Using Cell Phones for Mosquito Vector Surveillance and Control

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***Abstract*—Novel, low-cost approaches to improving prevention and control of vector-borne diseases, such as mosquito-borne dengue and malaria, are needed in resource-constrained environments. The Chaak application supports the use of cell phones for field capture and rapid transfer of mosquito vector surveillance data to a central database. The cell phones exploit existing communication infrastructure, introduce near real-time monitoring, and provide rapid feedback to field data collectors. Dengue is a mostly an urban disease, thus occurring in environments that often have good cell phone coverage. Cell phones eliminate the need for physical data communication. A preliminary evaluation shows that the use of cell phones can lower labor costs, data collection time, and transcription errors.**

Keywords-Android applications; dengue; mosquito control; mosquito immatures; public health; field testing

I. Introduction

Vector-borne diseases, such as mosquito-borne dengue and malaria inflict a terrible and unacceptable burden on mankind and block socio-economic development in many parts of the world. Colorado State University and partners in Mexico (Universidad Autonoma de Yucatan and the public health institution of Servicios de Salud de Yucatan) have developed a software application as a low-cost solution to improve the surveillance and control of mosquito vectors of dengue virus. Data collected with this application can help public health institutions to determine where and when mosquito control efforts should be focused.

Since mosquito *immatures* (larvae and pupae) develop in water, the risk of mosquito exposure can be estimated by collecting information about the presence of immatures in stagnant water. Surveyors typically go door-to-door to count the containers on the premises (inside and outside) with and without water. Containers may include buckets, tires, and cisterns. The surveyors also count the containers holding immatures. This data is collected on paper forms and entered by humans into a computer in batches. This process of data entry is both error-prone and time consuming, which reduces the accuracy and slows vector control responses. A timely response is critical for diseases with explosive outbreak dynamics, such as dengue [4, 6, 13].

The new Chaak application uses cell phones to collect data. Chaak eliminates the need for manual data entry from a paper form, avoiding data transcription errors. The process is also faster; data can be transmitted to a central database as soon as it is entered into the phone. Using cell phones also eliminates the need to carry bulky laptops and transfer data via flash drives. Dengue is primarily an urban disease, and cell phone infrastructure is generally available in urban areas in developing countries.

II. Design and Implementation of Chaak

Chaak users include a system administrator, management personnel for vector control, and surveyors who enter container data into the phones. System administrators and management personnel use a desktop client and surveyors use Android phones to enter the data.

A simple geographic information system based on Lozano-Fuentes *et al.* [9] was extended to allow the system to create maps and manage geographic data. Reports are generated for managers to view mosquito data in various geographic areas.

A. Roles and functionality

System administrators can create valid Chaak users. Administrators can also register authorized cell phones for use in collecting data. Managers can define geographical entities to be surveyed, container types, and assign tasks to surveyors.

Every country has its own geographical hierarchy (e.g., country, states, cities, and neighborhoods). Addresses are expressed in country-specific ways. A geographical hierarchy is matched with the printed address of the premises so that surveyors can be assigned tasks involving visits to a set of premises. Defining geographic entities involves (1) defining the elements in the hierarchy (GeoClasses, such as Country) and (2) defining instances of elements (GeoEntities, i.e., Mexico).

Container types (e.g., buckets, tires, or cisterns) are defined and added for data collection.

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Managers create surveillance tasks — specific premises are assigned to surveyors for completion in a given time period. A new task will include specific geo-entities (premises in neighborhoods) and surveyors.

Surveyors log in to a phone to see a list of premises to visit. Figure 1 is a phone screenshot showing the list of premises as used in Merida, Mexico. Surveyors enter the number of each type of container and the number containing larvae or pupae using the interface shown in Figure 2. A surveyor can transmit the data or save the data in the phone and upload it later.

For robust performance, the cell phone can connect to the main server using three options:

1. ***Continuous Internet Access:*** The surveyor enters data into the phone and sends it instantly to the main server over the internet.
2. ***Periodic Indirect Access:*** The surveyor enters data and saves it in the local application database on the phone. The surveyor sends the data to the main server over the internet when a connection is available.
3. ***Desktop/laptop Data Transfer:*** The surveyor enters data and saves it in database on the phone. The data is transferred to a computer at the main office. An internet connection is not needed.

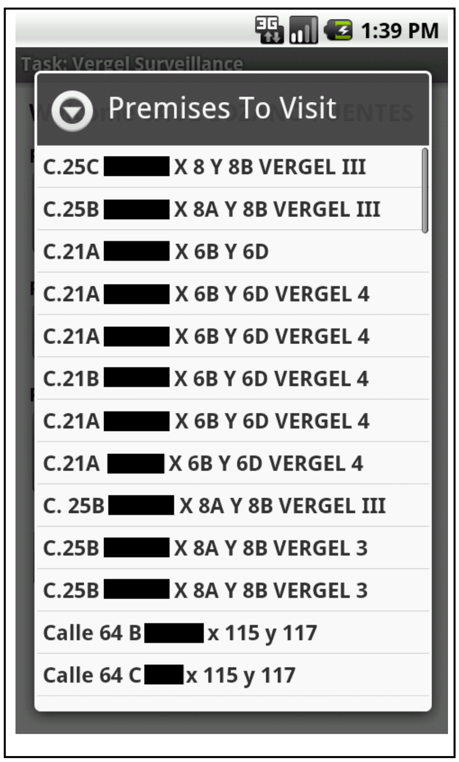

Figure 1. Phone Client Screenshot Showing List of Premises

Figure 2. Phone Client Screenshot Showing Details of One House

B. *Design and Implementation*

Chaak is a multi-tier application. The top tier is the application tier consisting of thin clients on desktops running Windows .NET and smartphones running Android. We used a variety of Android phones (Google Nexus 1, S and Galaxy Nexus, HTC Desire, HTC Legend and Motorola Backflip) running Android versions 2.1 and higher. The Android application communicates with the Business Tier using web services in the Business Access Tier. The web services are hosted on an Apache webserver on Mono. The business tier supports data validation, decisions, evaluations, calculations, and CRUD operations. Data is stored in a PostgreSQL server. A PostGIS plugin manages spatial data such as blocks and premises represented as polygons and dots in space.

III. Empirical Evaluation and Field Test

The goal of our evaluation was to determine whether or not using cell phones as the data capturing device would increase the surveyor’s performance and decrease the number of errors made. The performance could instead decrease because surveyors had to learn to use a new device and the device itself can be difficult to read under direct sunlight. Additionally, simple things like sweat or body oils can interfere with the touchscreen response. Error in data capture might increase by adding new sources of errors in the workflow.

The surveyors had extensive experience performing entomological surveys using paper forms, giving an advantage to the pen-and-paper method. However, the surveyors were familiar with cell phones and touchscreen technology. To minimize the discrepancy between the methods, the surveyors were trained in the use of the cell phone interface.

To assess differences between the methods, we performed two experiments. One measured time differences and the other measured error. The time experiment was performed in actual houses under field conditions and the error experiment was performed in a controlled environment because even experienced surveyors can overlook breeding sites..

Time experiment. We hypothesized that the time used for completing entomological surveys was the same regardless of the method used. Through a pilot study, the required experiment sample size was estimated at 118 premises to be visited per survey method.

To achieve the desired sample size, we randomly selected 13 neighborhoods in the city of Merida, and from each neighborhood we randomly picked 2 blocks. All premises in the selected blocks were to be visited and if possible, surveyed by one of two teams. Each surveying team consisted of 3 surveyors. One block was surveyed using only mobile devices and the other using only pen-and-paper.

The survey time was defined as the time used to complete a survey from the entry of the surveyor into the premises, having obtained permission from the tenant, until the surveyor left the premises. We did not record the time used moving between premises or between the headquarters and the premises because this time is independent of the method used. On the other hand, the surveyors that used the pen-and-paper method had to re-enter the data in the paper forms into a computer spreadsheet. We added this time to the time used for surveying.

Due to logistical difficulties, only 10 neighborhoods of the selected 13 were visited. Using a cellphone, 300 premises were visited, and 299 premises were visited using pen-and-paper. Despite the effort, not all visited premises were surveyed either because the tenant was not home or because the surveyor was not allowed to enter the premises. Only 24% of the visited premises were surveyed using a cellphone and 34% using paper. The total time utilized during the survey was similar for both methods with 567 and 552 minutes for paper and mobile method respectively. However, it took an additional 384 minutes to reenter data from the paper forms into the system.

TABLE I. METHOD PERFORMANCE

Method	Total time	No. of Surveys	Minutes/survey
Paper	961	100	9.6
Mobile	552	71	7.8

In all, the pen-and-paper method required 961 minutes of effort with a performance of 9.6 minutes per survey. In contrast, the surveyor using mobile devices had a performance of 7.8 minutes per survey (Table 1). This increase in performance translates into a 19% improvement when using mobile devices.

We tested the hypothesis that the average time ($T\mu$) was the same for both methods at $\alpha = 0.05$:

$$H_0\text{: } T\mu_{mobile} = T\mu_{paper}$$

We obtained $|Z| = 2.4$ and $P(|Z| \leq 2.4) = 0.016$ thus rejecting the H_0. Therefore there are significant differences between the amounts of time used by the methods. Having found this statistical difference, we proceeded to perform a one-sided test.

$$H_0\text{: } T\mu_{mobile} \geq T\mu_{paper}$$

In this test $Z = -2.4$ and $P(Z \geq -2.4) = 0.0082$ consequently we reject the null hypothesis. Thus, there is no statistical evidence to affirm that the time used while using the mobile device is greater or equal than the time using pen-and-paper.

Error experiment. The objective was to evaluate if there was a significant difference in the number of errors made between the two data collection methods. The pen and paper method was divided in two stages: the survey and the transcription to an electronic spreadsheet. In the cell phone method, only one stage is performed because there is no need to re-capture the data entered on the mobile devices.

In order to have exact numbers for this experiment, the containers and the premises were simulated. The containers were represented with printouts in letter size paper divided in four panels. The first panel had a drawing representing the container type, panel 2 the presence of water, panel 3 whether the container had larvae, and panel 4 whether the container had pupae. Only containers with water had larvae and/or pupae. The premises were represented by sections in a large room divided into 6 sections.

In each mock premises we places 20 and 35 container printouts with varying numbers of immatures. The number of containers and their condition (with water and immatures) were selected at random. The entire experiment was divided into 10 rounds of 5 minutes each. The survey method was assigned randomly to each surveyor. In summary, each surveyor made 10 mock entomological surveys, completing 30 surveys for method. At the end of the day, the surveyors using pen-and-paper reentered the collected data on a computer.

Errors were scored as deviations from the known exact value. A value of 0 means a perfect score and a value of 1 means that the surveyor recorded all possible values incorrectly. Each breeding site has 4 records in the survey form as previously described. Because there are 11 different container types in the survey we can say that the surveyors had to record 44 values, i.e., they had 44 chances of success. Thus, the proportion of errors is the total sum of errors divided by the total number of chances of success. The total proportion of errors (E) is simply the averaged proportion of errors by method.

The proportion of errors for the pen-and-paper method was $E_{paper} = 0.23$ while the proportion of errors for the mobile method was $E_{mobile} = 0.17$. We tested the following one-sided hypothesis:

$$H_0\text{: } E_{mobile} \geq E_{paper}$$

We obtained $Z = 3.865$ accordingly $P(Z \leq 3.865) < 0.001$, and thus we can reject the null hypothesis. Consequently the proportion of errors using cell phones is less than the proportion of errors using the pen-and-paper method.

IV. RELATED WORK

Donner [3] documents the growth of cell phone use throughout the developing world. Mobile phones are now commonplace throughout most of the world, with “over a billion mobile phones in the developing world” by 2008.

Brewer *et al.* [1] find that cell phone technology supports data collection improvements for disease management. In developing countries, effectiveness requires it “be designed around asynchronous communication and only intermittent connectivity". Chaak can pass information between clients and server through undependable connections.

Cell phone use is commonplace throughout the developing world. Thus, field workers with cell phones do not look out of place, even in the poorest communities. Curioso [2] reports that by replacing stacks of folders with a cell phone, public health nurses in Peru can discretely and more safely visit the poorest rural communities without arousing the suspicions of residents, or appearing as likely robbery victims. The success of the project is Peru is because, in part, the system developers understood the problem domain, and obtained feedback from health professionals. That is why we developed Chaak in close association with field workers and entomologists in Merida, Mexico. Kahn *et al.* [5] emphasize the need for evaluations of the benefits of using what they call "mobile health or m-health" technologies. That is why we conducted comprehensive field tests of the cell phone client data collection systems.

Kaplan [7] did not find convincing evidence that cell phone technology can be an effective tool for healthcare interventions for two primary reasons: lack of access to phones by citizens, and limited evaluations of effectiveness. The Chaak system relies on cell phone use by field workers rather than community members, and we are evaluating effectiveness.

Krishna *et al.* [8] conducted a systematic literature review that identified 25 empirical evaluations of the effects of cell phone use on public health. These studies focused on relationships between health care providers and patients and the effects on patient outcomes. Our study focuses on cell phone use by field workers rather than patients, and on the collection of data for the management of the insect vector of the disease.

In a study conducted near Durban South Africa, Tomlinson *et al.* [12] found that the use of cell phones by community health workers to collect field data provided significant benefits over the use of personal digital assistants (PDAs) as well as paper forms. The cell phones uploaded data directly to a server from the field, and avoided the delays and labor of processing paper forms. Data was uploaded as it was gathered, dramatically reducing data loss.

In multiple large-scale evaluations conducted in South Africa, Seebregts *et al.* [11] found that the use of Palm™ Pilot PDAs provided benefits over paper forms in collecting health-oriented survey data. Both respondents and field workers preferred the PDA system to paper, with significantly lower overall costs. These studies collected approximately 90,000 interview records using as many as 200 Palm™ Pilot PDAs used for approximately 50 device-years. Battery life was the major problem encountered.

V. CONCLUSIONS

We present the design, implementation, and field evaluation in Mexico of a smartphone-based application for the collection of data on mosquito vectors of dengue virus. The application improved the accuracy of data collection and significantly increased the speed of data transcription.

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