Digitization of Perioperative Medical Records

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Abstract

Five billion people, from disproportionately low and middle-income countries, are unable to access safe, timely, and affordable surgical and anesthesia care [1]. Patients in Africa are twice as likely to die after surgery when compared with the global average for postoperative deaths [2]. Most of this mortality happens after surgery, and it is therefore imperative to identify patients at high risk of complications and rapidly intervene. The perioperative mortality rate (POMR) has been identified by the World Health Organization as a global measure of the quality of surgical procedures. Perioperative data collected during surgery can predict adverse surgical outcomes. Access to such data is essential for decreasing perioperative mortality rates and improving medical treatment. In many low and middle-income countries, perioperative data is manually recorded on paper flowsheets, restricting the ability to discover medical trends. This method of data collection inhibits easy and efficient data aggregation and analysis. Thus, systems put in place to digitize these flowsheets are key in utilizing perioperative data to improve overall healthcare. By streamlining the digitalization of intraoperative flowsheets, more data will be collected while minimizing the time while optimizing the quality. In order to optimize the digitization process, the research team has made several improvements to the current system. One of the largest improvements includes a complete redesign of the digital upload process in the form of a mobile app that integrates scanner functionality and upload capability into one convenient and efficient step, thereby reducing devices and platforms needed for doctors and hospital staff to upload a flowsheet. This redesign also provided increased user feedback and corrected issues in which flowsheet uploads failed. In addition to creating a new mobile upload platform, improvements were also made to the SARA (Scanning Apparatus for Remote Access). SARA is a wooden box used to ensure the consistency of images captured. The design of the box

provides a standardized distance, lighting, and background for each scan, improving readability. Testing is currently being performed to improve the reliability of the current lighting setup. Possible replacement power supplies are being examined for durability, ease of repair, and functionality. Additionally, usability testing and evaluation is being completed to measure increases in successful task completion and decrease in time and steps required. The goal of this project is to design a system to digitize the information contained in surgical flowsheets at the University Teaching Hospital of Kigali in Rwanda in the most efficient and effective manner. To accomplish this goal, the research team reduced the time and devices needed to upload a surgical sheet by 78% and 50%, respectively. Hardware and software malfunctions were fixed, and the longevity of the system was improved as procedural checklists to upkeep and correctly utilize the system were implemented.

Introduction

Health metrics such as perioperative mortality rate (POMR) are important measures in determining the quality of surgical care and safety [3]. In order to determine important metrics such as POMR, medical data in digital form is ideal for analysis. However, low and middle income countries face several barriers in implementing electronic record systems that have become common in higher income countries for reasons including, but not limited to, lack of funding, lack of infrastructure, and legal hurdles. Therefore, the use of electronic health records and data is much lower in LMIC with only about 15% of low-income countries adopting electronic health records while over 50% of high-income countries have adopted EHRs [4]. Thus many hospitals in LMICs utilize paper records or flowsheets to record data. In order to transform data recorded on physical sheets into electronic data that is more readily accessible for analysis there have been some attempts at creating digitization systems. However, while these systems may address many of the root issues preventing adoption of electronic health records, considering and optimizing their efficiency and ease of use is imperative in increasing user adoption and accurate data collection. In order to implement digitization systems, care must be taken to ensure that these systems operate efficiently and accurately. This paper details the improvements and optimization of the digitization system currently in place at the University Teaching Hospital (CHUK) in Kigali, Rwanda that was created through a collaboration between teams at the University of Virginia and providers at CHUK. While this system addresses many of the challenges in digitizing medical data in low and middle income countries, there are key issues relating to the system's efficiency, accuracy, and ease of use. In the past year approximately 375 sheets have been digitized through the system, but increased system efficiency would aid in digitizing CHUK's large collection of physical sheets, helping to provide more historical data for analysis. In order to optimize the digitization process we have replaced the web application with a mobile application that decreases the time and steps required to upload images and provides clearer user feedback. Additionally, while this paper focuses solely on the system in place at CHUK, this approach could be replicated at other hospitals and medical providers in LMIC facing similar obstacles in medical data collection and records.

Prior Work/Literature Review

In 2020 Rho et al. [5] at the University of Virginia implemented a system to digitize surgical flowsheets at University Teaching Hospital of Kigali, in Kigali, Rwanda. The system begins with the Scanning Apparatus for Remote Access (SARA), a wooden box with lighting that provides consistency in lighting, distance, and angle of images. Inside the SARA box is a tray to hold surgical flowsheets at an appropriate distance, and a battery powered light source. The top of the SARA box has a small round hole for images to be taken through. The group chose to implement the SARA device due to concerns from doctors about resource availability and maintenance for a more traditional scanner. Images are then typically taken using a mobile phone or tablet with a third party scanning app, such as Tiny Scanner, and are then sent to a computer. From the computer the user accesses the image upload web application where images are sent to a UVA email address, where images are then downloaded and processed to extract data which is then populated into a PostgreSQL database.

While the use of electronic medical records in Africa falls behind world averages, there has been a marketable increase in usage since the early 2000s. This increase has been driven by increases in computer ownership and increased internet access, which increased 2,357.3% between 2000 and 2010 in Africa [6]. In many cases the adoption of electronic medical records in Africa is driven by research collaborations between African health institutions and international institutions, namely regarding HIV and AIDS research [7]. A 2017 review of the adoption of electronic health records in sub-saharan Africa outlines four key barriers to adoption: high implementation and maintenance costs, limited computer skills, lack of constant internet connectivity, and lack of prioritization of EHRs [8]. While these barriers may not consistently have significance in all LMIC, one or several are likely to stand as an obstacle to adoption.

Researchers at Vanderbilt University developed and deployed electronic data collection systems in a Kenyan tertiary hospital. The system was built upon the Research Electronic Data Capture (REDCap), a free, internet-based data collection tool. Due to constraints on internet access the researchers created an asynchronous version of the system to operate while internet connection was unavailable. This system allowed a shift from manual to electronic data collection, allowing for additional data analysis and reporting. While this approach was successful, resources vary greatly in different LMIC that may act as a barrier to implementing a similar solution [9].

In a 2012 paper from Amity University in India, researchers created a system to scan and digitize electrocardiogram (ECG) graphs. ECG results are typically printed onto thermal paper, these records are then typically kept in storage for future reference. In this study the researchers note using the camera in a mobile phone for scanning the images. Once scanned the images were further processed using Laplacian filtering, a method to reduce background noise in the image, and by color based segmentation to create a binarized image of only black and white pixels [10].

While many hospitals and providers move toward completely digital records, the Khayelitsha Hospital in Western Cape, South Africa, has created a dual physical and digital system. Due to legal restrictions from the South African government the hospital currently requires “hardcopy” documentation, thus has implemented a large scale digitization system [11]. The hospital system includes a system where handwritten notes or documentation are placed in folders, these documents are then transcribed by clerks into the electronic record system, and then are finally scanned and stored. The folders of records are then stored as well, therefore, three separate records of each document exist, the physical copy, the transcription, and the scanned image [12]. While this system has been successful in this hospital it relies on large investments in not only software and technical infrastructure, but also human resources to scan and transcribe all documents.

System Design

The current system incurred software malfunctions, insufficient understanding and communication of the current system between stakeholders tied to the University of Virginia and CHUK, inefficiencies for medical personnel in CHUK, and hardware failures.

Within the existing applications, there were issues within both the backend of the code and within the frontend's user experience. One of the most significant issues on the backend involved sheets uploaded through the web application was often "lost" in that they were uploaded into the web application's internal storage and were encrypted, but the process failed when sending the file through the email. Sheets were able to be manually recovered through the back end of the application but could not be connected to a patient identification number. In October 2020, 24% of uploaded sheets to the web app never successfully sent through email. Significant changes were needed to avoid losing nearly a quarter of the data uploaded.

A lack of storage within the existing web application resulted in a manual reset approximately every four months. The application only had 512 MB allowed on the free level, and the design of the application stored all sheets uploaded within the app. When the storage maximum was met, no more sheets could be successfully uploaded, and application administrators had to manually delete files from the application, which was time-consuming and required continual monitoring and attention. With these issues in mind, the mobile application was designed so that the images are not saved locally within the application after upload, creating no strain on available storage.

Besides constant monitoring required to ensure storage space was available, the free application host required that the application be refreshed every three months to keep the website active. This again is resolved with the move to a mobile application. While many of these backend issues could be resolved with revisions to the web application, several other overarching issues involving user experience still existed from incomplete tabs and pages within the web application. To address these challenges of efficiency, intuitiveness, and effectiveness of the current digitization upload process, a new Android mobile Android app was developed.

A. *Mobile App Development*

Incorporating the entire upload process into a singular app will significantly decrease the time and steps required for each uploaded patient medical record. The upload process begins with a login screen. The user must log into the application with a provided username and password that is authenticated by Google’s Firebase authentication service. Users must request login credentials from the research team as a measure to ensure higher security standards. The login screen is just one of several security measures that were implemented in order to uphold patient confidentiality regarding their medical data.

Once the user is successfully logged in they are directed to a minimalist home screen where they can begin the upload process. The design of the home screen serves to reduce the amount of time and clicks required to submit a sheet and to create an easy and intuitive interface for any user. The previous web application included several tabs, most of which were not functional. Furthermore, the web application required the image to be manually sent to an email account prior to being manually uploaded to the application, creating an extra step in the process. For a standard upload, the process only requires entering one identifier, taking one image, and clicking three buttons. To upload a flowsheet image, the user must first enter the patient’s identification number. This number is different from the patient’s MRNO, as a measure to protect patient privacy. Patient identification numbers are unique numbers that are randomly assigned using an excel function by the users in Rwanda. To ensure data privacy, the true MRNOs are not known by anyone further in the process.

After the user has entered the patient identification number they must indicate the side of the sheet that is being uploaded using the radio buttons. These buttons concatenate an identifier which labels the surgical sheet as Intraoperative or Anesthesia. The inclusion of these buttons help to reduce issues in the previous system where there was no way to differentiate between sheets. In the future this function could be expanded to include options for other classifications of sheets as well. Unlike the previous system, this mobile application does not allow the user to incorrectly advance without filling out the patient identifier and surgical sheet side.

Figure 1. *Mobile App Login Page*

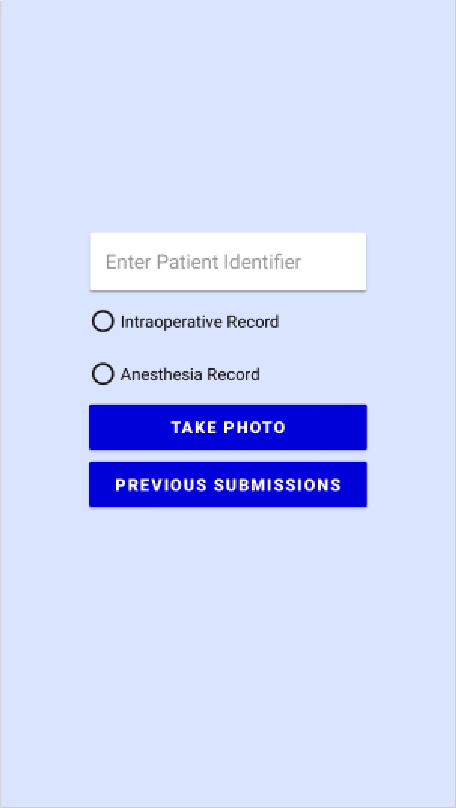

Figure 2. Mobile App Upload Page

Once the information is entered, the user can click the "take photo" button which will launch the device's camera. Using the camera functionality that is integrated into the application the user can "scan" the flowsheet using the app and the SARA box. Once the user clicks *send*, the image is instantaneously encrypted to a dedicated University of Virginia email address. The subject line of each email is the patient identification number that the user enters prior to opening the camera. Once the image is taken the user has the option to discard the image and take another, go back to the home page, or to continue. In terms of the encryption method chosen, the app utilizes the Advanced Encryption Standard (AES). AES encryption is a symmetric-key algorithm that utilizes block cipher to achieve data encryption. The algorithm takes a bitmap data type and converts the image into an array containing each byte of the image [13]. Byte by byte, these pieces of information are encrypted to ensure that should the image fall into the wrong hands, it could not be viewed without the private key which is shared only with collaborators at CHUK and the University of Virginia.

Continuing through the flow of the system, the encrypted image will be decrypted at the start of the digitization process. Following this decryption, the image will be subject to several image processing tools in order to ensure the data will be translated with maximum accuracy. To start, edge detection methods will be passed in order to ensure that none of the data is cut off and missing in the database. Following this, the image will be converted to grayscale in order to maximize contrast and facilitate the natural language processing algorithms used to convert the images to hard data.

Results and Discussion

A. *Upload Process Improvements*

With the integration of the camera into the upload application, the need for a third-party app is removed, and the number of devices required for upload are halved. The previous system required users to use a third-party scanning app on a mobile phone or tablet and then send the scanned image to a computer for upload. The mobile application includes pop-up messages throughout the user's experiences, updating them on accurate login information, requiring all patient fields to be filled in, and giving instant feedback once the patient chart is successfully sent to the email. The user experience is dramatically improved by decreasing the number of steps required to upload a photo.

Comprehensive user testing of both systems was performed to compare processes and test the systems' efficiency, intuition, and effectiveness. Participants were randomly assigned a system to test first to remove learning bias. The directions of each system were given to the participant, and the time, fatal errors, and post experimental survey were recorded. As this was only a test of the scan and upload process, the sheet remained in the box across all tests. This eliminated possible error from users having varying comfort with using the box itself.

The directions for each system are listed below:

Web Application

1. Open an external scanning app on phone
2. Scan sheet

3. Send scan to specified email
4. Download image on computer
5. Upload image to web application
6. Enter patient information
7. Send

Mobile Application

1. Enter patient information
2. Take photo
3. Approve photo (Sends automatically upon approval)

Compared to the old system, the average time to upload a sheet is reduced by 79% from 3 minutes to 40 seconds when using the newer, mobile application. The number of fatal errors where the user is unable to proceed without being prompted reduces from 89% to 0%. 100% of the users preferred the mobile application. In a post-usage survey, the two most common answers to the question “What do you think was the hardest/worst part of the process when using the web app?” related to the manual emailing of the file and the upload process. These two actions of that system are performed automatically in our app, thereby alleviating the core user complaints. Without the handicap of having to send the files manually, the team believes the upload time following a quick learning curve will lower the average upload time per sheet. In the medical field, any amount of time saved is essential to ensure all patients are being attended to and other work is getting done. This was the driving force behind the design of the system - to decrease the amount of time to upload a single medical record in order to save the doctor's time and incentivize thorough data collection.

B. Hardware Improvements

Beyond the implementation of a new upload application, other changes were made to the system as a whole and to the SARA device. One limitation of the original construction is the use of advanced cutting technology, namely waterjet cutting, to build precise pieces that were sent to Rwanda. This results in a high transport cost and a lack of reproducibility. As such, we sought to develop a version of the SARA box that was reproducible with tools and materials that were easily obtainable in Rwanda. To do so, we built a box by hand with the same dimensions and lower-quality plywood, using basic power tools. We retained the original lighting system for consistency. Even though this box was built to much higher tolerances than the previous model, the image quality was the same as the previous box. The scanner app also appeared to have better cropping capabilities in this box, which led us to investigate the effect of contrast on cropping.

The most significant limitation of the physical scanning process was consistently incorrect cropping. We were able to identify two suspected sources of this error. The first was an incorrect distance from camera lens to the sheet being scanned. On some phones being used, the scope of the image either did not include the full sheet, or filled to the exact edge. This prevented the image from being properly scanned and led to data loss. The initial design of the box utilized a tray to raise and lower the sheet, with screw mounts being used to adjust the height. In examinations of usage practices in Rwanda, we noticed that the screw mounts were not being used at all, and the tray laid on the bottom of the box for maximum distance. This led us to test the efficacy of eliminating the tray altogether. While this ensured the entire sheet was contained in each image, the cropping was still imperfect. This led us to our next correction for cropping error.

This second error was the contrast between the sheet being scanned and the wood of the tray. The type of plywood used was very lightly colored and may have hindered the scanning app's ability to identify the sheet outline. When constructing the second variation of the box, a darker shade of plywood was used, and the cropping was consistently correct. This led us to hypothesize that the darker frame color would improve cropping capabilities, and as a result we used black tape to border the sheets in our full-app testing. Using an exact replica of the box being used in Rwanda, with a border of black tape and the tray removed, we saw zero crops that were too small and/or resulted in data loss.

While the intention of the SARA device was to ensure consistency in lighting, image angle, and cropping, there was great variability in these metrics in images that were taken using SARA. In order to address these problems, we incorporated a number of smaller changes with the lighting, alignment guides, and training materials.

Dr. Christian and his team at CHUK encountered a lighting failure within SARA and were unable to fix it with a lack of instructions and understanding of the current lighting system. The importance of clear documentation and communication of the system highlighted the necessity and creation of checklists for every part of the process: mobile application, web application, SARA box, and lighting system.

Using both the pictures of the lighting system in Rwanda and materials left from the previous Capstone team, we found typical 1.5 Volt C batteries were connected in series producing 3 Volts from lead to lead. For a white LED battery, the required voltage ranges from 3 Volts to 5 Volts. Battery voltage diminishes with remaining energy, so 1.5 Volt output on each C battery does not last long and therefore may barely reach the full 3 Volts minimum before decreasing. Voltage can also decay in storage and other conditions. This could be the sole reason for the lighting issue, given LED light bulbs won't operate unless you exceed their required voltage. As a result of the findings the lighting system was redesigned. A short and long term solution was developed. In the short term two LED strip lights, velcro, and a small tube was shipped to Rwanda. This is a rechargeable light that uses the same USB cords as the standard Android phones used throughout CHUK. Sold in a pack of two, one can be in the box as the other one is charging. This was tested and proved to ensure the quality of light is not overexposing nor underlighting the box.

The long-term lighting solution is leveraging a 12 Volt motorcycle battery to power the LED bulb. This has several advantages. First off, motorcycles and mopeds are common in Africa. Assuming the majority of these vehicles contain a battery, this system should be replicable anywhere. The socket and 12 Volt LED bulb draw 3 Amperes, so under ideal scenarios, we should have 10 hours of use. Furthermore, this system could be a potential solution for repeatable scanning in remote regions. Since a motorcycle battery charges while the engine is on, if a remote clinic has a camera, they can take the battery out of a motorcycle or moped, connect to the system, scan the documents they need to scan, and put the battery back in their vehicle.

Conclusion and Future Work

After evaluating the descriptive scenario of the current medical record upload system, there were several areas of improvement that the team decided to study and optimize. Through this research, we were able to develop and implement a functional application for the digitization and encryption of documents, specifically intraoperative flowsheets for the purpose of the study. We succeeded in improving upon the web application constructed by Rho et al. by reducing the average process time by 79%, and average occurrence of inhibiting errors by 89%. This drastically improves the efficiency of the digitization process. Additionally, by removing the web application altogether and developing our system on the Android operating system, we have removed the limiting need for a computer. This allows for a higher number of users in the hospital and easier integration into standard operating procedure.

Usability of the box was also improved through the identification of the sources of cropping errors. Analyzing the medical records that have been scanned and uploaded via the web application, the team found insight into the reasons for images with poor quality (these typically came in the form of poor contrast, dark images, or sheets with cut-off edges. Overcropping and imperfect scanning resulted in data loss on many sheets examined through the previous system, and preventing this will improve the value of our system.

Future work will consist of the maintenance and improvement of the application, as well as the continued improvement and simplification of the box design. The adoption and longevity of this system will rely on the ease of understanding for a wide range of users, and the repeatability of box construction. Further research on the SARA box can explore the accessibility of certain components across developing nations, and the continuation of a construction manual that requires only locally procurable parts.

Further research on the application can examine adding multiple language support to expand the user base to non-english speakers. Additionally, research can improve upon the user interface of our application. The sole criticism we received on our application during testing was that for the older generation, and those less familiar with technology, the application may be difficult to navigate. Therefore, there is room for further development. However, with the simplistic nature of the application and backend system design, the team believes that any doctor can adjust to the slight learning curve and drastically decrease the amount of time spent digitizing their patient medical record database in its current state.

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