**Project Background:**
Warfarin is an anticoagulant used for blood clotting medical conditions. Dosages of warfarin need to be frequently adjusted to maintain effectiveness. For the first few months of the regimen, adjustments are made based on weekly or bi-weekly blood test results. This requires frequent coordination with the physician, patient and pharmacist.

**Problem Statement:**
Frequent coordination between the physician, patient, and pharmacist is time consuming, inconvenient, and poses a risk to the patient’s health by increasing the chances of error or a missed dose. Since patients taking warfarin require frequent dosage changes, a real-time adaptive system needs to be developed.

**Needs Assessment:**
**ME Requirements:**
- Easily transportable.
- Enclosed and latched with tamper evident indicator.
- Contain one month supply of warfarin.
- Loading of device done easily and quickly.
- Clearly labeled bins.
- Spill-proof.
- Large / easily visible buttons for dose retrieval and information.
- Rapid delivery of dose after dose button push.
- Deliver correct dose without error.
- Enable one pill to be moved from bulk compartment to delivery compartment at a time.
- Quickly demonstrable.
- Reasonably quiet.

**EE Requirements:**
- Backlit color screen with large characters for messages.
- Rapid delivery of dose after dose button push.
- Quickly demonstrable.
- Alert for service when pill supply low.
- Check presence of pill(s) in delivery cup.
- Delivery compartment with removable dose cup needs to be in place prior to dispensing.
- Audio/visual alarm to alert patient that it is time to take medication.
CE Requirements:
  • Remote dose programming through interactive software interface.
  • Programmable messages from programmer to dispenser.
  • Rapid delivery of dose after dose button push.
  • Update dosing information by physician.
  • Quickly demonstrable.
  • Alert for service when pill supply low.
  • Check presence of pill(s) in delivery cup.
  • Audio/visual alarm to alert patient that it is time to take medication.
  • System to alert designated care-provider if medication dose not taken.
  • Track dose, with data available to physician on web.
### Frictional Force the Servo Motor Needs to Overcomes

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of 31 pills</td>
<td>114.7 mm</td>
</tr>
<tr>
<td>Weight of 31 pills</td>
<td>0.066904 N</td>
</tr>
</tbody>
</table>

#### Spring Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Preload Deflection</td>
<td>35.85 mm</td>
</tr>
<tr>
<td>Spring Preload</td>
<td>0.062783 N</td>
</tr>
<tr>
<td>Force from Spring</td>
<td>0.263653 N</td>
</tr>
</tbody>
</table>

#### Steel Plate Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>AISI 1013 Low Carbon Steel</td>
</tr>
<tr>
<td>Density</td>
<td>7.87 g/cm³</td>
</tr>
<tr>
<td>Steel Plate Volume</td>
<td>2.98115 cm³</td>
</tr>
<tr>
<td>Mass of Steel Plate</td>
<td>0.023462 kg</td>
</tr>
<tr>
<td>Weight of Steel Plate</td>
<td>0.230159 N</td>
</tr>
</tbody>
</table>

#### Pill Follower Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>DuPont Zytel 70G33L BK031</td>
</tr>
<tr>
<td>Density</td>
<td>1.39 g/cm³</td>
</tr>
<tr>
<td>Pill Follower Volume</td>
<td>1.93167 cm³</td>
</tr>
<tr>
<td>Mass of Pill Follower</td>
<td>0.002685 kg</td>
</tr>
<tr>
<td>Weight of Pill Follower</td>
<td>0.02634 N</td>
</tr>
</tbody>
</table>

#### Friction Data

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>μ_steel/pill</td>
<td>0.4</td>
</tr>
<tr>
<td>Ff_stick</td>
<td>0.142759 N</td>
</tr>
<tr>
<td>μ_steel/alum</td>
<td>0.61</td>
</tr>
<tr>
<td>Ff_plate</td>
<td>0.358104 N</td>
</tr>
<tr>
<td>Ff_TOTAL</td>
<td>0.500864 N</td>
</tr>
</tbody>
</table>

#### Servo-Motor Requirements

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Servo-Arm</td>
<td>15 mm</td>
</tr>
<tr>
<td>Start Angle</td>
<td>30 degrees</td>
</tr>
<tr>
<td>Ff_Total Equiv.</td>
<td>0.504625 N</td>
</tr>
<tr>
<td>Torque Required, MIN</td>
<td>8.740361 N-mm</td>
</tr>
<tr>
<td></td>
<td>0.00874 N·m</td>
</tr>
<tr>
<td></td>
<td>1.237739 ounce-inches</td>
</tr>
</tbody>
</table>

### Pill Specs

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>3.7 mm</td>
</tr>
<tr>
<td>Diameter</td>
<td>8.8 mm</td>
</tr>
<tr>
<td>Mass</td>
<td>220 mg</td>
</tr>
<tr>
<td>Weight</td>
<td>0.002158 N</td>
</tr>
</tbody>
</table>

### Minimal Spring Constant

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>k_crit</td>
<td>0.583297297 N/m</td>
</tr>
<tr>
<td>k_min (F=5)</td>
<td>2.916486486 N/m</td>
</tr>
<tr>
<td>Quantity</td>
<td>Part Name</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Upper Body</td>
</tr>
<tr>
<td>1</td>
<td>Lower Body</td>
</tr>
<tr>
<td>1</td>
<td>Cup Plate</td>
</tr>
<tr>
<td>1</td>
<td>Servo Holder</td>
</tr>
<tr>
<td>1</td>
<td>Side Plate Left</td>
</tr>
<tr>
<td>1</td>
<td>Side Plate Right</td>
</tr>
<tr>
<td>1</td>
<td>Ramp</td>
</tr>
<tr>
<td>1</td>
<td>Base</td>
</tr>
<tr>
<td>6</td>
<td>Pill Plate</td>
</tr>
<tr>
<td>6</td>
<td>Servo Link</td>
</tr>
<tr>
<td>1</td>
<td>Tube Holder</td>
</tr>
<tr>
<td>1</td>
<td>Guide Plate</td>
</tr>
<tr>
<td>6</td>
<td>Bottom Hub</td>
</tr>
<tr>
<td>6</td>
<td>Top Hub</td>
</tr>
<tr>
<td>6</td>
<td>Pill Follower</td>
</tr>
<tr>
<td>6</td>
<td>Outer Tube</td>
</tr>
<tr>
<td>6</td>
<td>Inner Tube</td>
</tr>
<tr>
<td>6</td>
<td>Spring</td>
</tr>
<tr>
<td>1</td>
<td>2.5 ounce cup</td>
</tr>
<tr>
<td>6</td>
<td>Servo-motor</td>
</tr>
<tr>
<td>6</td>
<td>Servo-arm</td>
</tr>
<tr>
<td>2</td>
<td>Hinges</td>
</tr>
<tr>
<td>1</td>
<td>Lock</td>
</tr>
</tbody>
</table>
## Electrical Bill of Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Part number</th>
<th>Vendor</th>
<th>Unit Price</th>
<th>Qty</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5A Dual-Input, USB/AC Adapter Charger and Smart Power Selector</td>
<td>MAX8677A</td>
<td>Digikey</td>
<td>1.95</td>
<td>1</td>
<td>1.95</td>
</tr>
<tr>
<td>2</td>
<td>RELAY POWER 5A 12VDC PCB</td>
<td>JW2A5N-DC12V</td>
<td>Digikey</td>
<td>2.28</td>
<td>1</td>
<td>2.28</td>
</tr>
<tr>
<td>3</td>
<td>5V voltage regulator</td>
<td>*</td>
<td>Digikey</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Li-Ion Battery Module : 7.2V 4000mah</td>
<td>4LI18650RPB4000</td>
<td>Battery Space</td>
<td>26.95</td>
<td>1</td>
<td>26.95</td>
</tr>
<tr>
<td>5</td>
<td>Universal Power Adapter 70W 15-24V with multi DC Plug</td>
<td>AD-SMP-70W</td>
<td>Battery Space</td>
<td>29.95</td>
<td>1</td>
<td>29.95</td>
</tr>
<tr>
<td>6</td>
<td>LED IR EMITTING 880NM 2-PLCC</td>
<td>QEB421</td>
<td>Digikey</td>
<td>0.15</td>
<td>1</td>
<td>0.15</td>
</tr>
<tr>
<td>7</td>
<td>IC AMP MONOLITH/PHOTOD 8-DIP SMD</td>
<td>OPT101P-J</td>
<td>Digikey</td>
<td>5.5</td>
<td>1</td>
<td>5.5</td>
</tr>
<tr>
<td>8</td>
<td>IC MOSFET LS DRIVER 5A SOT-223</td>
<td>IPS021L</td>
<td>Digikey</td>
<td>1.39</td>
<td>6</td>
<td>8.34</td>
</tr>
<tr>
<td>9</td>
<td>Eval board with 3.5” Samsung TFT LCD</td>
<td>SBC2410-II</td>
<td>Microcontroller shop</td>
<td>519</td>
<td>1</td>
<td>519</td>
</tr>
</tbody>
</table>

**Total: 604.12**
Electrical System Block Diagram
Battery Charging Circuit
Motor Control Circuit

NOTE: 500 Ω Resistor may be required on the gate of the MOSFETS
Pill and Cup Detection Circuit
Eval Board I/O
I/O Summary

Motor Control

- EINT0 - PWM Motor Control Signal
- EINT4 - Motor1 on/off
- EINT5 - Motor2 on/off
- EINT6 - Motor3 on/off
- EINT11 - Motor4 on/off
- EINT13 - Motor5 on/off
- EINT14 - Motor6 on/off

Pill and Cup Detection

- EINT15 - Infrared LED On/Off
- AIN1 - OPT101 Output to A/D Converter

Speaker

- Con-Phone- PJ-215-B

User I/O Buttons

- EINT16 - LED Alert
- EINT19 - Message Button
- AIN0 - Dispense Pills

LCD Interface

- Con-LED- Header2
Battery Charger

When the system is not plugged into a wall socket, power for the system is drawn directly from the battery.

When the system is plugged in,
- power is sent to the MAX8677A chip
- the coil in the relay is energized
- battery output to the system is disconnected
- CEN (Pin 4) goes to ground and enables battery charging.
- Power from the AC-DC adaptor goes to through a 5V voltage regulator and then goes to the system.

MAX8677A chip
- used for battery recharging
- adaptor inputs
- input overvoltage protection to 16V
- battery charge current is set up to 1.5 A

IPS021L MOSFET
- overcurrent shutdown
- shutdown current = 5A
- shutdown voltage = 50V
- turn on/off time = 1.5µs
- continuous drain current = 1.4A
Block Diagram for Computer Component of Pill Dispenser

- Sensors
  - Cup Detect
  - Pill Detect
- Keyboard
  - Message Key
  - Dispense Key
  - Pill Reload Key
- A/D Converter
- Battery Charger
- Oscillator
- Real Time Clock
- NVRAM
- RAM
- Indicators
  - Dispense Light
  - Message Light
  - Speaker
- A/D Converter
- Serial/USB Port
  - Motor Position
  - Motor Select
- I/O Controller
  - PWM
- Microprocessor
  - Inverter or LED Driver
  - Backlight
- LCD Panel
- Power
Embest SBC2410-II Single Board Computer

Features
Battery backed real time clock
PWM that can generate pulses from 1-2 ms with a period of 20 ms for servo motor control
Example: Using clock divider = 1/2 and prescaler = 8, can obtain a resolution of 0.32 us, timer compare = 62500 for 20 ms period.
4 key Keyboard (for dispense key and message key)
4 LEDs (for output message indicator and dosage ready indicator)
Audio out built-in (as a speaker jack)
LCD controller built-in
64MB RAM to hold variables, frame buffer, OS kernel (if needed)
64MB Flash RAM to hold system state and history

External I/O Requirements
3 analog input 10 bit ADC to measure battery voltage, 2x light sensor levels for cup/pill detection
1 output Battery charger enable
6 outputs Enable motors to dispense pill
1 I/O External communication (RS232) or USB host

Uses 3 AIN pin and 7 EIN pins on the GPIO expansion connector.

Other Specifications
Dimensions: 120x90mm
Power supply: +5V
Samsung S3C2410X (ARM920T core with MMU capable of 266 + MHz operation)
Flash: 1Mbyte Nor Flash, 64Mbyte Nand Flash
SDRAM: 64Mbyte

Development Environment
- x86 architecture PC
- x86 based ARM9 simulator using open source program SkyEye.
- Compiling done with arm-linux-toolchains, uploaded to evaluation board using root-for-nfs (to write to target filesystem).
  Included with evaluation board.

Using ARM9 vs x86 Architecture
1. x86 systems tend to have physically larger processors and must dissipate more heat.
2. x86 systems tend to require a northbridge and southbridge for I/O, increasing component count, board size, and power consumption. There could be a need to use a local bus such as PCI, ISA, or a DB9 to GPIO converter card + ADC for I/O.
3. x86 evaluation systems usually include VGA connectors that provide analog signals for CRT monitors. With a TFT LCD display, there would be a unnecessary A-D and D-A conversion.
4. Could not find an evaluation system that satisfies so many requirements at once compared to the Embest SBC.
Doctor's External PC Communication Program User Interface

File   Help
Exit   Help Contents
       About

Dosing time: 20:00

<table>
<thead>
<tr>
<th>Su</th>
<th>Mo</th>
<th>Tu</th>
<th>We</th>
<th>Th</th>
<th>Fr</th>
<th>Sa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>10</td>
<td>10.5</td>
<td>10.5</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>10.5</td>
<td>10.5</td>
<td>10.5</td>
<td>11.0</td>
<td>11.0</td>
<td>11.0</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

-5 weeks -1 week Today +1 week +5 weeks
Macro View History

Macro Dialog Box
-----------------------
Start Date: --/--/--
End Date: --/--/--
Sequence: --------------------------------------------------------------- [max 255 chars]

OK   Cancel Help
### Dispense History Dialog Box

<table>
<thead>
<tr>
<th>Scheduled</th>
<th>Actual</th>
<th>Dosage Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007-03-10 20:00</td>
<td>no data</td>
<td>10.5</td>
</tr>
<tr>
<td>2007-03-09 20:00</td>
<td>2007-03-09 18:00</td>
<td>10.5</td>
</tr>
<tr>
<td>2007-03-08 20:00</td>
<td>2007-03-09 01:02</td>
<td>10.5</td>
</tr>
<tr>
<td>2007-03-07 20:00</td>
<td>no data</td>
<td>10.5</td>
</tr>
<tr>
<td>2007-03-06 20:00</td>
<td>2007-03-06 20:03</td>
<td>10.0</td>
</tr>
<tr>
<td>2007-03-05 20:00</td>
<td>2007-03-05 20:05</td>
<td>10.0</td>
</tr>
<tr>
<td>2007-03-04 20:00</td>
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</tr>
<tr>
<td>2007-03-03 20:00</td>
<td>2007-03-03 20:08</td>
<td>5.0</td>
</tr>
<tr>
<td>2007-03-02 20:00</td>
<td>2007-03-02 20:19</td>
<td>5.0</td>
</tr>
<tr>
<td>2007-03-01 20:00</td>
<td>2007-03-01 21:37</td>
<td>5.0</td>
</tr>
</tbody>
</table>

### Dispenser UI (Idle)

<table>
<thead>
<tr>
<th>We</th>
<th>Th</th>
<th>Fr</th>
<th>Sa</th>
<th>Su</th>
<th>Mo</th>
<th>Tu</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Dispense 8:00 PM     In 3 h 18 mins

### Dispenser Program Flow

Event driven using interrupts to make use of power saving mode – minimal use of busy loops.

On power on

---------

Is serial connection available?
Yes

Send handshaking data
Read schedule
If valid schedule, enable all system interrupts

No
If failed, prompt "No connection"
Periodically retest serial connection availability

Dispense button interrupt:
--------------------------
Is it in power saving mode?
Yes
    Enable backlight
    Indicate "Dispensing..."
Is RTC between Dispense Time and Dispense Time + Late Interval?
Yes
    Disable audio visual alerts
    Disable late timer
Is cup detected?
Yes
    Is cup empty?
    Yes
        Get dosage
        Compute required pills
        Set PWM
        Set motor select
        Wait for motor engage time
        Set PWM to motor reset position
        Wait for pill drop time
        Is cup empty?
        No
            Decrement pill counters
            Push schedule
    No

No

Set RTC alarm to next scheduled dose
Prompt user to take pills and show picture of pillset
Write history (successful dispense)
Send history
Yes
Prompt dispense error - take unit for service and call doctor or hit Dispense to retry
No
Prompt user to empty cup and hit dispense again
No
Prompt user to replace cup and hit Dispense again
No
Prompt: No dosage needed at this time
Set LCD timer to powersave

Message button interrupt:
-------------------------
Is it in power saving mode?
Yes
Show current message, enable backlight
No
Show next message or loop to first message
Mark message as read
Delete message if already viewed and too old
Set LCD timer to powersave

LCD Timer interrupt
------------------
Disable LCD backlight

Pill Count Reset Key Interrupt
-------------------------------
Set all elements of pill[] to 31. Button is hidden, should be accessed by pharmacist only

RTC Alarm Interrupt
-------------------
Enable audio visual alerts
Enable late timer

Late Timer Interrupt
-------------------
Disable audio visual alerts
Add message "You missed a dose on Date, Time"
Enable message alert
Write history (missed dosage)
Send history

Serial Connection Detect Interrupt
-------------------------------
Handshake
Send any unsent history
Indicate "no connection" if serial connection is broken
Read schedule
Write schedule to NVRAM