microSense metrics

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23 April 2005

Mr. Lakshman One
School of Engineering Science
Simon Fraser University
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Re: ENSC 440 Posture Measurement and Data Logging System Post-Mortem

Dear Mr. One:

The attached document, *Posture Measurement and Data Logging System Post-Mortem*, is a reflection on the engineering design process that we have undertaken on our project over the past four months. Our current progress, design challenges, timeline, and budget are discussed. Personal reflections on our learning experience are also included.

The microSense team of Brandon Ngai, Lawrence Wong, and Josephine Wong intends to continue to improve our system in the coming months. If you have any further comments or concerns, please contact us by e-mail at ensc440-u-sense@sfu.ca or by phone at (604) 724-8864. Thank you for your time.

Sincerely,

Josephine Wong

Josephine Wong
President and Chief Executive Officer
microSense metrics

Enclosure: *Posture Measurement and Data Logging System Post-Mortem*

cc: Mike Sjoerdsma
Scott Logie
Amir Niroumand
Tony Ottaviani
Steve Whitmore

Posture Measurement and Data Logging System

Post-Mortem

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Issue Date:	23 April 2005
Revision:	1.0

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Glossary

ADC	Analog-to-Digital Converter
CSV	Comma Separated Values file format
DFN	Dual Fine Pitch No Lead package
DIP	Dual In-Line Package
GUI	Graphical User Interface
LCC	Leadless Chip Carrier package
MCU	Microcontroller
MEMS	Micro-electromechanical System
PC	Personal Computer
PCB	Printed Circuit Board
SMT	Surface-Mount
TQFP	Thin Quad Flat Pack package
TSOP	Thin Small Outline Package
USB	Universal Serial Bus
USB 2.0	Most updated Universal Serial Bus Standard

1. Introduction

microSense metrics set out to design a portable posture measurement and data logging system to aid researchers in preventing injuries in construction workers and the elderly in November 2004 [1]. Our device was inspired by a lack of comparable commercial solutions that satisfied the research needs of Dr. Stephen Robinovitch and Dr. David Rempel. We were asked to develop a device that measured the rotation of various points of a subject's body with respect to gravity. Possible usage scenarios and basic performance requirements were also presented by our faculty experts.

The microSense team has devoted many long hours towards designing our product. We consulted regularly with our faculty advisors to develop a joint vision that would accommodate their intended research applications. As with any design project, we encountered a number of unexpected challenges and technical difficulties along the way. These difficulties have led to delays in the implementation and testing of our system. However, the team remains very committed to the project, and fully intend to continue to develop and improve our project over the coming months.

We intend to have a final prototype ready for usability testing by August 2005. This usability testing will be led by Dr. Robinovitch and Dr. Rempel, and will evaluate the performance of our device in a research setting in comparison to similar products such as the MicroStrain Virtual Corset™ [2].

2. System Overview

The microSense posture measurement and data logging system consists of a number of inclination sensor modules that operate autonomously from one another [2]. Each sensor module is strapped tightly onto a segment of the subject's body during testing. The movement of the body segment is tracked by measuring its rotation respect to gravity at discrete intervals. Each module is subdivided into three major functional blocks: data acquisition, data storage, and data transmission [3].

Our system block diagram is shown in Figure 1.

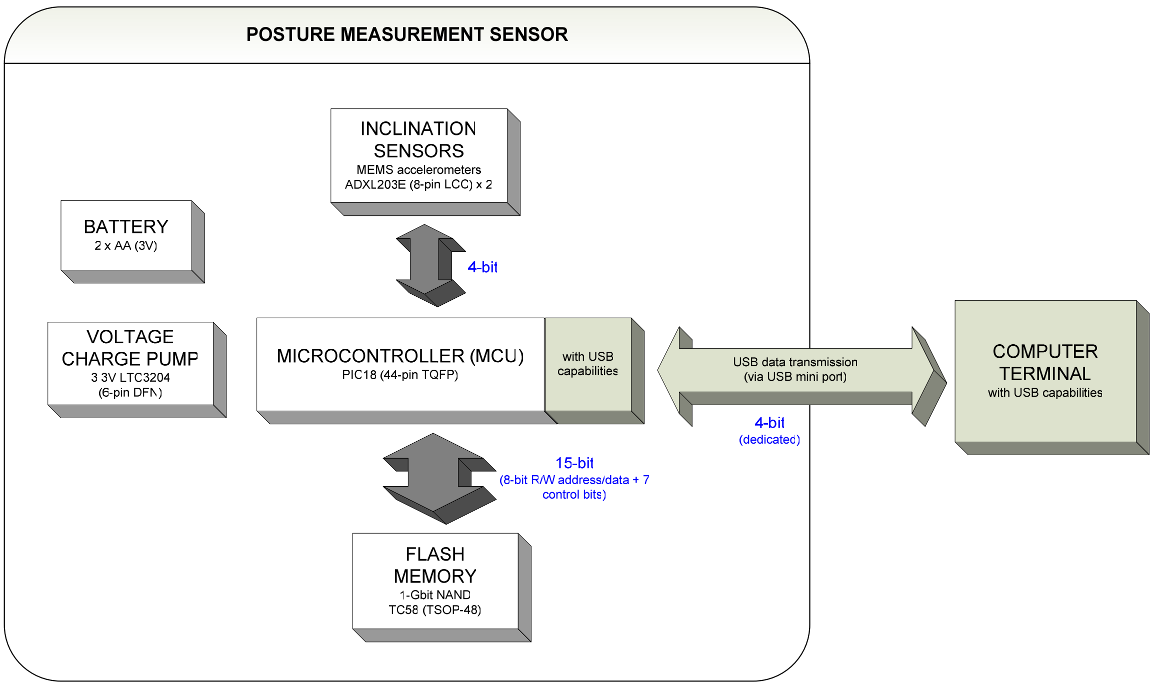

Figure 1: System Block Diagram

In the data acquisition stage, two dual-axis ADXL203E MEMS accelerometers are used to measure the angle of inclination of the device with respect to gravity. These accelerometers generate continuous analog outputs that are proportional to the angle of inclination. Their outputs are connected to the analog-to-digital converter of the microcontroller and sampled at the base sampling rate of 32 samples per second. The two accelerometers are mounted perpendicularly to each other within the sensor unit. This design enables us to offset the reduced resolution of the accelerometer chips as their measurement axis is rotated towards the force of gravity.

In the data storage stage, the sampled data is recorded in the NAND flash memory. With a data structure of 4 bytes per sample, our 1-Gbit flash chip will accommodate a sampling rate of 32 samples per second, with a resolution of 0.5^{o}, for a maximum of 12 days.

In the data transmission stage, the captured data is transferred from the module to a computer terminal via a USB connection at the request of the user. The raw data is then parsed and processed by an in-house software package and outputted as a Microsoft Excel-compatible comma separated value (CSV) data file.

Our device will be powered by two non-rechargeable AA batteries. A voltage charge pump capable of outputting up to 50mA of current will be used to maintain a steady input voltage to our other components.

3. Current Status

Our team has successfully implemented most of the core functionality of our system. We have established communication between our sensors and the microcontroller, enabled USB data transfer between the microcontroller and the computer, and are able to write small blocks of data into the flash memory.

3.1 Data Acquisition

For the data acquisition stage, we have finalized the type and placement of the inclination sensors that form the core of our measurement device. The sensor selection was a time-consuming process due to the amount of testing that needed to determine the type and number of sensors to use. We have interfaced our sensors with the built-in ADC on the microcontroller, and are able to transfer the sampled data points to a computer via USB. We have been able to convert the ADC output to an angle value, and display the results continuously on the computer screen.

We have conducted some preliminary static testing of this part of our system by holding our sensor at different angles and comparing the output of our sensor with the output of a digital level. We found that our accelerometers are reasonably accurate after calibration when the tilt angle about the measured axis is between 0° and 45°. Unfortunately, the sensor performance deteriorates sharply as the tilt angle approaches 90°. The limitation prompted us to use the two-sensor design and develop a software algorithm that selects the active sensor channels based on the level of tilt. Unfortunately, our algorithm at times leads to unexpected and inaccurate results.

The next stage will involve debugging the sensor-switching algorithm, and testing the reliability of our sensor measurements using a two-dimensional testing apparatus that is being constructed.

3.2 Data Storage

The data storage stage involves writing data into flash memory and reading it back for verification. We have been able to store and retrieve up to 32 bytes of data in our testing thus far.

More debugging is needed to enable the storage and retrieval of up to 1 Gbit of data in flash memory.

3.3 Data Transmission

USB communication between the microcontroller and the computer terminal is vital for testing and debugging the data acquisition and data storage capabilities of the system. We therefore implemented this functionality early in the design cycle.

Our device has been tested for compatibility with Windows 2000 and XP. Our sensors are automatically detected by both operating systems. We have also verified compliance with the USB 1.1 standard through bidirectional data transfer between the microcontroller and the PC.

3.4 Data Processing

The acceleration-to-angle calculations will be conducted after the data has been loaded onto the computer.

We are in the process of developing a GUI that will allow the user to establish a connection to a specified sensor and retrieve the data from the device. The process will output a time-stamped CSV file that presents the angle measurements at each sampling time.

3.5 System Integration

We began the process of integrating the system in the week preceding our demo. We will be ironing out the bugs in the system in the coming weeks.

3.6 Device Testing

Limited testing has been conducted on the system as a whole. We will begin accuracy and reliability testing once the core functions have been fully implemented and debugged, and our new testing apparatus becomes available.

3.7 Power Considerations

Our current prototype is powered by 3 AA batteries, and the output voltage is regulated down to 3.3V by a voltage regulator.

We intend to power up our final design using only 2 AA batteries to minimize the size and weight of our device. We will be testing our voltage charge pumps to verify that they can output up to 50mA of current as promised in their datasheets.

4. Design Challenges

Our team encountered several significant design challenges during the product development cycle. These challenges included difficulty in identifying and acquiring components, working with the chosen components in our prototype, clearly defining how the device works, maintaining low power consumption, and testing and debugging the system.

Some of the challenges resulted from our lack of prior expertise with the components that we needed to use, particularly the inclination sensors and the flash memory. Other challenges were caused by inherent conflicts in the functional requirements that were identified in our discussions with our faculty advisors. Selecting appropriate batteries to power up the device proofed to be particularly challenging as we sought to find a balance between low-cost, durability, and the size and weight of our device.

4.1 Component Identification and Acquisition

A lot of research was put into selecting appropriate components for our device. Low power consumption and small size were guiding factors, but we found it difficult at times to select the best components based on the manufacturer datasheets alone.

A case in point is the inclination sensors. We had no prior experience with either inclinometers or accelerometers, and had to acquire and test both types of sensors before settling on an accelerometer. However, the further testing late in the design process revealed the limitations of our chosen sensor, and this lead to a last-minute change to another model in the Analog Devices line of MEMS accelerometers.

Component acquisition also proved to be problematic at times. We often encountered long delay times in the delivery of components, as was the case with the voltage charge pump. The delay in acquiring that component meant that we were not able to test the charge pump and integrate it into our design. We also encountered difficulties in acquiring a 2-Gbit flash memory chip. Although the technology is available, we were unable to acquire the part in a timely fashion since it was not available through distribution channels such as DigiKey.

We also found it difficult to acquire many of our desired components in DIP packages. The flash memory only came in a 48-pin TSOP packages, and acquiring the TSOP-to-DIP adaptor boards needed to integrate the flash memory with our prototype circuit proofed to be a time-intensive and difficult process. Similarly, mounting the 8-pin LCC accelerometers onto the circuit was rather challenging. We could have saved a lot of development time if our components were available in larger DIP packages.

4.2 Rotation in Three-Dimensional Space

Implementation of the data acquisition stage required a clear vision of dual-axis rotation in three-dimensional space. Establishing a clear, common vision was challenging since we had varying abilities to think spatially. We were often confused by the reference frame that we needed to consider. This confusion made it very difficult to define the x- and y-axis of the device and to implement our sensor-switching algorithm.

4.3 Minimizing Power Consumption

Minimizing the power consumption of our device is a design challenge that we continue to struggle with. Writing to flash memory requires a significant amount of current and draws heavily on the battery pack. Since the intention is to capture data for up to 12 days at a time, we need creative strategies for reducing the continuous drain on the battery. Our current power consumption of approximately 50mA will deplete two AA batteries in two to three days. The goal is to reduce the power consumption to no more than 20mA since using eight or more AA batteries is clearly and unacceptable solution.

The desire of the intended users to have the sensor use common and affordable batteries also greatly restricts the design options that we have available to us. For example, the new Prismatic batteries from Duracell, which offer a very high volume-to-capacity ratio, were rejected due to high per unit costs and limited availability at this time.

4.4 System Testing and Debugging

System testing and debugging is another ongoing design challenge that we have struggled with. The various functional blocks are so dependent on each other that it becomes difficult to test any part of the system without having implemented the complete system. In particular, we could not even begin to verify the data acquisition and data capture until the USB communications had been put in place.

We also lack the apparatus needed to conduct accuracy and reliability testing in a controlled manner. This problem will likely be rectified in the next couple of months as a testing apparatus is being constructed to aid in our project testing.

5. Budget Comparison

Table 1 shows the estimated cost and the actual cost for each sensor module as of April 24, 2005.

Table 1: Estimated Cost vs. Actual Cost (per sensor module)

Materials	Estimated Cost	Actual Cost
Sensors (Inclinometers)	$100	Free Sample
Microcontroller	$40	Free Sample
Power Supply	$60	9.11
Memory Storage	$120	$29.43
Data Transmission Module	$90 (USB)	$18.74
Case	$20	-
PCB	$100	-
Total	$530	$57.28

Due to a delay in the project timeline, we are unable to create the enclosure and PCB for the sensor module. Therefore, we will omit their actual cost in the above comparison. The actual cost for each sensor module excluding enclosure and PCB is $48.17. It is a lot lower than the estimated cost in the proposal because we were able to get free samples for the sensors and the microcontroller. The most significant cost is the memory storage, which is the 1Gbit NAND flash unit.

The actual development cost is shown in Table 2.

Table 2: Actual Development Cost

Materials	Development Cost
Sensors Research	$194.77
Digital Level	$125.84
Power Supply Research	$9.11
Memory Storage	$94.64
Data Transmission Module	$18.74
Prototype board	$12.99
Microcontroller Research	$43.40
Miscellaneous	$87.46
Total	$586.95

The sensors research is the most expensive category and it is the cost of acquiring another type of inclinometer which was eventually replaced with the current free sensors. The digital level is acquired to provide a measurement reference for calibration purpose. The memory storage is more than double of the actual per unit cost because we have ordered two memory units and two TSOP adapters for prototyping purpose. The adapters will not be used on the PCB, thus they are omitted in the per unit cost. Although we were able to get free microcontroller samples, we had ordered spare units from other source and thus the microcontrollers costs $43.40 in the development cost. The miscellaneous section includes various low cost components, such as crystals, capacitors, LEDs, resistors, terminal blocks, sockets and switches. The development cost will be fully reimbursed by Dr. Robinovitch through the School of Kinesiology at SFU.

6. Project Timeline

Our team had a difficult time adhering to the timeline that we defined early in the semester. We fell increasing behind schedule since we drastically underestimated the work associated with many parts of the system. The implementation of the data acquisition and data storage stages took weeks longer than had been anticipated. Long shipping times for key components such as the TSOP-to-DIP adaptor boards also exacerbated the problem. Finally, we were forced to spend many long hours in the lab learning to solder the numerous tiny surface-mount components in our device.

In retrospect, we should have been more realistic in our estimates of workload and of our availability and skill sets. We also should have kept better track of where we were in the design process as a group and regularly updated our to-do lists. We also needed to set aside more time for system integration, testing, and debugging. We attempted to integrate the project at the 11th-hour, and struggled to iron out the major bugs that were introduced in time for our project demo.

Our group has devised our timeline for the remainder of the project. We now intend to present a working and reliable prototype unit to Dr. Robinovich and Dr. Rempel by August 2005. The unit can then be subjected to usability testing in a lab setting by the researchers and compared against current industry standards such as MicroStrain Virtual Corset™.

7. Future Plans

The microSense team is committed to continuing to develop our posture measurement device in the coming months. We intend to present Dr. Robinovitch and Dr. Rempel with a working prototype for usability testing in August 2005.

We have also set out a number of specific tasks for each team member and established more reasonable deadlines. This revised task list is provided in Appendix A.

8. Personal Comments

8.1 Brandon Ngai

Since first year, I have observed upper year friends suffer through impeding deadlines and sleep deprivation, characteristics of *the* project course. And so the thought that I, too, would someday have to tackle ENSC 440 has always filled me with dread. Now at the end of the semester, I am proud to report that I have survived an experience that was both a valuable learning opportunity and a challenge to my personality.

My major contribution was implementing the NAND flash memory, which required some creativity in the design due to the differences between our requirements and what the chip was designed to do. For this, I had to balance between ease of programming and our specifications, and I had to decide which tradeoffs to make.

I had originally suggested programming our firmware in assembly because I felt much more comfortable with it. However, I was persuaded to use C instead. I was thrust out of my comfort zone and had to relearn a language that I was only vaguely familiar with from a previous course. Looking back, I am glad that I was persuaded. Although my design skills in C could still be improved, the opportunity to strengthen and expand my skill set is greatly desirable.

If we were to do this project all over again, I would be more realistic in our design and scheduling. At the start, I would insist that we carefully consider all factors of the project and question whether our design proposals would be feasible and efficient. Once we have found a solution, I would advocate creating a timeline that reflects our actual understanding of the problem and our abilities to implement the solution. Our timeline would be revised each week and tasks left incomplete would be prioritized and redistributed to team members.

As with any group working under intense pressure and stress, our team definitely had our fair share of bickering and misunderstanding. But we also gave each other the support that was needed when the times were rough. I am glad to have been able to work as part of this team. We have learned a lot about each other and ourselves and for that, I am grateful.

8.2 Lawrence Wong

After the past 13 exhausting weeks, I have gained a much deeper understanding in myself. Throughout the semester, I have pushed myself to the limit, aiming to finish the project on time. My team and I have spent countless nights in the lab, trying to meet the specific goal at different stages of the project. In February, in order to prepare a prototype for the Employer Open House, we worked in the lab non-stop for almost two days. In that thirty-something hours, we successfully built a prototype, presented it in the open house and had a really great time. Nevertheless, if we could plan a better schedule, we would not have to put ourselves in such a stressful situation.

From my personal point of view, this project has sacrificed too much of my study time for other courses, and my personal time with my family and friends. If I can start this project all over again, I would not put myself and my team into this stressful situation, as it is exhaustive and our productivity are low during the time.

In terms of technical experience, I have gained some valuable experiences working with USB and NAND flash devices, which are some latest technology in the field. Although I am quite confident programming in C and C++, it still took me a long time to implement certain functions and debug programs. I have overestimated my productivity and underestimated the workload from my other courses, which has significantly slowed down my programming progress.

Time is the most expensive resource when you are working on an engineering project. With better schedule planning and time management skills, I believe that we could have set a more realistic goal for ourselves and be more conservative in our schedule planning.

8.3 Josephine Wong

When I reflect back on the past 13 weeks, I am astounded by the number of sleepless nights we spent stumbling dazed around the lab, twisting ourselves into a pretzel (literally!) as we pondered how our posture measurement system is ever supposed to work. I am equally astounded by the progress that we have made since our first encounter with Dr. Robinovitch last November. Our task seemed hopelessly daunting at the time; and although we will undoubtedly be devouring more Timbits in the lab in the coming months, I am confident that we will one day solve the problem that I affectionately refer to as the “440 monster”. ☺

My primary contribution was in the area of technical communications. I have spent many hours hunched over my laptop, typing away throughout the night as I did tonight. This was a role that I was happy to play, since my programming skills are mostly non-existent. I think this worked out well for the most part, since we were each able to bring our respective skill sets to the project. I also spent endless hours in the lab researching components, engaging in group discussions, building our schematic and protoboard, and teaching myself how to solder tiny SMT components. I amazed myself last week by successfully soldering 6 wires onto a 2mm x 2mm 6-pin DFN package. It was fun!

If we were to step back in time, I would set more realistic timelines and milestones for our project. I would also limit the scope of the project for the purposes of this course. However, I do not regret the life or educational experiences that I have gained. I look forward to presenting a new-and-improved prototype towards the end of the summer semester.

9. Conclusion

The past four months has provided much valuable engineering design experience to members of microSense metrics, and has given us the opportunity and motivation to expand our technical skill set.

We will continue to implement and improve our design in the coming months, and look forward to presenting a working prototype to everyone involved in the project in August 2005.

10. References

[1] J. Wong, L. Wong, and B. Ngai, “Project Proposal for a Posture Measurement and Data Logging System,” microSense metrics, Burnaby, Canada, January 2005.

[2] MicroStrain Inc. 23 January 2005 <http://www.microstrain.com/>

[3] J. Wong, L. Wong, and B. Ngai, “Functional Specifications for a Posture Measurement and Data Logging System,” microSense metrics, Burnaby, BC, Canada, February 2005.

[4] J. Wong, L. Wong, and B. Ngai, “Design Specifications for a Posture Measurement and Data Logging System,” microSense metrics, Burnaby, BC, Canada, March 2005.

Appendix A

This section outlines the design tasks that each team member will be undertaking in the coming months.

Goal:	Power consumptions and supplies verified
Deadline:	June 1

Owner	*Tasks*	*Deadline*
Lawrence	Investigate minimizing power consumption	April 30
Lawrence	Test voltage boosters maximum current output, minimum voltage input	April 30
Lawrence	Build test circuits with current consumption at 20mA and 40mA	April 30
Josephine	Test lifetimes of regular alkaline AA and titanium e2 AA batteries with test circuits	June 1

Goal:	Components available for prototyping
Deadline:	June 1

Owner	*Tasks*	*Deadline*
Brandon	Order additional TC58s	April 24
Josephine	Order additional PIC18s, ADXL203s	May 24
Lawrence	Obtain quotes for SMT resistors and capacitors	May 1
Brandon	Receive components	June 1

Goal:	Prototype developed
Deadline:	June 8

Owner	*Tasks*	*Deadline*
Lawrence	Confirm components and circuit design	May 1
Josephine	Complete PCB layout	May 8
Josephine	Obtain quotes from PCB manufacturers	May 13
Josephine	Receive finished PCB	June 1
Josephine	Assemble components onto PCB	June 8

Goal:	Flash memory can store 12 days of data
Deadline:	June 8

Owner	*Tasks*	*Deadline*
Brandon	Test process to write to entire flash memory	June 8

Goal:	Clock and time-stamping function are accurate
Deadline:	June 20

Owner	*Tasks*	*Deadline*
Brandon	Test timer for interval accuracy	June 17
Brandon	Fine tune time-stamping accuracy (if necessary)	June 20

Goal:	Packaging is watertight
Deadline:	July 4

Owner	*Tasks*	*Deadline*
Josephine	Contact expert to discuss watertight enclosure	June 19
Josephine	Design enclosure based on discussions	July 4

Goal:	User can interface with device
Deadline:	July 9

Owner	*Tasks*	*Deadline*
Lawrence	Implement real-time mode display	June 1
Lawrence	Implement complete data download from flash	June 6
Lawrence	Implement data export to CSV file	June 13
Lawrence	Implement synchronization routine	June 22
Lawrence	Implement time-stamping algorithm	June 30
Lawrence	Implement software calibration algorithm	July 9

Goal:	Device is accurate and reliable
Deadline:	August 12

Owner	*Tasks*	*Deadline*
Brandon	Design detailed test plan	June 10
Brandon	Design test apparatus and equipment	June 24
Brandon	Build Dave's test apparatus	July 9
Josephine	Conduct static testing using Dave's test apparatus	July 21
Brandon	Build motor and mount device onto rotating bar	July 21
Josephine	Conduct dynamic testing at high acceleration rates	August 5
Brandon	Calibrate device and retest (if necessary)	August 10