Improving the Quality and Lowering Costs of Household Survey Data Using Personal Digital Assistants (PDAs). An Application for Costa Rica

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Abstract

Population data in developing countries come mostly from household visits. Armies of interviewers collect those data using paper and pencil (the PAPI method). But that information is infested with nonrandom errors. Newly developed "computer aided personal interviewing" technology (CAPI) is an important advance over PAPI in terms of reducing errors and shortening time lags for data availability. But CAPI has proved to be difficult to implement in developing countries because of the ergonomics, costs, and delinquency restrictions of laptops. In response, we developed a CAPI system for PDAs that may revolutionize the way data is gathered, by reducing fraud, errors and costs and by opening opportunities for collecting complex information. At the core of our PDA-CAPI is an "electronic questionnaire markup language" (EQML) we developed after analyzing thousands of existing questions. This paper reports the lessons learned from using our PDA-CAPI in a complex survey in Costa Rica.

Introduction

The development by the social sciences of survey research represents the largest advance in social science methodology in the last fifty years. Not only do all fields of social science use survey samples to gather data about human populations, virtually all areas of public policy analysis rely on survey data to make informed decisions. The combination of efficient, reliable and cost effective sampling methods and sophisticated questionnaire designs make the survey the data collection method of choice for literally thousands of studies each year, both academic and policy-oriented.

In developing countries, all or most population data come from survey data collected door-to door in household visits, since telephones have limited coverage and administrative records (such as social security, vital and voting registries, disease reports, and so on) are non-existent or of poor-quality. Armies of trained interviewers, social and health workers are collecting those data using paper and pencil (the PAPI method). Newly developed computer assisted interviewing techniques (CAPI for personal interviews and CATI for telephone interviews) are an important advance over PAPI but these have proved to be difficult to implement in developing countries (Hewett 2003).

This paper reports the development of an application for gathering household survey information using palmtop computers, also known as Personal Digital Assistants (PDAs). Although the application intends to be generic, friendly and widely available, at this point in time we are using a prototype in a complex study of elderly Costa Ricans that includes a two-hour, cumbersome questionnaire, a 20-minute diet questionnaire, and forms for collecting specimens and recording biomarkers such as weight, height, and blood pressure.

The paper includes first a brief description of survey data errors in developing countries as the rationale for moving from PAPI to CAPI in survey research. Then we justify the need of a PDA-based CAPI application. We then describe existing PDA-based applications in the market and the desirable features that the CAPI system should have. The remaining sections in the paper describe the PDA-based application we have developed in the University of Costa Rica. In particular, based on our field work experience with PDAs, we report results regarding issues of reliability, use of graffiti, hardware and software failure, and other lessons learned.

Data errors in survey research

Despite the explosion in the use of surveys, there are good reasons for concerns about their quality in the developing world since the standards that are routinely used in the U.S. and Western Europe assuring data quality are often brushed aside in Asia, Africa and Latin America. One wonders even more how much to trust the surveys that are now being conducted in the Islamic world where the tradition of survey research and the availability of scientifically qualified personnel to carry them out are both very limited.

The world invests considerable amount of resources gathering information with surveys in the developing world. The data gathered in these surveys serve to guide policy making and to evaluate impact. If the data have deficiencies, then policies and evaluations will miss the mark. The WFS and DHS projects, the Latin American Migration survey, and comparative surveys to the elderly, are, among other, important examples of international surveys in the population field.

Good data needs to be as error-free as possible. Random error reduces precision of estimates, usually weakening true associations (Type II error) and sometimes also generating false associations (Type I error). Statisticians do a good job handling and documenting random errors throughout sample design and inference analyses, including confidence intervals. Non-random error is more problematical because it biases estimates usually in unknown directions and magnitudes. There are numerous ways in which non-random error can emerge in survey data.

In the developing world, where maps, transportation and telecommunication are often rudimentary, the prospects for error are greatly increased. Poorly drawn and out-of-date maps, for example, can guide interviewers to the wrong sample point, and even when the maps are accurate, the absence of road signs, street signs and house numbers often make it impossible for interviewers to be certain that the indicated dwelling unit in the sample frame is actually the one being visited. Most homes in developing countries do not have land-line phones (especially in poor or rural areas), and cell phones, although increasingly popular, are not yet reliable, which limit the use of the telephones to improve quality of interviews and supervision.

The lack of good transportation and geographic remoteness often make it impossible or simply not cost effective to have adequate supervision of interviewers to both help insure that the correct household has been contacted and, more importantly, that the interviewer is actually carrying out the interview in its entirety and not falsifying all or parts of the responses. A further effect of transportation problems is that it is often difficult if not impossible to ship completed questionnaires back to the central office, so shortcuts are taken. For example, in some countries interviewers are given only one copy of the questionnaire and asked to record answers on a separate sheet, which is then shipped to the main office. This practice greatly increases errors in recording answers since interviewers frequently mark the wrong column or row on the answer sheet, invalidating responses. Such coding sheets are machine read in some countries, when machine reading is notorious in its unreliability, even with new scanning equipment. Erased responses cause multiple questions to be misread. Furthermore, interviews conducted in homes with poor lighting (by interviewers themselves who may need reading glasses but who cannot afford them), often result in misread questions. Moreover, it is very common to find interviewers who have inadvertently skipped a question or an entire series of questions because they cannot follow the complex instructions or because pages are missing on the questionnaire owing to faulty copying machine. (Many developing countries do not have automatic collating machines attached to photocopy machines.).

In addition, data entry errors are rampant. Although excellent and widely available data-entry programs that can limit such errors are readily available (e.g., CSPro, available for free (US Census Bureau, 2005)), the use of such programs is rare and data verification (i.e., double entry) is the exception rather than the rule. Moreover, delays in data entry are common as developing countries often cannot afford sufficient numbers of data entry stations, leading to enormous backlogs that can delay the production of the data set for months or even years. Such delays on some occasions have resulted in the complete loss of the database as floods, fires and other disasters consume questionnaires that have been lying around in offices.

Data errors and the PAPI and CAPI methods

Although some errors can be detected with proper review of questionnaires, a key issue is that in the traditional method of paper and pencil interviewing (the PAPI method) data error detection and editing takes place in a different place and time than the interview, which makes costly and difficult, even impossible, any effort to go back to the field to retrieve the right data (Hidalgo 2004). The end result is a number, sometimes substantial, of observations with missing, wrong or inputted data. Computer assisted personal interviewing (CAPI) can reduce or eliminate virtually all of these problems, making errors evident in the field when it is very easy to repeat a question or to ask a clarification to the subject providing the information (Couper 1998).

Using desktop computers in telephone interviewing (CATI) is straightforward and software applications are readily available. Telephone interviewing is, however, not an option in developing countries given coverage limitations.

In principle, the CAPI method for gathering household survey data allows to simultaneously accomplish the following goals 1) lower the costs of fieldwork and data entry; 2) sharply increase the quality of the data base; and 3) speed up fieldwork and reduce, practically to zero, the time to have the data available for analysis. The development of laptop computers has made CAPI possible in household visits. However, using laptops in developing countries has proved to be problematic, which made us to consider using palmtop computers or PDAs as the tool of choice to replace paper and pencil interviewing.

Rationale for a PDA-based CAPI

All or most population data in developing countries come from door-to-door household surveys. CATI simply cannot be used since most households do not have a telephone line. In turn, a major barrier to use CAPI in household visits is the high cost of laptop computers, which have become commonplace in rich countries but cannot reasonably be afforded in developing countries. Beyond the fundamental issue of cost, there are numerous other limitations to the use of laptops in data collection in developing countries. Laptops make the interviewers a ripe target for thieves. They also encounter serious ergonomic problems: they make difficult interaction with subjects and are difficult if not impossible to operate in some circumstances, such as when standing at a household's door, which is the most common place for interviews to take place in conflict-ridden countries or high crime neighborhoods where interviewers fear admitting strangers to their households. In countries with conservative traditions in which women are culturally constrained from having strange men in their homes, virtually all interviews are conducted while standing at the doorstep, making the use of laptops impossible.

An additional problem has been reliability of laptops, given the harsh and dusty roads, tropical downpours, sand storms and the like that can damage all but the most hardened laptops, the cost per unit of which would certainly be too high for widespread adoption. Battery duration is another constraint in most laptops.

PDAs, in turn, have striking advantages over laptops in reliability (no hard drive or mobile parts to fail), the ease with which they can be protected from the elements and dust, battery duration, and the ease with which they can incorporate wireless communication, in addition to very low unit cost and elimination of the ergonomic problems listed above. The way information is entered in the PDA—by tapping on the screen—may also be another advantage over laptops.

The low cost and high storage capacity of new PDAs in the market have made it possible to implement CAPI on them even for long and complex questionnaires. For example, a basic device costing about $200, can easily handle two-hour long interviews, store hundreds of interviews, use databases contained in the unit with such information as sampling details, lists of facilities, administrative divisions or long codebooks. Such devices can work a full day with no need of recharging the battery. Adding back up memory cards/sticks, GPS, digital photograph capacity, or cell-phone capabilities is simple, although it will add to the cost a few hundred dollars more. We have calculated that the total cost of purchasing a set of PDA's for the collection of data it would be about the same as the data entry costs alone on one survey. This means that any future surveys would produce dramatic cost savings.

PDA-based applications share well known advantages of CAPI, including: full control of the flow of questions (skips and filters), eliminating inconsistencies on the spot, out-of-range, blank, and null responses, as well as data entry errors, reducing costs by eliminating paper forms and data entry, and immediate data retrieval (Hidalgo 2004). In addition to these advantages, little programming may virtually eliminate fraud by monitoring the real place (using GPS) and time of the interview and questions' duration (through built-in timers and logs). An important side benefit of this fraud prevention protocol is that it improves the sampling implementation by guaranteeing that the household chosen is within no more than 30-50 feet of the location specified for the sampling point. This situation of interviewing in the wrong household, is a real and common problem, although denied by many survey researchers.

PDA-based CAPI applications in the market

Our efforts to locate a versatile and affordable PDA-CAPI system in the market were frustrating. We found that overwhelmingly in rich countries interviews are conducted over the telephone. Moreover, in those cases where automated systems are in use for door-to-door interviews, laptops are in use. We have encountered only very limited and rather primitive efforts to use PDAs for gathering data for marketing research, again, because the phone and laptop offer such attractive alternatives in rich countries. Table 1 summarizes the applications in the market

Table 1. PDA CAPI products in the market

Product	URL	Platform	Cost US$	Features*
SurveyView	http://www.surveyview.com/	Web, PocketPC, **Palm**, paper	$2000	1, 4
Snap	http://www.mercatorcorp.com/	Web, paper, PocketPC	$1300 + $1000 (5 initial users) + $600*(following 5-user groups)	1, 2, 4
Pendragon Forms	http://www.pendragonsoftware.com/	**Palm**	$230 + $55 additional user	1, 4, 9, 12
Ethnos CAPI 4	http://www.soft-concept.com/ethnos	Paper (scanner), Web, CATI, PocketPC	5600€ + 1000€ each group of 5 licenses	1, 2, 4, 8
Entryware Pro	http://www.techneos.com/	**Palm**	Depends on each project	1, 4
SyncSurvey	http://www.syncsurvey.com/	**Palm**	Monthly fees depending on users and informants	1
MobileSurvey	http://www.perseus.com/	Paper, Web, Email, **Palm**, PocketPC, Symbian	$1000 + $195*PDA	1, 2, 4
EZSurvey	http://www.raosoft.com/	Paper, Web, Email, **Palm**	$400	1, 4
AccessPoint	http://www.globalbay.com/	**Palm**, PocketPC, Tablet	Not available	1, 4, 8
Mobile Memoir	http://mobilememoir.com	PocketPC, Tablet, Laptop, PC	Not available	1, 2, 4

* the codes are explained in the text. Twelve desirable features were identified.

We have found 10 PDA-based systems for data collection offered in the North America and EU markets (Table 1). These, however, are somehow primitive applications just for asking questions and recording responses, appropriate only for very simple commercial research, as those conducted in marketing and opinion polls. More complex research as household or health surveys can hardly be conducted using these applications. In addition, these systems are usually expensive, since they are tied to consulting services. None of these systems includes more than four, out of the twelve, desirable features we describe below.

Desirable features in a PDA-based CAPI application

CAPI is not just matter of displaying the questionnaire in a screen and providing means to input answers. We have identified the following twelve desirable features in a CAPI system, either for PDAs or laptops.

1. *Four basic types of questioning.* Handling the four basic types of questions, namely:
   i) One choice answers
   ii) Multiple choice answers
   iii) Numeric response (dates could be considered a separate category)
   iv) Open ended question (write a text answer).
   This is the minimal feature that a CAPI must offer. All reviewed PDA applications have it.

2. *Sub questioning.* Capability of nesting questions inside questions. The simplest example is for expanding responses of the type "other", which usually is the last response category. This feature adds versatility to the CAPI. If not available, sub questions are handled as independent, additional questions. Four of the CAPI in the market have this feature, although only for the last response item.

3. *Long lists of possible answers.* If a question has a long list of possible answers (e.g., occupations, diseases, world countries), which cannot be shown in a single screen, CAPI and PAPI questionnaires usually change the question from "choice answers" to write text (or a code). There are, however, several ways of implementing features to handle this kind of information, among them: scrolling with a side bar, hierarchical branching (e.g. for places: choice the state, and then the county, and then the township), and writing a few words in a search engine (Hidalgo 2004). None of the 10 PDA-CAPI in the market offers this facility, which is important for reducing errors and saving costs of coding.

4. *Skips and consistency rules.* Capability of redirecting the flow of the interview with question skips and filters, as well as the capability for checking consistency rules between questions and ranges of possible answers. These capabilities are some of the major advantages of CAPI over PAPI, since they reduce data errors—or make them evident for correction—in the field. Most PDA-CAPI in the market allow skips; only two seem to provide consistency rule checks.

6. *Sections with a hierarchy.* Capability of organizing the questionnaire in sections and subsections. If there is a multilevel structure, this feature should also allow for multiple occurrences, so called "rosters" (examples: children, marriages, jobs, support networks). This is a hierarchy of sections. Having a questionnaire structure with sections and subsections facilitates the process of testing and improving it, as well as handling it in the field and processing it. None of the CAPI in the market has this feature.

6. *Hierarchical entities.* Handling, as part of a single observation, several hierarchical "entities" that are organized in a multilevel fashion. A common four-level structure in demographic surveys would be something like this:

   Household
      Individuals
         Her/his children
         Migration events
            Jobs

   This is an important, although sophisticated, feature that saves memory and disk space in the PDA and later on facilitates data processing (generation of rectangular data files for each entity that popular statistical software can handle). None of the CAPI in the market seems to offer this feature.

7. *Identifying observations hierarchically.* The identification of individuals and sampling clusters is usually organized in a hierarchy. For example: country, then province/state, municipality/county, township/neighborhood, enumeration unit/cluster, dwelling, and household (Antich 1997). This datum structure, which is usually given by the sampling frame, is useful for organizing fieldwork and controlling processes, as well as for efficient geographic aggregation. None of the CAPI in the market has it.

8. *Controls for data collection flow.* Features for controlling data collection both in the PDA and later on in the desktop computer, including checks for duplications, pending interviews, re-interview, and so on. This feature is useful for having a clean data set with no duplications or incomplete observations (Hidalgo 2004). Two of the 10 CAPI in the market seem to offer these controls.

9. *Precise time and space coordinates.* Integrating into the data interview the exact timing of questions and the exact place where the interview took place (using GPS information). These feature can be important to reduce fraud and for feedback of information to improve a questionnaire. Only one of the CAPI in the market has it.

10. *Logs.* Keeping retrievable logs of all actions performed by the interviewer. For example: whether a correction was made; whether a number was entered using graffiti or the screen keyboard. This feature is useful for quality control of the fieldwork (to find out and to correct systematic errors). None of the CAPI in the market offers it.

11. *Coding open questions.* For open-ended questions (text answers), an intelligent CAPI can code frequent occurrences as information accumulates in the field. For example, one can start with an open question of medicines taken, after a while one realizes that most people report the same few medicines. Those popular medicines are coded and integrated to the question as choice answers. None of the CAPI in the market offers this feature.

12. *External information.* Adding to each observation some external information such as a picture or a sound byte recorded during the interview. Only one of the CAPI in the market offers this feature.

The CCP's PDA-CAPI application

At the Central American Population Center (CCP) of the University of Costa Rica, we have developed a preliminary PDA-CAPI application, which was first used by our students in a data collection effort in San José neighborhoods in early 2004 (Hidalgo 2004). We are currently using it, although it is not full featured, in a large, longitudinal study on aging funded by the Wellcome Trust.

Figure 1 shows a roster-question implemented in our PDA-CAPI. This is a repeatable section about household's individuals. The PDA screen in the picture is just the end product (the interface for interviewing subjects) of a complex data collection system. Behind that interface there is a complex architecture that includes three modules and a core for preparing "electronic questionnaires" (EQ) as described by Figure 2.

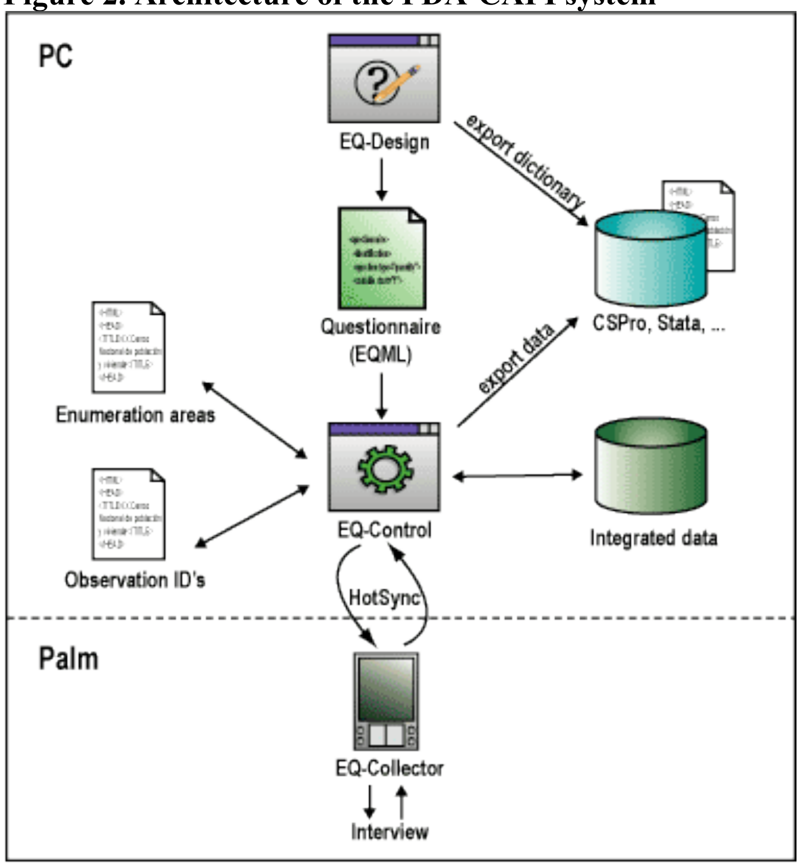
Figure 1. A screen in the PDA-based application

The core of our CAPI application is an "electronic questionnaire markup language" (EQML) that we developed using XML (Goldfarb 1999) after analyzing thousands of existing questions in census and surveys. Our EQML is a notation for representing questionnaires, or by that matter, any type of data collection forms in a standard format. It includes a data model that is able of handling different entities or types of observations (e.g. dwellings, individuals, biomarkers) organized in hierarchical structures, sections, questions, variables of different types, skips, consistency rules, instructions to the operator, and so on. EQML facilitates the work with the three modules and could even be used in other applications, such as web-based questionnaires or data-entry applications (e.g. CSpro). The following is a very simple question of the Costa Rican 2000 census written in our EQML:

```
<question type="cat" name="pSanitario">
        <text>¿Tiene esta vivienda servicio sanitario...</text>
        <categories>
                <category code="1">conectado a alcantarilla pública?</category>
                <category code="2">conectado a tanque séptico?</category>
                <category code="3">de pozo negro o letrina?</category>
                <category code="4">con otro sistema?</category>
                <category code="5">
                        <text>No tiene</text>
                        <skip-to name="pLuzElectrica"/>
                </category>
        </categories>
        <variable name="Sanitario"/>
</question>
```

The three modules or pieces of software to handle electronic questionnaires defined using EQML are (Figure 2):

Figure 2. Architecture of the PDA-CAPI system



1. EQ-DESIGN allows any individual to prepare a questionnaire on a PC. This is an application in C++ language (Stroustrup 1997) to specify questionnaires in EQML. It entails implementing concepts such as identification, the data model, sections, questions, variables, response categories, skips, rules of consistency, and rosters.

2. EQ-CONTROL handles workload assignments among the field personnel, identifications, enumeration areas, sampling points, and lists of individuals. It also handles the transfer of data from and to the PDA, including control of duplicates and not collected

observations. This module can also export data to widely used formats such as FoxPro, SPSS, SAS or Stata. This application is being written in C++ language.

3. EQ-COLLECTOR. This application translates the questionnaire written in EQML for use in PDAs. It provides the interface for conducting interviews. It controls the flow of questions, checks consistencies, and saves responses in the PDA memory. We are developing this application in CodeWarrior for Palm OS (Foster 2002). We plan to develop EQ-Collector also for other platforms, such as web pages, Pocket PC, tablet PCs, and just plain computers

Field test of the PDA-CAPI

We first tested our PDA-CAPI with college students in a short survey about San Jose neighborhoods (Hidalgo 2004), as well as in a pilot-test of the questionnaire (20, 3-hour-long interviews) for the aforementioned study of Costa Rican elders. Then we started using the PDA-CAPI in the full-scale survey of elders in November 2004 (being longitudinal, this survey will take at least 4 years of field work). Up to mid February 2005 we have conducted about 400 interviews in 70 PDA-weeks (1,200 hours) of fieldwork. The following is a report based on these experiences, particularly in the full-scale survey.

Hardware issues

We are using mostly Palm Zire-71 PDAs for interviewing, which was the least expensive PDA (about $200) with photography capabilities in the market by mid-2004

If the PDA is correctly charged overnight, battery duration is enough for collecting information during a workday (about 4 hours of real-time use). Once in a while a PDA runs out of battery. This happens when it has not been properly placed on the cradle for charging. For those situations we have battery back up devices in the field as well as chargers in project's cars.

We have had a failure rate of less than one per 100-hour use of Zire71s. The failure takes place in the screen-tapping system and usually goes away after turning of the computer. We have not suffered information losses because of this problem. Incidentally, this problem does not occur in Sony Clié PDAs that we are also using for collecting simpler information on biomarkers, which suggests is a deficiency of the particular model (or series) of PDAs we purchased.

Given the possibility of PDA failure, field workers always carry on a hard copy of the questionnaire. They have had to use that hard copy only twice (in 400 interviews) to complete interviews due to the aforementioned PDA hardware failure. We have not lost information because of it.

So far, our assessment is that PDAs are very reliable and resistant pieces of hardware.

Because of cost considerations we are not using GPS integrated to the PDA. Instead, the teams share one GPS device per vehicle. The car driver is the person in charge of taking the geographic coordinates of each household. In addition to adding that information to the database, we are using it sometimes the next day to locate households for drawing blood samples and to picking up urine collected overnight.

Software issues

Electronic questionnaire definition was a highly interactive process. It required intensive programmer-time during the pilot survey and the first couple of weeks of fieldwork. Programmers were involved in the design of the questionnaire and worked close to the research team in the pilot test and at the beginning of the survey (Antich 1997). Failures in the program occurred mostly because of errors designing, or modifying, the questionnaire (wrong skips, filters, or value ranges).

Because of software failure, two interviews had to be completed on paper and we loss one full interview. The bugs causing these problems were fixed immediately.

The language (EQML) we developed for questionnaires' definition, it was key for implementing and fine-tuning the application. It also pushed researchers into a more structured design of the questionnaire.

Acceptance issues

All innovations usually generate resistances. We were told that both interviewers and interviewees might reject this new technology. This has not been the case, though. Fieldworkers are extremely pleased with this new device and proud of using it. They say they will never go back to the PAPI method. In turn, there are no reports of rejections in the population to the use of PDAs. On the contrary, often interviewees are intrigued and amused with the device, especially when they see their picture on the screen.

Training of interviewers in the use of PDAs was straightforward. Most had substantial experience with PAPI, but none with the use of PDAs or CAPI. It seems they already had the intuition of basic PDA's operations such as tapping or scrolling, perhaps from using videogames, computers and cell phones.

Another related concern was the possibility of assaults to steal the PDAs in some neighborhoods. We have not had this kind of incident so far. Although we know that, for example, cell-phones are target for some robberies, this has not been the case with our PDAs, perhaps because their use is still little known by most people. Being a highly specialized device, a PDA does not seem to attract robberies.

Data quality (tapping reliability)

There were some concerns that tapping errors –marking the wrong response on the PDA screen– would be a problem. We actually don't see why tapping on a PDA screen can result in more errors than marking responses on a sheet of paper. Moreover, comparing PDAs with conventional laptops or desktops, we would expect that tapping is probably more accurate (and simpler and faster) than marking responses with a mouse or a keyboard.

To somehow check the reliability of tapping a screen--against marking on a paper—a second fieldworker recorded on paper the responses to the PDA-based interview during the pilot test of the questionnaire. In more than 5,000 responses, we found a reliability, or coincidence, rate of 96% (Table 2). The discrepancies were 3% in questions with two or three choice responses, which is the most common type in questionnaires. Discrepancies doubled for questions with many choices or numeric responses. There is no way of knowing with these data whether errors come mostly form the PDA or the paper or both. Considering that during this pilot survey we were training interviewers and testing the questionnaire, it is very likely that in the real survey error is substantially lower and tapping reliability may be above 99%.

Table 2. PDA vs. paper discrepancy

Question type	Discrepancy	(Responses compared)
2-3 choices	3.1%	(3,276)
4+ choices	6.2%	(1,170)
Number	7.0%	(884)
Total	4.4%	(5,330)

Graffiti

Using graffiti to enter text or numerical information into the PDA was another issue. There were concerns about the learning curve of fieldworkers, the efficiency of graffiti writing, and its accuracy. The existence of logs that record all actions performed by interviewers on the PDA, allows us to examine some of these issues. The following results are based on data for two questions, one textual and one numeric, in about 300 interviews in eight fieldwork weeks. The questions examined were the name of all residents in the household (textual, about 3 names per household) and the subject's age (number). It is worth noting that one can tap the information on a screen keyboard as an alternative to use PDA's graffiti.

Interviewers used graffiti 57% of the time according to the aforementioned logs (Table 3). The use of graffiti appears 50% higher for numbers than for text. Contrary to our expectations, there was not a "learning curve", which would have increased the use of graffiti over time (Table 3). It looks like there are adopters and no-adopters from the start and they stick to their preference over time. Three interviewers are graffiti users, one uses it most of the time for numbers but not for text, and another one seldom uses it.

Table 3. Percentage who used graffiti

Variable	Text	Number	Both
At the field			
1-2 weeks	48%	82%	57%
3-6 weeks	51%	74%	57%
7-8 weeks	55%	69%	58%
Interviewer			
Interv-1	3%	11%	5%
Interv-2	100%	100%	100%
Interv-3	98%	100%	99%
Interv-4	4%	76%	21%
Interv-5	85%	94%	88%
Total	52%	75%	57%
(N)	(906)	(308)	(1,304)

Crude data suggest that graffiti is less efficient than the screen keyboard. It requires 22% more time to enter a character (Table 4). That association is, however, confounded by the differential use of graffiti by interviewers and the type of information (number or text) entered. After adjusting these confounders with Poisson regression, graffiti writing showed to be 33% faster.

Table 4. Data entry duration with graffiti and keyboard
(Seconds per character)

Device	Observed	Adjusted*
Keyboard	1.85	2.06
Graffiti	2.25	1.37
Ratio G/K	1.22	0.67

*Controlled (with Poisson regression) for interviewer, text/number, and field work period

We do not have precise data on reliability or accuracy of graffiti writing. However, the PDA's logs allow us to determine the rate of correction of characters entered with graffiti. That rate is 37 corrections per 100 characters (Table 5). Text characters are corrected 4 times more often than numeric ones. The data also shows a small improvement in the rate of corrections over time, but this is restricted to the first couple of weeks only.

Table 5. Rate of graffiti corrections (per 100 characters)

At the field	Text	Number	Both	Adjusted*
1-2 weeks	43%	8%	38%	41%
3-6 weeks	40%	11%	36%	36%
7-8 weeks	43%	9%	39%	36%
Total	41%	10%	37%	37%

*Controlled (with Poisson regression) for interviewer and text/number

Information transfer

An often-neglected component of survey research in general, and CAPI in particular, is the transfer of databases to other applications or their integration with other data. We gave high priority to this component, which is handled by the "EQ-Control" module of our PDA-CAPI architecture. This module handles procedures for backing up the data in the PDA's, transferring them to a central, cumulative database, and timely generating working files (i.e. in Stata and FoxPro). The module also handled the transfer of information about sampling points to the PDAs, which in this case were lists of individuals, grouped in working lots, with information about their location and individual characteristics like name, age, and identification number.

There is a justifiable concern that moving from PAPI to CAPI may increase the risk of data losses, especially catastrophic data losses. For example, data (even large amounts of data) may disappear because of failures in computer hardware or software, human errors, an accident, or a robbery. In contrast with paper questionnaires, one can lose dozens of interviews in a computer not even noticing it.

Since we were really concern with the possibility of data losses, we established redundant mechanisms for backing up, transferring and accumulating the data, including the use of memory cards, daily transfer of data from and to PDAs, and sending data from remote locations throughout telephone lines. We do not have data losses to report. Several cumulative databases in Stata are weekly updated and made available for analyses. These are essentially "clean" databases.

Discussion

This paper reports the use of palmtop computers, also known as Personal Digital Assistants (PDA), to collect household information in a complex, full-scale survey in Costa Rica. We believe that PDAs offer a cost effective opportunity to substantially improve the quality and increase the speed of gathering census and household-survey data in developing countries. Given the increasing processing power, memory and expandability of PDAs, along with their rapidly dropping costs, we believe that such applications may revolutionize the way household data are collected in developing countries, as well as substantially reduce costs and time lags, while markedly improving data quality.

The CAPI technology, which is already of common use in survey research in developed countries with laptop computers, is a well-known improvement over the PAPI technology. The most important CAPI advantage comes from the fact that data error detection and editing takes place in the same place and time: during the interview. Another important CAPI advantage is its handling of complex questionnaires, including skip patterns, filters and rosters, which are difficult to implement, and prone to error, when are on paper. Laptop-based CAPI, however, have proved to be difficult to adopt in developing countries because of high costs, adverse environments, and ergonomic limitations. PDAs seem to be the answer to them.

Although the market offers about a dozen PDA-CAPI applications, none has all or most features needed to properly conduct a socio-demographic or health survey. The available applications are usually expensive and good only for plain opinion or market polls, with very simple questionnaires and sampling designs.

At the University of Costa Rica we are developing an application that fits the needs of complex survey research. We are using a prototype of it in a Wellcome Trust funded longitudinal study of aging. This paper shares our experience developing the PDA-CAPI and using it since November 2004.

The application is not just a piece of software for reading questions and recording answers in a PDA. The interface doing that, and much more, is just one of three modules of the application. The other modules handle: (1) the flow of information into and out of the PDA, and (2) the design and operationalization of a questionnaire. As part of the application we have developed a computer language (EQML) that facilitates the creation of electronic questionnaires with quite complex structures, including multilevel hierarchies, rosters, filters, skips, and consistency and range checks. The PDA interface itself optimize the use of the screen, its tapping and scrolling capabilities, and the use of screen-keys to move around the application and the questionnaire.

The use of our PDA-based application during more than 1,200 hours so far, has demonstrated that: (1) it can be done; (2) it is well accepted by interviewers and interviewees; (2) tapping error (marking the wrong answer) is not a problem; (3) text and numbers can be efficiently entered using graffiti or, as alternative, the on-screen keyboard; (4) the hardware is reliable, (5) battery duration is appropriate, and (6) data losses are 100% avoidable.

Although the system is working out properly, it is clear from the reported experiences that considerable polishing needs to be carried out in order to have an application for general use, including the required desktop applications. Selection of the most cost effective hardware, issues of battery life, screen and font size, recording of open-ended questions, cell phone uploading of data, backups, and the like all need to be worked out. It is also desirable to conduct a formal operation research field test to assess the gains and losses of PDA-CAPI compared to PAPI, in terms of costs, data quality, and timing.

The implementation of this application in a full-scale survey required a lot of programming time and the involvement of highly qualified programmers, which is expensive. In some circumstances such human resource may not be available. We intend, however, to continue developing the application until we can offer friendly software that researchers with no programming skills can use.

The development of a fully operational PDA-based CAPI in Costa Rica has been one of those rare occasions in which a native computer technology has been locally developed. (Although, that should not be a surprise since software is the fastest growing export in Costa Rica). Such technology has been developed and tested to respond to the specific needs of a developing country. The use of this technology may increase data quality and timing, with the consequent positive impacts on research and decision-making.

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