Progress Report

Data Acquisition System in Low Resource Settings

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BME 401A

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1. Overview

Cerebral malaria (CM) is a common infection that primarily affects African children less than 5 years of age. The mortality rate of CM in Malawi is high, and survival is complicated by secondary conditions like long-term neurocognitive impairment.[1] Diagnosis and treatment development have been limited by lack of resources, such as high end imaging equipment, that are necessary to quantify the progression of CM.

The Blantyre Malaria Project (BMP) is investigating the use of ECG and ART waveforms as alternative measures of patient outcomes in a clinical study at the Queen Elizabeth Central Hospital in Malawi. In collaboration with an analytics company in Boston, MA, high resolution data will be used to predict diagnosis and treatment success. To support their efforts, this project will design a system to send data from patient monitors in the Pediatric Intensive Care Unit (PICU) and store it on a remotely accessible server. The data will be accessed from the research building, which is a separate building at the hospital, and from the United States. The proposed solution will be cost-effective, support remote access, and maintain resolution fidelity.

2. Updates from Preliminary Report

2.1 Need

There have been no changes to the need statement.

2.2 Scope

There have been no changes to the scope.

2.3 Team Responsibilities

There have been no changes to team responsibilities.

2.4 Design Schedule

There have been no changes to the design schedule.

2.5 Design Specifications

The project design specifications are listed and described in Table 1. There have been no changes made to the design specifications.

Specification	Metric	
	Data Acquisition Unit	
Compatibility	GE Solar 8000i Patient Monitor and related hardware	
Safety	No harm to patient or staff.	
Cost	< $500 for eight units	
Size and Weight	Portable. Fits on medical cart. Less than 10x20x8" 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	
Frequency	min: 100 Hz	ideal: 200 Hz
Sampling Amplitude	16-bit	
Resolution Range	ECG: 0.5 - 5 V	BP: 0.0V +/- 0.025 V
Transmission	Wireless. Real-time. Digital output to server.	
	Between buildings. Across brick & steel walls. 200 - 300 yards.	
Software	User-friendly interface	
	Server Unit	
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 1. Initial design specifications for the data acquisition system.

3. Statement of Design Alternatives

There are two different categories of design alternatives: transmission-based solutions and server-based solutions. Transmission-based solutions connect the GE Solar 8000i monitors in the PICU to the research building, whereas server-based solutions connect the GE Solar 8000i monitors in the PICU to a server in the same building.

3.1 Transmission-Based Solutions

To have the server in the research building, the data must be transmitted between the PICU and the research building. Although both sites have Wi-Fi capability, they are connected to different networks, separated by thick walls, and distance. Solutions based on transmission method are discussed in the following sections with emphases on these obstacles. Figure 1 shows how the system can be visualized.

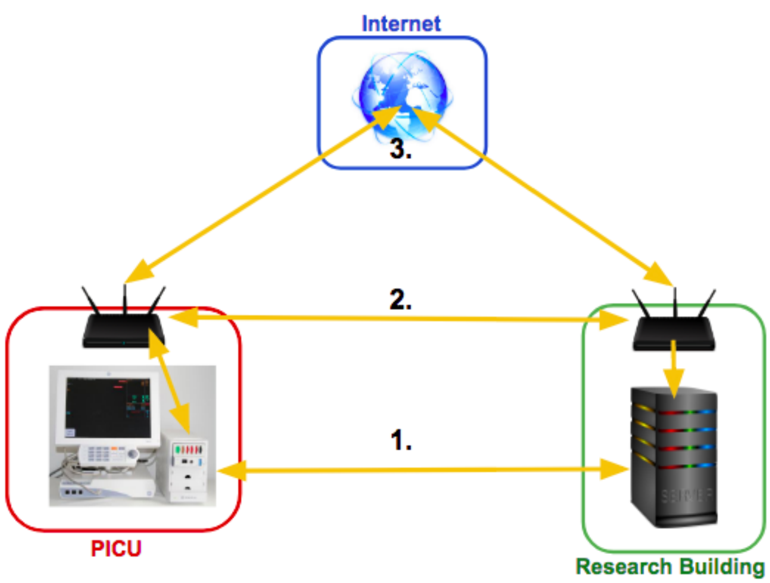

Figure 1.[29, 30, 31, 32, 33] *Transmission-based solutions. To store the data in a server in the research building, the data must be transmitted from the PICU (red box) and received*

*at the research building (green box). There are three possible signal routes: **1.** Wirelessly without Wi-Fi, **2.** Wi-Fi without internet, **3.** Wi-Fi through the internet.*

3.1.1 Ethernet Local Area Network (LAN) (IEEE 802.3)

Ethernet is a wired technology used with LANs that determines how much data can be transferred over a LAN.[2] Devices connect to each other via cables plugged into Ethernet ports.[3] A typical Ethernet signal rate is 10Mbps,[4] however, the signal can be interrupted with other wires and cables. Because of its wired nature, Ethernet's range of data transmission is restricted to the same building.[2] At BMP, the patient monitors reside in the PICU in a separate building from the research building. The sites cannot support new hardwiring.

3.1.2 Infrared (IR)

Infrared wireless transmits data using infrared radiation instead of the usual radio frequency. IR wireless technology is primarily used for short range communication and operates in two modes: line-of-sight mode, in which there must be an unobstructed direct line through space between the two objects, and scatter mode, where the two objects must still be in close proximity to each other but not necessarily directly visible to each other.[5] This is due to the fact that IR is easily blocked and cannot pass through walls. For this same reason, there is little interference between IR systems and thus IR offers a more secure and private connection than radio frequency (RF).[6]

3.1.3 Bluetooth (IEEE 802.15.1)

Bluetooth is a wireless technology designed for short-range usage for portable devices within wireless personal area networks (WPAN). The basic cell is a piconet, which is a WPAN where a Bluetooth device serves as a master and other Bluetooth devices serve as slaves. The maximum signal rate using Bluetooth is 1 Mbps.[4]

Although the maximum range of data transmission is up to 100m, Bluetooth is easily disrupted by walls. The typical cost of a Bluetooth-transmitting device is around $50.[25]

3.1.4 ZigBee (IEEE 802.15.4)

ZigBee is a wireless, mesh network with a long battery life used in low-rate WPAN for communication between different personal devices, up to a space of 10m.[4] It typically supports simpler devices that require less power, such as full-function devices (FFD) or reduced-function devices (RFD).[4] This form of wireless technology is not meant for sending large amounts of data. The maximum signal rate using ZigBee is 250 kbps, and the maximum range of data transmission is 100 m.[4] ZigBee technology could cost up to $30.[7]

3.1.5 Ultra-Wideband (UWB) (IEEE 802.15.3)

Ultra-Wideband (UWB) is designed for short-range usage (typically indoor applications) often used in home networks (also WPAN) for audio and video multimedia.[4] It transmits data using radio waves over a wide frequency band.[8] Because it is for mostly for indoor use, it has a range of up to 10m, and has a maximum signal rate of 110Mbps. The basic cell is also a piconet, just like Bluetooth.[4] An antenna that uses UWB costs around $40.[9]

3.1.6 Wi-Fi with Directional Antenna

A traditional wireless Wi-Fi router has a limited range (less than 50 m); however, through the use of directional antennas, the range can be extended to several kilometers.[10] A directional antenna allows one to focus the signal in the direction of one’s choosing; a higher dBi rating corresponds to a smaller radiation pattern, which makes the antenna stronger but harder to aim. To complete the long-range Wi-Fi connection from one building to another, there will need to be a Wi-Fi antenna at both ends. Additional infrastructure elements include a coaxial cable to connect the network router to the antenna. Other considerations include antenna shape, outdoor antenna placement, and a clear line of sight.[11] This method of wireless transmission has already been effectively deployed in developing countries and remote geographical monitoring locations.[12,13]

3.1.7 Wi-Fi with VPN Tunnel

Using a Virtual Private Network (VPN), a secure, connection can be made over public internet between two locations or networks.[14] Data from the VPN client is encrypted and sent through the internet to another site where it is decrypted by a VPN server. Site-to-site tunnels may be used to create a network similar to a wide area network by connecting VPN routers. The VPN router then serves as a connection point for local devices in the second location. The speed and security of the tunnel depends on the VPN protocol utilized.[15]

Since the data is sent through the Internet, there are no issues in transmission due to physical obstructions and distance. VPN routers may cost between $50-500.[16] The cost and capability of the router depends on the amount of data transfer needed. In the scope of this project, a lower end router will have sufficient power and the bandwidth should not exceed any limit set by the local internet service provider (ISP). To connect VPN routers, the IP addresses of both routers must be known to make a connection. Thus, there is an additional cost for a static IP, which is typically more expensive than a dynamic IP, or for a dynamic domain name system, which may have a monthly cost. Additionally, the speed of transmission is limited by the local internet service provider. At BMP, internet service is provided by Telecom Networks Malawi (TNM) with an average bandwidth of 6 Mbps and download/upload speeds of 4 Mbps.

3.1.8 Ultra High Frequency (UHF) Radio

Radio frequency (RF) refers to the rate of oscillating radio waves and the alternating currents (AC) that are carrying those radio waves. There are many different bands in the radio spectrum, but the ultra high frequency (UHF) band is the most relevant as it is the band most frequently used by Bluetooth and wireless LANs. The radio waves are then accepted by an antenna and turned into electrical signals that could be further analyzed.[18] Radio waves can be easily disrupted through polarization of either the wave or the antenna, or even if there is no clear line of sight between the transmitter and the receiver.[17] UHF radio waves can transmit data over a range of 1.5 to 4 km with visible obstructions, and the maximum data transmission rate of normal radio waves is 1-2 Mbps.[19, 20] The cost varies between different brands of UHF radios, but it can be as low as $100.[21]

3.2 Server-Based Solutions

If the server is not in the research building, the physical obstacles related to transmission are no longer pertinent. Access from the research building and other remote locations would be possible through internet connection. This alternate system is visualized in Figure 2.

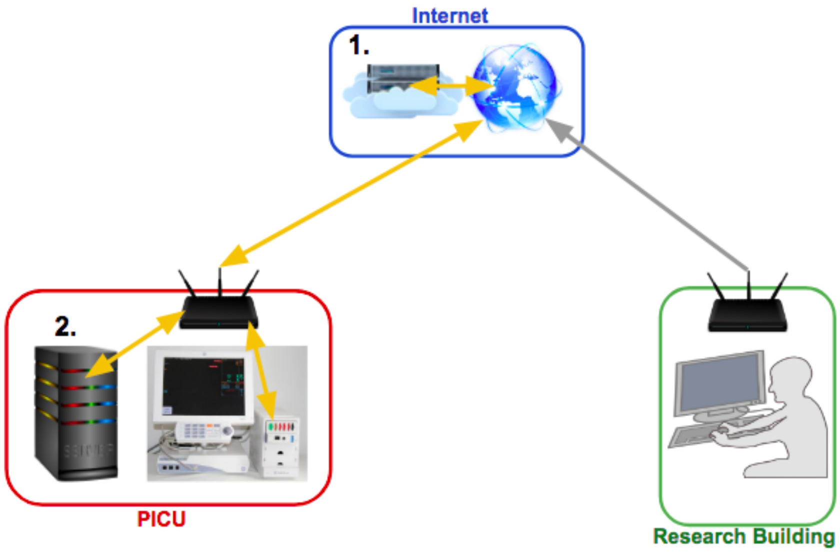

Figure 2.[29, 30, 31, 32, 33, 34] *Cloud-based solutions. To avoid physical barriers, the server can be kept outside of the research building (green box) and instead accessed remotely from the research building. There are two possible signal routes:* ***1.*** *Wi-Fi to a web-based cloud server* ***2.*** *Wi-Fi to a network drive in the PICU.*

3.2.1 Wi-Fi with Cloud

The data could also be sent using Wi-Fi from each monitor to a cloud-based server. Cloud-based servers serve the same function as normal servers, but can be remotely accessed.[22] Having a cloud-based server eliminates the need for a physical server in the PICU, but is limited to Wi-Fi speed. There are many different companies that provide cloud-based server services, such as UpCloud and OwnCloud, and the cost of implementing it could range from $5 to $50 a month, with some companies charging extra for storage space.[23,24]

3.2.2 Wi-Fi with Remote Access VPN

A VPN can also be used to create a remote access network.[14] Then, remote computers can make a secure connection to the VPN and its resources via the internet. The data can be collected and stored on a server connected to the network in the PICU. The simplest storage could be a hard drive connected to a VPN router. This network drive could be accessed remotely through internet connection. Since the span of this project is limited in size, a lightweight to moderately robust VPN router would be sufficient enough to support data collection and a few people's worth of remote access.

4. Analysis of Chosen Solution

The transmission-based and server-based solutions were compared in a Pugh chart analysis. The results are shown in Table 2.

Category	Criteria	Weight	Transmission-based								Server-based	
		(1 is least important, 5 is most important)	Ethernet	Infrared (IR)	Bluetooth	ZigBee	Ultra-Wideband (UWB)	Wi-Fi with Directional Antenna	Wi-Fi with VPN Tunnel	Ultra High Frequency (UHF) Radio	Wi-Fi with Cloud	Wi-Fi with Remote Access VPN
	Ease of Installation	1	1	1	4	3	2	2	4	2	5	5
Logistics	Cost	3	3	2	5	5	5	5	4	2	3	4
	Wireless	5	0	5	5	5	5	5	5	5	5	5
	Range	5	0	1	2	2	1	5	5	5	5	5
	Interference	4	3	2	2	2	2	5	4	3	4	4
Transmission	Speed (Delay)	2	4	4	3	1	4	4	3	2	3	4
Data	Resolution (data rate)	4	5	2	4	2	4	5	3	2	3	5
		Weighted Total	50	61	84	71	79	115	100	82	98	111

Table 2: Pugh chart analysis for various methods of data transmission. Lower weights were given to criteria that were deemed less important, and lower scores were given to methods that were farthest from the ideal.

From the Pugh chart, the optimal solution for the project would be the use of directional antennas with Wi-Fi as the transmission method. This decision was made on the following criteria.

In terms of logistics, the measures that were taken into consideration were ease of installation and cost. Ease of installation refers to how feasible it would be for the said method to be implemented into the existing infrastructure. If the method required more supporting infrastructure, such as extra wires or antennas, it was given a lower score. Due to the limited budget provided for this project, and that this data acquisition system will be made for use in low-resource settings, the cost of the method has to be low. If the method required more materials than just the device to implement it, the cost would inherently be higher, and it was given a lower score. Wi-Fi with directional antenna is a bit more difficult to execute correctly than some of the other methods, since installing and aiming the antennas would require some technical skill or detailed instructions; however, none of the parts are particularly costly and difficult to obtain. The other criteria help cement the choice for the use of directional antennas to extend Wi-Fi range.

For data transmission, the criteria that were taken into consideration were wirelessness, range, probability for interference, and delays in speed (Mbps). Since the hospital in Malawi cannot support electrical wiring between the buildings, the method had to be wireless. If it was not wireless, it was automatically given a score of ‘0.’ The data needs to be sent from one building to another, which is a distance of about 300 m. Many of the wireless solutions, such as Bluetooth, ZigBee, IR, all fell short of this criteria as they could only operate across shorter ranges; however, directional antennas can easily reach this range which is primarily why this solution is preferred.

Interference referred to whether the signal would be interrupted while it was being sent. Certain methods were susceptible to physical interruptions, such as walls or buildings, or electrical interruptions, such as other radio waves or electrical cables. It is imperative that the signal would not be distorted while it was being transmitted. This was taken into account for the Wi-Fi with directional antenna since the antennas must be placed within line-of-sight of each other on the outside of the building. As long as this is true, there should be minimal interference with the signal, especially since there are not many electrical devices in use yet in a developing country like Malawi. If it was easily disrupted, that method was given a lower score. Finally, in wireless transmissions there are often delays in the speed at which the data is received. This can result in lagging in real-time streaming processes. However, delays using Wi-Fi should be minimal and not detrimental for use by the research ward.

Lastly, data resolution was given the highest weight possible because the main problem that this project aims to solve is to be able to transmit the biological data at a high signal data rate. Solutions such as ZigBee and UHF radio work on the order of kbps or low Mbps, while other methods work on the order of hundreds of Mbps. Therefore, those were given relatively low scores. Given the results from the Pugh chart, the best solution would have to use some sort of Wi-Fi.

5. Overview of Chosen Solution

The overall design architecture of the system is depicted in Figure 3. The biometric data, such as ECG and arterial blood pressure, will first be collected in the ICU by the GE Tram Rac, which will send it to display on a GE Solar 8000i monitor as well as through an analog-to-digital (A/D) converter. After the initial analog signal has been converted to a digital signal by the A/D converter, it will be sent wirelessly to a computer server in the research ward by a wireless transmitter device. Based on the Pugh chart analysis, Wi-Fi with directional antenna was determined to be the best method of wireless transmission across those two buildings. Basic software will be written on the server to allow for the storing of the biometric data. The data on the server will then be accessible to researchers and physicians in different parts of the world.

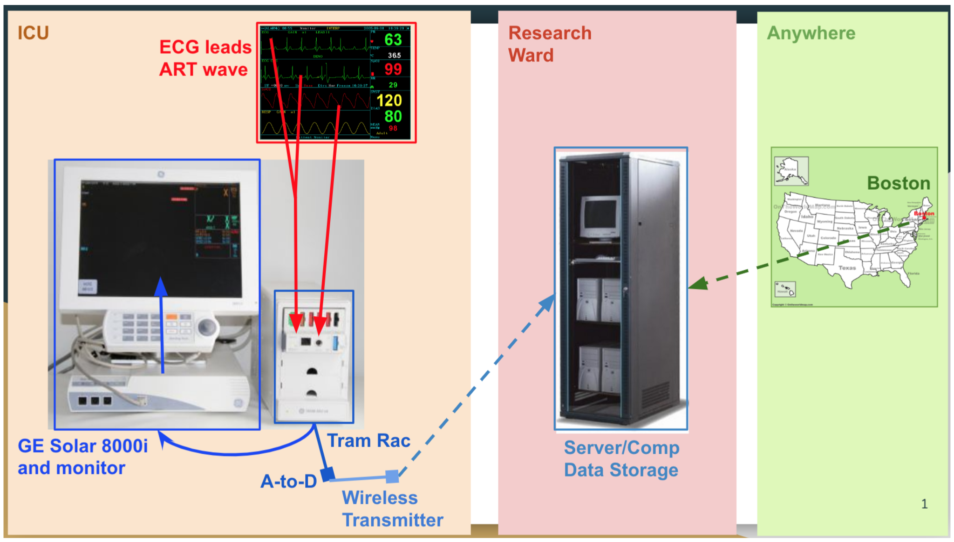

Figure 3. Overall system design.

6. Proposed Budget

The proposed budget for this project is shown in Table 3. Since this device is to be implemented in a low-resource environment, one of the design criteria was affordability which is reflected in the choices made. The client, Dr. Allan Doctor, will be able to provide the funding for the system that totals $500 and supports recording from eight patient monitors. This will include the budget for two Wi-Fi directional antennas, the corresponding coaxial cables, the A/D converter, and any additional, small circuit components. These will be needed to make the Wi-Fi connection between the research ward and the PICU, and to collect the data from the GE Solar Tram Rac. All software will be developed at Washington University so there will be no added cost. Finally, the server for data storage is to be provided by the client.

Item	Cost	Source
Wi-Fi Antenna (2)	$24.99 (each)	Amazon[26]
Coaxial Cable (2)	$9.47 (each)	Amazon[27]
A/D Converter (8)	$8.45 (each)	Walmart[28]
Computer Server	Provided by client	NA

Table 3. Proposed budget.

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Images for the Figures

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