Wireless Heart Rate Monitor

Group #7
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Project Description

- Consists of two units
  - TSU: Transmitting Sensor Unit
  - RDU: Receiving Display Unit
- TSU worn by patient, RDU monitored by caregiver
- Finger sensor obtains data, the TSU calculates the heart rate and transmits the information to the RDU where it is displayed
Goals

- Ultimately to monitor infants at risk of SIDS
- Less obtrusive and more easily worn for long periods of time compared to hospital units
- More affordable than existing wireless units
- Remote monitoring
- Ideal for a wide variety of users
- Maximum protection at minimal cost
Objectives

Transmitting Sensor Unit (TSU)
- Able to be worn on the wrist with an attached finger sensor
- Battery powered
- Control the Pulse Sensor
- Make calculations to achieve accurate Pulse data
- Monitor unit’s battery life
- Transmit data to the RDU

Receiving Display Unit (RDU)
- Receive data from the TSU
- Display Patient’s Pulse
- Wall powered
- Display TSU Battery life
- Audible alerts for critical conditions, loss of signal and low battery
Wireless Option

- Transmission Methods
  - Bluetooth
  - Zigbee
  - Custom Radio Frequency and Protocol
- Custom RF protocol chosen
  - Alternatives have high overhead and a large amount of unnecessary features
  - Requires less power
  - Lower cost parts
Microcontroller

- Ideally, would use CC430 from Texas Instruments.
  - Composed of MSP430 with internal CC1101
  - 9mm x 9mm QFN
  - 32 GPIOs, 12-bit ADC, 2-channel USART
  - Production delayed
- Using MSP430F1610 and CC1101 instead
  - 12mm x 12mm LQFP, 48 GPIOs and two 12-bit DACs
  - 5mm x 5mm QFN, Sub 1GHz transceiver operating at 915 MHz in the ISM band (FCC 15.247)
  - Communicate using SPI
CC1101 Switch to CC2500

• Problem
  ◦ 915MHz band too noisy
  ◦ All data sent was received on the other side but the CRC never checked out

• Solution
  ◦ Use CC2500 on 2.4GHz band
TSU
Optical Pulse Sensing

- Non-invasive optical measurement of heart rate
- Infrared light is attenuated less by body tissues and more by blood (940nm)
- Light shines through finger and strikes a photodiode, which creates a very small current based on the amount of light incident on the photodiode
- Determine attenuation of light based on output of photodiode
TSU Specifications

- Sensor
  - Photodiode must detect light at 940 nm
  - Convert photodiode current to voltage values between 0V and 2.5V
  - Accuracy of ±2 BPM
- Transmit a minimum of 10 ft
- MCU
  - Two 12-bit DACs
  - Three 12-bit ADCs
  - 12 GPIOs
Block Diagram TSU

ADC

DAC

MCU

ADC

DC/DC Buck converter EP5368QI

DiffAmp LT6242

Trans Amp LT6242

ADC in

V_{AC}

V_{DC}

ADC in

IR

Current

Photodiode OED-SP-23

IR LED APT1608F3C

DAC in

V_{AC} + DC

ADC in

V_{ir}

LED Control Circuit
Sensor

- To calculate pulse the photodiode current is converted to a voltage
- This voltage has both a DC and AC component that represents attenuation of light
- DC – constant volume of blood
- AC – ebbing and flowing of blood
- AC used for measurements
- DC used for AGC
Sensor Control

- DAC controls current to LED
- LED intensity must be high enough to pass through the finger
- To save on power, when no finger is detected intensity is reduced using DAC
Automatic Gain Control

- MCU determines DAC output based on DC component input
- Output from the DAC on the MCU controls current to LED
- AGC constantly monitors output from photodiode and adjusts the LED level to maintain a steady voltage
Heart Rate Calculation

- Read in whole heart beat wave
- Digitally filter using symmetric FIR filter and a noise shaped DC estimator
- Follow the falling edge until the value goes below a threshold
- Follow the rising edge until the value goes above a threshold
- Count one beat
- When three beats have been recording wake up the MCU for the heart beat calculation

\[
\text{Heartbeat} = \frac{60 \times \# \text{ of samples per second} \times \# \text{ of heartbeats counted}}{\# \text{ of samples counted}}
\]
RDU Specifications

- **MCU**
  - 18 GPIOs
  - 2 SPI interfaces
- Receive from source approximately 10 feet away
- **Display**
  - Minimum 0.4in
  - Minimum 3 digits
  - Can be seen from 10ft away
- **Speaker producing sound at a minimum of a 60dB sound pressure level**
Display

- Bright and has large numbers to be seen from across a room
- 3-digit, 7-segment display measures 1.5in x 0.75in with 0.56in tall digits
- LED driver, Maxim part number MAX6957, used to drive the display, Lumex part number LDT-A512RI
Alarms

- Maximize safety by utilizing audible alarm
- Speaker
  - Audible alerts for:
    - Danger conditions
    - Loss of signal
    - Low power
  - Surface mount speaker
    PUI Audio part number SMT-0540-T-6-R
Speaker to Buzzer

Problem
- MCU unable to supply enough current to drive the speaker

Solution
- Use a low cost buzzer in its place
  - Buzzer requires:
    - 1.5 to 3VDC
    - Max current 15mA
PCB Fabrication

- Altium Designer to create schematics and PCB layouts
- 3 TSU boards and 2 RDU boards for testing and prototyping
- Sunstone Circuits ValueProto™ PCB service
  - Specifically for low quantities of small area, two layer boards
  - 10-day turn around can be expedited
- PCB Fab Express – Bare Bone PCB
  - Low cost, Fast turn pcb service
- Total cost approximately $220
- Populated boards ourselves
Mechanical Design

- Case sizes are based on PCB and battery dimensions
- RDU
  - PCB measures 2in x 2.5in
  - Case measures 6in x 4in x 2in
- TSU
  - PCB measures 0.85in x 2.5in
  - Battery measures 0.70in diameter x 2.65in long
  - Case measures 4in x 2in x 1in
  - Wrist strap on the bottom
RDU case
TSU case
Mechanical Design

- Sensor mechanical design more difficult
- Pre-made cases are not available as they are for the TSU and RDU
- Several different options
  - Ready-made sensor
  - Fabric cuff with Velcro or elastic
  - Silicon or alginate mold
- Depends on final budget
Software
Software

- Efficient and fit inside the parameters of the MCU 5KB RAM and 32KB Flash
- The primary language is C with the ability to use assembly if needed
- TI Code Composer Studio v4 IDE
- Olimex MSP430F1611 Development Board
TSU Software

- TSU responsible for calculating
  - Heart rate
  - Battery Life
- Communicates data to the CC2500 for RF transmission
- Time multiplexed sampling

Diagram:
- Switch turned on
  - Setup SPI with CC2500
    - Setup Send and Battery Life Timer
      - Setup ADC
      - Setup DAC
    - Calculation Loop
  - Setup CC2500 comm settings
    - Setup LED Select Timer
Transmission

Packet:

- MSP430 communicates with CC2500 using SPI
- CC2500 notifies MSP430 using interrupts whether a packet has been received or sent successfully
- CC2500 library to handle communication between MSP430 and the CC2500

```
  Header | Heart Rate 2 Byte | Battery Life 1 Byte | CRC

Receive Packet from CC2500

Receiver Interrupt

Send Timer Interrupt

Send Packet

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<th>Pin</th>
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<td>CS_CC</td>
<td>7</td>
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<td>Int_CC</td>
<td>6</td>
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<td></td>
<td>3</td>
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<tr>
<td>CS_CC</td>
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<tr>
<td>SCLK_CC</td>
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</table>
```
SimpliciTI

- Texas Instruments Custom RF Protocol
- Similar to the TCP/IP stack
- Access Point and End Device Model
- Internalizes all of the SPI calls and wireless transmission functionality
- RDU constantly polling for TSU after set up
- TSU waits to sync to RDU before monitoring

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<tr>
<td>29</td>
<td>SDI CC</td>
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<td>30</td>
<td>SDO CC</td>
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<td>SCLK CC</td>
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<td></td>
<td>3</td>
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</table>
Software driven Sensor

- Timer Interrupt driven sampling
  - 500 samples per second
- LED has its current controlled by the DAC

```
0.1uF C19

10uF C20

47pF C50
```
Software driven Sensor

- LED Select Timer Interrupt
- Digitally process AC signal
- Increment Heart Beat counter sample
- Wake up for heart rate calculation every 3 whole heart beat waves
- Read AC+DC voltage
- Supply DC Offset to OpAmp
- Read in AC only Signal
- Wake up for heart rate calculation every 3 whole heart beat waves
Software RDU

- RDU responsible for receiving calculated data from the CC2500 upon RF reception
- Analyze the data
  - Sound alarms
  - Changing status indicators
- Display Heart Rate

Diagram:
- Switch turned on
  - Setup SPI with CC2500
    - Setup CC2500 comm settings
  - Setup MAX6957 Ports and Intensity
    - Setup SPI with MAX6957
  - Setup ADC
    - Setup Timer for Battery Life, Alarm check and Display
      - Polling for End Device
Software driven Display

- SPI communication tells MAX6957 which segments to turn on
- LEDs turned on based on remaining battery life
Software driven Sound

- Buzzer used to create an alarm
- Interrupt used to vary the sound created by the buzzer
- Trial and error was used to determine the correct sounds for the alarm conditions

```
+3.3V
|      |
|---|---|
| R13 | 250k |
| R16 |

1
---
2

SP1

1
---
2

GND
```
Software Battery Monitoring

- For the TSU the battery was drained on a simulated load.
- Based on this drain we created a table to lookup the battery life.
- To determine the battery life cycle several drain tests have been performed to understand the battery life of our system. We have chosen values to represent 25% increments and change the status whenever the life falls below these values.
Power
Power Specifications – TSU

The TSU requires a small amount of current at a low voltage for a long time.
- Drain 50mA or less
- Power regulated to be 3.3V
- Run at least 8 hours

Battery Requirement
- Working voltage greater than 3.3V
- Charge capacity greater than 400mAh
- Smaller than a C Cell Battery (50mm x 26.2mm)
- Rechargeable within 4 hours
Power Specifications – RDU

The RDU requires a larger amount of current at a low voltage for a long time.

- Estimated draw of 150mA
- Power regulated to 3.3V
- Run at least 8 hours
- Primary power from external 120V AC/DC supply

External AC/DC supply

- COTS equipment
- 5V DC supplied and rated for 1A
DC/DC Conversion

Enpirion EP5368QI

- 600mA Synchronous Buck Regulator
- Voltage is set to 3.3V
- Minimal external components needed
- Input is stabilized by the 4.7uF capacitor
- Ripple performance is improved by the 10uF capacitors
- Ideal for space limited RF designs
- 3mm x 3mm QFN
DC/DC Conversion

Enpirion EP5368QI Issues:
- No solder mask on RDU PCB
- Small size and unique footprint
- High cost component

Replaced on RDU
- National Semiconductors LMZ10504-Demo
- Capable of converting from 5.5V down to 3.3V
- Use of development board guarantees working circuit
Batteries - TSU

Lithium Ion Battery Pack w/ Built in safety
- 3.7V with 940mAh
- Safeties include 4.2V Over-voltage Protection, 2.5V Under-voltage Protections and 3A Over-current Protection
- Dimensions: 17mm diameter by 67mm length
- Weighs 27g (0.95oz)
- Estimated Charge Life:
  Actual drain of 75mA
  Charge life = 940mAh / 75mA = 12.53 hours

Charger
- Smart Charger (0.5A) for 3.7V Li-ion/Polymer Rechargeable Battery Packs
- $4.2V_{DC}$ at 0.5A
- Charge time = $(0.94 \text{ Ah} \times 1.5) / (0.5 \text{ A}) = 2.82 \text{ hours}$
Battery Monitoring

The battery connects to a voltage divider, Op Amp, and one of the ADC inputs of the MCU.

Max Voltage at ADC of MCU: 2.5V
Max Voltage of TSU Battery: 4.2V
4.2V * (100k / 186.6k) = 2.25V
(Values chosen to account for resistor tolerances)

This voltage is fed back to the output of the operation amplifier so that the voltage and current coming out of the operational amplifier are acceptable for the ADC input on the MCU.
There are four major systems that have been tested for our project:

- **Sensor Functionality**
  - Data processed is in a legitimate range
  - Voltages read into ADC are correct
  - Data can be obtained from MCU and plotted to show heart waveform
  - Medical Comparison to Home-Use Pulse Monitors resulted in an accuracy of $\pm 2$ BPM

- **Successful Transmission**
  - The TSU & RDU communicating the correct information
  - Issues with 915MHz design prevented it’s implementation
  - Replaced with a 2.4GHz module
Testing

- Accurate Display
  - The RDU displays the correct information on the display
  - 3-digit, 7-segment display lights according to requirement
  - The RDU creates the necessary audible alerts when required

- Power Usage
  - DC/DC Conversions produced accurate and stable voltage at 3.26V
  - TSU runs for at least 8 hours on its battery
  - Current consumption of TSU and RDU higher than estimated
  - Battery has plenty of energy to spare
# Budget

## Parts

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
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<tbody>
<tr>
<td>TSU IC’s</td>
<td>$28.66</td>
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<tr>
<td>Passive</td>
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<td>Transistor</td>
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<td>Other</td>
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<td><strong>Price per TSU</strong></td>
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<td><strong>3 TSUs</strong></td>
<td><strong>$121.85</strong></td>
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<td><strong>Cost/TSU after samples</strong></td>
<td><strong>$17.59</strong></td>
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<tr>
<td><strong>3 TSUs including samples</strong></td>
<td><strong>$52.77</strong></td>
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<td><strong>Price per RDU</strong></td>
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<td><strong>2 RDUs</strong></td>
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<td><strong>Cost/RDU after samples</strong></td>
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<td><strong>$93.56</strong></td>
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## Total Costs

- **Parts** $262.86
- **PCBs** $233.25
- **DEV boards** $45.00
- **Battery** $11.00
- **Battery Charger** $11.00

**Total** $543.11

- **Parts including samples** $146.33
- **PCBs** $233.25
- **DEV boards** $45.00
- **Battery** $11.00
- **Battery Charger** $11.00

**Total including samples** $426.58
Questions?
Demonstration