ArachnoBotics Research Inc.

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

April 23, 2010

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Capstone Project: *Post-Mortem: ArachnoBot™ Project*

Dear Dr. Rawicz,

Please find attached the document titled *Post-Mortem: ArachnoBot™ Project*, for our ENSC 440 Capstone Engineering Project.

The enclosed document describes the submitted project shown at our demonstration. It explains its deviation from the original design proposal and outlines future plans for our project. Included also are personal reflections from all the members of the team.

ArachnoBotics Research Inc. consists of four highly motivated, innovative and talented fifth year engineering students experienced in a wide range of technical disciplines: Daniel Naaykens, Pavel Bloch, Pranav Gupta and Stefan Strbac.

If you have any concerns or questions regarding our proposal, please feel free to contact me by phone (778.893.3303) or by email (pranav_gupta@sfu.ca).

Yours sincerely,

Pranav Gupta
Chief Executive Officer
ArachnoBotics Research Inc.

Enclosed: *Post-Mortem: ArachnoBot™ Progress*

ArachnoBotics Research Inc.

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

ArachnoBotics Research Inc.

© Daniel Naaykens

Post-Mortem: ArachnoBot™ Project

Project Team:
Pavel Bloch
Pranav Gupta
Daniel Naaykens
Stefan Strbac

Created For:
ENSC 440 - Dr. Andrew Rawicz
ENSC 305 - Steve Whitmore

Team Contact:
Pranav Gupta
778.893.3303

Document Details:
Created: April 20, 2010
Revised: April 23, 2010
Revision: 0.2.0

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

Table of Contents

ArachnoBotics Research Inc.

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

List of Figures

List of Tables

List of Acronyms

CAD - Computer Aided Design
DC - Direct Current
DOF - Degrees of Freedom
ESA - European Space Agency
EMS - Electronic Manufacture Service (Provider)
PID Controller - Proportional-Integral-Derivative Controller
PWM - Pulse Width Modulation

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

1. Introduction

ArachnoBotics Research Inc. began work on the Phase I *ArachnoBot*™ system in January of 2010 and after 4 months has been able to produce a working prototype framework. This document will describe the current state of the ArachnoBot project and outlines plans for further development. In addition, personal summaries are given by each member of the team.

2. Current State of Prototype ArachnoBot™

The *ArachnoBot*™ project is meant to produce a fully autonomous robotic hexapod walker, based on a project commissioned by the European Space Agency (ESA). This hexapod walker is designed to be a small, lightweight robot capable of scaling any complex terrain, and subsisting in extreme environments. Currently, our prototype meets the requirements of the Phase I *ArachnoBot*™ system [1].

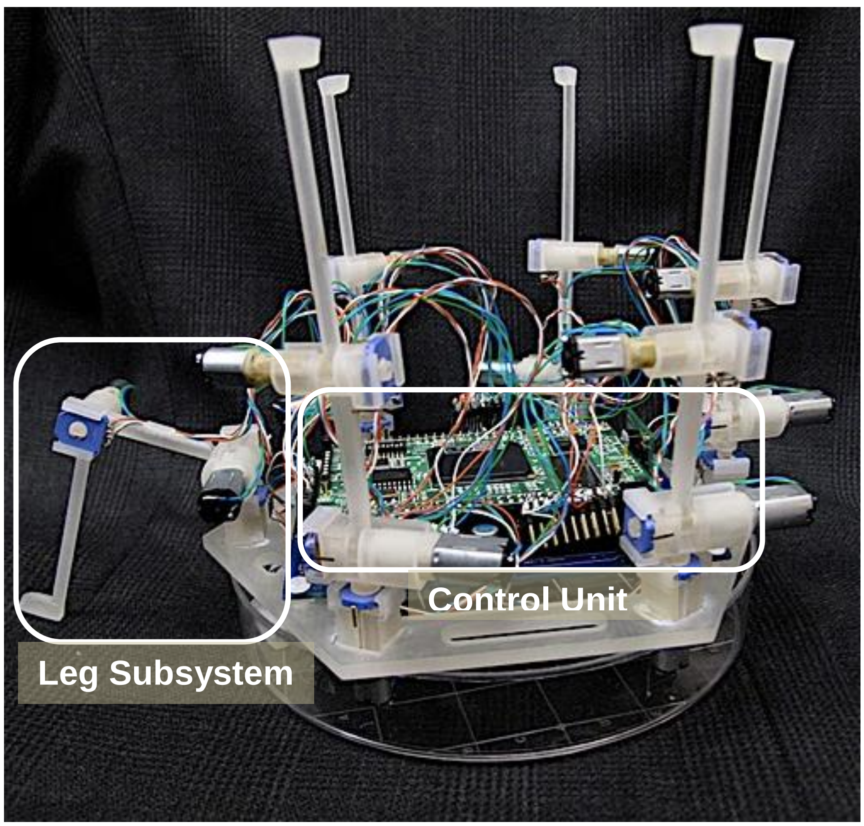


Figure 1: Assembled prototype system

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

3. Hardware Status

The ArachnoBot™ hardware has been designed to meet the functional, and design specifications of our project. This meant determining an appropriate sensor and actuator pair for each joint of the leg, as well as adhering to other strict principles in terms of the final size and weight of the ArachnoBot™. During the final assembly, the original size constraint of 15cm x 15cm x 15cm has to be expanded to allow for full component integration, as well as to increase the freedom of rotation of the legs. Also, due to the weight of all the smaller, and previously considered weightless components of the ArachnoBot™, including wires and headers, our final weight came in at approximately 230g.

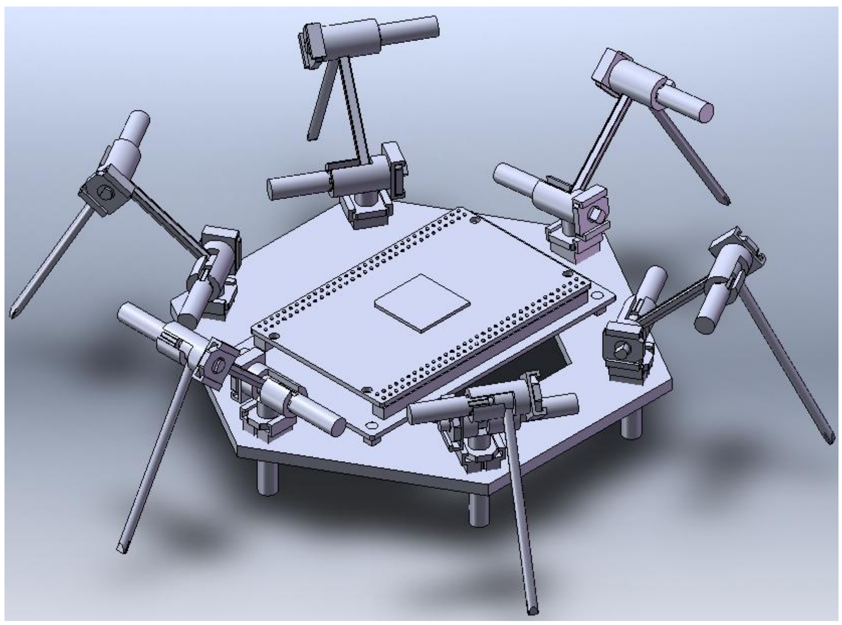


Figure 2: ArachnoBot™ SolidWorks 3D model

Once the mechanical frame was finalized, a trajectory lookup table was generated from the dimensions of the robot using Inverse kinematics. Due to the complex nature of the hexapod walk cycle, a simplified trajectory was chosen where each leg moves in the correct sequence, although only one leg moves at a time. This was chosen so as to aid in de-bugging the final software, as once the ArachnoBot™ can easily complete this simple trajectory it only becomes a matter of parallelization of the trajectory.

4. Electronics Status

The electronic system of the ArachnoBot™ prototype described in the design specifications was completed. The custom designed drive module was compatible with the processing module, *XCM-016* [3], containing the FPGA implemented control system control system. Figure 3 below shows the drive module the team designed; a two-layer PCB with 6 Quad H-bridge ICs and 5 Quad Comparator ICs and their associated discrete components.

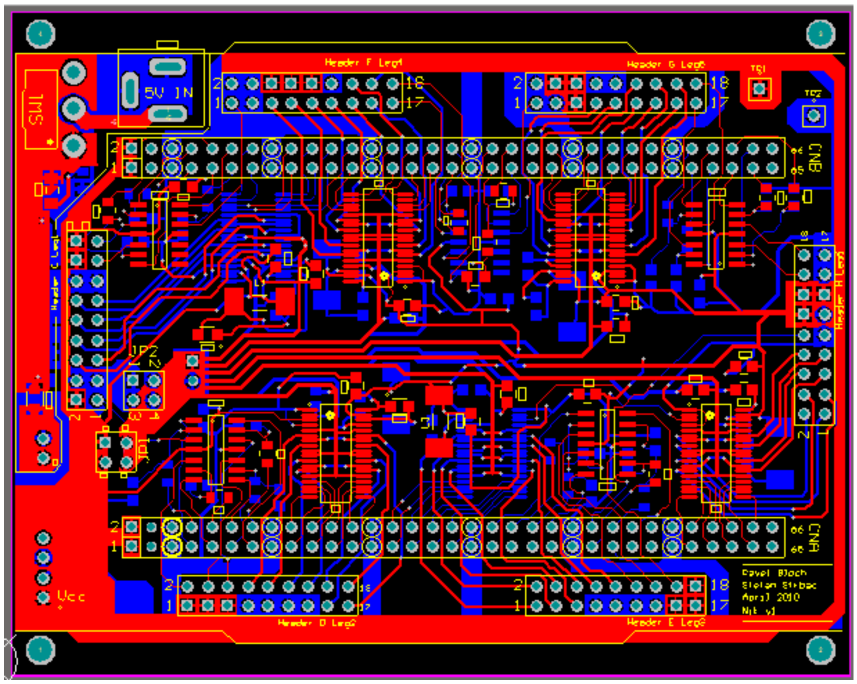


Figure 3: CAD screenshot showing the different layers of the Drive Module

The two-layer PCB approach was followed to minimize the cost of the module but this created more constraints. Nonetheless, a final two-layer design was completed. Fortunately, the PCB manufacturer EMS provider Enigma Interconnect Inc. offered to fabricate the PCB at no cost, which helped the final budget.

Populating the PCB was still done manually which proved a cumbersome task namely because of the fine-pitch of all the surface-mount components used on the module. Area was also a constraint since the PCB is approximately 10 cm. x 8 cm. Soldering was done using solder paste and a hot-air gun. The results were very good which meant rework on the board was kept at a minimum.

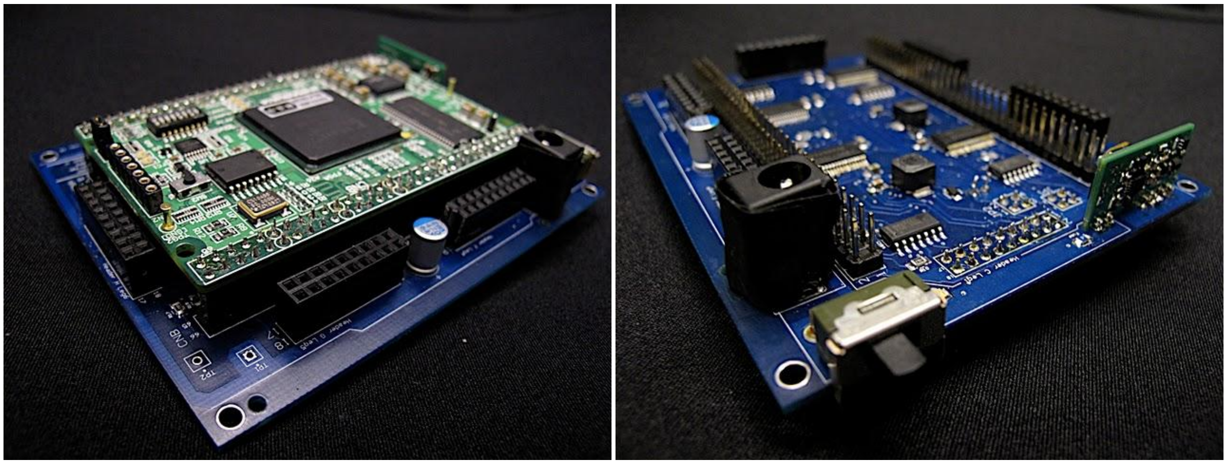


Figure 4 Photos showing realization of electronic system

Once all the mounting was completed, board testing concluded that the design was correct. The separate ground and power planes on the PCB and the smaller size of the PCB, in addition to the use of surface mount components, showed a better noise profile then the bread-boarded prototype circuit.

5. Software and Control System Status

The 7 processor FPGA implemented control system was completed and required only minor changes during testing. This framework system fits within the maximum resources available on the FPGA module XCM-016*[3].*

The logic utilization of the system on the Spartan 3 FPGA, xc3sd3400a device, from the EDK design summary is shown below:

Logic Utilization	
Total Number Slice Registers:	21,046 out of 47,744 44%
Total Number of 4 input LUTs:	26,668 out of 47,744 55%
Number of occupied Slices:	20,341 out of 23,872 85%
Number of bonded IOBs:	113 out of 469 24%
Number of BUFGMUXs:	2 out of 24 8%
Number of DCMs:	1 out of 8 12%
Number of BSCANs:	1 out of 1 100%
Number of bonded IOBs:	113 out of 469 24%
Number of DSP48As:	21 out of 126 16%
Number of RAMB16BWERs:	67 out of 126 53%

Table 1: FPGA resources utilization of system

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

The main changes made during testing of the assembled system were software in nature. The voltage to angle translation had to calibrate for each joint on each leg and this was hard coded into the control programs for each processor.
The control framework is complete consisting of seven processors and the necessary FSL links for inter-processor communication. Each leg processor has its own PLB bus and peripheral cores.

Currently systems utilizing one, two, three, and seven processors have been developed. The simpler systems were used for

Using the framework complex motion commands in the form of trajectory data can loading into the system and executed on startup or by the user pressing on the reset button. Alternatively, the debug module can be used to step through each command.

6. Future Plans

Walking on a plane surface was a milestone in itself, but future systems will need to travel across more complex terrain, including walking on vertical surfaces. Vertical travel will incorporate sticky pads on the robots legs which inevitably will introduce new issues. Namely, the control system will have to compensate for changing torque and elastic overshoot caused by the adhesion to surfaces by the sticky pads.

Even thou the current prototype control system can fit within in the current FPGA, additional features and complexity required by the functional specifications of Phase II and Phase III ArachnoBot™ systems will need a FPGA with a bigger capacity.

To further bring down the total weight of the robot, the processing module and the drive module will need to be integrated onto a single multi-layer PCB. One alternative to this is to find a smaller FPGA module but here currently doesn't seem to exist a module of smaller size with equal or greater number of I/Os and an equally powerful FPGA on board.

The robot's frame can also be integrated with the PCB which can offer structural support instead of the frame supporting the PCB which is the case with the current prototype.

Ultimately, the ArachnoBot™ will need to be fully autonomous. This will require the system to be battery powered. Current battery packages introduce a considerable amount of weight. More effort will be required to solve this obstacle. Another condition for being autonomous is a more complicated control system. The future control system will require force feedback either in the form of a contact sensor on the pads or in the form of current sensing H-Bridges. Both methods are feasible but again will require a more capable control system.

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

7. Actual and Estimated Budget

Table 2: Proposed and Actual Final Budget

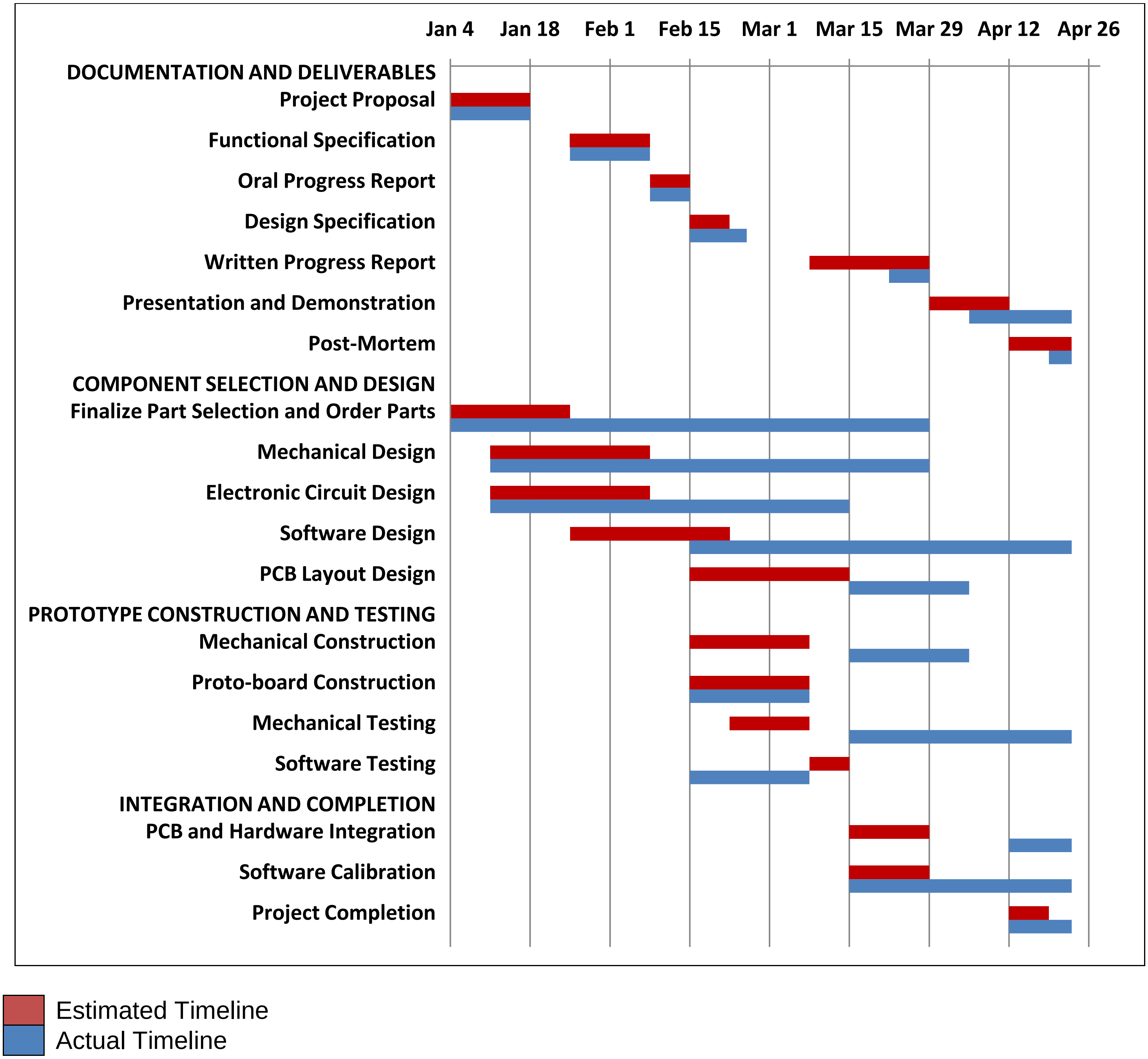
Part	Proposed	Actual
FPGA Development Board	$200	$450
JTAG Programming Cable	$0	$300
Printed Circuit Board Manufacturing	$1000	$1200(Donated)
Rapid Prototyping	$100	$1500(Donated)
Sensors	$200	$150
Actuators	$250	$600
Circuit Elements	$400	$600
Contingency	$150	$0
Final	$2,300	$4800
Difference:		$2500

Our estimated budget at the beginning of project differed greatly from the actual budget total at the end of the semester. As can be seen in table 2 above, the main miscalculation was with the cost of the 3D prototyping material. Fortunately the final cost of the project was mitigated by the donations from SFU and Enigma Interconnect. All in all, lessons were learned.

8. Actual and Estimated Project Timeline

The Project Timeline deviated greatly from what was expected at the start of the semester. An extension to the demo date was required due to the unplanned schedule. Below a Gantt chart shows the comparison between the estimated and actual project timeline.

Table 3: Gantt chart of Tasks



8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

The main reason for the delayed schedule was that design took longer than expected. The mechanical, electronic and software design were greatly dependent on each other and for this reason the design timeline was extended. For example parts could not be ordered before their compatibility was confirmed with all the parts of the design.

Assembly and construction took longer than expected since great amount of care had to be taken to prevent parts from breaking because of their small size and sensitive composition. Calibration and testing merged and since the legs had to be tested prior to assembling the whole system with all the legs connected.

On the bright side, all the project documentation was completed reasonably on time.

9. Personal Reflections

Pavel Bloch

At the beginning of the semester, I set two personal goals: to complete the project, and to learn something new. Although I feel that my 440 experience was mixed, looking back I feel proud of what we accomplished and the learning I gained was invaluable.

Heading into the project, there was a common underestimation about the degree of difficulty of the project. Members seemed very confident about completing the project on time, and this hurt the group's initial productivity.

The beginning to middle stage of the project requires the most sound judgment and effort as this sets the tone for the rest of the semester. Moreover, this is the stage where all the constraints are considered and countless components are tested to determine the optimal direction to tackle the problem. I felt that valuable time was lost the most in this stage, and motivation was lacking in members who did not grasp the enormity of the task.
After various tests and meetings with professors, the general direction was decided for the system in late February and this clarified the group's direction. I feel that the group came together very well in the second half of the semester once it was clear that significant effort would be needed to meet the deadline.

Personally, my greatest accomplishment was designing a working two-layer PCB. It was a lot of work but well worth the result and learning experienced.

The complex nature of the project was a huge challenge in itself that required countless nights spent in the labs, and at times seemed too large a task to complete. Therefore, having a completed and working design (without the ability to walk) is the most rewarding feeling that I have experienced in my undergraduate degree. I realize the difficulty in designing custom-made mechanical and electrical systems and given this I am very proud of how far along we came. For future projects, I would create weekly meetings and progress updates for the

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

group. I would also increase transparency between members, such as electronic (PCB) design and mechanical design. I thank my group members for the opportunity to work together and any outside assistance that was received by us.

Pranav Gupta

ENSC 440 was perhaps the best learning experience in my undergraduate career. Our group had a strong background in mechanics, programming and analog circuits. Given this mix, the idea of building the ArachnoBot™ was extremely lucrative as it was highly suited to our skill set. The ArachnoBot™ required a sturdy but light mechanical structure, a custom PCB and efficient embedded programming given the enormous control task presented to us. The robot had to have six legs, with three joints, each joint run by its own motor, with a total of 18 motors.

Working on the robot was quite challenging from the start, looking for parts was difficult as we wanted to be able to prototype the robot on the breadboard, and then use the same parts in our final PCB. Interfacing between analog and high speed digital circuitry was tough as a slight noise in the analog circuits led to major variations on the digital circuit. Another major challenge was the group dynamics, as engineers, group members would get lazy impacting deadlines for the project leading to tensions within the group. As a group leader, I found it challenging to motivate the members and would often be forced to call them or email them repeatedly in case their task was incomplete. However towards the end of the semester, as the ArachnoBot™ took shape, the entire group worked day and night as a team to achieve the task at hand.

Besides improving on my leadership and interpersonal skills, I also improved upon my technical skills. Working with FPGAs, interfacing them with analog circuits was definitely a fun task and helped me work on analog skills. I feel that this experience would have been enhanced if I had worked on designing the PCB along with my fellow group members, but there was already enough on my plate as designing a 7 microprocessor programming system for the FPGA was a task by itself.

All in all I thoroughly enjoyed working on ENSC 440 and the time I spent on it was like an exponential learning curve

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

Daniel Naaykens

This has been the most complex project I have ever been a part of, and I am very proud of the progress we made in just 4 months time. The multifaceted nature of the ArachnoBot™ meant that there was something for each group member to apply their skill sets to, and provided a valuable opportunity to learn more specialized skills from the others as we progressed.

The greatest challenge we faced in the last four months was effective communication and scheduling. By the end of the project it was clear that we work better together as a large group, rather than apart in smaller sections, as without face-time, other group members would discount work that was not completed in their presence. This has been a rewarding experience and I am proud of how much I have learned in the last four months. I feel that the skills I knew in the beginning of the project I know much better now and I have picked up new knowledge along the way.

In closing, I'd like to thank Dr. C Menon and Dr. L. Shannon for their interest and direction in our project, and of course my group members, with whom I am proud to have worked with.

Stefan Strbac

In short, the past 4 months proved to be an awarding experience. From the outset, the hexapod showed its complexity, namely with very constraining specifications. These specifications required us to design a relatively sophisticated control system in a low weight and small sized package. Admittedly, we underestimated the importance of extrapolating every small change in our design to these specifications.

In my view, communication was the main, if the only, problem in the group but was taken as a good learning experience in group dynamics. By the end of the semester, communication between group members improved greatly and this helped in accelerating the project's progress.

I want to thank everyone who assisted us both technically and in their interest in our project, especially Dr. C. Menon and Dr. L. Shannon for their direction. With equal value, I want to also thank my group members who I had a great 4 months working with.

8888 University Drive
Burnaby, BC, Canada
V5A 1S6
778.893.3303

10. References

[1] ArachnoBotics Research Inc., *Functional Specifications of the ArachnoBot™.* Feb 8, 2010

[2] ArachnoBotics Research Inc., *Design Specifications of the ArachnoBot™.* March 11, 2010

[3] *XCM-016*, HumanData Ltd.
Available: http://www.hdl.co.jp/en/spc/XCM/xcm-016/index.html
[Accessed: March 22, 2010]

10.1. Photo References