PRELIMINARY REPORT

Data Acquisition System in Low-Resource Settings

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1. Background

Cerebral malaria (CM) is a common infection caused by *Plasmodium falciparum* that primarily affects African children less than 5 years of age. Most of the 675,000 malaria deaths each year are due to CM.[1] The mortality rate of CM in the region is high, and survival is complicated by secondary conditions, such as long-term neurocognitive impairment.[1] In addition, in low-resource settings (LRS), healthcare providers have limited training and access to essential critical care technology to effectively decrease death and disability rates. The Blantyre Malaria Project (BMP) has been studying different interventions for CM in children at Queen Elizabeth Central Hospital in Blantyre, Malawi. Though the BMP has helped significantly reduce the cases of CM using rapid diagnostic tests, it is the hope of medical experts that a combination of patient monitoring indices may also be used to further improve CM treatment methods.[2]

The identification of marginally compensated physiological states could be significant for the successful treatment of diseases like CM. In these pre-failure states, the body maintains vital signs and metabolic parameters despite declining reserve for compensation.[3] The likelihood of a positive patient outcome is significantly increased if the patient is treated before deterioration. With appropriate equipment, the onset of decompensation can be detected through physiological monitoring by analyzing heart rate variability (HRV) and pulse waveform (PW). Decline in HRV and PW are indicators of cardiac failure, which reflect overall physiological distress. In non-LRS, these measurements have been successfully integrated into algorithms to predict shock in ICU patients.

In addition, HRV and PW analyses could be used to identify more subtle markers in CM progression and predict the risk associated with different treatment methods. Although the BMP facilities have the necessary equipment to measure these biomarkers, there is no method to obtain the data at the appropriate resolution for analytical research. Acquiring additional monitoring equipment is restricted by cost and would have to be obtained by donation. Furthermore, technological improvement is limited by frequent power outages and lack of structured electrical wiring. Data analysis also requires the ability for remote access, so that data can be analyzed by a team of experts in other parts of the world with access to sophisticated software.

These limitations in disease management and hospital resources are common problems in many LRS. Development of technologies to overcome these challenges can potentially benefit other LRS, including third-world countries, and be utilized in limited care environments, such as ambulances. Successful implementation of remote, data driven patient intervention can exemplify alternative treatment strategies for other diseases prevalent in LRS. Ultimately, the goal is to reduce mortality and morbidity levels at every level of treatment.

2. Project Scope

2.1 Need Statement

There is a need for a device to digitally transmit and archive high-resolution physiological data from patient monitors in LRS, so that remote medical experts can develop new diagnostic and treatment protocols.

2.2 Scope

Research studies on cerebral malaria in LRS, such as Malawi, are hindered by data collection devices that are not outputting physiological data at frequencies high enough for comprehensive study. Thus, there is a need for a device that can digitally collect data so that it can be transmitted to remote researchers and doctors to help develop new diagnostic and therapeutic methods. This device will need to collect and archive real-time 4-lead ECG and arterial waveform data at a high resolution (100-200 Hz), as well as discrete blood pressure and oxygen saturation from a GE Solar 8000i monitor. The biomarker data will need to be uploaded onto a central hub to be accessed from any location for interpretation and medical advising. The device will also need to be portable, cost-efficient (<$500), and easily reproducible. In April 2019, the electronic hardware and associated software compatible with the existing monitor, along with any user manuals and circuit diagrams, will be delivered to the client, Dr. Allan Doctor.

3. Design Specifications

Due to the constraints placed on this device by the low-resource environment, there are several specific parameters to consider. Some of these limitations relate to the existing instruments and facilities in Malawi, such as the power source, space restrictions, and technology available there. Other considerations have to do with how the data needs to be processed and transmitted in order to be easily accessed. The design specifications that determine how the data acquisition system will be designed and built are listed in Table 1 and 2. These specifications are preliminary and are subject to change once the prototyping begins.

Data Acquisition Unit	
Specification:	**Metric:**
Compatibility	GE Solar 8000i Patient Monitor and related hardware
Safety	No harm to patient or staff.
Cost	< $500
Size and Weight	Portable. Fits on medical cart. Less than 10”x20”x8” and 15 lbs.
Power	Wall power: 230 V, 50 Hz, single phase
	Backup generator
Mode of Operation	Continuous during length of stay
Measurement	Waveform: ECG (4 lead), invasive arterial blood pressure
	Discrete: non-invasive blood pressure, pulse oximetry

Data Acquisition Unit (continued)		
Specification:	**Metric:**	
Frequency	Min: 100 Hz	Ideal: 200 Hz
Sampling amplitude	16-bit	
Resolution range	ECG: 0.5 – 5 V	BP: 0.0V +/- 0.025V
Transmission	Wireless. Real-time. Digital output to server.	
	Between buildings, across brick and steel walls. 200-300 yards.	
Software	User-friendly interface	

Table 1. Initial design specifications for the data acquisition unit.[4]

Server Unit	
Specification:	**Metric:**
Storage	Flexible. Will depend on data format and remote storage by client.
Power	Wall power: 230 V, 50 Hz, single phase
Software	Receives and archives data in real-time from multiple monitors
Accessibility	Remotely view and download real time data archived data
Maintenance	Remote access of software code for maintenance and updates

Table 2. Initial design specifications for the server unit.[4]

4. Existing Solutions

There are some existing data acquisition modules, wireless monitoring devices, and other patient monitors that are being used in non-LRS to capture useful physiological data and help physicians make clinical decisions and diagnoses. However, due to the unique limitations in Malawi, no alternative solution meets all of the needs of this project. The following subsections will describe these existing technologies and the feasibility of their implementation.

4.1 Wireless Monitoring Devices

Multiple wireless monitoring devices available on the market, and many of them are made as wearables. These devices tend to measure vital signs and are able to output this information to a phone application wirelessly. This can help physicians to diagnose of their patients quickly, while having readily available information at hand.

For example, the Caretaker®, is a finger cuff that measures blood pressure, heart rate, and sends that information via Bluetooth to an Android application that can be viewed by physicians remotely (Figure 1).[5] It can even take data from other types of devices, such as thermometers and glucometers, and integrate it with the data that it collects itself. However, this device, along with other wearables, would not be an appropriate solution, since it does not collect invasive blood pressure measurements. In addition, the other complementary devices (like the thermometer and glucometer) would have to be Bluetooth-enabled to work with the Caretaker® app. Lastly, this device has no way of archiving the information.

Figure 1. Caretaker® by Caretaker Medical.[18]

4.2 Telemedicine

Telemedicine is real-time, interactive communication that allows a physician to provide healthcare for patients from a different location.[6] It has been proven to be helpful in rural areas where there is a lack of healthcare accessibility and allows for physicians to collaborate outside of their home institutions. This is accomplished via special telemedicine equipment, such as examination cameras, medical scopes, software systems, and even more advanced telemedicine robots like the one designed by InTouch Health (Figure 2).[7,8] In an LRS such as Malawi, however, there is little existing infrastructure to support a system like this. Limitations in technology and number of remote physicians available prevent this from being a feasible solution for the majority of hospital patients. Also, telemedicine does not solve the data storage and transmission problem that is at the center of this project. The more cost-effective and appropriate solution would be to create a device that is compatible with the equipment already in Malawi.

Figure 2. InTouch Health telemedicine robot in action.[16]

4.3 Networking Software

Existing networking systems connect and archive data from multiple patient monitors to a central, accessible database. Examples include the Unity Network and NantHealth® by GE Healthcare, ICM+ software package, and BedMasterEx by Anandic Medical Systems (Figure 3).[9,15,10] These systems are designed to collect waveforms and other physiological data via wired, ethernet connections to each patient monitor, as well as provide real-time, multimodal analysis. While convenient for advanced medical centers, the intended hospital in Malawi has no ethernet wiring and cannot support the construction of new hardwiring. Moreover, these commercially available types of software are not able to archive high-resolution waveforms from the GE Solar 8000i monitor specifically, since the bedside monitor lacks an analog interface that is compatible with these systems.

Figure 3. BedMasterEx by Anadic Medical Systems.[19]

4.4 Patient Monitors

Several patient monitors are available that can store data for export and archive via network connection. An example would be the CNS Monitor by Moberg ICU Solutions. However, this monitor collects EEG signals, which are not the signals of interest in this project.[11] Other monitors that better fit the specifications required for this project include the Phillips Intellivue X2, which is capable of high-acuity monitoring and wireless data networking.[13] Additionally, in non-LRS, sophisticated monitors are used with analytic platforms such as WAVE (Excel Medical) to integrate medical resources and apply predictive algorithms to patient treatments.[8] Although this monitoring system is technologically ideal, the equipment is cost-prohibitive. A single Phillips Intellivue X2 monitor (Figure 4) costs $2000-3000.[13, 14]

Figure 4. Phillips Intellivue X2.[17]

5. Preliminary Design Schedule

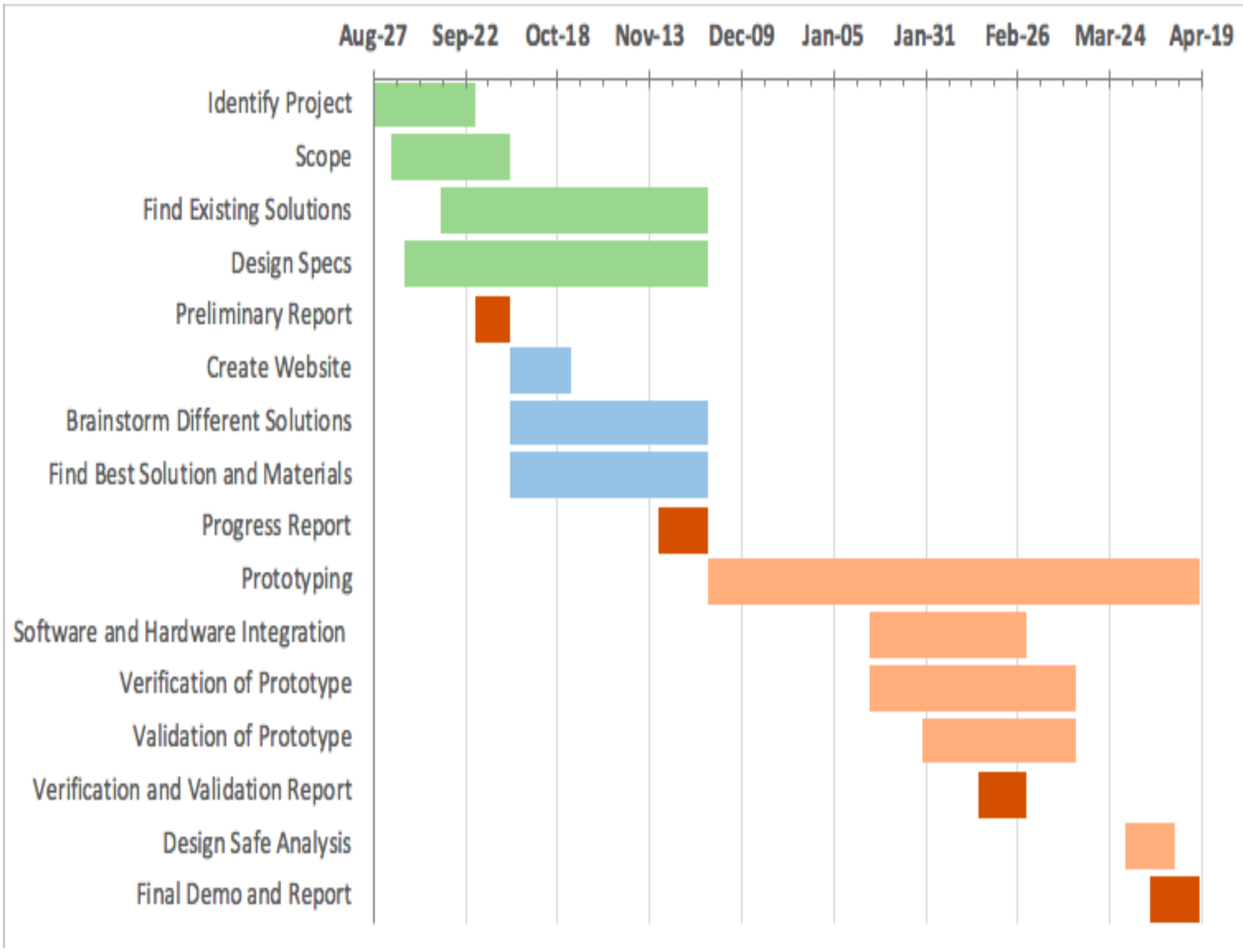

Figure 5. Gantt chart for the design of the data acquisition system.

6. Organization of Team Responsibilities

The demands of the project are shared evenly amongst team members. All members will contribute to research, prototyping, testing, and documentation. Distribution of other specific project tasks and responsibilities are shown in Table 3.

Task:	**Team Members:**		
	Connie Lee	*Alexeis Ong*	*Tina Tang*
Research and Design	x	x	x
Hardware Development		x	x
Software Development	x		x
Testing	x	x	x
System Integration	x	x	
Communications and Client Support	x		x
Website Maintenance	x	x	
Budget			x
Weekly Reports		x	

Table 3. Distribution of team responsibilities.

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