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Med-vest: A wearable sensory platform

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Abstract

Sickle cell disease is a genetic mutation that causes sickling of the red blood cells, affecting between 90,000 and 100,000 Americans. Researchers must develop methods of data acquisition capable of maximizing both the amount of data being collected and types of data being collected to form the most accurate diagnosis and treatment for patients. Popular data acquisition forms are the use of mobile phones, sensory systems, and wearable technology. In this paper, we attempt to bridge the gap between the three, combining a wearable sensory system with the computation and communication power of mobile phones. We propose the application of sickle cell disease as a structure around which to design a textile-based data acquisition system.

INTRODUCTION

Sickle cell disease (SCD) is a haemoglobin disorder that causes sickling of the red blood cells, affecting between 90,000 and 100,000 Americans [1]. Worldwide, an estimated 300,000 people are born with haemoglobin disorders such as SCD per year with disease carriers spanning almost 5% of the population [2]. Bae *et al.* have investigated the implementation of sensors in textiles using the “exposome” concept of an environment’s impact on patients, but have only focused on the application needs of asthma patients [3]. The acute pain episodes and chronic conditions associated with SCD create a need for patients to be frequently monitored, often in the form of hospital visits. Additionally, the lower oxygen levels and increased blood pressure present in SCD causes homeostasis complications, so events such as fever can result in hospitalization for patients. It is recommended that patients maintain regular physical activity, but when unmonitored, extraneous activity can lead to heat-illnesses such as heat stroke and muscle breakdown in SCD patients [4]. Also, because activity is an essential measurement for SCD, an accelerometer is a necessary sensor for this application [5]. Mobile applications have been developed for monitoring SCD patients to track information such as position and activity levels [6]. However, a mobile-only solution is limited to capturing data in increments by the battery life of the mobile phone and cannot detect important data such as bodily or environmental temperature. We addressed this need by designing the Med-Vest: a prototype

low cost and easy-to-assemble sensing module to continuously monitor movement and environment in conjunction with a mobile phone application.

Groups at the National Center for Scientific Research identified the change from wired to unwired systems as a detriment to operation complexity and user upkeep, and ultimately the user's overall confidence in the technology [7]. Lombardi *et al.* have used mobile phones for transmitting data from SCD patients to healthcare professionals, focusing primarily on children, but do not possess the added sensory capabilities of a textile system [8]. When the wearer logs when he/she is feeling pain, a textile's sensors can detect and log the wearer's vital signs at that moment for later review. Seto *et al.* designed a system for monitoring asthma patients using sensory systems and a mobile phone, even using the Bluetooth protocol [9]. However, we found that our application allowed us to use many of the sensors already integrated into mobile phones, reducing the development cost and complexity of the custom circuits designed. For monitoring other illnesses like asthma, the Med-Vest system can be outfit with appropriate sensors such as heart rate monitors and air quality detectors.

The Med-Vest system takes advantage of the increasingly popular 3D printed PLA construction method as well as open source circuitry. We avoid the issue of complexity associated with custom FPGA systems by using well documented and commercially available Arduino platform microcontrollers alongside the user-friendly Bluetooth protocol. Designing with open source platforms such as these allows us to target sickle cell patients as well as adapt the sensors to the needs of comparable illnesses. In using heavily documented components and both wired and wireless circuitry, our system minimizes the maintenance and learning curve for operation needed of the wearer.

DESIGN

A. Textile

As a cornerstone for our system, we chose textiles as a base for sensors alongside custom circuitry with a wearable enclosure and mobile connectivity in the Med-Vest as shown in Fig. 1. An elastic sports shirt was chosen as the textile base for its ability to remain close to the wearer's skin throughout movement. These shirts can be purchased from any sports retailer at a low cost. The shirt's material has the added benefit of wicking sweat from the wearer's skin, increasing the level of comfort during prolonged use. The elasticity of the fabric ensures that the sensors contact at the desired locations across multiple wearers.

B. Sensors

Two temperature sensors were integrated into the textile base; one for monitoring bodily temperature via the armpit and one for monitoring external environment temperature, shown in Fig. 2. The Texas Instruments LM35 temperature sensor was chosen for its tight tolerances and overall simplicity. The two LM35 sensors were packaged as standard through-hole components and were sewn into the textile base using threading. The two temperature sensors were connected to the main circuit board using 28AWG solid core hookup wire for testing purposes. The Lilypad accelerometer board, included for 3-axis movement detection, was integrated into the main circuit board instead of the textile base.

C. Circuit

To maintain the benefits of open source hardware, the Med-Vest circuit, shown in Fig. 3, was designed around using the popular Arduino development platform and having the capability of easily adding various sensors. An Arduino Mini Pro was chosen as the central processing board for its small form factor and expansive I/O. For a power source, compatibility with the Sparkfun Lithium Ion battery adapter was added to the circuit. This allows the use of various sizes of Lithium Ion rechargeable batteries. As previously mentioned, the Lilypad accelerometer board was integrated into the circuit, so the necessary I/O connections were run directly to the sensor board instead of to external pin outs.

To maintain electrical isolation between the patient and the circuit, optocouplers were placed between the processor board and the mini USB connection. To make logged data easily accessible, a micro SD memory card surface mounted connector was added. Because the micro SD memory card operates on a different logic level voltage than the processor board, a hex converter chip was added between the micro SD connector and the processor board. For wireless connectivity to other mobile devices, a Sparkfun Bluetooth Mate Gold was chosen for its matched pin layout with the Arduino Mini Pro. For conversion of RS-232 to serial, the FTDI FT232RL chip was chosen for its added benefit of having integrated AVCC filtering between 5 volts and 3.3 volts for the various circuit components alongside the very easy to use FTDI Virtual Com Port drivers that aid in initiating USB connectivity between the circuit and a computer. For connectivity via USB between the circuit and a computer, a mini USB connector was added to the corresponding USB input pins of the FT232RL.

D. Pcb

As the circuit will be worn on the patient, the size of the circuit board has a major effect on the comfort level of the wearer. Before modeling the single board version, the circuit was reproduced using prototype perforated solder pad boards to ensure that the circuit functioned. Using Proteus ARES PCB CAD software, a 2-layer board was modeled for production. Extra care was taken in ensuring that the boards and components could be soldered together by hand for ease of distribution. A 2-layer board, shown in Fig. 4, was chosen vs. a 4 or more layer board because of the low cost in producing two layer boards. Extra care was taken in the placement of certain components on the board. The FT232RL (UI) chip was kept away from the PCB's via so as to reduce the effects of present EMF. The micro SD (101) and mini USB (102) connectors were placed facing either end of the PCB to streamline user access. The GPIO solder pads (J1, J2, and J3) were kept to one end of the board to make sure all sensor wires could be easily routed through the wiring outlet in the enclosure. The power line connection (J4) was extended to individual solder pads so a panel-mounted toggle switch on the enclosure could be used as a power switch.

E. Enclosure

The enclosure was designed around user comfort and ease of construction. As 3D printing is becoming a more common construction method among the Do-It-Yourself (DIY) community, PLA plastic was chosen as the material. The enclosure, shown in Fig. 5, was split into two components; a body and a top lid. Both components are small enough to be produced using any commercially available 3D printer. Using an elastic band sewn at either

end to the lower back of the textile base, the enclosure is held close to a human being's center of gravity to reduce movement noise in the accelerometer. To reduce the amount of hardware necessary for construction, the enclosure was designed such that the PCB is held tight inside the enclosure against the elastic band, eliminating the need for excess mounting bolts. The underside of the body was given a lumbar contour for added wearer comfort. In order to withstand daily wear, the top lid was given a dome structure instead of a flat top to increase structural integrity. However, the dome structure was slotted at the corners to allow for the clearance necessary for socket-head bolts. Depending on the layer size capabilities of the 3D printer used, different thread sizes can be drilled and tapped at the slotted corners. It is recommended that 20 nylon socket-head bolts are used with most 3D printers to keep the PLA threads from stripping. Slots were placed on the bottom side only to keep rainfall and sweat from entering the enclosure from the top. The slots hold both the power switch and serve as an exit port for wires connecting sensors.

F. Wireless Networking

Bluetooth was implemented in our system because of its smaller range, high power efficiency, and added security. A low-cost and simple pre-assembled Bluetooth transceiver board was sourced that fit well within our PCB layout's max dimensions and matched the pin out of the Arduino Mini Pro, which we added to our PCB layout's design. We were content with conventional GSM and/or LTE communications as a means of transmitting data from the patient after it has been retrieved from the Med-Vest circuit, as nearly all current smartphones are capable of at least 3G connectivity.

G. Mobile Application

Using the Android Development Kit (ADK), we developed an android mobile application, see Fig. 6, for testing the Bluetooth data stream between a mobile device and the Med-Vest circuitry. The application selects the Med-Vest transceiver from the list of connected devices and begins accepting the data stream via serial. As the sensor values are received over the connection, the application plots the data on a set of axes in real time for the user.

RESULTS AND DISCUSSION

Following construction of the prototype circuit, a simple program was written and programmed onto the processor board which recorded data from the temperature and accelerometer sensors and then logged the resulting data onto a connected micro SD card and broadcast over the established Bluetooth network. Data was successfully stored in a local CSV file, which could be opened and read in any spreadsheet software. The T092 package of the LM35 temperature sensor was used for simplicity, but the SOIC-8 packaged version would ultimately be better for textile application due to its flat layout. In building around the philosophy of simple construction, a custom circuit was designed for our application that can be manufactured for roughly \$112, as shown in Table 1.

CONCLUSION AND FUTURE WORK

We designed a textile based sensory system for SCD patients to capture continuous data and potentially detect harmful conditions. We used popular construction methods as well as open source hardware to minimize maintenance and learning curve required of the wearer. We designed a custom circuit and PCB to utilize this open source hardware which can be produced and populated for roughly \$112. In the future, we plan to investigate the use of flexible PCBs in place of a 3D printed enclosure and rigid PCB. The Bluetooth capabilities of the system allow for the use of more complex computations performed on the connected mobile device and cloud computing through the mobile network. Future addition of more advanced peripherals may prove the Med-Vest to be a competitive open source hardware product [10]. Ultimately, the Med-Vest can be combined with the previously developed sickleREMOTE mobile application for testing on SCD patients [11].

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REFERENCES

- [1]. Data & Statistics. [Retrieved April 20, 2014] Centers for Disease Control and Prevention. Sep 16, 2011. from <http://www.cdc.gov/ncbddd/sicklecell/data.html>
- [2]. Organization WH. Fact Sheet. 2011. Sickle-cell disease and other haemoglobin disorders.
- [3]. Bae W, Alkobaisi S, Narayanappa S, Liu C. A Real- time Health Monitoring System for Evaluating Environmental Exposures. Journal Of Software. 2013; 8(4):791–801. DOI: 10.4304/jsw.8.4.791-801
- [4]. Living With Sickle Cell Anemia. [Retrieved May 20, 2014] NHLBI, NIH. (n.d.)from <http://www.nhlbi.nih.gov/health/health-topics/topics/sca/livingwith.html>
- [5]. Venugopalan J, Brown C, Cheng ChihwenStokes TH, Wang MD. Activity and school attendance monitoring system for adolescents with Sickle cell disease. Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE; Aug. 28 2012-Sept. 1 2012; 2456–2459.
- [6]. Venugopalan J, Brown C, Cheng ChihwenStokes TH, Wang MD. Activity and school attendance monitoring system for adolescents with Sickle cell disease. Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE; Aug. 28 2012-Sept. 1 2012; 2456–2459.
- [7]. Lombardi A, Ferri M, Rescio G, Grassi M, Malcovati P. Wearable wireless accelerometer with embedded fall-detection logic for multi-sensor ambient assisted living applications. Sensors, 2009 IEEE. Oct.2009 :1967–1970. DOI: 10.1109/ICSENS.2009.5398327
- [8]. Yang SungwonJacob E, Gerla M. Web-based mobile e-Diary for youth with Sickle Cell Disease. Consumer Communications and Networking Conference (CCNC), 2012 IEEE; Jan.. 2012 385–389.
- [9]. Seto EYW, Giani A, Shia V, Wang C, Yan PosuYang AY, Jerrett M, Bajcsy R. A wireless body sensor network for the prevention and management of asthma. Industrial Embedded Systems, 2009. SIES '09. IEEE International Symposium on; Jul 8-10, 2009 120–123.
- [10]. Harnett C. Open source hardware for instrumentation and measurement. Instrumentation & Measurement Magazine, IEEE. Jun; 2011 14(no.3):34–38. DOI: 10.1109/MIM.2011.5773535
- [11]. Cheng ChihwenBrown C, New T, Stokes TH, Dampier C, Wang MD. SickleREMOTE: A two-way text messaging system for pediatric sickle cell disease patients. Biomedical and Health Informatics (BHI), 2012 IEEE-EMBS International Conference on; Jan.. 2012 408–411.

Table I

Circuit Board Per Unit Bill of Materials

Component	Approximate Cost Per Unit
Arduino Mini Pro	\$9.95
Lilypad Accelerometer	\$24.95
LiPower Board	\$14.95
Bluetooth Mate	\$39.85
HEX Converter	\$0.84
Serial-RS232 Converter	\$4.50
MicroSD Connector	\$2.58
MiniUSB Connector	\$0.58
4.7k Resistor	\$0.08
10k Resistor	\$0.08
PCB	\$10.00
Toggle Switch	\$3.84
Total	\$112.30

Costs factored for low-volume production