The University of Texas at Austin

Engineering World Health

FreePulse: A Low-Cost Patient Monitor

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1 Abstract

A patient monitor is a mechanical and electrical medical device designed to continually monitor a patient's vital signs in order to identify respiratory or cardiac distress. Patient monitors play a crucial role in virtually all aspects of medical care, including emergency and surgical units, intensive and critical care units, and other non-critical units. Patient monitors are a staple item in developed world hospitals; however, in crowded developing world hospitals, a low patient-monitor-to-patient ratio prevents doctors from performing a sufficient number of surgeries to meet the needs of the local population as well as effectively treat patients in critical care. The reason for this shortage of patient monitors can be primarily attributed to cost of current market models, ranging anywhere from $1,000 to $10,000. This high cost forces developing hospitals to largely depend on outside donations for new devices, an infrequent and unreliable source of critical equipment. There is a clear and demonstrated need for a low-cost patient monitor that can be purchased in bulk by developing world hospitals, thus giving many more patients the monitoring they need. Our project, the FreePulse low-cost patient monitor, aims to fill this gap in developing world healthcare and provide a durable, reliable, and accessible monitor. FreePulse provides basic monitoring for heart rate, electrocardiogram signals (ECG), and percent saturated oxygen (SpO_2) with analog and digital filtering. Visual alerts are implemented to warn nurses if a patient begins to experience cardiac or respiratory distress, matching the capability of current market devices. A replaceable backup battery and uninterrupted power circuit ensures that the device continues to function even in unstable power conditions.

Furthermore, our design aims to provide a low-cost platform for many different medical parameters through its modular hardware configuration and abstracted software constructs. FreePulse not only presents a solution for increasing patient monitor accessibility in the developing world, but also provides a powerful platform upon which low-cost medical equipment can be developed and implemented for many years to come.

2 Clinical Need

In a case study of a large public hospital in Gitarama, Rwanda, one of our team members working with Engineering World Health found that although the hospital had over 400 beds for patients, only five patient monitors could be accounted for in the hospital's inventory. In the emergency care ward, only one monitor was available to keep track of three intensive care beds; when multiple patients in the emergency care ward were unstable, the nurses continually cycled the patient monitor between the three beds. Furthermore, although the hospital had multiple rooms and anesthesia machines in the surgery ward, only two surgeries could be performed at a time due to a lack of monitoring equipment. This bottleneck meant that patients waited for days before undergoing crucial surgeries, thus slowing the flow of patients and, inevitably, creating more patients whose condition needed to be monitored constantly. This problem is not by any means isolated to this one public hospital, and due to this shortage of patient monitors, hospitals cannot effectively take care of their patients. Clearly, the lack of accessible monitoring equipment is a crippling issue for developing world healthcare systems.

In response to this problem, we developed FreePulse, a low-cost patient monitor that serves as an accessible and affordable alternative to conventional patient monitor technologies. FreePulse provides the same critical services as existing patient monitors, including electrocardiogram data (ECG), peripheral capillary oxygen saturation (SpO_2), and heart rate, while costing substantially less than currently existing market equivalents [1, 2]. Furthermore, it is designed with developing world hospital environments in mind; a rugged plastic case allows the device to endure rough and consistent usage, while a 1200 mAh rechargeable battery with uninterrupted power supply keeps the monitor running even in inconsistent power conditions. It is common for devices to be used by untrained or overworked staff, especially in larger public hospitals in developing countries, and as a result, overly-complex devices are often abandoned or marked as broken and never see use on the hospital floor; FreePulse takes this into account by using an extremely intuitive touch screen interface, requiring virtually no training to begin using the device. With these features and an approximate manufacturing price point of $72, FreePulse offers the consistent monitoring that patients require at a cost that developing world hospitals can afford in bulk.

Given the widespread need for this technology, even a small distribution of FreePulse monitors can make an enormous difference in the lives of patients in developing world hospitals. Take our case study in Rwanda for example: there are 47 district hospitals and 500 health care centers that service about 7.65 million people annually, according to the Demographic and Health Surveys Program [3, 4, 5]. If we can provide at least 12 monitors per hospital and 8 monitors per health care center, we could immediately help millions of people in Rwanda. Twelve more monitors in a hospital means that nurses wouldn't have to switch monitors between patients in intensive care, reducing the risk of infection; it means that there would be more monitors available for surgery wards and faster patient turnover, helping people recover more quickly and return to supporting their families. As production of FreePulse monitors scales up, so will the impact, and given breadth and depth of harm that is caused by a lack of patient monitoring, this impact is desperately needed.

3 Design

The FreePulse patient monitor is designed with the developing world in mind. Its portable and durable casing and design makes it an excellent fit for a wide variety of medical applications. While prototyping FreePulse, some key user experiences were assessed.

3.1 Durability

A sliding latch with an O-ring seal is one of the key features that contribute to the durability of the FreePulse monitor. The O-ring makes the monitor and interior circuit components waterproof and improves the durability of the monitor. Additionally, the latch allows easy access to these interior components, thus eliminating the need for screws in the FreePulse design. This lack of screws is a major plus for use in the developing world due to the tendency of screws to strip or break under stress.

Another design choice that improves the durability of the FreePulse monitor is the use of ABS plastics on the exterior. The use of ABS plastics make the FreePulse casing very resistant to chemical corrosion, increasing the device's overall life span. These same plastics allow ergonomic and portable design. If the casing were to deteriorate, a new one could be printed using an ABS 3D printer and models downloaded from a publicly available server.

Finally, the production model of FreePulse will include resin-coated electrical components, greatly increasing the durability and life span of the monitor. As a result of the resin coating on our electrical components, fluctuations in humidity will have negligible effects on the circuit components. This feature combined with the O-ring design provides a fail-safe mechanism for protection from accidental water exposure.

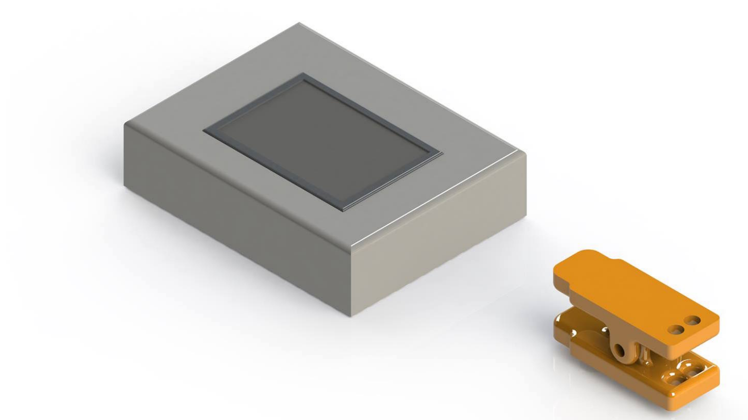


Figure 1: The FreePulse monitor uses only a touchscreen for user interaction and is surrounded by an enclosure made of ABS plastics.

3.2 User Experience

The limited number of user input mechanisms on the FreePulse monitor simplifies the user learning curve. The lack of mechanical devices greatly increases the monitor's durability and reduces mechanical complexity. The simplicity of a single touch screen allows the monitor to have an intuitive

UI that is also easily extensible. Text can be translated into the native language of the user, colors can be changed to suit the user's preference, alert systems can be tailored to the user's tastes, and all of these capabilities come from a simple buttonless interface.

Furthermore, the modular design in the production model of the FreePulse monitor adds tremendous value to it as a product and as a platform. Currently, the monitor supports SpO_2 and ECG readings. However, the same circuit can be expanded to monitoring muscle activation, analyzing patient temperature fluctuations, and body imaging capabilities. This extensible design allows for damaged modules to be swapped out easily and effectively. It also allows seamless hardware upgrades, preventing the user from having to replace the entire system. This key feature of the FreePulse monitor reduces waste and emphasizes sustainability.

3.3 Hardware

The Teensy microcontroller is the heart of the FreePulse circuit. Its low cost coupled with its 74 MHz processing speed gives FreePulse the sampling rate of a state-of-the-art monitor without the price point. This processing power is used to manage the sampling rates for both the ECG and SpO_2 probes as well as run the display and power all of the connected peripheral circuits. Furthermore, low-cost miniaturized voltage regulators are used to run the entire circuit from a single voltage source despite differing components and even differing grounds. The ECG circuit uses an active low-pass filter to amplify physiological signals up to 5000 times, while both passive and active filters were used to reject noise and extract a clear waveform to display on the screen. Overall, these disparate hardware components communicate smoothly through the GPIO pins of the Teensy microcontroller, producing a quality signal that rivals the functionality of current market competitors, but at a fraction of the cost.

3.4 Software

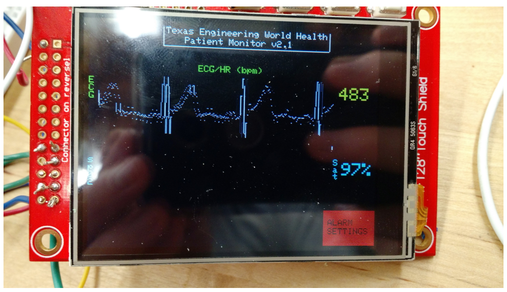
Mirroring the modularity of the hardware design, the software for FreePulse was written with extensibility and speed in mind. The interface's components are written as block items, meaning that they can be stretched and rearranged depending on the screen needs for that iteration of the product. Template classes for signal traces and efficient input buffer systems already exist for the ECG and SpO_2 and can be easily extended to be used with any medical input probe. In order to keep the memory footprint of the program as small as possible and optimize operations for this product's use case, custom classes were written for standard library constructs such as vectors. By keeping low-level control over the transfer and storage of data, we were able to maximize the memory and processing resources of the Teensy and create a fluid, responsive, and versatile system.

4 Prototype

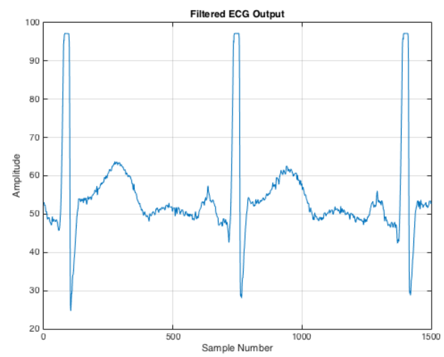
We have demonstrated proof of concept for FreePulse through stage-by-stage testing of our prototype.

4.1 ECG Testing

The most complex hardware component of our design is the filtering and amplification circuit for an ECG signal. Critical to the success of signal acquisition is a sampling rate that allows for clear visualization of the input signal; we have set the sampling rate at a controlled 121 Hz to achieve optimal signal clarity while retaining a smooth and responsive user interface.



(a) FreePulse capturing and filtering an ECG.



(b) Data read directly from FreePulse's input buffer for the ECG signal. All features of the P-QRS-T complex are clearly distinguishable.

4.2 Peripheral Capillary Oxygen Saturation

Our current prototype utilizes both visible and IR LEDs paired with phototransistors to measure the amount of light transmitted through a user's tissue. The LEDs and diodes are housed in a plastic case similar in form factor to traditional finger clip pulse oximeters, and the output of the phototransistors is filtered by a passive low-pass filter. We are currently still developing our calibration algorithm for calculating oxygen saturation from this curve, as it is a very hardware-dependent process; however, initial signal processing is already showing a clear view of the transmittance waveform.

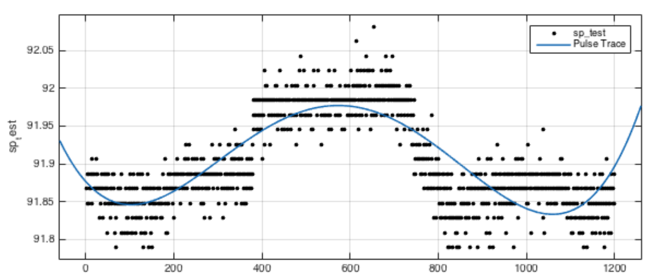


Figure 3: Signal processing allows us to extract the pulse curvature in the transmittance signal.

4.3 Battery Capacity

In order to be useful in an inconsistent power environment, FreePulse must be able to run on battery power for a reasonably long time frame. The lithium ion battery in FreePulse has a capacity of 1200 mAh; we also have measured it to have an average power draw of 185 mA with all LEDs illuminated and probes running, meaning the system can run for approximately 6 hours on a single charge. This capacity means that FreePulse is more than capable of continuing to monitor patients during a power outage and can last long enough for the backup power to be initiated or the power grid restored.

4.4 Form Factor

Finally, we have tested the feasibility of our product design by producing PCBs and casing for the monitor. Using circuit layout software, we designed a PCB that was small enough to fit neatly behind the touch screen while remaining two layers, reducing manufacturing cost. This circuitry is completely self-contained, running solely on the rechargeable battery due to the use of voltage regulators; this allows FreePulse to be handheld in size.

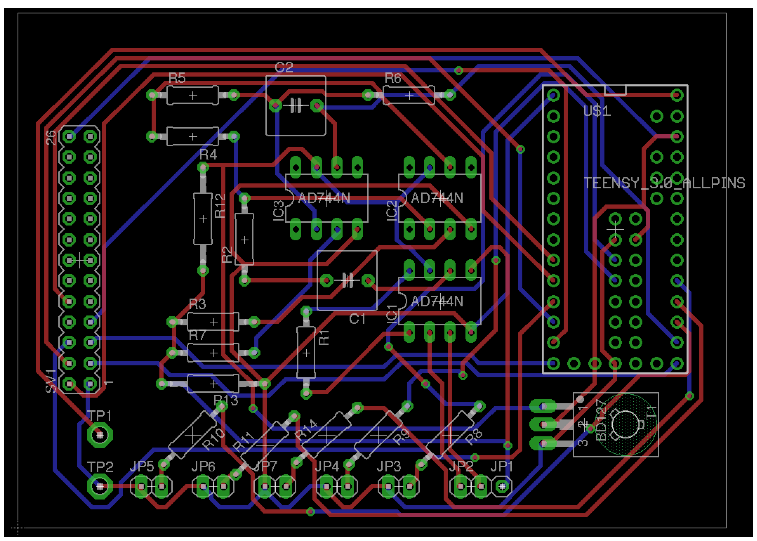


Figure 4: All of the hardware required for the FreePulse patient monitor is organized into a small two-layer PCB.

The data from our prototype serves as a proof of concept that FreePulse can indeed fulfill its core purpose: to provide quality patient monitoring at a cost that is affordable to developing world hospitals. Its high-resolution signal acquisition, six hour battery life, and compact shape suit it perfectly for working in developing world hospitals.

To hear more about the FreePulse patient monitor and its importance for developing world healthcare, watch the following video at:
https://www.youtube.com/watch?v=NApNLTBnjBY

References

[1] Philips Patient Monitors *IntelliVue MP50 Bedside Patient Monitor*, 2015. Retrieved from http://www.usa.philips.com/healthcare-product/HC862116/intellivue-mp40-mp50-patient-monitor

[2] GE Healthcare *CARESCAPE Monitor B650* 2015. Retrieved from http://www3.gehealthcare.com/en/products/categories/patient_monitoring/patient_monitors/carescape_monitor_b650

[3] Rwandan Development Board, *Investing in Rwanda: An Overview*, African Development Bank Group, 2014.

[4] National Institute of Statistics, Rwandan Ministry of Health, and Macro International, *Rwanda Service Provision Assessment Survey 2007*, The Demographic and Health Surveys Program, 2007.

[5] Sekabaraga et al., *Can innovative health financing policies increase access to MDG-related services? Evidence from Rwanda*, Health Policy and Planning, vol. 26, pp.52-62, 2011.