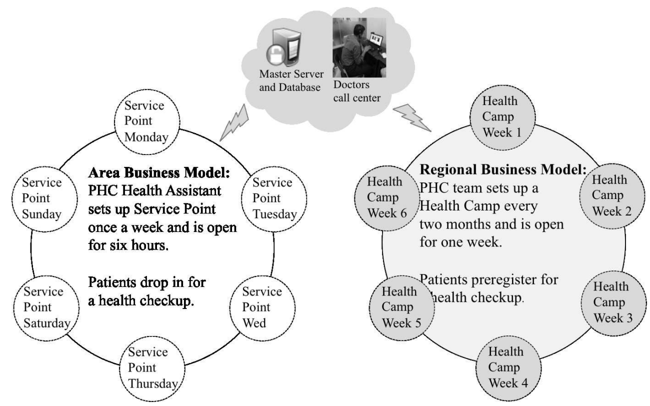

Fig. 4 Portable Health Clinic sustainable business models.

structured, but inquiry data (complaint, symptom, family and life style information) are Q&A text type and are semi-structured;

Check-up data contain clinical measurement data. All data are structured and used for triage of patients, cohort analysis and comparison with past data. Triaged and colored sensor data items give not only the value on each item for doctor but also some quantitative and educational information (crucial, risky, attention, healthy) for patients;

Conversation data are captured by an audio recorder. These data are completely unstructured. In order to analyze these data, it is necessary to convert the data from speech to text;

Prescription data contain the prescription including statements of chief complaints, suggested medications and guidelines. In the prescription data, the disease names are not mentioned and they need to be classified into disease categories.

To provide on the job training for the healthcare assistants and doctors, we are currently preprocessing the GramHealth database to create a CDSS. Preprocessing includes converting the audio data into text, shaping the unstructured data into a structured form (see Fig. 3). The processed data will be linked to produce meaningful medical information. Once the data are ready, it will be fetched by the applications for Big Data analysis (CDSS and trending).

3. Experiment Design, Results and Analysis

Portable health clinic has been tested against a sample population from unreached communities in Bangladesh. The experiment design involved conducting validity experiments in urban, sub-urban and rural areas between September 2012 and January 2013. The experimental environment consisted of the following facilities:

- Small call center in Dhaka (the capital city of Bangladesh) with two female and two male doctors, and one transcript writer;
- A portable health clinic briefcase with 12 diagnostic tools;
- Mobile health check-up team comprising two healthcare assistantss, 3 program assistants and one quality check officer. Patient data were captured from diagnostic tools wireless BAN and manually inserted into our GramHealth database through a user-friendly web interface;
- Off-line version of GramHealth to store the patient's health profile and synchronize it with the central server when the sufficient network bandwidth is available;
- On-line GramHealth software tools to process and store patient electronic health records.

The mobile health team applied a regional business model to test the effectiveness of PHC in communities with poor infrastructure (Fig. 4). The team visited rural villages and urban factories, and set up a PHC health camp service for one week. There was a marketing campaign 2 weeks in advance so that subjects could preregister for the event and schedule a time for a health check-up. The health team revisited the areas every two months to repeat the measures. Patients who were previously measured as risky (orange and red) were asked to join the next health camp for a new check up.

During the first experimental time frame, 8,690 patients received a health check and their EHRs were stored in the GramHealth database. The experiment was carried out in two rural regions: Ekhlaspur in Chandpur district and Chhoygaon in Shariatpur district. The total number of rural patients from the study regions was 2,728 (31.28% of total patients). The number of suburban patients (women working in garment factories and daily laborers in construction companies) was 2,890 (33.3% of total patients). The number of urban patients from the three industries was 3,072 (35.42% of the total patients). In Ekhlaspur, there is no mobile network coverage and the offline GramHealth(local sensor server) analyzed the data and classified patients into four groups. Telemedicine with the doctor from this area point was not possible.

The Portable Health Clinic is currently being tested using an area business model by a different health teams. This is a smaller set up in which one healthcare assistants offers

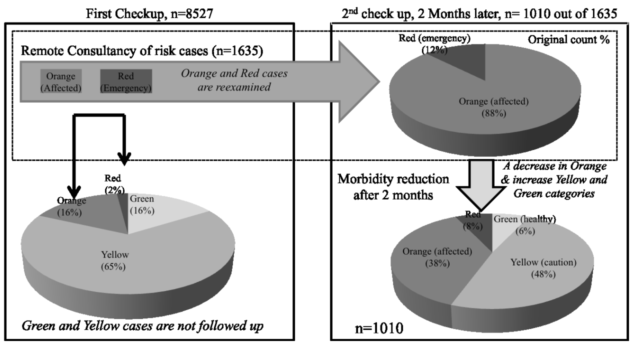

Fig. 5 PHC results show reduction of morbidity for patients at risk (Orange and Red) after two months.

PHC services at a service point once a week for 6 hours. She travels to the same 6 service points every week. This mode of operation is applicable for a large village or several nearby villages. The GramHealth back-end and medical call center provides the consultancy service regardless of the front-end set up and business model (Fig. 4).

3.1 Results: Portability Health Clinic Tests

The preliminary results show a decrease in morbidity following intervention by the portable health clinic. In the first health check-up phase, 8,527 subjects were tested. PHC categorized 6,892 patients as low risk (Green 1,364 and Yellow 5,542). Caution (yellow) subjects were given health guideline booklets. PHC categorized 1,631 patients as high risk and the same number of patient-doctor remote consultancies were established (Orange 1,364 and Red 170). The high-risk patients were prescribed medicine and were advised to attend the next PHC healthcare camp for a follow-up health check-up, scheduled 2 months later.

In the second phase (after 2 months) 1,010 patients (62% of the original high risk patients) were re-examined using the same sensor procedure. The purpose was to measure the validity of the EHRs, the effectiveness of remote consultation and the suitability of the prescribed drugs on the patient. The follow-up triage measurements showed a marked improvement in the patients previously categorized as Orange 426 (48%) patients had moved to the Yellow category and 52 (6%) patients had moved to the Green zone. This left 532 (46%) patients remaining in the Orange and Red categories (Fig. 5).

The records are currently being statistically evaluated and will be published subsequently.

3.2 Discussion

The portable health clinic is a low cost and efficient e-Health system designed to target morbidity in unreached communities. It is a highly focused solution to the extent that a small team or a female healthcare assistants can conduct advanced health check-up services in any environment that has mobile network coverage. The intensity of morbidity is identified by an automated triage system and only patients at risk (affected or emergency) receive telemedicine consultancy. Patients at risk received e-Prescription and their EHR was stored for future consultancies. Preliminary results showed a decrease in morbidity for patients identified as affected or emergency (orange or red) within two months. This is because these patients underwent a remote health consultancy, received an e prescription and locally purchased medicine. However, there are constraints to the Portable Healthcare system concerning scale, adaptability and interoperability. The portable health clinic is a nimble small-scale solution and cannot be compared to a large diffusive health system such as a hospital. It can treat thousands of patients and not millions of patients. The current PHC briefcase contains sensors that measure non-communicable morbidity (hypertension, diabetes, heart disease) but not contagious diseases (cholera, measles). Therefore, the current healthcare sessions are more focused on lifestyle and not on the infectious diseases. The EHRs are not interoperable with other e-Health systems and the EHR stay with the GramHeath database until there is a standardized EHR format. Accepting these limitations, the Portable Health Clinic does provide ‘on the ground’ practical heath care for unreached communities: low-income populations, remote infirm elderly groups, and for short-term catastrophe coverage. It is based on a sustainable business model where the workers are localized (semi skilled entrepreneurs and healthcare assistants) and the experts consultants (doctors) do not travel or move to undesirable areas.

4. Conclusion and Future Works

In this work, we introduced the Portable Health Clinic system. We explained the system components, operations and data structure. We reported on the experimental design and how it was tested against a large sample population in Bangladesh. Results showed that PHC could be used to identify morbidity and help reduce morbidity by providing health consultancy in unreached areas. We discussed the challenges in terns of deployment scale, adaptability and interoperability. As future work, we will analyze the collected BigData to turn our Database into a knowledgebase so that the patients, researchers and common people find the system more useful as a source of info-medicine.

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References

[1] Global Health Issues http:www.globalissues.orgissue587health-issues, accessed on March 1, 2013.
[2] The Remote and Rural Steering Group.: Delivering for Remote and Rural Healthcare. The Scottish government, Edinburg, Nov. 30, 2007.

[3] N. Chaudhury, J. Hammer, M. Kremer, K. Muralidharan, and F.H. Rogers, "Missing in action: Teacher and health worker absence in developing countries," J. Economic Perspectives, vol.20, no.1, Winter 2006, pp.91–116(26), 2006.
[4] A. Ahmed and T. Osugi, ICT to change BOP: Case Study: Bangladesh, pp.139–155, Shukosha, Fukuoka, 2009.
[5] H.P. Chase, J.A. Pearson, C. Wightman, M.D. Roberts, A.D. Oderberg, and S.K. Garg, "Modem transmission of glucose values reduces the costs and need for clinic visits," Diabetes Care 2003, vol.26, no.5, pp.1475–1479, 2003.
[6] J.A. Cafazzo, K. Leonard, A.C. Easty, P.G. Rossos, and C.T. Chan, "Bridging the self-care deficit gap: Remote patient monitoring and hospital at home," In Electronic Healthcare First International Conference, eHealth 2008.
[7] E. Bayliss, J.F. Steiner, D.H. Fernald, L.A. Crane, and D.S. Main, "Descriptions of barriers to self-care by persons with comorbid chronic diseases," Ann Fam Med, vol.1, no.1, pp.15–21, 2003.
[8] A. Ahmed, S. Inoue, E. Kai, N. Nakashima, and Y. Nohara, "Portable Health Clinic: A pervasive way to serve the unreached community for preventive healthcare," Proc. 15th International Conference on Human-Computer Interaction (HCI 2013), Nevada, USA July.
[9] N. Nakashima, Y. Nohara, A. Ahmed, M. Kuroda, S. Inoue, P. Ghosh, R. Islam, T. Hiramatsu, K. Kobayashi, T. Inoguchi, and M. Kitsuregawa, "An affordable, usable and sustainable preventive healthcare system for unreached people in Bangladesh," 2013.
[10] A. Ahmed, L. Kabir, E. Kai, and S. Inoue, "GramHeath: A bottom-up approach to provide preventive healthcare services for unreached community," Proc. 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC'13). 2013.
[11] A. Nessa, M. Ameen, S. Ullah, and K. Kwak, "Applicability of telemedicine in Bangladesh: Current status and future prospects," The International Arab Journal of Information Technology, vol.7, pp.138–145, 2010.
[12] E. Kai and A. Ahmed, "Technical challenges in providing remote health consultancy services for the unreached community," Proc. 27th IEEE International Conference (AINA), FINA-2013 Workshop, Barcelona, Spain, March 2013.
[13] A. Ahmed, K. Ishida, M. Okada, and H. Yasuura, "Poor-friendly technology initiative in Japan: Grameen technology lab," The journal of social business, vol.1, no.1, pp.92–105, Jan. 2011.

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