Data Pipeline for Digitizing Perioperative Flowsheets from Low-Middle Income Countries

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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*- In Rwanda and many low-and-middle-income countries (LMIC), surgical, critical care, and anesthesia flowsheets are handwritten by medical professionals due to the lack of digital infrastructure necessary to support digitization systems. Therefore, many LMIC lack macro-level health data that can be utilized to quantify and improve existing healthcare outcomes. Literature has championed post operative mortality rate (POMR) as a key indicator for institutional and national surgical safety [1]. Many surgical operations deemed as "low-risk" in high income countries (HIC) have a surgical mortality rate in LMIC more than ten times that of HIC[2]. Striving to lower POMR in LMIC, the University of Virginia (UVA) is partnering with the University Teaching Hospital of Kigali in Rwanda (CHUK) to digitize anesthesia and intraoperative paper health records. Over the past two years, UVA student capstone teams have contributed in establishing a consistent and reliable system to scan and obtain the surgical flowsheets. The focus of 2021-2022 is to design and implement a data pipeline system that enables Rwandan medical professionals at CHUK to digitize paper surgical flowsheets via a mobile application and receive rapid risk-based notifications. The application enables medical professionals to quickly engage with pertinent perioperative data relevant for improving patient outcomes while also ensuring secure storage of the data, which in turn enables macro-level research for Rwanda's healthcare system. The design presented in this paper enables the user to rapidly upload anesthesia records and receive an email notification regarding hypotension risk data in, on average, 37 seconds. Leveraging AWS storage enables 1000 GB per month and demand-based scaling, dwarfing previous storage capabilities. Compared to the previous system, the average upload time decreased 81.7% from 40 seconds to 7.34 seconds with the usage of the newly designed system. In addition, the new system does not lead to an increase in system failures, where the user is unable to proceed with the usage of the application, which remains at 0% in the newly designed version.**

Introduction

Prior to the 2000s, the Rwandan healthcare system was unstructured, inconvenient, and expensive, even in comparison to neighboring countries[3], in large part a result of the devastation wrought by the genocide against the Tutsis of 1994. The small number of hospitals and clinics were often unused as they were too expensive for the average citizen and too removed from many Rwandans who lived in rural areas[3]. In the late 1990s, preventable illnesses like malaria, cholera, and HIV/AIDS were rapidly spreading in the region, which posed a significant challenge to the Rwandan government. Since then, the Rwandan government has focused efforts on improving the healthcare system[3]. To support the initiative, many organizations have provided equipment, vaccines, and financial aid to Rwanda allowing them to operate a universal health system and become one of the highest-quality health systems in Africa [2][4][5]. With the increased focus on the healthcare system, Rwanda built additional hospitals and clinics and trained additional nurses and doctors. However, despite the additional efforts, as of 2015, the average number of healthcare workers was 7.8 doctors, nurses, and midwives per 10,000 people, a value lower than the World Health Organization's (WHO) recommended critical minimum threshold of 23. Hence, the hospitals and clinics are often understaffed. Despite the significant improvements in the healthcare system, Rwanda has not migrated to an electronic medical record (EMR) system, but rather still uses handwritten records to document medical information[6]. Integrated EMR systems are not feasible in many under-resourced environments, such as Rwanda, due to the prohibitive cost of such systems, lack of trained IT personnel to implement and maintain them, and lack of standardization in monitors and other operating room and labor ward equipment[7]. Currently, only 15% of LMIC adopt electronic health records while over 50% of HIC have adopted EMRs [7]. Due to the lack of EMRs, surgeries that are deemed "low-risk" in HIC often have a relatively high postoperative mortality rate (POMR) in Rwanda, showing a need for continual improvement of their healthcare system [1].

This paper details the improvements and optimization of the digitization system developed by the University of Virginia with the University Teaching Hospital (CHUK) in Kigali, Rwanda using the work of previous student capstone teams[7][8]. While the previous system provided a solution and allowed for the digitization of perioperative handwritten health records, key issues relating to the system's efficiency, accuracy, and ease of use remained. To further optimize the digitization process, our team developed a mobile-app, both android and iOS compatible, with secure sign-in, connection to a secure AWS Simple Storage Service (S3) bucket for image storage, and tested a sample case of patient risk notification regarding intraoperative hypotension using data from patient records uploaded into the application.

Prior Work

This project was initiated in 2019 as a collaboration between physicians in CHUK and the University of Virginia Anesthesiology department. In 2020, Rho, et al. implemented the first iteration of the system to digitize surgical flowsheets at CHUK. Images were taken using a mobile phone with a third party scanning app, such as Tiny Scanner, and were then sent to a dedicated email address. From a web application, the user could access and download the image to send to a UVA email address using AES-256 encryption, where the images were then decrypted and processed. The scope of the 2020 research team was to develop a system that allows for images to be sent securely to the University of Virginia to provide the training and testing data set for the machine learning models that will digitize the surgical flowsheets [8][9].

In 2021, Blankemeier, et al. migrated the existing system from a web application to the first iteration of a mobile application, only compatible with Android operating systems. The upload process began with a login screen authenticated by Google's Firebase authentication service. Once the user was successfully logged in, they were directed to a home screen to begin the upload process. To upload a flowsheet image, the user must first enter the patient's identification number and then indicate the side of the sheet that is being uploaded. Once the information was entered, the user could click the "take photo" button which launches a camera. Thereafter, the camera allowed the user to capture a picture of the flowsheet. When the user clicked "send", the image was instantly encrypted and sent to a dedicated UVA email address with the subject line of each email being the patient identification number. The image was then decrypted and the digitization process could be started [7].

Discussion

The digitization of paper medical records is a tested and proven reliable methodology of healthcare data analysis. At Amity University in India, paper electrocardiogram (ECG) results were digitized successfully, and the data was extracted and used to populate data tables including information regarding heart rate detection, peaks in the heart rate, and stability observed[10]. In this study, researchers used smartphones to take and upload scanned images of the individual ECGs, which is of similarity to this project. The success in this study indicates that data can be correctly extracted from medical graphs and flowsheets if utilizing the proper algorithms and approaches. These methodologies and processes can be expanded upon to include automated medical analysis for perioperative flowsheets using predictive modeling, which is the goal of the partnership between CHUK and UVA.

Digitizing medical records and providing healthcare providers with indicators of risk is a successful way of increasing patient health outcomes and improving hospital practices as seen in a study performed by Chiang Mai University in Thailand. In China, Thailand, and Indonesia, disease-specific recommendations were made to medical professionals, which led to improved patient care, including the reduction of the time needed to provide proper medical care by over 73 seconds on average [11]. The usage of digital medical records in Japan with a user interface led to improvements in organizational culture [12, 3.2.2]. Issues cited within this study include, but are not limited to, consistent access to power, a lack of funds for public healthcare, language barriers, and access to mobile networks. However, when those conditions were met, hospitals in many participating countries reported successful results in terms of both hospital culture and patient health [12].

In some LMIC, research experiments have been conducted with more advanced forms of medical records. Specifically, the Khayelitsha Hospital in Western Cape, South Africa has created a dual physical and digital system in which the hospital system includes handwritten notes and documents placed in folders. The folders of records are then also stored as a scanned image. The limiting factor with this approach is that it relies heavily on large investments in not only software and technical infrastructure, but also human resources to scan and transcribe the documents. The goal of the initiative between CHUK and UVA is to allow for a hybrid system without the needed human resources. [14] [15].

System Requirements & Design

Through conversations with UVA School of Medicine (UVA SoM) advisors and CHUK doctors, the most critical improvement for the second iteration of the application is the proof of concept of the pipeline through the creation of a real-time hypotension risk notification. The notification initiates a valuable hypotension risk diagnosis capable of improving patient outcomes by alerting doctors of patients who require additional care. The second improvement is a streamlined storage and retrieval process for the images. In the previous system, the images were stored in a Google Drive connected to a UVA email account. The images were then downloaded and stored into a PostgreSQL database. This process was inefficient and can result in lost images in the account due to an unstructured folder environment and limited available storage. The two requested improvements by UVA SoM advisors and CHUK doctors were taken into consideration when developing the second iteration of the application.

The second iteration, and current iteration, of the design includes the full-stack development of a mobile application, which is hosted on the Amazon Web Services (AWS) cloud computing platform to allow for scaling. To address the design and implementation of a hypotension risk notification, the research group examined relevant literature and spoke with UVA SoM advisors. The creation of the risk notification enables medical professionals to develop synergistic relationships with digitization rolls, reduces their workload, and effectively improves patient care. To further improve medical professionals' care, the design and interface of the application has been updated based on user feedback.

To improve the storage and retrieval process for the images, the current application implements a relational database to address data needs, ensuring that data collection omits sensitive personally identifiable information (PII). The health record is protected at-rest at the AES-256 standard. The last significant system design change is the compatibility with iOS and Android OS. While the majority of Rwanda operates on the Android OS, restricting the application compatibility to Android, as with the first iteration of the application, limits the potential user pool of the application. The application has undergone testing within the AWS ecosystem and brief user testing with the client.

System Architecture

The architecture for the mobile application can be seen in the figure below. The mobile application is written using react native and hosted on AWS using AWS Amplify. The users are then authenticated using AWS Cognito, and the uploaded images are stored in a designated S3 bucket. Once an image is uploaded in S3, a lambda function is triggered to run python machine learning scripts to attain the systolic blood pressure and diastolic blood pressure from the image. The output of the lambda function is whether the patient is at risk for hypotension. Once the hypotension risk is determined, the result is sent through an email via SNS to a selected group of users. To receive the SNS email notification, the user must be authenticated.

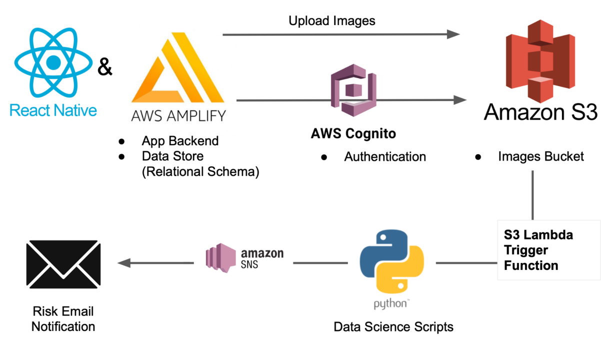

Figure 1: AWS System Architecture

Mobile Application Process

The process for using the application is seen below with the first step being secure sign-on, followed by uploading or taking an image, followed by entering a patient identifier and choosing the record type which then enables the lambda function to return a result, via email, regarding the hypotension risk. Past submissions for a unique patient are visible through selecting the appropriate patient identifier.

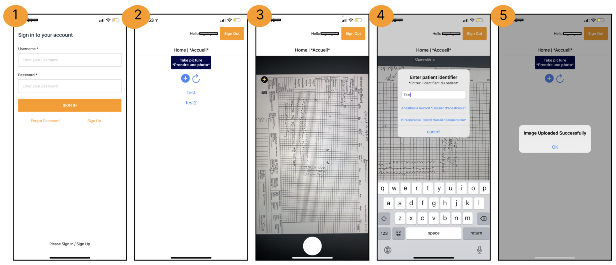

Figure 2: Mobile Application Steps

1. *Secure Sign-on/ Sign-out*

Hosting the application on AWS allows for user authentication and secure sign-on. The application, when first opened, prompts the user to create an account with an appropriate email address, username, and password. Through using the AWS Cognito service, the user then receives an email from AWS that includes a confirmation to verify the user's identity. The user must then enter the confirmation code correctly to verify and authenticate their account. The application remembers the secure sign-on for the user when using the same device. At any point in the application, the user can sign out through clicking the sign-out button on the top right corner as seen in the image below.

2. *Uploading/Taking Images*

Once the user has been authenticated and signed in, the application opens to a home page with several options: taking images, uploading images from camera roll, refreshing, or choosing a patient identifier. To take an image in real-time through the application, the user should click the "Take Image *Prendre une photo*" button on the home page. If the image exists on the camera roll, the user can upload the image through the "+" icon on the home page. After choosing the image to upload or taking the image, an alert will appear to enter the patient identifier and choose the type of record. After the information is entered, the images are stored in an AWS database, S3. This year's team acquired funding for AWS from the Center for Global Inquiry & Innovation at the University of Virginia and created an S3 bucket for the storage of the flowsheets images. Each patient has their own folder within the S3 bucket. Server-side encryption with AWS-managed AWS Server Side Encryption-S3 (SSE-S3) keys utilize the 256-bit Advanced Encryption Standard (AES-256), which is one of the strongest block ciphers available and ensures data security. When the image is successfully loaded, an alert will appear indicating the image has been successfully uploaded.

3. *Risk Notification*

Once the record is uploaded into the S3 bucket, an AWS Lambda function will trigger the execution of the machine learning python scripts to analyze the image and determine if the systolic blood pressure (SBP) and diastolic blood pressure (DBP) are within the appropriate range. For the patient to be at risk of hypotension, the SBP value must be under 70 mmHG for 5 or more minutes or the DBP must be under 30 mmHg for 5 or more minutes. If any of the aforementioned conditions are met, the email risk notification will alert the user that the patient is at risk of hypotension. On the other hand, if the conditions are not met, the email risk notification will alert the user that the patient is not at risk of hypotension. The email notification will, on average, be sent to the user within 2 minutes of the user uploading the image.

4. Past Submissions & Deleting Images

Lastly, if the user would like to view the past submissions for a specific patient, the user can click the associated patient identifier on the home screen which will navigate the user to a new screen with all the past images uploaded for the patient. On this page, the user has the option to delete images if the image should no longer be stored digitally. To ensure images are not deleted accidentally, after clicking the delete icon, the user will receive an alert to verify that the image should be deleted. Upon clicking yes, the image will be deleted.

Results and Impact

The results and impact of the research presented in this paper span three categories: patient care value-add improvements, accessibility improvements, and upload process improvements.

A. Patient Care Value-Add Improvements

1. Hypotension Risk Notification

The largest addition to the research project with regard to patient care is the addition of a real-time hypotension email risk notification. When any patient record is uploaded, the diastolic and systolic blood pressure graphs are digitized and an email notification is returned indicating whether the patient is at risk for hypotension. The hypotension risk, delivered in 37 seconds on average, enables technology-assisted decision making in the clinical setting, reducing the workload burden for medical practitioners which further incentivizes data collection. The average time, based on 17 trials, for receiving the risk notification after receiving the notification that an image is uploaded is 36.2 seconds. However, there were several instances in which the notification took longer than 2 minutes to arrive.

2. Retrieval of Previous Submissions

In addition to adding the risk notification functionality, the research team also added the previous submissions page. Each user can view all records that have been uploaded for a given patient. To view previously uploaded records, the user can select the specific patient identifier and view a scrollable menu populated with the previously uploaded images. Storing the images in S3 allows for a smooth and efficient process for retrieving the images and displaying them. This serves as an algorithmic validation mechanism, allowing for the user to verify that the risk alert matches the expected output. This is important in diagnosing issues and improvements with the digitization process, as well as allowing a human-in-the-loop design to ensure practitioners can easily verify risk with expert knowledge. This functionality enables future algorithm improvements and reduces the number of devices necessary to retrieve and access uploaded anesthesia records by 50%.

B. Accessibility Improvements

1. Camera Roll Upload & Image Deletion

The last major functionality that was added to the application is the ability to upload from the camera roll. Previously, the only manner in which the user could upload a paper medical record was to take the image in the application. The naming conventions for uploading an image through the camera roll are identical to uploading an image through the application camera. This provides greater flexibility for the medical professional who is uploading the paper medical record and allows for the easiest and best user experience. The uploading of an image takes 5.34 seconds and taking an image through the application takes about 2 seconds. Image deletion was also added to ensure that the user can delete any unwanted images.

2. iOS Compatibility

The mobile application developed in the previous year is only operable on devices with an Android operating system. Although Rwanda mostly operates on the Android operating system, limiting the application to Android devices limits the potential impact of the application. In recent years, the iOS operating system has been increasing in usage in Rwanda, with market share more than doubling between 2018 and 2021, with a market share of 14.5% as of June 2021 [17]. Hence, the current mobile application has been developed with broader compatibility as a priority, and is compatible with Android and iOS to reduce accessibility errors as iOS adoption continues to increase in Rwanda. In addition, this allows for further testing and support from the team at the University of Virginia, as the United States mainly has iOS users.

C. Upload Process Improvements

1. Upload Process Improvements

User testing of the new system was performed to test the efficiency of the process. Participants were given instructions on how to utilize the new system, and the user testing process instructions were identical with the instructions utilized by Blankemeier, et al.[7] to ensure comparable results, as shown below:

1) Enter patient information
2) Take photo
3) Save/Approve photo

Compared to the previous system, the average upload time decreased 81.7% from 40 seconds to 7.34 seconds with the usage of the newly designed system. In addition, this did not lead to an increase in system errors, which remains at 0% in the newly designed version. This allows for rapid uptake of sheets at a rate 5.5 times quicker than was expected with the previous application.

Conclusion and Future Work

After hosting discussions with UVA SoM advisors, there were several areas of improvements the team decided to study and optimize. The first improvement is developing an application compatible with iOS and Android OS hosted on AWS. Hosting the application on AWS allows for the images to be securely stored in S3 and for the images to be analyzed through an AWS lambda function. The new design decreases the average upload time by 81.7%. The next feature enhancement that the research team developed is an email hypotension risk notification. On average, based on 17 trials, the hypotension risk notification takes 37 seconds from the time of upload to be sent to the user. This tool will create synergistic relationships between digitization efforts and practitioners as technology-assisted decision making reduces practitioner burden and verifies digitization efforts.

Future work will consist of maintenance and feature enhancements to the application for increased efficiency, effectiveness, and adaptability to healthcare practices in other countries. The improvements include improving the lambda function to fully digitize the flowsheets and output the digitized flowsheet and to identify different risks that can be determined through the flowsheets, developing the relational database of the application, implementing an image scoring system to ensure that all images uploaded are of high quality, and increasing the languages within the application.

The current lambda function only uses the SBP and DBP machine learning models to identify abnormal SBP and DBP values. Future work consists of digitizing the entire flowsheet to determine MAP, drugs used, and fluids given to the patient. Identifying and implementing new risk notifications on additional metrics, such as those aforementioned, can be utilized to aid in decision making.

Continuing to adapt the application to be usable in different languages will allow for medical professionals, especially those with a different native language, to use the app effectively. The increase in usability will allow for a greater efficiency in the utilization of the application within the healthcare system and reduces the potential for misunderstandings. Increasing the language compatibility alongside scalability will enable the application to effectively serve other LMIC countries.

The next recommendation for future work pertains to generating a dashboard of macro-level health metrics for the physicians to quickly identify trends. Some metrics that would be extractable from the paper anesthesia record include existing medical software measures such as ASPIRE measures: BP-01, BP-03, TEMP-03, NMB-01, PUL-02. Additional metrics could be used to quantify healthcare delivery and enable patient care improvements at the practitioner-level and organizational level.

The last feature enhancement for future work is implementing a score for the quality of the scanned images and ensuring that all uploaded images attain the minimum threshold score. Adding the image scoring feature will both increase the ability of the models to accurately digitize flowsheets and improve patient care, making the application more accessible to a wider range of medical professionals and healthcare systems as well as improving the post-procedure care and attention provided to the patients.

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