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Intelligent Technologies for Self-Sustaining, RFID-Based, Rural E-Health Systems

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Community-based healthcare is increasingly important for the well-being of inhabitants of emerging economies. The community model is needed partly because roads are less developed, limiting patients' ability to commute from distant villages to central medical facilities [1]. Also, developing countries have a large rural population base. Some estimates are that rural agriculture employs 75% of the population in developing countries [2].

It is difficult at times for community-based healthcare workers in developing countries to access medical records of individual patients in the field if the records are maintained and stored at a central health facility. In some instances, individual patients must keep their own paper-based medical record and carry it with them to the central medical facility for follow up visits and treatment. This type of system can be unreliable, cumbersome, and susceptible to human errors. Consistent medical histories of individual patients can easily be lost leading to errors in diagnosis, medication, and treatment. At best, there are cost and efficiency implications. At worst, it could put people's life at risk. In order to overcome some of these difficulties, a versatile central electronic medical record system that can be accessed by the community healthcare workers in the field could prove useful.

We propose a radio frequency identification (RFID)-based community e-health system where a patient is given a "passive" RFID card or an equivalent device (such as a stylized bracelet in accordance to the local custom) and the community healthcare workers are each given a mobile RFID read/write device that can also access the central electronic medical record system. The technology is relatively simple but the process to make it work well in a real life situation is expected to be complex. We studied how to implement this model in such a way that it is self-sustaining, rather than relying on recurring external funding, such as charitable support.

The solution proposed is by no means exhaustive in its possibilities. We also propose some potential service enhancements and address issues such as risk exposures and environmental impact. A brief, quantitative example is also given to illustrate the principles of the basic solution with the support of appropriate computational intelligence.

Goals for an RFID-Backed Community Healthcare System

The goal of an RFID-backed community healthcare solution is to enable easy and reliable identification of individual patients, maintain more accurate medical records, facilitate better healthcare, and enhance the quality of life in communities that are remote from a central medical facility. In addition, it can also help to relieve the workload pressure on the central medical facility when it is overcrowded and can increase revenue opportunities by broadening the base of patients to include more remote locations. It may also help to improve the efficiency of the central medical facility, allowing it to focus resources on cases that require more specialized attention and care.

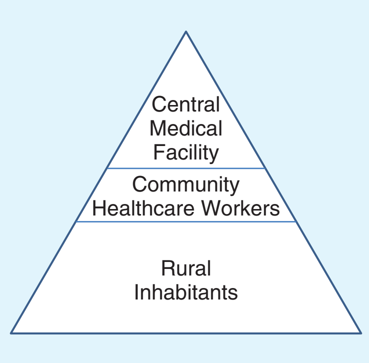

Fig. 1. The hierarchical relationship in a community healthcare system.

Community-based healthcare is increasingly important for the well-being of inhabitants of emerging economies.

The key stakeholders in the value chain of medical care in a developing country are typically 1) the administrator and physicians at the central medical facility, 2) affiliated community healthcare workers, 3) the patients and the inhabitants in the immediate communities, 4) the equipment and e-health recorder solution providers and 5) the wide area communication provider. These stakeholders will have to derive value from the system in order for the scheme to be self-sustainable. The essential hierarchical relationships among the main constituents are the central medical facility at the top of the pyramid, which manages a number of community healthcare workers, who in turn look after a large base of inhabitants in the rural community. See Fig 1. The equipment and resource providers are facilitators and horizontal platform enablers.

A sustainable community healthcare solution should be able to simultaneously provide direct benefits to patients, ensure the well-being of the associated population, create opportunities for community healthcare workers, and streamline

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the operation of the central medical facility. Without a multiple-win model, the system will not work well.

The patients are nominally the end customers in remote, rural locations. These people are generally from underprivileged families, and many live with some degree of poverty. A solution should provide better healthcare at an equivalent or lower cost than the existing system. Community healthcare workers should benefit from new income streams and job opportunities. For the central medical facility, the main benefit will be an increase in operational efficiency with the potential of increasing their patient base. As a byproduct, our proposed solution will also bring business opportunities to suppliers and other affiliated service providers.

Technology

Radio Frequency Identification is an established wireless technology. The use of "near field communications" or RFID for public health in developing countries is not completely new [3]. The solution described here is built on established concepts, but leverages collaboration between community healthcare workers and a central medical facility to design a sustainable solution that can potentially improve the quality of life for people at remote, rural locations.

In the solution design, the mobile RFID read/write device utilized by community healthcare workers can be a proprietary piece of equipment but it can also be a specially-adapted, data communication-enabled mobile phone that can communicate with the remote centralized database of a medical facility in addition to servicing RFID tags locally. Wide-area data communication enables remote transfer and retrieval of medical record information in the field. At the same time, the system allows read and writes of the individual RFID-enabled "medical card" locally.

These RFID cards are preferably "passive," meaning that the energy for the RFID tag is harvested from the read/write device through electrical induction; the tag has no inherent power source. High-frequency RFID tags using 13.56 MHz are frequently used for very short range, high cost sensitive applications. Several incompatible standards exist for these including ISO/IEC 14443 type A and B, ISO 15693 and FeliCa standards.

RFID, electronic medical record system and mobile RFID read/write devices all are mature technologies that are often used in medical facilities, such as hospitals, for patient tracking and enhancing work flow [4]. The use of such devices for servicing outpatients in remote locations is still rare [5] for cost reasons, even though the use of RFID for asset tracking is widespread in pharmaceutical industries, laboratory automation, and inventory management [6]. The solution proposed here utilizes these mature components of RFID systems to facilitate a self-sustainable community e-health solution. This solution utilizes the illustrative framework of a business model that enables revenue sharing between healthcare workers and a central medical facility.

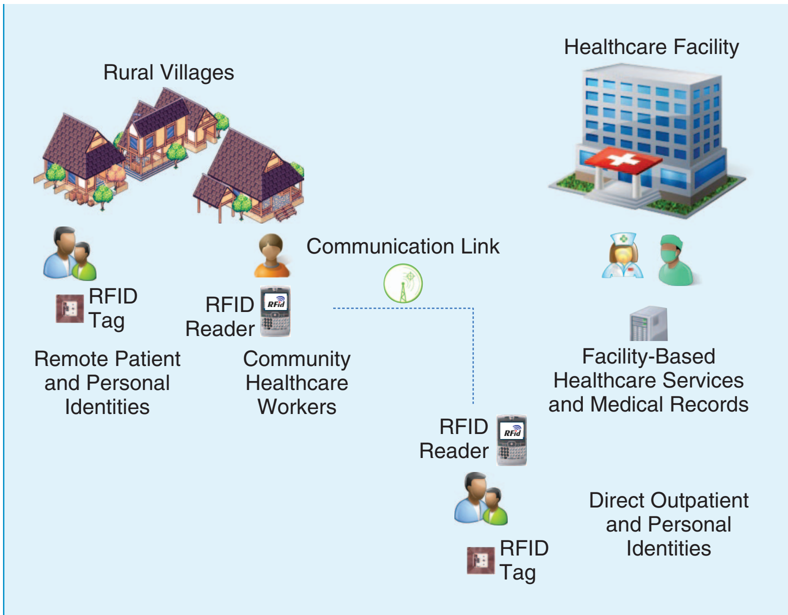

Fig. 2. The RFID e-health system.

Basic System Configuration

The proposed RFID solution needs to work in concert with an electronic medical record system. The basic configuration is shown in Fig 2. Specifically, the RFID system is used to register and monitor the transactions between the community healthcare worker and the patients in the field, and enables the healthcare worker to upload and download medical record information from the database at the central medical facility.

All patients are provided with individual RFID medical cards or their equivalent. An RFID medical card may record a selection of the patient's personal information such as name, a photo, and potentially some form of biometric verification information, such as a thumb print. The card may also store essential medical information, such as blood type and allergies. However, the system is not designed for supporting mission-critical medical cases as the wide-area communication infrastructure may not always be sufficiently robust at remote locations.

The community healthcare workers are each provided with a mobile RFID read/write device equipped with a graphic display so that information on a patient's RFID medical card and information retrieved from the central facility can both be utilized. This RFID read/write device may also have a small keyboard or a soft keypad based on touchscreen technology. In addition, sufficient onboard memory is needed within the RFID read/write device to hold essential information, especially when not "online."

The mobile RFID read/write device has to be password or biometrically protected so that if the device is stolen or lost, it cannot be used by third parties to perform unauthorized reading of a patient's medical card or retrieval of information from the central medical record database.

The RFID read/write device will also be equipped for wide-area wireless data (and preferably voice) communications. Global positioning system (GPS) based location information can also be included in the device to provide position and time stamps for each transaction.

> The goal of an RFID-backed community healthcare solution is to enable easy and reliable identification of individual patients, maintain more accurate medical records, facilitate better healthcare, and enhance the quality of life in communities that are remote from a central medical facility.

Service Process

For the system to work, certain service processes have to be in place. The operation of the system will require a patient to bring his/her RFID medical card when visiting a community healthcare worker or the central facility. When a patient interacts with a healthcare worker in the field or at the central medical facility, the patient's RFID medical card will be read to verify the person's identity. This will also facilitate the download of the most up-to-date version of the person's medical record information from the central database to the mobile RFID device. At the conclusion of the healthcare service transaction, the healthcare worker can update both the RFID medical card as well as the central medical record database. This execution of the read/write process by the mobile RFID device also serves to notify the central medical facility of the transaction in order to facilitate account reconciliation with the community healthcare worker or any other third parties at a later time.

When a community healthcare worker is operating at remote locations, the download or upload of information is facilitated by a wide-area communication link. In the situation where fixed wireless access is not available, which is likely to be the case in many emerging economies, cellular-based wide area communications is frequently assumed. Thus an underlying assumption for the system to function well is that the remote communities will need to have mobile communication coverage available.

If this is not the case, the updating of the central database will have to be done on a non-real time, offline basis. In this case, a copy of the last known medical record of the patients may be stored in the mobile RFID reader device by each of the associated healthcare workers. Given that for most remote locations, the data transfer rates of mobile systems would likely to be relatively slow, e.g. over General Packet Radio Service (GPRS) or Enhanced Data-rate for GSM Evolution (EDGE), it is necessary that information provisioned over the mobile communication link be concise. For the GPRS/EDGE family of systems, the mobile RFID read/write device will need to be equipped with a subscriber identity module, commonly known as SIM cards, specific to a mobile data service provider.

Data Communication and Support

The community healthcare worker is expected to retrieve and upload data during each transaction. The volume of data to be retrieved from the central facility should be kept to a minimum to avoid transmission delay and in most cases should be limited to text-based information. This information includes the latest medical records of the patient. Thus for each transaction, the amount of data to be transferred is expected to be of the order of few tens of kilobytes in both the uplink and downlink directions.

With this amount of data transfer, the potential data transfer delay is expected to be small even over a low data rate GPRS channel. For instance, assume a case load of 2400 community healthcare transactions per month and that each transaction takes 50 kilobytes; the data transferred will be of the order of 2400×50 kB = 120 MB or 0.12 GB for one central medical facility. This amount of data transfer is unlikely to put any strain on the capacity of the cellular network, even when the service scales to include other medical facilities.

The data service transactions are essentially machine-to-machine based, even though managed by community healthcare workers. Most machine-to-machine communications are not expected to demand much customer service support and maintenance effort from the network provider once the solution is set up and tested.

Potential Business Model

The cost structure associated with the RFID-backed community healthcare outreach scheme generally has both a capital and a recurring cost component. The capital expenses of the system include the cost of the RFID medical cards, the mobile RFID read/write devices, equivalent RFID read/write devices at the central medical facility, the electronic medical record system and server, the cost for training personnel and the cost of deploying the system. Recurring operating cost include the wages of the community healthcare workers, wide-area communication costs, and the cost of supporting and maintaining all the system components.

The operating or business model is of vital importance to ensure a long-term self-sustaining system. The system needs to generate sufficient revenues in order to cover, at least, the cost, if not a reasonable profit. To facilitate this, the healthcare worker will have to collect a fee from the patient for every service transaction. The amount could be similar to the fee that the patient has to pay if s/he visits the central medical facility in person. We may also adjust the fee to include a "convenience premium for home visit." The convenience for the patient includes shorter travel distance to seek medical help, extended service hours of medical services, access to urgent out-of-hour services within his/her neighborhood, reduced loss-of-earnings due to taking time to travel, avoiding the need for escort by relatives, and reduced costs of travel.

As an illustration, we propose to split the revenue from the transaction fee between the healthcare worker and the central medical facility on a revenue-shared basis. For instance, if the fee paid by the patient is \$A, the community healthcare worker will take a cut of \$a. The remainder, \$R = \$A-a will be the revenue that goes to the central medical facility, see Fig 3. The medical facility may also provide a basic retention wage to the community healthcare worker, but the majority of the income will come from the transaction fee with the patient. A revenue sharing model will encourage the community healthcare workers to become more proactive with reaching out to the remote communities in her/his neighborhood.

This will also reduce the loading of the central medical facility by mundane and routine ailments and enable the concentration of resources on more serious cases – the cases that cannot be serviced by the community healthcare workers. The part of the patient fee for the central medical facility is needed to support the operation of the electronic medical record system and the mobile RFID system. If the community healthcare worker is not able to handle a case, it has to be referred to the medical facility for attention. This referral process can help the medical facility to become efficient in both handling specialized cases and managing inpatient admission.

An alternative operating model is that the central medical facility may increase the charge to people attending the facility in-person as an outpatient, as the facility is now supposed to be handling more specialized medical cases. This also has the effect of driving people with less critical illnesses to rely on the community healthcare. With this operating model, the central facility may subsidize patients in remote locations to encourage them to use the local services provided by community healthcare workers. The increase in charge for outpatients attending the central facility directly will have to offset the cross-subsidy to the remote patients in order to ensure self-sustainability.

Yet another alternative revenue model is to fund the system through a micro-health-insurance scheme [7]. The micro-health-insurance scheme may be run by the central medical

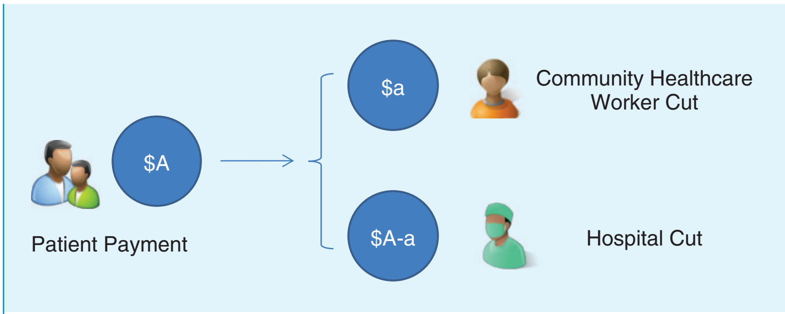

Fig. 3. Revenue sharing model between community healthcare worker and central medical facility.

facility or by its affiliate third party provider to ensure that there is a sufficiently large subscription base to support the operation. People in the rural community can be invited to subscribe to the micro-health-insurance in exchange for low or no cost healthcare by community healthcare workers. The money raised through the insurance premium will be used to fund both the community healthcare workers and the central medical facility.

To ensure perceived value by the end customers, the quality of community healthcare workers is crucial. The healthcare workers need to be sufficiently professionally trained and proactive in reaching out to patients, especially for preventive medical services.

There are constant exposures to risk components.

Key Risk Exposures

There are many layers of risk exposures associated with the proposed solution, including technical risks, human factors, and operationally related impairments. While technical issues are important, frequently it is the latter two risk components that can lead to premature failures of a scheme.

With the large number of people and components involved in a community healthcare system, there are constant exposures to the risk components. It is important to identify the risks early and derive mitigation and safeguard strategies during system design, and to factor risks into the evaluation of the solution.

One of the most fundamental risks is the acceptance of the solution by the various stakeholders, including the people at the central medical facility, the community healthcare workers, and the rural community inhabitants. Without adequate support and buy-in by all these groups, the solution will fail. To secure buy-in, it is critical that the value of the solution is clear for everyone.

Even if all the stakeholders embrace the solution, sustainability can only be preserved if the generated revenue is sufficient to provide reasonable benefits to all. These include adequate income for the community healthcare workers at a fair market pay level and sufficient compensation to the central medical facility for running the electronic medical record system and the RFID medical card system. In addition, the number of patients participating in the scheme, the patients' willingness to pay for the services, and the quality of healthcare service that can be provided are key factors that will determine the long-term viability of such a community e-health solution.

The ongoing maintenance of equipment, continuous training of healthcare workers, and accurate and safe keeping of personal health records will determine the reputation of the scheme and the support of the community. If any of these elements breaks down or if there are any serious errors or malpractices, it can lead to irreparable, long-term damage to the mutual trust between the provider and the community.

Fraud is another risk exposure that may threaten the system. There are potential cash transfers within the system; the community healthcare workers can potentially bypass the system entirely and take the full fee from the patients without passing on the agreed share to the central medical facility. The community healthcare workers may even negotiate a lower rate with the patients to encourage the patient to undercut the central medical facility and participate in the fraud. In this situation the healthcare workers will not be able to update the medical record of the patient or retrieve medical records from the central medical facility. This is a source of revenue leakage even though it still helps to ease the loading of the central medical facility. This revenue leakage is not easy to plug completely apart from the use of tight supervision and tracking of performance and impose disciplinary actions against offending healthcare workers if foul plays are discovered. Good training together with some form of competition among the community healthcare workers or incentive scheme may help to minimize the temptation of fraudulent practices and instill a sense of pride and loyalty. The use of analytics can also help to identify systematic fraudulent activities.

Privacy and security are valid concerns when personal health information is being handled, transferred, and recorded, especially in the field. Adequate security measures have to be put in place to ensure that personal information is not exposed or intercepted by third parties during storage or being transmitted. To this end password protected access to the mobile RFID device is of critical importance; adequate training for the community healthcare workers on ethical practice would also be useful. Many of the issues including the custodian of the personal clinical information, transmission of the record, storage of the content, the technical approach to security and authentication, and the party who authorizes access to the information are of critical importance to protect the individuals. In addition to basic security measures, secure transmission techniques including secure socket layer for encryption information over the network or secure tunnels such as virtual private network or secure shell technology will be appropriate as part of the implementation.

Depending on the local regulatory environment on healthcare, an e-health solution may attract regulatory scrutiny or be subject to legislative constraints. This may come from the perspective of health and safety, privacy, or scope of services, and will have to be addressed on a case-by-case basis in accordance to the local health law and practices over the basic requirements.

In the long run, the upkeep of the system technically will help to bring the solution up-to-date but will require additional maintenance cost. This will have to be factored into the long-term development budget.

Technology Aspects and Computational Intelligence

A number of technologies are applicable for individual identification, and for storing and retrieving records. However, a remaining challenge is system integration of multiple technologies into a coherent solution tailored for use with specific institutions. Computational intelligence (CI) paradigms offer some advantages in automating and creating a human-like capability in healthcare applications [8].

A generic biometrics system captures, usually in real-time, the characteristics of an individual [9], then processes and stores a record in a database [10]. Biometric techniques can be chosen from among fingerprint systems and facial, voice, and iris recognition. In general, a combination of biometrics and human-readable alphanumeric characters such as a name and a number, barcodes, or RFID tags, are needed. Electronic record systems for a remote area should be simple [11] and have a user interface that adapts to the local culture and language(s). A summary of recent efforts to create such systems in developing countries is found in [12]. This paper discusses projects in Kenya, Peru, Haiti, Uganda, Malawi, and Brazil.

CI-based techniques are suggested for process mining in hospital information systems [13]. Mining of electronic medical records to examine physician decisions is suggested, to identify the impact of physician decision on patient outcomes and hospital costs [14]. This is of significant importance in environments where physicians are not held accountable for their costs in a healthcare environment, perhaps due to regulatory limitations. In fact, the adoption of record systems in developed countries indicates that change management, policy, and strategy issues are the primary problems, rather than technology [15]. In addition, training and managing healthcare staffs to deal with technological systems are significant issues [16]. CI-based biometric technologies are reported for the representation and recognition of incomplete biometric data, discriminative feature extraction, biometric matching, and online template updating [17]. Wireless systems for patient-to-point-of-care communications will need careful consideration of data processing designs based on when, where and how the information is obtained and stored [18]. A tailor-made solution for tracking information integrates RFID, GPS and Wi-Fi [19], with the need to assess information security risk and adjustment of technologies and procedures allowing access to authorized personnel [20]. Intelligent optimization methods have an important role in event mining of network activities in RFID logistics applications [21], including the optimization of RFID sensory capabilities [22].

A Simplified Example

In order to put the discussion of the solution into perspective, it is instructive to describe an example healthcare system to illustrate the overall principle quantitatively. In our example, we make an assumption of three community healthcare workers per central medical facility and that the central medical facility has an addressable patient base of 8000 inhabitants. In other words, the ratio of central medical facility to community healthcare worker to addressable inhabitants is 1:3:8000, respectively.

If we assume that 1% of the addressable patient base is not feeling well each day, there will be an average of 80 patients using the system per day. Dividing the workload among the three community healthcare workers each will have a case load of attending to about 27 transactions each working day. For a 10 hour shift, each patient will have a transaction time of about 20 minutes, which may include commuting time by the community healthcare worker if it is an outreach family visit. We may assume that the time is reasonable as most of the illness probably would be routine.

Also in our example, we assume each month the central medical facility will handle $80 \times 30 = 2400$ transactions. Over the same period, each community healthcare worker will handle about $27 \times 30 = 810$ transactions. For each transaction a patient is assumed to be charged \$1, so the total revenue for sharing between the healthcare workers and the central medical facility amounts to \$2400. If the healthcare worker takes 60% of the revenue, the monthly income for each worker is $2400 \times 0.6/3 = \$480$ or \$16 per day. The central medical facility will have a monthly-revenue of \$960.

For locations where people generally live on less than \$2 a day, charging \$1 for seeing a community healthcare worker could be a heavy burden. If the patient fee is reduced, it will weaken the income for both the community healthcare workers and the central medical facility. Some kind of local business approach has to be implemented to make the case sustainable.

One way is to overlay the system with a micro-health-insurance scheme so that people can pay a subscription on a long-term basis to cover the healthcare cost. In other words, for a "free" service without co-payment, the cost of $2400 has to be equally shared by the 8000 inhabitants in the community. This amounts to each paying $0.3 per month as a contribution to the micro-health-insurance scheme.

In the above example we have not built in additional enhancement to the basic system such as incentive scheme and sliding base pay scale for the community healthcare workers to drive loyalty and combat fraud. The intention is to keep the example simple. More complex solutions can be designed as described earlier in this article, and evaluated quantitatively.

Self-Sustaining Model

A RFID-based community e-health system is proposed that works in concert with an electronic medical record system to support the development of out-reach healthcare for rural communities. By adopting a revenue sharing model, it is anticipated the system will be self-sustainable and be able to improve healthcare and quality-of-life among people living in remote areas. The system carries risks that need to be mitigated as well as opportunities for enhancing the service that could be implemented as appropriate.

The proposed implementation framework supports a research and development facility, allowing interdisciplinary international contributions aiming to enhance the outcome of the implementation. This will facilitate deployment of CI-based techniques within the system, while monitoring and studying the pilot test.

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