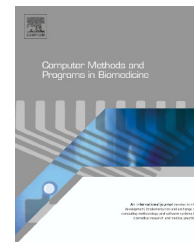




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A prototype of a novel cell phone application for tracking the vaccination coverage of children in rural communities

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ABSTRACT

Immunization saves millions of lives against vaccine-preventable diseases. Yet, 24 million children born every year do not receive proper immunization during their first year. UNICEF and WHO have emphasized the need to strengthen the immunization surveillance and monitoring in developing countries to reduce childhood deaths. In this regard, we present a software application called *Jeev* to track the vaccination coverage of children in rural communities. *Jeev* synergistically combines the power of smartphones and the ubiquity of cellular infrastructure, QR codes, and national identification cards. We present the design of *Jeev* and highlight its unique features along with a detailed evaluation of its performance and power consumption using the National Immunization Survey datasets. We are in discussion with a non-profit organization in Haiti to pilot test *Jeev* in order to study its effectiveness and identify socio-cultural issues that may arise in a large-scale deployment.

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1. Introduction

Immunization saves millions of lives against vaccine-preventable diseases. Through financial support from organizations such as the GAVI Alliance, and more recently the Bill & Melinda Gates Foundation, a lot of progress has been made in immunizing children since 2000 towards the Global Immunization Vision Strategy (GIVS) [51]. The number of deaths in children under 5 years of age has decreased. Yet, 24 million

children born every year, do not receive proper immunization during their first year of life [51].

While the GIVS aims to achieve 90% vaccine coverage by 2015 and reduce the number of childhood deaths to 4.3 million, there are several constraints that must be overcome. According to UNICEF and WHO [51], the health care systems are weak in developing countries.¹ There is insufficient political and financial support. The monitoring infrastructure is weak and information systems are lacking. There is a shortage of trained health workers who can deliver immunization to the population. Many children live in poor, remote

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¹ The World Bank defines a country with low-income or middle-income economy to be a developing country [13].

areas where health care facilities and public services are weak. Due to lack of information about the importance of immunization, many children do not receive the required vaccines. Unexpected deaths and side effects create fear of immunization among parents, thereby reducing the number of children who receive a full course of vaccines.²

UNICEF and WHO have emphasized the need to strengthen immunization surveillance and monitoring in developing countries [51]. Immunization coverage information is useful to monitor the performance of immunization programs and improve the delivery of vaccines to the population [50]. Today, the use of paper records to track the immunization status of children in countries such as India leads to inconsistencies in the way information is recorded; immunization records may be lost or damaged [20,2,10]. Lack of immunization coverage information can lead to wastage of vaccines due to unnecessary revaccinations and poor forecasting of the vaccine demand [51,10].

There has been an unprecedented rise in the use of cell phones worldwide; today, there are more than 6 billion cell phone subscribers [11]. Through cell phones, it is now possible to communicate with vast populations in previously hard-to-reach areas. The ubiquity of cellular infrastructure provides new opportunities to develop cell phone-based solutions for tracking the vaccination coverage of a rural population. In India, a middle-income economy [13], about 40% of the rural population has cell phones (or mobile phones) [29]. In Haiti, a low-income economy [13], the cellular infrastructure has grown quickly since the devastating earthquake of 2010. Haitians are using cell phones to receive relief incentives [42]. Furthermore, UNICEF has identified countries like India and Haiti as priority countries where routine immunization coverage is low and must be improved [44,45]. (Immunization tracking is a challenge even in countries such as USA, but our focus is on developing countries.)

While tracking the vaccination coverage of a population has become a global challenge in public health,³ little research has been done in this domain. This is a timely opportunity for the health informatics community. In this work, we address the problem of tracking the vaccination coverage of children in hard-to-reach areas such as rural India, where cellular infrastructure is available. We present a low-cost cell phone application called *Jeev*.⁴ *Jeev* is unique in the sense that it synergistically combines the power of smartphones and ubiquity of cellular infrastructure, Quick Response (QR) codes, and national identification cards. *Jeev* is based on a client-server model: the data collected by the clients are synchronized at the server; the clients and server exchange small amounts of data using low-cost SMS text messaging. (The transmitted data is always encrypted for security and privacy reasons.) We report a detailed evaluation of *Jeev* to study its performance, scalability and power consumption, using the National

Immunization Survey datasets [4]. Although *Jeev* has not been deployed and studied in a rural community, we are planning to pilot test it in rural Haiti through Maison de Naissance [14], which is a community health care facility for delivering healthy mothers and healthy babies.

The rest of the paper is organized as follows. Section 2 provides the background and related work. Section 3 presents the design of *Jeev*. Section 4 describes the communication protocol in *Jeev*. In Section 5, we report the performance evaluation of *Jeev*. Section 6 discusses our next steps for pilot testing *Jeev* in a rural community. Finally, we provide some points for discussion and our concluding remarks in Sections 7 and 8, respectively.

A preliminary version of this paper appeared in the 2013 IEEE International Conference on Healthcare Informatics [32].

2. Background and related work

2.1. Cellular infrastructure in developing countries

Today, there are more than 6 billion cell phone subscribers [11]. The cellular infrastructure is ubiquitous in many developing countries and provides an easy way to connect to vast populations in hard-to-reach areas [21,29,42]. Smartphones have become popular and affordable; they have powerful processors, several GBs of storage, high resolution cameras, several hours of battery life, and touch screen technology. SMS text messaging provides an inexpensive way to communicate small amounts of data in hard-to-reach areas. Today, it costs less than \$0.02 to send a text message in countries like India, Pakistan, Bangladesh and Haiti [19]. Data can be encrypted for security and privacy reasons.

2.2. Quick response codes

Quick Response (QR) codes have fast readability and higher storage capacity (up to 400 times more) as compared to standard UPC barcodes [15,38]. QR codes are 2-dimensional and can encode any type of data and even encrypted data. They have become popular in businesses and among consumers. QR codes use advanced error correcting codes. Even with up to 30% damage, a QR code can still be decoded [7] (see Fig. 1(a)). QR codes can also be modified for artistic reasons and still be decoded (see Fig. 1(b)). They can be easily decoded using applications on smartphones [12].

2.3. National identity cards

National identity cards have become increasingly important in many developing countries to prevent voter fraud and corruption, and to take advantage of banking services, government incentives and subsidies. For example, in rural India, such cards are required to receive subsidies on food and grains [5] and open bank accounts [9]. In post earthquake Haiti, national ID cards are giving citizens access to work, banking services, and voting privileges [26]. These cards are usually laminated or made of plastic and are more durable than paper records.

² Recently, polio vaccines caused paralysis in 47,500 children in India [36].

³ Recently, the Bill and Melinda Gates Foundation solicited proposals for developing low-cost cell phone applications to improve the uptake and coverage of childhood vaccinations as one of the grand challenges for 2011 [2].

⁴ *Jeev* means 'life' in the Sanskrit language.

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