GKS DIGITAL
1396 El Camino Drive, Coquitlam, BC, V3E 2W6
Phone: 604-789-6840
Fax: 604-467-8142
Email: inquiries@gksdigital.com

February 17, 2006

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

Re: GKS Digital Hydra Post Mortem

Dear Dr. Rawicz,

GKS Digital has completed the development of the functional prototype as specified in our proposal in September 2005. We have developed the prototype of the Hydra, an octophonic guitar pickup, that meets or surpasses the majority of the functional specifications for the first two product iterations.

At this stage in the project development, we must turn our gaze back upon ourselves and upon the project that has been completed. We must analyse how well the project met our commitments in terms of functionality, schedule and budget. We must also analyse our team, how we interacted, and what we learnt from the experience.

The post mortem report that you can find attached, *GKS Digital Hydra Post Mortem*, outlines this introspection and should provide you with some insight into how our project has developed and how we have developed as a team. If you have any questions, please contact me at eli.gibson@gksdigital.com

Sincerely,

Eli Gibson CEO GKS Digital

Enclosure: GKS Digital Hydra Post Mortem

cc: Mr. Steve Whitmore, Mr. Mike Sjoerdsma, Mr. Brad Oldham

Hydra

Octophonic Guitar Pickup

Post Mortem Report

Management Team: Eli Gibson, CEO
Kamil Kisiel, CTO & Marketing Manager
Derek Sahota, CFO & R&D Manager

Contact: Eli Gibson eli.gibson@gksdigital.com

Submitted to: Dr. Andrew Rawicz
Mr. Michael Sjoerdsma
Mr. Steve Whitmore
Mr. Brad Oldham
School of Engineering Science
Simon Fraser University

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Introduction

GKS Digital brought together a cohesive team of three developers. After fifteen weeks of development, and the creation of the first functional prototype, it is important to reflect on the project and the team.

This document outlines the status of the functional prototype, and how it compares to the original functional specifications for the prototype. It contrasts the actual budget and schedule with those outlined in the project proposal. Finally, it examines the interpersonal and technical development of the GKS Digital team.

The insight this document provides allows both external and internal evaluation of the success of the project, and allows the GKS Digital team to take away lessons for the future.

While GKS Digital was formed well in advance of September 2005, the concept and design of the Hydra Octophonic Guitar Pickup did not begin until September 24, 2005. Completing the Hydra in the 14 weeks we had before leaving for WEC 2006 required a tremendous amount of dedication and perseverance from the three members of GKS Digital. Despite personal difficulties faced by all of our team members, we managed to support each other and finish just in time for our key external deadlines. The functional operation of the Hydra matches closely with our stated functional specifications although our ideal prototype would be significantly different from our current prototype.

Current Prototype State

GKS Digital's product can be broken into two main components, the Hydra hardware and the Chimera software suite. The Hydra hardware is responsible for digitizing and transmitting the eight signals measured on the guitar: two magnetic pickup channels and six individual piezoelectric pickups, to a standard PC. Once the digital signals have been received by the PC, the Chimera software takes over. Chimera transforms the sound into several different formats depending on the application needed. More information about the state of the Hydra and Chimera will be given in the appropriate sections below.

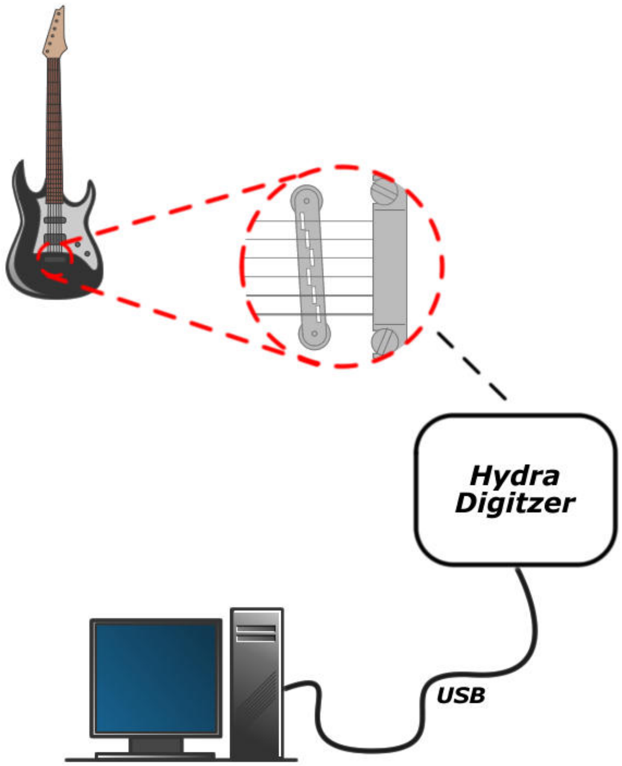

Figure 1: GKS Digital Hydra system overview

Hardware State

The Hydra hardware is currently in an early prototype state on a series of solderable breadboards. A signal acquisition and buffering breadboard has been placed within the body of the guitar, shown in Figure 2. Eight signal outputs, one for each pickup, leave the signal acquisition board and travel via a DB-25 cable to the Hydra prototype box. Only ground and +5 power are given to the signal acquisition board as inputs. The Hydra prototype box, shown in Figure 2, contains the analog to digital converters, the USB microcontroller development board and other supporting circuitry including flip-flops, buffers and clock generators. Besides the signal acquisition board, the only other input to the Hydra prototype box is a standard USB 2.0 cable with a +5V power line, ground line and two data lines. The hardware itself is fully functional to specification, however, the packaging is not in final form.

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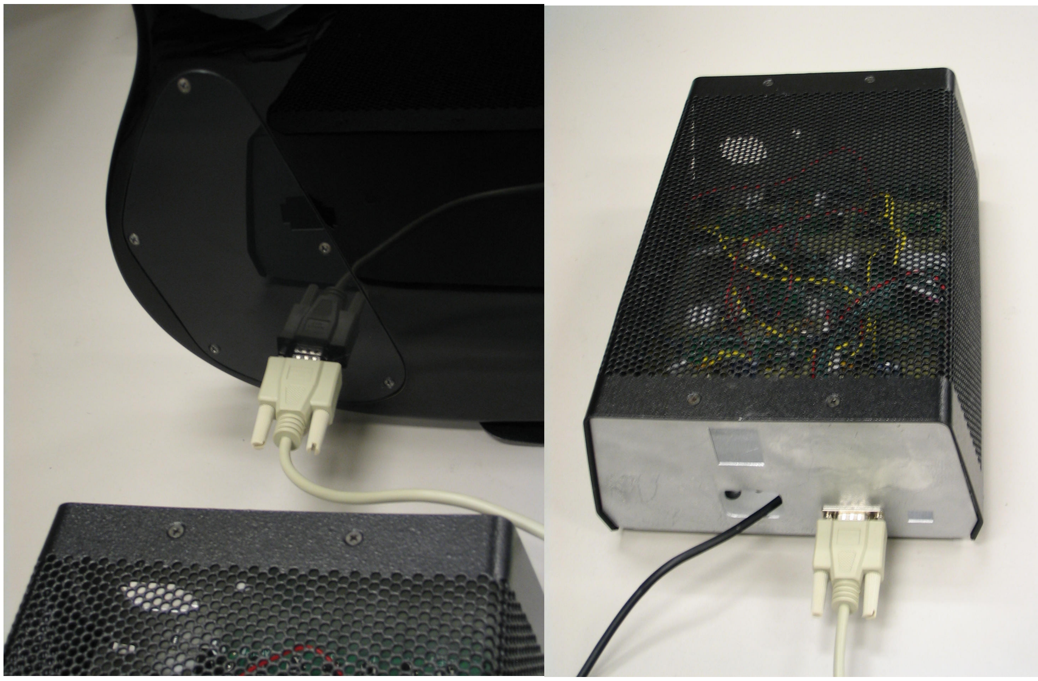

Figure 2: GKS Digital Hydra functional prototype hardware

Software State

The Chimera software is also in a prototype state, however, significant portions of the implementation are nearly production ready. Currently, MIDI, PCM and ASIO output are all currently possible through Chimera software which can interface to industry standard audio applications.

The Chimera prototype software consists of 5 components. The most basic component handles the data collection, by handling communication over the USB and processing the data into a usable form. This data can be used by one of 2 secondary components: the recording system, and the pitch detection system. The recording system allows the data to be recorded directly, or sent to a recording application using ASIO. The pitch detection system uses the YIN algorithm to extract pitch, volume and fingering information from the data streams. This data can be used by the MIDI output system to send MIDI control messages to external applications or to external hardware, or it can be used by the visualization system for instructional use.

One component of the functional prototype demonstration, consisting of the data collection, pitch detection and visualization systems, is shown in Figure 3

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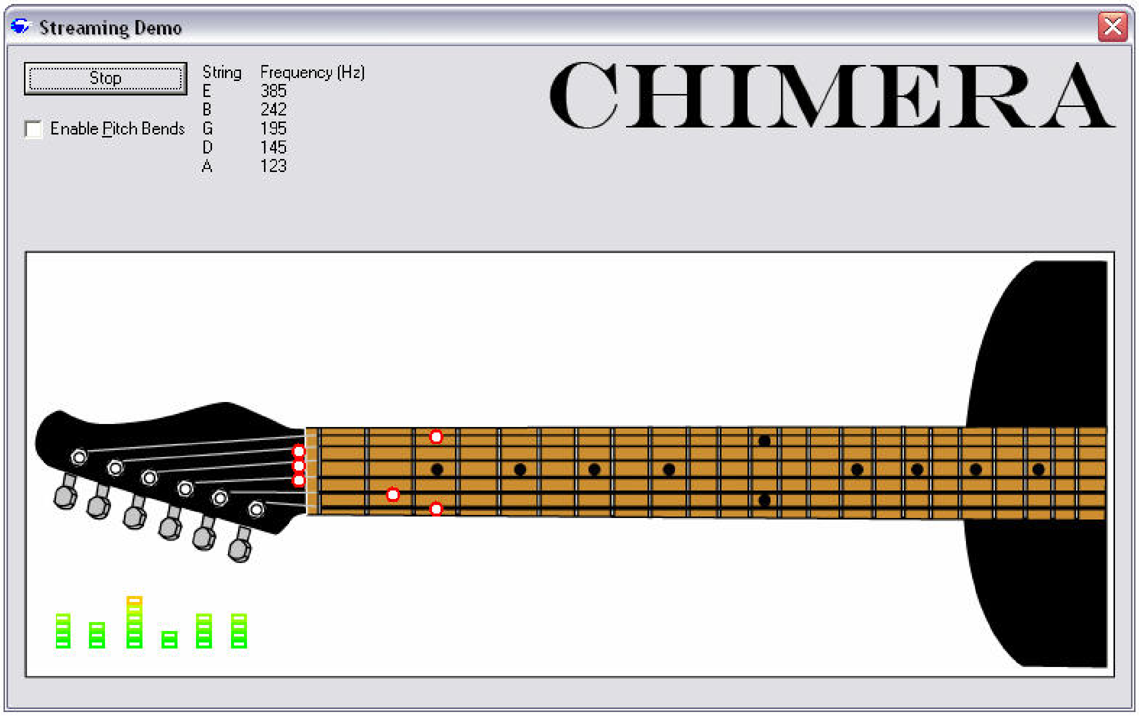

Figure 3: GKS Digital Chimera demonstration application screen shot

Deviations from Specification

There are two important specifications for the product development: the functional specification and the design specification. Due to our iterative design process, outlining the deviations from the design specification is a difficult task. The design document we submitted was a snapshot of an evolving document that was taken very near the completion of our current prototype hardware, making an analysis of discrepancies meaningless. Instead, this section will focus on the differences between the functional specification and our final product, as well as the differences between our initial conceptions, or misconceptions, of the Hydra system and the current prototype.

Overall Hardware

As mentioned previously, the current prototype hardware has been divided into two modules. While the specification for full integration into the guitar was only for our final product, we had envisioned that only a single board would be required for the presented prototype. Due to our iterative design methodology, our final design document very closely resembles our current hardware as the submitted document was a snapshot of our ongoing document.

Modeling

While our initial functional specification was vague on the implementation of the modeling software, the vision which we had in our minds did deviate. The current Hydra hardware and Chimera software actually meet all of the modeling requirements of the functional specification; however, much of the processing is being done through a 3rd party platform, rather than as a new plug-in as we had hoped.

The original hope of a sound transformation and modeling suite became untenable due to time and resource constraints. By early January it was apparent that without a sound studio and a version of the hardware on PCB, the desired modeling was simply not possible. An executive decision was made to reinterpret our functional specifications and shift our focus towards doing the modeling through MIDI. The effects of this change will be discussed in the following section.

MIDI

The most important aspect of the software for the prototype was its ability to demonstrate the advantages and strengths of the Hydra. While our first attempt to harness this power failed due to other resource constraints, we chose to satisfy the functional requirements with a different aspect of the Hydra's abilities. Instead of designing an effects toolbox for the Hydra, we built a pitch detection and analysis system. This system takes advantage of the Hydra's string by string input to create a MIDI guitar system that rivals or surpasses that of competitors. This system allows the Hydra to meet not only most of the 2nd iteration functional requirements, but also many of the 3rd iteration goals as well.

Future Work

Both the Hydra hardware and Chimera software are works in progress. As this post-mortem is being written, electronics design work is ongoing in several areas and new software applications are being sketched out and implemented. Some of the more significant areas of future work are outlined below.

Further Research into Modeling

The modeling potential through software still exists and still is an achievable goal; however, it is going to require a lot more resources. To begin with, studio quality records of acoustic guitars will be needed. The guitars will be recording playing a standard set of techniques and repeating over them to reduce any player induced characteristics. To get good acoustic transformation input data, we will need the final prototype of the Hydra hardware to minimize the effects of noise. With those two inputs, the final input is a significant amount of research time. This process simply requires a lot of mathematics, statistics and optimization that must be done by a dedicated team over a period of weeks to months and then refined over several years. A complete treatment of the problem and solutions would require a doctoral thesis on the subject.

Automatic tuning software

The Chimera suite currently contains pitch detection software that relies on the guitar being in tune to determine the fingering. There are two applications that should be added to this suite.

The first application is a tuning system to help a musician tune their guitar. While this has been done before, it is often difficult to tune using the acoustic signal. Tuning based on the vibration signals should provide more reliable results.

The second application is one that avoids the tuning altogether, by allowing the musician to calibrate their guitar's tuning at the beginning of a playing session. Once the calibration has been completed, the musician can pick any standard tuning and have the guitar play MIDI or audio in the appropriate tuning through software adjustment to compensate for the calibration.

Hydra Hardware Iteration 2.0

For a second development generation of the hardware, we propose fabricating two separate PCB's. The first PCB will contain the analog front-end and the analog to digital conversion circuitry. This PCB will only require two layers and be designed to fit within the guitar. The second PCB will be a mini development board containing the power circuitry and the USB 2.0 chip. This board will be rather expensive as it will require four layers. However, the board will be useful for other developers who want to use the Cypress USB 2.0 chips but who don't want the bulk of the full development board. The USB 2.0 board will not likely fit into the guitar so it may be placed in an external enclosure or attached to the outside of the guitar.

Hydra Hardware Iteration 3.0

For the third development generation of the Hydra hardware, the two separate PCBs mentioned above will be placed onto a single board for a complete system integration. The board will be small enough to fit within the electronics cavity of most electric guitars and will essentially be the final hardware version unless more problems arise.

Resource Issues

During the production of the Hydra we deviated from our budget and schedule specifications in some significant ways. These deviations and the motivation for them will be outlined in the following sections.

Budget

When we initially proposed the Hydra it was after only 2 days of research as a our previous idea had just been unveiled by Nintendo. As a result our initial budget was very rough and we ended up varying from the forecast significantly. Table 1 below shows both our original forecast and our current spending level on various line items.

Item	Original Forecast	Current Spending	Over / Under	Why
Guitar Body	$150	$150	$0	
Piezoelectric Pickups	$195	$485	$-290	Original purchase didn't fit
Prototyping Equipment	$310	$845	$-535	Bad dev kit advice, extra prototyping boards
Signal Path Electronics	$60	$63	$-3	
Miscellaneous Electronics	$65	$62	$3	
PCB Fabrication	$300	$0	$300	Decided against due to cost for 4 layers and time
Soldering Equipment	$0	$140	-$140	The school doesn't provide what they should
Net	$1080	$1745	-$665	

Table 1: Budget analysis

Four key line items stick out when examining budget differences: the Piezoelectric Pickups, the Prototyping Equipment, the PCB Fabrication and the Soldering Equipment. Each of these line items will be discussed in detail.

The initial order for the piezoelectric pickups was for a set of L.R. Baggs pickups ordered from the U.S. as the gross cost was far cheaper. Despite the assurances of the sales team and the technical information from L.R. Baggs, the pickup was slightly too small for the guitar. As switching guitars was an even more expensive proposition, we researched some more and found a modular system by Graph Tech that would fit the guitar and purchased it. The end result was a $290 cost overrun due to the extra purchase.

The prototyping line item is the most significantly over budget but again this was due to external constraints. The key extra expenditure here was an additional $450 above and beyond the budgeted $200 for a USB 2.0 development kit. The more expensive kit was purchased as a requirement to get funding from the ESSEF. An additional $80 in overruns related to prototyping occurred mostly due to building of a case and the ordering of extra prototyping boards. We initially planned to demo a product on a PCB; however, due to constraints mentioned several times, we were unable to do so and had to modify our spending accordingly.

As mentioned before, the PCB was not fabricated due to time, money and resource constraints. The money budgeted towards the PCB was spent on prototyping and soldering equipment.

A totally unexpected expense was for a significant amount of soldering equipment. While we do recognize that the School of Engineering Science technically does give us access to soldering equipment, there is a significant difference between access and usability. Due to our iterative design process, we would often need to use the SMT soldering station on a few days notice; however, use of the school's station realistically needed a few months notice. During the semester the following problems were noted: the light stand was broken, the solder sucker did not operate, the magnifying lens was distorted beyond use and the small SMT tips were burnt beyond use. All of this forced us to make some capital purchases that we in no way regret; we could never have finished the project if we had any dependence on SFU for soldering equipment.

Lessons Learnt

Our budgeting issues taught us several key lessons. First, despite due diligence and background research, third party parts can still come in and not meet specification. When purchasing expensive parts that need to meet stringent specifications, like the piezoelectric pickups, an extra contingency budget line item should be established with an assigned amount that is directly related to probability of cost overruns. Second, never depend on third parties for shared resources. Finally, we learned that budgeting for iterative development is hard and that either more design selection must be done before doing component procurement or larger contingency funds must be established.

Scheduling

The schedule implemented during this development process differed significantly from the schedule initially proposed. Shortly after the proposal, the development team sat down to discuss design methodologies. We decided that the pseudo-waterfall schedule that was proposed would not allow us to complete the design in sufficient time, and would put us at a risk of not having a demonstrable product for the Western Engineering Competition, should we run into scheduling overruns. Instead, we chose to use iterative design, meaning that multiple iterations of the product, at various levels of completeness would be implemented. This has 2 major advantages: first, we would be able to discover incompatibilities and quality problems early in the design; second, we would have a demonstrable prototype even if we ran out of time.

Figure 4 shows the comparison between our proposed schedule, in blue horizontal marks, and our implemented schedule, in red vertical marks. While the implemented schedule seems to take longer to accomplish each task, the work for each task is in fact sparser, as design specification, implementation and integration are done once per iteration.

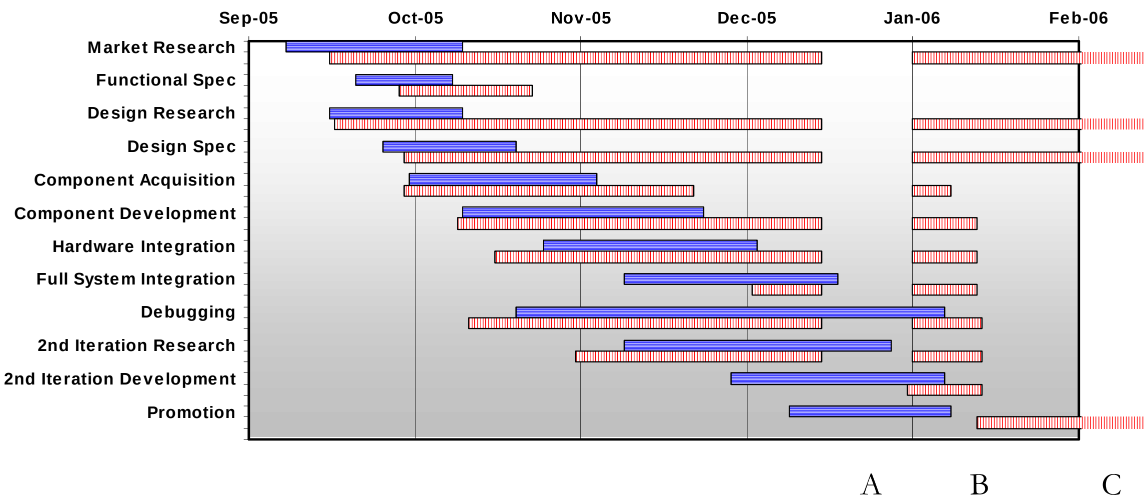

Figure 4: Prototype development schedule: proposed (horizontal stripes) and actual (vertical stripes).

There are several key points to note in our schedule. Point A shows the 17 day break that was taken in late December, which was necessary to prevent burnout from the combination of project work, other course work and personal difficulties. Point B shows the critical marketing deadline for this project, which was met with an impressive functional prototype. Point C shows the activities that continue to be ongoing, as we prepare for the next stage of development.

Lessons Learnt

Despite the success of our scheduling, there are several lessons to take away from this project.

The most significant mis-scheduling was the lateness of the iteration that first allowed data recording. Because we could not begin detailed research or implementation of the modeling software until we had at least one high quality recording of the output, the research period was overly constrained. Had we rearranged the design iterations to aim for a minimally working device earlier in the design schedule, we would have had more time for the software implementation.

This led to a second difficulty. As mentioned earlier, because of time constraints, as well as the advanced nature of the modeling that we were attempting, the results that were achieved by early January were not acceptable. We were forced to make an executive decision to abandon that form of modeling, and replace it with another aspect of the software capabilities of the system. While the team came together well to implement the new software system in time for the critical marketing demonstrations, it was a difficult decision and a risky gamble. The lesson to draw from this is the importance of analyzing the state of current tasks to be able to recognise when to cut losses as soon as possible.

Finally, there was some difficulty with internal deadlines. Due to the odd schedule of our projects compared to those of other ENSC440 groups, our deadlines were less strict than those of other groups. Because of this flexibility, and because of the heavy schedules of our team through the development process, we often found ourselves renegotiating deadlines with our stakeholders. The most significant example of this was the design specification, which was delivered as a snapshot of the active design at the time of demonstration, as opposed to an apriori design document. While this submission did suit our iterative development methodology better, it was not the document that was initially committed to in the project proposal.

Interpersonal and Technical Experiences

Eli Gibson

Eli Gibson is the Chief Executive Officer of GKS Digital and a fifth year Computer Engineering Student.

Technical Experience

While I have extensive experience in software development, it has focused primarily on end-user programming. This project gave me the opportunity to adapt my software skills for the development of low-level drivers and firmware. These software domains have constraints and methodologies that are very different from end-user programming. This experience has allowed me to broaden my software toolset, and has given me a new perspective on development.

The most evident set of skills I have developed over the course of this work is the debugging and testing of software systems without access to a debugger. I have accumulated experience with testing-by-data analysis, and firmware testing using an oscilloscope.

Although I was not the primary hardware developer, I also developed extensive skills in hardware development as I helped with assembly and debugging of hardware components while helping other team members. I have developed hardware soldering and debugging skills that I had not previously had the opportunity to develop.

Interpersonal Experience

As nominal CEO of GKS Digital, the personal interactions of our group were very important to me. I have the pleasure of being able to report that I have never worked with a group as cohesive and supportive as GKS Digital. GKS Digital completed an ambitious project in an even more ambitious timeline, without any interpersonal difficulties. All three of our group members were faced with intense project work and heavy workloads outside of the project. On top of that schedule, each group member has had significant personal challenges to handle.

GKS Digital was able to maintain open communication throughout those challenges, and consistently came through with support when it was needed. Our group dynamic allowed us to succeed in the face of the challenges we faced.

Kamil Kisiel

Kamil Kisiel is the Chief Technical Officer of GKS Digital and a fourth year Computer Engineering student.

Technical Experience

Coming from a primarily software-oriented computer engineering background, I did not have much experience doing actual hardware design. Our original proposed project was more software oriented than the one we ended up creating, but when it was scrapped I didn't have much choice but to take on a hardware design role, as I was the one who had the most experience with using pro audio hardware.

During the course of the project, I picked up many valuable skills, the first of which is being able to take a concept in my mind and through consultation with other potential users turn that concept in to a functional specification that can form the basis for an actual project.

Our project was based around the principle of iterative design, a concept I was quite familiar with from software development; however, it was the first time I had attempted to apply it to a hardware design. This, coupled with the fact that it was our first time attempting to create a mixed analog / digital design from scratch, and using a high speed interface such as USB 2.0, presented many challenges. In the end, I believe our design was more than able to meet standards we had set out and it was a great learning experience. In particular I was able to explore the extremely wide variety of components available for our purpose and learn to balance a variety of constraints such as power and size to develop the best solution.

Finally, since I spent so much time in assembling our prototype, I picked up a lot of hardware assembly skills, such as how to solder surface mount components, and lay out a prototype design that is flexible enough to allow a fair degree of experimentation with the components to finalize the design.

I found the process of creating this project an extremely valuable experience and I'm certain the experience gained will help me with my future projects.

Interpersonal Experience

2005-3 was originally supposed to be a light semester for me as I had intended to focus primarily on working on the project. However, with my acceptance in to the co-op Japan program and a 1 year co-op term there possible, I had to take on a much higher course load than originally anticipated in order to meet a reasonable graduation date. I was enrolled in 12 ENSC credits as well as a 4 credit CMPT project course in addition to working on the project, something which stressed my working and time management skills to the limit.

Unlike my other projects at the time, at no point did I feel that anyone in our project was not pulling their weight and whenever any one of us was having any problems, either academically or personally, the other members stepped up to carry the load and keep the project moving. I never felt let down by the quality or amount of work put in by our group. I believe I can claim without hesitation that this is the best and most successful project group I have ever had the fortune to be a part of, and I hope that any of my future projects could be like this one.

Derek Sahota

Derek Sahota is the Chief Financial Officer (CFO) of GKS Digital and a fifth year Engineering Physics student.

Technical Experience

From a technical standpoint, I came into this project lacking a significant amount of the hardware knowledge needed to complete the project. One of my initial key responsibilities became finding and sourcing parts, as well as working with Kamil to design and assemble circuits. During the course of this work, I honed my soldering skills, both through hole (which we did a lot of on solderable breadboards) as well as surface mount.

The other side of my work on the Hydra was in algorithms and modeling. I'll begin with algorithms because that is what really made the Hydra work. I had no prior experience with algorithms for pitch detection and had to do a significant literary study before I found the YIN method we ended up implementing. While I certainly could have hacked together a Fourier domain peak search method, Fourier methods simply were not sufficient for our needs. The algorithms research gave me a chance to practise my Matlab skills and also to use simulations to test various algorithms.

While I could continue on into the many other minor areas I gained experience in, the honest truth is that the technical experience I gained on the Hydra was the main contributing factor in gaining me a senior R&D assistant's job in the audio processing field. This fact alone speaks volumes to the amount of technical knowledge I've gained in barely four months of working on the Hydra.

It should also be noted that I managed the finances, budgeting, procurement and general administration tasks of GKS Digital. While these tasks are not hard, they did consume a reasonable amount of my time and were certainly a contribution to the group. I do feel that I gained a taste of what it would be like to be running a start-up company without a dedicated financial professional and, given my career goals, that experience is also very valuable.

Interpersonal Experience

Part of the reason we undertook such an ambitious project on such a tight time schedule was because the G, K and S in GKS Digital are able to work extremely well together even under the most stressful circumstances. Whether it was the marathon 40 hour poster preparation session before WEC, the 3am presentation rehearsals or the all night debugging sessions, the three of us were able to work co-operatively as a team without getting overly frustrated. In my case, I went through a particularly emotional December due to external issues relating to my family. Whenever I couldn't make a deadline or needed to push something back, Kamil and Eli were there to help out and support me. We truly worked together as a team and our cohesion and individual understanding of others' difficulties were key components of our success.

Conclusion

The GKS Digital development team has successfully completed the functional prototype within the constraints of our key marketing deadlines. The team has met with few exceptions the functional specifications set out for the project, and where there were discrepancies, was able to create equivalent functionality.

The reaction to the product speaks for itself: dozens of musicians have come up to demonstrations of the Hydra prototype with looks of amazement in their eyes. From beginning guitarists to electronic music aficionados, the Hydra offers significant improvements in functionality, cost and ease of use over currently competing solutions.

The GKS Digital team was able to work together or apart effectively, efficiently and without complaint, despite the significant technical and personal hurdles we had to face. We have developed technically, and as a team. The experience gained from the design of the Hydra will last the entirety of our engineering careers and will provide a valuable cornerstone in the base of knowledge that will enable us to become effective engineers