Leveraging IoT Biometrics and Zephyr™ RTOS for Neonatal Nursing in Uganda

Teresa Cauvel – Co-founder, Neopenda

11 October, 2016 - ELCE OpenIoT Summit
Agenda

- Problem statement
- Introduction to Neopenda
- Prototypes
- Selection criteria
- Software development
- Test results
- Android application
- Timeline
- Issues
- Conclusion
A Global Challenge: Ending Preventable Newborn Deaths

Every year in the developing world:

- 46 million newborns need special care from complications at birth
- 3 million newborns die
- 80% are from causes that are considered preventable and treatable by the WHO

Special Care Baby Unit at Mulago National Referral Hospital, Kampala, Uganda
Why Are Newborns Dying?

3 primary causes: all addressable with proper resources

- 34% preterm birth
- 24% infections
- 22% other

A major challenge area is providing quality care in resource-constrained hospital settings.

Key problem we are seeking to address: Hospitals in low resource settings severely lack staff and equipment, and are overburdened with patients.
Newborn Mortality Is a Solvable Problem

- U.N. Sustainable Development Goal, target 3.1: By 2030, end preventable deaths of newborns and children under 5 years of age
- IoT for good: new cost and power friendly technologies offer benefits as easy to implement, scalable point-of-care solutions
- Where can technology make a difference?

Unmet need = opportunity for innovative tech solutions to have high impact
What Is Neopenda?

- **Our mission:** To engineer innovative healthcare solutions that give newborns in low-resource settings the healthy start they deserve

- **About me:** Teresa Cauvel, MS in Biomedical Engineering from Columbia University. Co-founder and CTO.

- **History:**
  - Started project in a graduate course at Columbia University in early 2015
  - Formed the company August 2015 and went on first trip to Uganda
  - Participated in accelerator program Relevant Health 2015-2016
  - Now based in Chicago, IL

- **Our partners include:**
Our Product Vision

- A wearable vital signs monitor that measures heart rate, respiratory rate, blood oxygen saturation, and temperature
- Wireless communication to tablet, where health workers can view the status of every newborn in the room and be alerted in real-time of newborns in distress

**Key constraints:**
- Wireless
- Low-power
- Affordability
- Ruggedness
- Scalability
Early Prototyping

- Built with Arduino HW: first with Arduino Uno, then cut down to ATMega328 8-bit microcontroller
- Default Arduino SW
- Pulse oximetry + temperature sensors
- Used Wi-Fi because familiarity, versatility
- Sending data to a Windows PC

- Transition needs: BLE, size, non-PC clients
Getting Closer to a Deployable Product

- Arduino 101 with Intel® Curie™: low power solution designed for wearable devices
- Zephyr™ Kernel: small, scalable open source RTOS
- Sensors: Pulse Sensor, LilyPad temperature sensor, dual-LED optical sensor for pulse oximetry
  - Off-the-shelf to reduce risk; leverage expertise from Arduino community during prototype phase
Why Curie™ and Zephyr™?

- **Intel® Curie™ Module**
  - Low cost, low power module with 12-bit A/D converters for accurate DSP measurement
  - Built-in Bluetooth LE radio
  - Built-in accelerometers and gyroscope sensors and pattern matching engine for further development
  - Size

- **Zephyr™ Kernel**
  - Supports ARC core (DSP subsystem) and x86 host chip concurrently
  - Support multi fibers & interrupts for complex sensors manipulation and communication
  - x86 chip has more RAM than others to support complex BLE applications
  - Rich support for drivers (ADC, GPIO, I2C, SPI, UART, BLE) and sensors, as well as sample codes
  - Reliable SDK with cross tool chain
Software Development with Zephyr™

- Zephyr™ SDK provides tool chains to compile for the DSP subsystem (ARC processor) and the host processor (X86)
  - Quick installation of compilers and tools chains.
  - GDB debugger working with both the DSP subsystem and the host processor. Eclipse IDE running with gdb for debugging.

- Many of sample codes for using BLE
  - Used peripheral_hr sample code as the starting point to get the heartrate measurement working with BLE.
Measuring the Four Vital Signs

- Pulse rate and respiratory rate: Both calculated from A/D measurement using Pulse Sensor
  - ARC core sensor subsystem measures analog input using ADC driver
- Temperature: Measurement with LilyPad's MCP9700 sensor
  - Adjustments to ARC system to support separate tasks
- Pulse oximeter: Red and Infra-Red LEDs, TSL235 Light-to-Frequency converter
  - Multiplexed between the two LEDs to calculate absorption ratio
  - Used GPIO driver and its callback API to calculate the frequency
- Data flow:

  ![Diagram showing data flow between Pulse Sensor, Temp Sensor, Pulse Ox, ARC, iPM driver, and x86 with Bluetooth communication to nRF51 Tools App for Heart Rate Service, Health Temperature Service, and New Gatt service for pulse ox.]

Neopenda
Test Results

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Preliminary Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Rate</td>
<td>Identical readings to commercial pulse oximeter</td>
</tr>
<tr>
<td>Respiratory Rate</td>
<td>Derived from heart rate measurement, has a consistent 20-30% offset</td>
</tr>
<tr>
<td>Temperature</td>
<td>Variance of plus or minus 2 degrees C compared to commercial thermometer</td>
</tr>
<tr>
<td>Blood Oxygen Sat</td>
<td>Resolution same as commercial pulse oximeter, but tracks less accurately below 95%</td>
</tr>
</tbody>
</table>
Android Application

- Zephyr Health Monitor
- HEALTH THERMOMETER MONITOR: 32.45°C
- HEART RATE MONITOR: 25 Respiratory Rate

Neopenda
<table>
<thead>
<tr>
<th>Task</th>
<th>Approximate Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp up on Zephyr™</td>
<td>1 week</td>
</tr>
<tr>
<td>Pulse rate measurement on Zephyr™</td>
<td>1 week</td>
</tr>
<tr>
<td>Respiratory rate measurement on Zephyr™</td>
<td>½ week</td>
</tr>
<tr>
<td>Temperature measurement on Zephyr™</td>
<td>1 week</td>
</tr>
<tr>
<td>Pulse oximeter hardware and measurement on Zephyr™</td>
<td>1 ½ weeks</td>
</tr>
<tr>
<td>Communicate and display measurements on Android application</td>
<td>2 ½ weeks</td>
</tr>
</tbody>
</table>
Issues

- Overestimation of arterial oxygen saturation in subjects with dark skin
- Cerebral pulse-ox sensors may induce more variation under hypoxic conditions
- Complex sensor and data manipulation
- BLE stability and connection control
- Power consumption: extending battery life
Conclusion

- We’re looking forward to deployment of the completed solution
- We have partnered with the Uganda Paediatrics Association and St. Francis Nsambya Hospital for planning and executing pilot studies in 2017
- We plan to demonstrate feasibility and impact in Uganda, then expand to other low-resource countries in East Africa and around the world
- Please come talk to me if you have personal contacts with newborn health initiatives or neonatal units in developing countries
- Please come talk to me if you’re working on health care solutions that use clever elements
Thank You