MTRX2700 Mechatronics 2

Major Project 2012

PULSE OXIMETER

The class is required to work in groups consisting of an integer number of students each containing no more than 2 and no less than 1 persons (preferably 2). The objective of the assignment is to design and implement a microprocessor-controlled Pulse Oximeter which must operate as described in the specifications below. Each group must work independently of the other groups. The design, implementation and documentation presented by a group must be the work of the group members only.

Organisation
The group should partition the project so that each member has clearly defined responsibilities, and a fair share of the work load. As described below, it is necessary in the final written report to identify each group members’ contribution to the project.

Product Specification
The instrument shall conform to the following general specification.

1. The instrument shall have a identifying product name.
2. The instrument shall be capable of measuring the number of beats per minute of the heart of the user.
3. The instrument shall calculate the blood oxygenation level of the user (as a percentage).
4. The Oscilloscope shall be used as a visual display of the waveform(s) being measured by the Oximeter.
5. Any logic required shall be implemented principally by an EVBPlus2 68HC11 Evaluation Board.
6. Additional interfacing circuits should not be necessary. However, if a group wishes to interface to additional hardware, please see a tutor or the lecturer to have the design approved.
7. 68HC11 Software shall be written in C and/or assembly language. 68HC11 code shall be generated by the IAR Systems ICC6811 compiler, or the Motorola assembler. If code is written to run on the Windows PC, it shall be compiled by the Microsoft Visual C++ compiler and be written in C or C++.
The instrument shall conform to the following functional specification:

1. The Pulse Oximeter circuit provided to you will be used as the main functional element of the system. This circuit MAY NOT be modified, and MUST be used as specified in the accompanying documentation.
2. Once the system has successfully initialised, it shall provide a continuous output of the users blood oxygenation level as a percentage.
3. As a minimum, the system shall provide a continuous display of blood oxygenation level on the 7-segment display, and provide an audible tone each time a heart beat is detected. The LCD display, serial transmission, or any other device may also be used to implement the user interface.
4. If serial data transmission is used, it shall conform to the RS-232C standard. The serial data format shall be 1 start bit, 8 data bits, 1 stop bit, no parity. The baud rate shall be 9600 baud.
5. An IBM-compatible PC shall be as the remote terminal (if one is used).
6. The Pulse Oximeter shall power-up and power-down in a well-defined way.
7. An appropriate attachment device for the LED/photodetector shall be manufactured by each group.

The above lists represent the minimum requirements for this assignment. Any group is free to add additional functionality.

Extension
All groups are encouraged to build upon the basic specifications listed above to introduce additional functionality to the device. However, make sure that the basic specifications are completed first (you will be asked to demonstrate them), and that any additional functionality extends, but does not replace the basic functionality of the device.

As with the short labs, if no extensions are attempted, the maximum possible mark is 75. For this assignment groups will be expected to create their own extension problems. Consult with the Lecturer or Tutors if you are not sure what would constitute a valid extension.

Suggestions for extensions:

- Conduct research into signal processing techniques used for detecting the AC part of the Pulse Oximeter signal – is it necessary to detect the high and low points of the waveform? Would integration be sufficient?
- Conduct research into the possibility of detecting irregular heartbeats using this instrument.
- Implement feedback control for the LEDs to maintain a constant voltage at the detector. If the detected voltage is too high, decrease the output. Too low, increase it.
- Warnings and/or display if an irregular heart beat is detected, or if the blood oxygenation exceeds or is below expected levels
- Use the push button connected to PA0 to switch between a blood oxygenation display, and a beats per minute display on the 7-Segment displays.
- External key-pad or buttons for local user interface
- Fancy graphical user interfaces.
- Other – whatever you can think of…
**Commissioning of the Instrument**

The instrument shall be demonstrated to the class in the laboratory during the last lab session of each group. At that time, the instrument's conformity with the specification will be assessed by subjecting it to a number of commissioning tests.

**Report**

Each group shall submit one report which documents the development and final configuration of the instrument. The contributions made by individual group members to the project must be identified and signed by each group member. The report must be submitted electronically, in either Word or PDF format (preferably PDF). The report must be submitted through the WebCT site for MTRX 2700. All reports must be received at the time of instrument commissioning.

The report should include a discussion of the major hardware and software design decisions: reasons should be given as to why various alternative designs were accepted or rejected. A commentary should be given on problems encountered during the instrument development, and on their resolution.

The report should also provide full documentation of the instrument. In this context, it should contain a functional description of the instrument, together with testing and calibration procedures, circuit diagrams if applicable (drawn with Protel), state transition diagrams and/or data flow diagrams, a memory map, and operating instructions. An annotated listing of all 'C' and assembly language programs should be provided as well. Any assembly language code used should be self-documenting, with well-defined entry and exit states, register requirements, details of flags affected and any timing considerations.

If the ‘C’ programming language is used, the code should be documented using ‘doxygen’ style comments, and the doxygen documentation (in HTML format) should be provided as an appendix or as supplementary reference material to the report.

**Assessment**

The **Pulse Oximeter implementation** will be worth **70%** of the major assignment mark. The **report** will be worth **30%** of the major assignment mark. The **implementation** will be assessed on the following basis:

- Is the basic functional specification met? [45%]

- **Extension** [25%]
  - does the Pulse Oximeter implement any extra functionality?

The criteria used in assessment will include (but are not limited to) the following:

- is the program design of high quality
- is the man-machine communication well designed?
- is the software well documented?
- how error proof is the system?
- how easy to use and well-behaved is the instrument?
- does the Pulse Oximeter implement any extra functionality?

The marking scheme is detailed below.
MTRX 2700 Major Assignment Marking Scheme

Meets Specifications (45%)

Oxygen Level 7
Heartbeat Detection 7
Attachment Device 4
Power up/down in well defined way 4
Program Design 6
Software Documentation 6
Reliability / Stability / Error Handling 6
Ease of Use 5

Extension (25%)

Additional Features 25
(see body of this document for details).

Report (30%)

The report template will be made available in Microsoft Word format on the MTRX 2700 WebCT site. The template outlines the requirements and expectations for the report.
Interfacing to the Pulse Oximeter Circuit

There are several ways to interface to the Pulse Oximeter circuit provided to you. Please read these notes with reference to the schematic supplied in this document. The interface methods are listed below, in order of complexity. Note that Method 1 is required to complete the ‘minimum’ part of the experiment. If any other method is used, it will be considered as part of the lab ‘extension’.

Method 1 – the ‘calibration’ approach

This method must be conducted before the system operates in its ‘normal’ mode.

1. Fix the LEDs to one side of a user’s fingertip, and the detector to the other. Connect the pulse oximeter circuit to the EVBPlus board and power up the device.
2. Write special calibration software for the EVBPlus board to drive the pins PC4 high, PC5 low, PC2 low, and PC3 high – this will enable the Red LED. Also make sure pins PA3 and PA4 are high to enable power to the LEDs.
3. Connect the Oscilloscope to the probe point labelled RDdc to measure the DC output of the Red LED. Adjust the variable resistor labelled R28A until the voltage is around 4 Volts with no saturation. The resistor sets the amount of current flowing through the LED, and therefore adjusts its brightness.
4. Repeat for the Infrared LED. (drive pins PC4 low, PC5 high, PC2 low, and PC3 low, connect to the probe point labelled IRdc, adjust the variable resistor labelled R28B)
5. The system is now calibrated and ready to use.

Method 2 – the ‘feedback’ approach

This method is iterative and should occur during ‘normal’ operation.

1. Fix the LEDs to one side of a user’s fingertip, and the detector to the other. Connect the pulse oximeter circuit to the EVBPlus board and power up the device.
2. During normal program operation, generate two separate approximately 1kHz PWM signals on pins PA4 and PA3 connected to the Red and Infrared LED drivers respectively. These PWM signals are filtered by the Pulse Oximeter circuit to vary the supply voltage to the LED driver circuit. By varying the duty-cycle of the PWM signal, we therefore vary the supply voltage to the LED driver, and therefore the brightness of the LEDs will vary.
3. Use a proportional controller to adjust the PWM duty cycle so that a desired DC voltage is achieved at the detector (approx 4.5 Volts would be a reasonable level). At each iteration of your algorithm, first, calculate the error \( e \) between your desired voltage, and the measured voltage at pin PE1 for the Red LED or pin PE3 for the Infrared LED \( (e = \text{desiredVolts} - \text{actualVolts}) \). Then, adjust the PWM duty cycle by an amount equal to \( K*e \), where \( K \) is a constant tuned to give reasonable response. Trial and error is fine here, you will learn more about feedback control systems in 3\(^{rd}\) year.

4. You should use separate controllers for the Red and Infrared LEDs.

5. If you set the desired voltage to be the same for both LEDs, you will simplify the calculations required to calculate the blood oxygen levels. Can you work out how?

**Measuring the Output (Normal Operation)**

There is only a single detector in use in the pulse oximenter circuit, however, we wish to capture the results of both the Red LED and the Infrared LED. How is this possible?

The answer is time multiplexing. In normal operation, the Red LED will be enabled for a short period of time. Then it will be switched off, and the Infrared LED enabled for a period of time. A timing diagram showing ideal timings is attached to this document. At the output of the detector is a simple ‘sample-and-hold’ circuit, so the output of each of the signals can be read at any time by the EVBPlus board.

You will need to analyse the AC part of each signal to detect heartbeats, and to calculate the current blood oxygenation level.

**Oximeter Connections to the EVBPlus2 Board:**

<table>
<thead>
<tr>
<th>Port</th>
<th>Name</th>
<th>POx pin</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port C:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC2</td>
<td>MUX B</td>
<td>15</td>
<td>Blue</td>
</tr>
<tr>
<td>PC3</td>
<td>MUX A</td>
<td>14</td>
<td>Green</td>
</tr>
<tr>
<td>PC4</td>
<td>Red on</td>
<td>5</td>
<td>White</td>
</tr>
<tr>
<td>PC5</td>
<td>IR on</td>
<td>6</td>
<td>Purple</td>
</tr>
<tr>
<td>Port A:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PA3</td>
<td>IR-PWM</td>
<td>7</td>
<td>Orange</td>
</tr>
<tr>
<td>PA4</td>
<td>Red-PWM</td>
<td>4</td>
<td>Yellow</td>
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Port E:

<table>
<thead>
<tr>
<th>Port</th>
<th>Function</th>
<th>Value</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE0</td>
<td>Red-AC</td>
<td>8</td>
<td>White</td>
</tr>
<tr>
<td>PE1</td>
<td>Red-DC</td>
<td>16</td>
<td>Red</td>
</tr>
<tr>
<td>PE2</td>
<td>IR-AC</td>
<td>11</td>
<td>Orange</td>
</tr>
<tr>
<td>PE3</td>
<td>IR-DC</td>
<td>10</td>
<td>Red</td>
</tr>
<tr>
<td>PE4</td>
<td>Ambient</td>
<td>1</td>
<td>Blue</td>
</tr>
<tr>
<td>PE5</td>
<td>Red-Signal (not used)</td>
<td>13</td>
<td>White</td>
</tr>
<tr>
<td>PE6</td>
<td>IR-Signal (not used)</td>
<td>12</td>
<td>Purple</td>
</tr>
</tbody>
</table>

Misc:

<table>
<thead>
<tr>
<th>Port</th>
<th>Function</th>
<th>Value</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gnd</td>
<td>Signal Ground</td>
<td>9</td>
<td>Black</td>
</tr>
</tbody>
</table>

Amplifier Gain

In order to boost the AC signal to a level that is measurable by the 8-bit A/D converter available on the 68HC11, the signal is passed through a series of op-amps. The total gain applied to the AC signal is approximately 8. You will need to take into account this multiplication factor when you calculate the ratio used for determining blood oxygenation levels.