# Bridging the Gap between Paper Patient Records and EHR Systems with the piClinic Console

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***Abstract*— Clinics with limited resources rely on paper patient records because they are easy to use, reliable, and can be supported by the clinics' financial and technical resources. Electronic health record (EHR) systems provide benefits in patient information management and reporting; however, they often require financial and technical resources that exceed those available to the clinics. This paper hypothesizes that limited-resource clinics could successfully install and sustain a patient-record automation system if it did not require resources beyond the reach of those clinics—if such a system was available. Because no system was found, the piClinic Console was developed to test this hypothesis. The piClinic Console is a Raspberry-Pi-based, patient-record automation system that provides essential patient-record automation functions and runs on hardware that costs less than $300 USD per clinic. This paper describes the features that provide the most benefit to the clinics and that run on a low-cost system as determined through end-user observation, participatory design, and iterative user testing. Preliminary testing shows that the piClinic Console can provide immediate benefits to clinic information processing and can prepare the clinic for a smoother transition to more complete EHR system when the resources to sustain one become available. The piClinic Console system is in its early stages of field testing and this paper describes the design and development process, the results of performance and user testing, and the plans for future research and development.**

***Keywords—Electronic Health Records; Limited-Resource Clinics; Patient Record Automation; ICT; ICT4D.***

## I. INTRODUCTION

Medical clinics with limited resources, such as many of those found in lower-middle-income countries (LMIC), currently rely on paper patient records because they are easy to use, reliable, and can be supported by the clinics' financial and technical resources. Paper patient records, however, present storage, access, and reporting challenges that an automated system can help alleviate. A common approach to automating patient records in clinics has been to install an existing electronic health record (EHR) system, which has presented several challenges. The cost of this approach puts it out of the reach of limited-resource clinics unless additional financial and technical resources are also provided. Typically, however, additional support is temporary, which limits the long-term sustainability of this approach [1]. Clinics that adopt existing information systems must train the clinic's staff and adapt their existing information processes to work with the new system. Limitations in training and support after a system was installed have frustrated this approach to introducing automation in limited-resource clinics [1]. Even in well-supported installations, the cost of installing, operating, training, and adapting existing systems and workflows to those of the EHR has been reported as an obstacle to success [2]. This suggests that introducing an EHR system into a clinic requires a minimum level of financial, technical, and personnel resources to be successful—a minimum that, unfortunately, puts these systems out of the reach of many clinics in LMIC.

Two options to match resource requirements of an automated solution to the resources of the clinic are 1) to augment the clinic's resources and 2) to reduce the resources required to install and support an automated solution. Providing additional resources to limited resource clinics has been successful in some cases, but is costly to scale. Solutions that reduce the resources required to install an automated solution into a clinic would be easier to scale; however, they are uncommon. One challenge to the latter approach is that it is likely to require limiting the functionality that an automated solution provides. However, if the functionality is limited to the functions that provide the most value to the clinic, such a tradeoff could be worthwhile.

Adapting, installing, operating, and training users on a new system in a limited-resource clinic could be simplified and made less resource-intensive by reviewing and accommodating each aspect. The cost for a clinic to adapt a solution could be reduced by matching the system to the established workflows and data used by a clinic. Installation and operating costs could become more sustainable by reducing the cost of hardware and technical infrastructure a solution requires. Training costs could be reduced by implementing a system that disrupts existing and familiar processes as little as possible. While the resulting system is likely to be much less capable than a complete EHR system, the features it offered could still provide immediate and sustainable benefits such that a clinic could begin automating patient information sooner than if it had to wait until it was ready to support an EHR.

Patient-record automation systems that address these adaptations, however, have not been available to limited-resource clinics. Until only recently, computing hardware that could perform the functions that even a minimal system would need to provide for a clinic could not be built for a price that limited-resource clinics could support on their own. Even cloud-based systems require local computing resources to run an app or a web browser in addition to the technical infrastructure necessary to connect to the Internet—resources that often are not available to limited-resource clinics.

To provide an alternative solution, the piClinic Console was developed to test the hypothesis that a low-cost, limited-function patient-record automation system could be developed to provide a sustainable patient-record automation solution for limited-resource clinics. The piClinic Console development applied a user-centered design methodology to identify the automation features that would provide the most benefit to a clinic that currently uses paper patient records and that fit in a low-cost platform. This paper describes the design and implementation of the piClinic Console to prepare it for field testing prior to a broader deployment into limited-resource clinics. The paper reviews the literature on which this project builds, the design methodology used to identify and test the features that are most valuable to the clinics, the technical specifications of the prototype, and the plans for future development and deployment.

## II. Background and Related Work

This section reviews the research and literature on which this system to automate patient records in limited-resource clinics and hospitals was developed. While this paper is based on the experiences of limited-resource clinics in Honduras, limited-resource clinics around the world share many characteristics of these clinics, so the solution described here should also benefit clinics in other LMIC.

### A. Geographic and Demographic Definitions

The World Bank defines lower-middle-income economies as those in countries that have a gross national income (GNI) per capita between $1,026 and $4,035 and refers to countries with lower-middle-income economies as lower-middle-income countries [3]. Countries with upper-middle-income economies are those with a GNI per capita between $4,036 and $12,475 and are referred to as upper-middle-income countries (UMIC) [3]. High-income countries (HIC) are those countries with a GNI per capita of $12,476 or more [3].

Field studies were conducted for this project in nine public and private clinics during 2017 and 2018 in Honduras, which, with a GNI per capita of $2,280, is classified by the World Bank as one of the 47 LMIC [4]. Regionally, the World Health Organization (WHO) includes Honduras in the WHO Region of the Americas, which includes the countries of North, Central, and South America and the islands of the Caribbean [5].

### B. Electronic Health Record System Definitions

The notion of electronic health records has evolved over time. This section describes the related terms as they are used in this paper. These terms and concepts are adapted from the World Health Organization (WHO) [6] and used in this paper to describe different types of electronic health record systems.

The WHO defines an electronic health record (EHR) as a record that:

- Contains all personal health information belonging to an individual;
- Is entered and accessed electronically by healthcare providers over the person's lifetime; and
- Extends beyond acute inpatient situations including all ambulatory care settings at which the patient receives care.

An EHR is the record of information that an Electronic Medical Record (EMR) stores and processes for each patient, ideally, over the patient's lifetime [6]. The WHO reference also describes different levels of patient record automation—levels that trace the history of EHR systems and, at the same time, describe a path from manual record keeping to automated, comprehensive record keeping.

- **Patient Master Index (PMI):** a list of all patients whose records are managed by an organization, such as a clinic or hospital. The master index is usually organized by a unique patient identification number and often contains demographic information about the patients beyond their identities [6].
- **Automated Health Records (AHR) System:** an automated system that stores patient records. This term originally referred to systems that stored images of patient records and provided automated access to them, while, typically, not tabulating or summarizing the data contained in those form images [6].
- **Computer-based Patient Record (CPR) System:** A paperless, medical record system that contains a patient's complete medical history linked to a single patient ID. This type of system is limited to the services provided in a single facility [6],
- **Electronic Medical Record (EMR) System:** A completely paperless medical record system that is integrated with other clinical services such as laboratory tests and results, pharmacy orders, and referrals to other providers, including those services provided at other facilities [6].

### C. Current Constraints that LMIC Have in Adopting EHRs

The benefits of EHR systems are consistently recognized in the literature. At the high level, the Pan American Health Organization (PAHO) [1] listed many benefits, such as improving the patient experience in the clinic and after the visit, the consistency of patient records, the efficiency of clinical operations and administration, and, ultimately, the quality of patient care. Other studies cite similar benefits [7]–[9]; however, the cost to obtain these benefits remains high.

Reports of successful EHR system adoptions are becoming more common. For example, a report by the PAHO listed successful case studies of EHR system installations in Chile, Argentina, Uruguay, and Brazil [10]; however, these reports are all from upper-middle-income countries (UMICs) and high-income countries (HICs). Reports on EHR system installations in LMIC and EHR systems in HICs are, unfortunately, not without their problems and those reports tend to describe more challenges than successes [10], [11]. The PAHO report [1], however, noted that data for the region is inconsistent—confounded in part by inconsistent definitions and terms used throughout the region.

*D. Brief History of Raspberry Pi Platform*

The Raspberry Pi is a single-board computer that was introduced in 2012 as a platform to teach basic computer science [12]. A single-board computer is a computer that has all of its central and peripheral circuits on a single circuit board, as compared to the modular construction often used in laptop and desktop computers. In the case of the Raspberry Pi, the complete circuit board measures 85mm x 56mm [13].

Since its introduction, the Raspberry Pi has undergone several revisions. The limited memory and less powerful processors found in earlier models limited their utility. The Model 3, with its 1.2 GHZ, 64-bit, quad-core, ARM v8 processor, and 1-gigabyte of random-access memory (RAM) is, however, quite capable [14]. The basic circuit card includes the processor and RAM, HDMI display port, built-in Wi-Fi, Bluetooth 4.1, one Fast Ethernet (100 Mb/s) port, and four USB 2.0 connectors [14]. The Raspberry Pi can be purchased in the United States for less than $50 USD and a complete system with a display, keyboard, and mouse can be assembled for less than $200 USD. Its low system cost and the availability of free software have made the Raspberry Pi a popular platform for a large community of developers and enthusiasts.

Raspberry Pi systems have been used in many end-user applications. For example, they have seen use in schools to teach the Linux operating system to students of different ages [15]. In another example, a Raspberry Pi-based server demonstrated its suitability to the Honduran environment while providing a local area network to a rural area of Honduras [16]. In laboratory testing of the piClinic Console, the Raspberry Pi 3 has proven to be a viable, low-cost platform for patient-record management applications.

*E. Platform Alternatives*

The following platforms and configurations were considered in the analysis and design of the piClinic Console.

*1) Existing Software Solutions*

Several of the many open-source EHR systems available were reviewed for this project [17]–[19]. While these systems provide much more complete EHR functionality and are available as open source software, their more complete feature set proved to be disadvantageous for the niche the piClinic Console is designed to fill. By the very nature of these systems being full-featured EHR systems, they require considerable preparation in the software and the clinic before a clinic can use them [10], [11]. The comprehensive scope of commercial and open-source EHR systems, even in their most limited applications, require technical resources in excess of those found in the small and remote clinics studied. The target clinic for the system described here has very limited to no access to technical support, very little, if any, existing network infrastructure, and limited to no reliable access to cloud services, which make most existing EHR systems impractical solutions for them.

For the clinics this system intends to serve—many of which still use patient records stored in manila folders—the transition from their current office processes to those of an EHR system would require considerable training and software development support—to a level that has been described as problematic [10], [11]. The goal of this system is to require only minimal training and modification to existing office processes and for the installation and configuration of the software to be performed, as much as possible, by the clinic staff.

Reviewing the systems beyond their web pages for this project was challenging in that we were unable to load or run any them to a meaningful degree. Each system evaluated offered a different challenge in installation and configuration. None of the systems demonstrated a “plug-and-play” capability. For EHR systems that provide many complex and customizable features, “plug-and-play” is not expected; however, complex configurations are not practical for a system that is destined for clinics with little in the way of information technology (IT) support. As a result, it was not possible to review, let alone test, every available EHR system for this project. Therefore, it is possible that there exists a system that could be installed in an incremental manner to perform the functions described in the system design. If so, such a system could possibly replace the software solution described in this paper, while the system’s hardware described in this paper could still help reduce the total cost of installation and maintenance of the resulting system.

*2) Tablet computers*

Tablet computers have become more diverse and more powerful in terms of form factor and computing resources in recent years. Tablets range in price from free to over $1,000 depending on the tablet’s screen size, operating system, and processing resources. There are tablet computers that have more than enough processing power to support application software that runs on a Raspberry Pi. Some tablets can also run web-server software such that the piClinic Console’s software developed for the Raspberry Pi platform could also run on a tablet computer with little or no modification.

Unfortunately, for however capable a tablet computer might be as the primary processing device or clinician’s console, its strength in portability is also its greatest weakness. A tablet that is good at performing the tasks of an automated patient master index, patient-record archive, or clinician’s console is capable of performing many other, potentially more attractive tasks, such as web browsing, video games, or interacting with social media apps making it a tempting target for theft. Devices exist to secure tablets to prevent theft; however, those devices increase the cost of the device and detract from the mobility that is unique to the tablet form factor.

While tablet computers are not part of the field test, a tablet computer could be an effective clinician’s console in a networked configuration. In that capacity, the tablet would still be a tempting target for theft in a networked installation; however, they would be controlled by clinic staff and sensitive patient data would reside on a server stored in a less vulnerable location.

*3) Desktop, Laptop, and Notebook Computers*

Laptop and notebook computers are -suitable platforms for this application and they offer more computing resources than the Raspberry Pi; however, they come with a much higher cost to procure and maintain than the Raspberry Pi-based platform. As with tablet computers, laptop and notebook computers are viable computing platforms that could possibly support the functions of a complete EHR. While laptop and notebook computers are still tempting theft targets, they can be secured without degrading their utility as much as the tablet security devices tend to do.

Desktop computers are another capable hardware platform on which to run the application software, but they suffer many of the same economic drawbacks of laptop and notebook computers in that they have a higher initial cost and cost to maintain. Desktop computers, as well as laptop and notebook computers, can run the clinic automation software; however, at a much higher cost.

#### 4) Cloud-Based Solutions

Cloud-based solutions in which some or all of the computing and storage resources exist in a remote resource that is accessed by using the Internet could support the application software, but only if the clinic has a reliable Internet connection of sufficient bandwidth. In many limited-resource clinics, however, such a connection is not available making this option impractical. The application software design of the piClinic Console, however, supports this option when it becomes practical. For example, the piClinic Console could provide standalone or locally networked solutions initially and then, when sufficient networking resources are available to the clinic, the system could be moved to or integrated with cloud-based services. The lack of reliable Internet connectivity at the target clinics, however, makes this option impractical for the initial deployment.

### F. Incremental System Development

Typically, a clinic information system that has not been automated requires a clinic or hospital to change almost every aspect of its operation when installing an EHR system [2]; however, as Pearl describes, applying this approach in a hospital system costs billions of US dollars when it works and billions more when it does not. Even when scaling this experience down to a single clinic in an LMIC, an approach that costly or that risky is not an option. Taking a more incremental approach, Honduras, has started automating patient information systems in large hospitals to help coordinate and organize existing paper patient records as a way to begin bridging the gap between no system and a complete EHR system [20], [21]. The Honduran system, however, is currently designed to support several orders of magnitude more patients at a cost of over $100,000, making it impractical for the more numerous, smaller clinics.

Large-scale software projects tend to be an ongoing process of requirements discovery [22]—something that is especially true when the success of the project relies on the success of many different users and stakeholders. Agile, or value-driven development, accommodates uncertainty in requirements and implementation and builds requirements discovery into the process by approaching a development project incrementally [22], [23]. Agile project management prioritizes product features by their value to the customer so as to deliver the most valuable functions first. As features are delivered to the customer, the priorities of the remaining features are reevaluated along with any new feature requirements such that the most valuable functions in the updated list are likely to be different than before [23], [24]. Lean software development methods describe how some of these decisions are made by using techniques that seek to improve the information used in the prioritization process as much as possible [22], [24]. Throughout an Agile project, requirements are discovered and evaluated constantly by reviewing product usage data and customer feedback so that actual customer experience with the product is used to inform feature prioritization.

Using an Agile, value-driven approach to design for limited-resource environments is not without precedent. Menold, et al. [25] suggested Agile as a way to identify communication interface requirements in disadvantaged environments through iterations. Were, et al. [26] suggested the scalable model for implementing EHR systems to address the resource limitations of the clinics in Uganda—limitations also found in Latin American clinics.

### G. Contextual Inquiry in Limited-Resource Clinics

In May 2017, I studied five limited-resource clinics in Honduras to review their patient-record systems and interview their staff. The largest of the five clinics had a paperless, automated patient-record system, while the other four used paper patient records. Two of the four clinics using paper records had an automated patient master index system that associated patients with a hospital-issued patient ID under which the patient's records were filed. Of the remaining two clinics visited, one used a manual patient master index and the other filed the patient records under the patient's last name and village. None of the clinics visited in 2017 had the resources to support a complete EHR system. Network connectivity, at the two clinics that had it, was slow and unreliable. Commercial electric power was also not reliable and, in some locations, not available at all. As a result, these clinics had adopted solutions that accommodated their available resources.

In 2018 several other clinics were visited in which the largest one had a slightly different information workflow, but the rest were very similar to those studied in 2017. All clinics had the same electric power and network connectivity constraints as the clinics visited in 2017. While not an exhaustive review, and possibly not completely representative, the clinics visited in these trips illustrated a spectrum of patient-record management methods that is consistent with the literature.

## III. System Design

The design goals for the piClinic Console are to identify the most valuable features of a patient information automation system that can run entirely on a low-cost, standalone, platform, such as one built around a Raspberry Pi 3 processor, and to apply the Principles of Digital Development [27] to create a platform that can be adopted and adapted by others. This section describes how these goals were pursued to develop the piClinic Console.

### A. User Context

The user context for the piClinic Console was selected to be a small, primary-care clinic that currently has no automated system in place to manage patient records or other clinical functions. These clinics are small enough to facilitate a field test and initial deployment, and numerous enough to have a considerable and measurable impact. The piClinic Console is intended for use in small clinics—clinics that see no more than an average 100 patients/day and have no more than 20,000 active patients on file. This volume represents at least four times the volume of patients seen in the clinics studied in 2017. Over 1,000 clinics in Honduras fit this description as do many clinics in other LMIC.

Researching the end-user context for this system consisted of a literature review and in-person visits to small, rural and neighborhood clinics during 2017 and 2018. Other stakeholders in public health and public-health data management were also interviewed in these visits. The automation features that were found to be most valuable based on the clinic observations and interviews were:

- Patient Master Index.
- Support an existing patient identification scheme.
- Ability to adopt and implement a unique patient identification system.
- Automated generation of existing clinic and morbidity data.

Other features requested at some clinics and by some of the health professionals included digitization of patient records, support for post-visit entry of visit data, support for bar-coded ID of patients and visits, basic payment tracking and reporting, and other features and integrations that are often found in complete EHR systems.

Reviewing the implementation of these features identified these additional requirements:

- Patient-visit encounter data entry.
- Support for ICD-10 (CIE-10) coding of diagnoses.
- Ability to export report data to spreadsheet tools (e.g. CSV output of report data).
- Support for multiple clinic information workflows:
  - Enter data as a patient moves through clinic.
  - Enter data after the patient has left clinic.
- Ability to secure access to the system and data.
- Help and support features provided by the system.

### B. General System Design

The vast array of EHR systems available today and the amount of research on the subject provide a sound foundation from which to determine the operational requirements of an EHR and more basic patient-record automation systems. However, a lack of information about applying a Raspberry Pi platform to this application presented these questions that would need to be answered in order to proceed with the system development: 1) How many and which functions could in Raspberry Pi-based system support? 2) Would that set of functions provide sufficient value to a clinic or public health system?

The user and stakeholder interviews described in the previous section helped identify the most valuable features and simulation of those features could provide general guideline to determine the computing resources required to provide them. Building a prototype system seemed to be the only practical way to test the combination of selected features on the target hardware in the target environment to answer these questions and identify the issues that result from their integration into a single platform.

The piClinic Console prototype was developed as a PHP/MySQL-based application hosted by the Apache web server that runs on the Raspberry Pi's Raspbian Linux operating system. Building on a Linux-based open-source software (OSS) stack provides portability across hardware platforms, simplifies the development environment by running on any web server, and does not require purchase or licensing fees to use. For prototype development, this portability has enabled development on virtual machines and testing on cloud-based servers, while supporting the Raspberry Pi platform. The web-based software design enables the use of a web browser to host the user interface.

### C. Application Functionality

The principal features selected for the field test of the piClinic Console are listed here. They consist of the most time-consuming tasks that clinic staff currently perform manually in clinics using paper-based patient-record systems and represent the minimum level of functionality that will be useful to the clinical staff. This list was arrived at by incrementally building and testing each feature in the order shown.

- Patient master index and basic patient information.
- Patient-visit encounter data with ICD-10 (CIE-10) diagnosis coding.
- Clinic data report generation and export.
- Multiple clinic workflow support.
- Basic cash accounting.
- Data backup and recovery.

To support a transition to an automated patient information system, the patient master index and basic patient information functions support, but do not require the clinic to provide a unique patient identifier. Clinics that already use a unique patient identifier can enter it as patients are added, while clinics developing such a system can add it later. The patient-visit encounter data function supports the ability to record payments and summary information about each patient visit, including their diagnoses coded in ICD-10 (CIE-10, in Spanish) diagnostic codes. Detailed patient-visit information is still recorded on paper and the summary information and diagnoses are entered into the piClinic Console as patients are admitted into and discharged from the clinic. Patient visit information can be tabulated into periodic, summary reports on patient visits and diagnoses. Data backup and recovery functions provide data security in the event of hardware failures.

### D. Hardware Platform

The Raspberry Pi Model 3 single-board computer was selected as the computer for the piClinic Console because of its ubiquity, community support, and low cost. The piClinic

Console mounts the Raspberry Pi to the VESA mounting holes of a 20" LED HDMI monitor. A small, switched power strip attached to the back of the monitor provides power to the monitor, the Raspberry Pi, and the USB expansion ports. A standard USB keyboard and mouse connect to the Raspberry Pi USB ports as does the USB expansion module. The USB expansion module provides user-accessible USB ports that are powered separately from the Raspberry Pi to minimize the chance of physical and electrical damage to the Raspberry Pi that might result from users connecting and disconnecting devices. The cost to build this configuration of the piClinic Console was less than $300 USD each, including an uninterruptible power supply (UPS).

The piClinic Console is designed to operate in a standalone configuration in which the operating environment is an interior office with access to commercial electric power and has no connection to a network. Power consumption of the Raspberry Pi 3 platform is less than 25 watts while connected to commercial power, dropping to about three watts when the monitor goes to sleep. Commercial electric power is assumed to be available for at least 70% of the day—during a 10-hour day, commercial power is assumed to be available for at least 7 hours per day so that the UPS powers the system when commercial power is not available. In the event of an extended power outage, patient visits can continue to be recorded on paper and entered into the system after power is restored.

### *E. Findings from Initial Testing*

The system was tested in laboratory studies and demonstrated the ability to support a simulated clinical-activity scenario of 100 patients/day with a local archive of 20,000 patient records. The CPU, storage, and memory resources used in these tests confirmed that the Raspberry Pi 3 platform meets the design requirements and suggest that the platform could support an even higher transaction and record-storage volume. Similar tests run on earlier, Model 1 B+ and Model 2, versions of the Raspberry Pi were not successful due to limitations of the CPU and memory found in those versions. The 1.2 GHz, 64-bit, quad-core processor, 1 gigabyte of on-board RAM, and a high-performance MicroSD memory card of the Raspberry Pi 3 provide considerable performance improvements and eliminated the resource bottlenecks experienced with the earlier versions of the Raspberry Pi platform. The Raspberry Pi-based system was also found to be fast enough to support searching the list of approximately 25,000 diagnostic codes in real-time to support dynamic loading of autofill fields to help users locate ICD-10 (CIE-10) diagnostic codes.

The Raspberry Pi's 1-gigabyte of RAM, however, appears to limit complex data-processing operations, such as compiling multi-dimensional summary reports of diagnosis incidence by date and physician. While the limited RAM affects piClinic Console features like report generation, the effect is not objectionable to end users. The 30-120 seconds the piClinic Consoles takes to produce a monthly summary report is still much faster and much less labor intensive the several days that are currently required to create the report manually.

The Raspberry Pi supports using a USB memory stick as a disk drive; however, performance testing demonstrated that USB memory was best suited to backup/restore and data-transfer functions and not as an online disk for file or database operations. Initial testing of USB memory sticks as a data-storage medium demonstrated unsatisfactorily slow performance, even when using high-performance microSD cards. Much better performance was observed by using a high-performance, microSD card in the Raspberry Pi's microSD card slot for data storage, even though that card is also used by the operating system. As a result, the piClinic Console uses the on-board microSD card for the operating system software, application software, and active data-record storage and uses the external USB memory for backup and data export.

Usability testing of the system shows that the system is easy for both expert and non-expert end-users to learn with only minimal prompting, and user tasks remain efficient after initial learning. The system also performs reporting tasks much faster than the current manual processes. For example tabulation of monthly summary reports of patient visits and diagnoses, a process that currently takes up to several days in a typical clinic, can be accomplished in about a minute by using the piClinic Console. The piClinic Console can output these reports as a PDF file, printed to a printer, or copied from the screen to the paper forms if no printer is available. Reports are also available as a JSON object and a CSV file for electronic data transfer—which also improves the speed and accuracy of upstream data collection and processing.

## IV. Discussion

Laboratory and field tests of the Raspberry Pi 3-based piClinic Console show that it can support the patient-record automation features necessary to add value to limited-resource clinic operations. A key component of that success is in clearly defining the appropriate clinic for the system and the clinics or environments for which it is not suited. In addition to identifying how the system works in a clinic, identifying where it will not work is equally important. This section reviews the known abilities and limitations of the system that were identified during the development and testing of the piClinic Console.

### *A. Building from Scratch vs. Adapting an Existing Product*

Software that can run on a small system can likely run well on a large system; however, the converse is less likely. While preliminary tests of the Raspberry Pi 3-based system have been encouraging throughout development and testing, some limitations have been observed. The EHR systems reviewed could be simplified as Celi et al. [28] suggest; however, not to the point where they could both fit into the Raspberry Pi and still provide a useful set of functionality.

### *B. Iterative User Testing*

Throughout the development of the piClinic Console, iterative user testing has played a key role in the development and verification of features and performance. After each major feature was developed, non-technical participants were invited to perform user tasks to test the reliability and usability of the system. Initial user-testing was done in the university labs. After establishing the collaboration with the faculty and students of the Universidad Nacional Autónoma de Honduras, usability testing and subject-matter reviews were conducted remotely as well.

Initial usability tests were conducted to test the usability of the system and the individual features as a way to test the underlying data management infrastructure. As such, non-technical participants with limited to no subject-matter expertise were used. These participants were able to use the system with only minimal prompting to complete the end-user tasks—demonstrating that the interaction was usable and that the back-end support was sufficient. As the features and interactions became more complex and assumed more domain knowledge on the part of the user, participants with health-care experience were used. Most recently, as the system is being readied for field testing, the Honduran graduate students, who also work in clinics similar to the target clinics, tested the system to provide feedback on the system's usability and functionality.

Iterative testing and development have proven to be very constructive methods for testing the interaction, learnability, and performance of the system and it has worked locally and remotely. While expensive and limiting iteration frequency, being able to build and revise an interactive, higher-fidelity prototype has made it easy to test and iterate across time zones.

### C. *Privacy and Data Security*

The guiding principle of the security model for this system is that, at a minimum, it should be at least as secure as the system it replaces—ideally, however, it should be more secure. While other countries might not need to comply with American data-privacy laws, they have their own privacy laws that govern the protection of personal and sensitive information, such as health information. Before this system can be deployed in a specific clinic, the laws governing the protection and security of health information for that jurisdiction will need to be reviewed for compliance.

The piClinic Console addresses data security and privacy by incorporating aspects of physical and data security. The system is designed to be physically secured from theft and unauthorized access and access to the application software is protected by user accounts and passwords. Access to the patient information is secured in the piClinic Console hardware by password access to the software and the data it manages. The current system is not designed for networked use and all sensitive data remain in the piClinic Console and backup storage media.

### D. *Additional Success Factors*

Having suitable training and documentation resources available to the system users was identified in the literature as a critical factor to the success of the types of systems described in this paper [1]. In some cases, clinic staff might have limited computer literacy and require training on basic computer operation in addition to using the applications. The technical proficiency of the clinic staff is one aspect that will be evaluated further when selecting field-test candidates.

Maintenance and ongoing support are also critical factors to long-term success. The clinic staff should be able to perform backup, recovery, and upgrade operations successfully without the need for the IT technician. The clinic staff should also have access to the resources necessary to perform basic troubleshooting and repair of the systems. These requirements have profound implications to the system design. With the Raspberry Pi-based design, the components are few, easily replaced in the field, and inexpensive making it possible for spare parts to be maintained at a low cost.

## V. CONCLUSIONS AND FUTURE WORK

This system is currently in the prototype stage, being readied for testing in Honduran clinics. The hardware has proven ready for field testing in laboratory tests and subject-matter experts in Honduras have also reviewed and tested the software. This section describes some of the plans for future development.

### A. *Software Development*

The software for the field-test version of the piClinic Console has focused on supporting the information-processing requirements of the Honduran clinics into which it will be installed. However, insofar as is the platform supports them, existing health information standards will be supported. For example, the field-test system supports diagnosis coding using the ICD-10 (CIE-10) codes. Other existing standards and formats, such as the functional requirements and formats described by Health Level Seven [29], [30], will be reviewed to apply or adapt them where appropriate. Some standards, however, require access to computing resources that exceed those provided by the Raspberry Pi solution. Efforts have already been started to adapt existing standards to limited-resource platforms [31]; however, they have not attracted a sustained interest.

While the prototype system is designed to not require any additional peripherals beyond the keyboard and mouse, it has been tested in several other configurations that:

- Add a printer support to print the patient visit forms.
- Add additional reports.
- Add barcode support to access patient- and visit-records.
- Support networked reporting.

### B. *User Interface Usability Testing*

User interfaces will be developed and tested in collaboration with Honduran public health students and faculty to test for cultural compatibility and suitability for the local users. By developing the application software in two languages and for a web-based platform, cloud-based web servers can continue to host the application software to facilitate international user-interface testing.

### C. *Future impact*

Deploying the final system into limited resource clinics is scheduled for 2019 and will provide benefits to various levels of healthcare and health-data management. For the clinics, it will simplify reporting and start the clinics on a path to more comprehensive automation and more complete EHR systems. Incorporating the system into a clinic can help the clinic begin transitioning to an identification scheme that is compatible and consistent with other clinics around the country. Automated generation and export of summary reports in a digital format will reduce data entry effort and its associated errors. At a national public health level, it will improve the accuracy and timeliness of data reported from the field to provide more accurate and more complete data on which to base public health decisions. The system offers these benefits to both public and private, NGO-managed clinics.


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