April 15, 2007

Lakshman One
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
Canada

Re: ENSC 440 Post-Mortem for computer input device

Dear Dr. One:

The attached document, *Post-Mortem for a Handheld Computer Pointing Device (SmartPoint)*, outlines the Post-Mortem for ENSC 440. We have built a prototype handheld computer pointing device that moves the mouse cursor as the device moves in the corresponding direction, which enables users to operate in situations where flat surfaces are not available.

This document will describe the current state of our device, and potential future modifications. We will also discuss the challenges during the implementation of our device, our project timeline and our budget analysis. Finally we will conclude this document with our own inter-personal experiences in building the SmartPoint.

Pointex consists of 5 motivated and dedicated senior SFU Engineering Science students: Frank Chen, Donavan Ho Sui, Randall Lim, Jeff Wong, and Kevin Yang. We can be contacted by e-mail at *ensc440-group-16@sfu.ca*.

Sincerely,

Frank Chen
CEO
Pointex

Enclosure: *Post-Mortem for a Handheld Computer Pointing Device*

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Post-Mortem for a Handheld Computer Pointing Device

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Submitted to:
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>	Steve Whitmore – ENSC 305
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List of Acronyms

CAD: Computer Aided Design

CSA: Canadian Standards Association

EMI: Electromagnetic Interference

EMS: Electromagnetic Stirring

FCC: Federal Communications Commission

FPS: Frames per Second

IEC: International Electrotechnical Commission

LED: Light Emitting Diode

OpenCV: Open Computer Vision

PC: Personal Computer

RoHS: Restriction of Hazardous Substances

USB: Universal Serial Bus

UL: Underwriters Laboratories Inc. (Standards for public Safety)

1. Introduction

For the past thirteen weeks, Pointex has strived to put together the SmartPoint computer pointing device. In this prototype stage, our main focus is on technical feasibility, and understanding the competition of similar products in the market. The current state of our device consists of four subsystems: The webcam subsystem, and handheld remote subsystem, the software subsystem and the rechargeable dock subsystem. Tasks were delegated according based on each team member's strengths. Having completed a prototype to prove the feasibility of our idea, we believe that given the conditions we do have a very big market for our product.

In this document we will discuss in detail the current state of our device and potential future modifications. We will also cover our project timeline and budget along with any challenges we encountered along the way. Lastly we will conclude the document with individual experiences and reflections from each Pointex member.

2. Current State of the Device

2.1 Web camera subsystem

In our current state, we have tested our device with both an integrated laptop web camera and an external USB web camera. The frame rate of capture for both these cameras is set to be at 30 fps (frames per second). Although this is the maximum hardware capability, OpenCV has not implemented a function for adjusted the frame rate when you run a web camera through Microsoft Visual Studio. Therefore, our prototype is operating with a web camera frame rate of 10 fps. The only other external item we need is the IR filter over the web camera lens to filter out all other light in other wavelengths.

2.2 Handheld device subsystem

Our current prototype consists of a handheld device with both the left click function and the right click function button implemented. Asides from the 2 buttons, our device consists of 5 infrared (IR) LEDs and 2 standard LEDs. The 5 infrared LEDs are use to distinguish the operation and orientation of where the mouse cursor will be. The two modes of operation (Drag and Tilt) use different number LEDs on the SmartPoint.

2.2.1 Drag Mode design

In Drag mode, only 1 LED is used for mouse movement tracking and 2 extra LEDs are used for the left and right click. The reason we used 1 LED in this mode is because there are no complex trigonometric calculations required to move the mouse cursor. Using only one LED also speeds up the processing time of each frame because there is less to detect and calculate. (See Drag Mode in the software subsystem for more detail)

2.2.2 Tilt Mode design

In Tilt mode, all 5 IR LEDs are used; 3 LEDs are used to distinguish mouse movements, and the 2 extra LEDs are for left and right click. The placements of the 3 position tracking LEDs are important because of the way we implement the math in this mode (see the Tilt Mode section in the software subsystem). A picture of the LED positioning is shown below. Essentially, for every angle in 3D space the handheld is oriented at, the camera will see a unique pattern formed by the 3-LED array. To achieve this, the 3 LED's were aligned in a row, with the center LED protruding outwards slightly, forming a plane in 3D space. The only limitation that this configuration has is that horizontal tilt is functional until the center LED begins to overlaps one of the side LED's on camera.
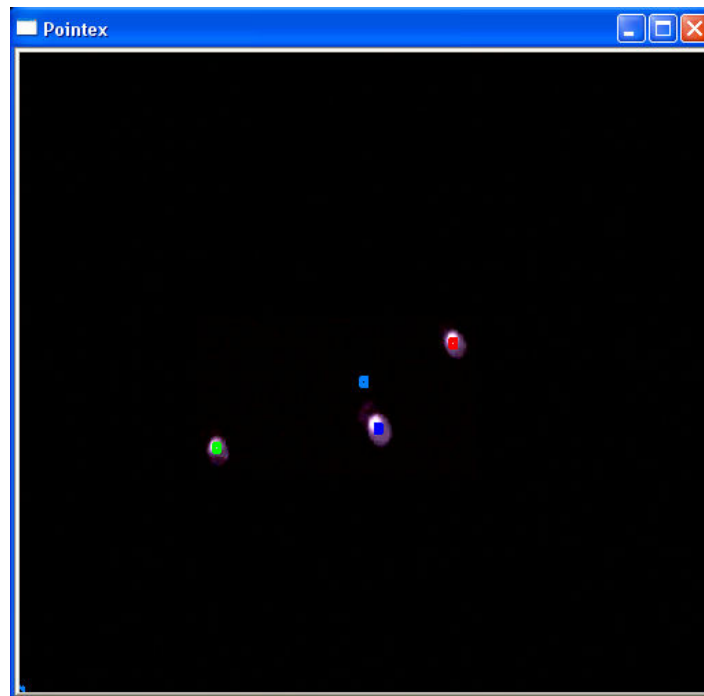
2.2.3 Power/Mode LEDs and Switches

The red LED tells the user if the SmartPoint is either on or off and the green LED distinguishes between Drag mode (LED off) and Tilt mode (LED on). 2 switches are on the SmartPoint for turning on the device and switching between the 2 modes.

2.3 Software subsystem

This is the most complicated subsystem in this project. We used OpenCV (Open Computer Vision) libraries to help us communicate with the web camera. With OpenCV we programmed our software using C++. This subsystem consists of Drag Mode, Tilt Mode, Background subtraction and finally software packaging.

2.3.1 Drag Mode

The reason we use only 1 LED for mouse movement is because we are taking the absolute movement of the SmartPoint to the mouse cursor on the screen. In other words, where you are pointing on your webcam will be translated to where you are pointing on your desktop. Of course web cameras today do not have resolutions to match the monitor, therefore we factor in a monitor to web camera resolution ratio for this to work properly.

2.3.2 Tilt Mode

The reason why this mode requires 3 LEDs is because we wanted to make our device move the mouse according to the orientation of the device. In another words, to move the mouse cursor, you would not need to physically displace the SmartPoint but rather "tilt" the controller to the direction in which you would like the mouse to move. This mode would require less physical movements for the user to operate our device.

This technique works by measuring the distances of the LED's as seen on camera, and using these quantities, triangulating the exact position of the point on the display where the handheld is pointing. Hardware limitations played a huge factor in accuracy and precision, as insufficient camera resolution quantized the movement of the cursor on the display.

The vertical Y-axis of tilt is substantially simpler to calculate. However, it has the limitation of excessive sensitivity as the handheld gets tilted lower. This is caused by inherent large changes in some trigonometric functions for small inputs.

While mounting the camera on the handheld while attaching LED's to the display like Nintendo's Wii has the advantage of accuracy and precision, one of the primary ideas behind the role reversal in our method is reduced power consumption, electronic simplicity, and the lack of the need of wireless RF communication

2.3.3 Background Subtraction

The current version of background subtraction is fairly accurate in removing any background infrared lighting such as lamplights, sun, and any other static IR sources. It operates by storing an initial frame upon program startup and assumes that all bright pixels picked up by the web camera in this frame are static lighting. It then uses this frame and subtracts this frame with all other subsequently captured frames. Furthermore, by setting a pixel value threshold after this operation, the program is able to distinguish the differences between the LEDs and the background noise using this algorithm.

However, it is somewhat limited in the sense that the initial frame only captures background lighting and that the user is not operating the device during program startup. Furthermore, if any of the background lighting moves to a different location the program will be unable to compensate for this difference and the user has to recapture the background lighting by pressing the "b" key during program execution.

2.3.4 Software Packaging

Although this initial prototype is meant for a feasibility study, we still wanted to create a package to give more of a polished and completed product meant for wide scale distribution. The program we used to package our software is a freeware called NSIS (Nullsoft Scriptable Installation Software). It is a script based software with a wide range of functions for all your needs in an installation file. Software you may be familiar that utilize this packaging product right now include Mozilla Firefox, Winamp, DivX and many more. Having packaged our software into one neat installation file with all the required library extensions and runtime libraries makes this project look that much more professional.

2.4 Rechargeable subsystem

The rechargeable subsystem consists of a Lithium-Ion battery rechargeable controller chip by Microchip Technology Inc. that is meant to monitor the recharging cycle, along with four capacitors to create a more steady voltage input used for charging up the battery. The controller is specifically meant for recharging Lithium-Ion batteries and thus reduces the risk of any fire hazards or explosions caused if the battery is charged in an appropriate way. The circuitry continues to charge the battery until either the battery is fully charged and also has LED indicators to notify the user when the charge cycle is complete. The approximate time to fully charge a depleted Lithium-Ion 850mAh cell takes about 1 hour and 30 minutes. With this short amount of charge time required and long battery life, the user will be less likely to have the SmartPoint run out of power as the device can operate for 50 hours on a single charge.

3. Design/Integration Challenges

3.1 Overall Integration

The main challenge for our project integration is keeping up with the timeline. An important thing we learned from this project is that it is really hard to put a time frame around research and coming up with a solution to a particular problem. A lot of our initial ideas had to be modified to maximize the utility of our prototype. Another issue is the project dependencies. Certain parts of our software could only be properly tested given that the previous part works. Again, this adds to keeping up with our project timeline.

3.2 Handheld Controller

3.2.1 Circuitry

From the initial concepts of the controller to the first controller prototype to the second, there was very little change in the controller in terms of functionality. However, a further

evolution to a third controller would entail many differences. The first challenge from concept to prototype for students is not knowing what resources are available to you. With that, it becomes difficult to get a mental picture of what realistic possibilities can be achieved. However, once researched in a certain area, a prototype can be conceptually conceived and then implemented into a design.

3.3 Software Design

Initially we explored many different ways which may accomplish our goal. We looked into shape detection and motion detection before landing on our idea of detecting IR LEDs. Originally we tested moving the mouse cursor based purely on motion. We set a reference point on the web camera where our device showed up to be and correlated the movement of the mouse cursor to the movement of the device. What we found was that when you move the device too fast in any direction you would lose track of the reference pointer. Next we tried moving the cursor using shape detection. We found that using this method it is really hard to have a consistent and reliable detection. Depending on the background condition, you program may pick up many other objects in the background that have similar shapes. Finally, we decided detecting LEDs using the web camera. But in order to detect these LEDs reliably, we needed to filter out the background the web camera would pick up to eliminate any confusion to the program. Hence we settled on using an IR filter over the web camera's lens along with IR LEDs on the SmartPoint to accomplish this task.

3.3.1 Bright Point detection

When we first successfully implemented Bright Point detection, we ran into a few problems. First of all, depending on the distance you at to the web camera, the size of LED captured would be different. Because we are scanning the screen for the brightest pixel, this point fluctuates very randomly as there is no way of distinguishing between each pixel in the LED. As a result, the mouse would move randomly as you move closer to the web camera. To fix this problem, we implemented the physical average of the LED by summing all the pixels past a certain color threshold captured by the web camera and dividing by the total number of pixels detected. This gave us a far more static and consistent point of detection as a mouse cursor reference point.

3.3.2 Multiple Bright Point detection

Another problem we encountered was when we took our concept of taking the average of an LED and implementing it into detecting multiple LEDs. First of all, simply just taking the physical average of a bright point when the web camera picks up multiple LEDs would give you an average position of all the LEDs. This is no good because this means the mouse cursor will jump every time we execute our clicking operation which requires the use of more LEDs. At first we came up with the solution to mask a region of the LED detection and ignore that specific region in the next scan. Using this method we did manage to detect the whereabouts of all the LEDs detected by the web camera. But

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another problem arises from this solution; we didn't have a way of distinguishing each LED from the others. We needed to set a certain LED as the reference point for moving the mouse and this point needed to be consistent. The final solution to this problem was we looked for displacement gaps in the x and y axis as we scanned through each frame. In another words, we separated each LED based on their x and y displacement from each other. Using this method and applying the proper conditions, we are able to locate a static reference point when the web camera picks up multiple LEDs. Based on some time constraints, we were only able to implement this to our Drag Mode.

3.3.1 Drag Mode

When we implemented this we found out that the mouse cursor response was a little too sensitive to the user's motion with the SmartPoint device. It was rather hard to hold the device perfectly still and the mouse would shake and jump around slightly when you shake your hand so it was really difficult to operate the clicking and dragging operations. So to compensate this we set up a region of error where the mouse cursor would not move until the user moves past this region. A trade off to this is obviously the true resolution of our mouse movement area. But we found that when we implemented this it was clearly much easier to operate the SmartPoint.

3.3.2 Tilt Mode

Tilt is by far the most mathematically rigorous software module to design. For the most part, tilt is essentially drawing out a diagram for X and Y axes, and figuring out angles using simple geometry. The resulting intermediate mathematical relationships for each axis then must be merged into one master equation for the computer to take care of. The real design challenge was the equation merges and finding cursor screen displacement for both axes as a function of the measured quantities in each camera frame.

3.3.3 Background Subtraction

Background subtraction could have been accomplished through a various number of methods, such as implementing motion detection, shape detection, bright pixel detection, or initial frame capture (which is currently being used). We had originally used motion detection to determine where the controller was. It was very effective in removing all unwanted background noise, however we ran into the problem in the case of when the user holds the SmartPoint in a static position. As a result, the position of the controller would be lost during certain frames as the program is unable to distinguish the controller from background lighting. Thus, we switch to the initial frame capture technique whereby the program captures an initial frame (assuming that the user is not operating the controller) and subsequently subtracts this frame with all future capture frames. This is another effective method but is limited by any change in the position of the background lighting. Every type of background subtraction algorithm has its advantages and disadvantages and based on the way the controller is being operated, we can further improve upon this algorithm such that there is a constant updating in the position of the background lighting.

4. Future Plans

4.1 Handheld controller

4.1.1 Controller Casing

Definitely in the future we will design a much more user friendly casing for our SmartPoint device. We would need to design this casing to fit the natural shape of a hand and increase the size of our mouse click buttons so it is more easily accessed. We will also make the whole controller smaller to make it more portable for travelers.

4.1.2 Functionality

Functions to add to our device will definitely extend to implementing the scroll wheel. This will make it much simpler for users to browse websites while relaxing at a distance away from their computer.

4.1.3 Circuitry

The power source currently used limits the amount of power at the output, thereby limiting the amount of IR "light". This directly relates to the range of the device, from the camera. More power means the device can be operational at a further distance. Therefore, a couple things may allow the device to reach a further distance. The first change would be to add a larger voltage power source with a decent maximum current output. This would increase the available amount of power we could use to light the IR LEDs. The second, since increasing power flow through the LEDs increases temperature and probability of breakdown, adding heat-sinks to IR LEDs would increase LED life and lower the chance of defecting the LEDs.

4.2 Software

4.2.1 Graphical User Interface

Due to some time constraints we did not have time to create a good software interface for our users. In the future this will definitely be implemented to enhance the user's experience when using our product.

4.2.2 Background subtraction

Distinguishing the background lighting from the IR light being emitted from SmartPoint during all modes of operation requires a more extensive code that is able to continuously identify where the positions of background lighting are. Unlike, the current version of background subtraction where the program only captures a single initial frame and applies it to all future frames, the future version of the program would be required to

match the locations of the background lighting with the previous frames and determine if it should store the new values of these position, or not store it and assume that this change in position is caused by the LEDs from SmartPoint. It would require the use of matrices and linear algebra in determining the causes of the lighting change, such as the laptop moving and not the background lighting itself.

4.2.3 Tilt Mode

I believe the only way to reduce quantization and increase speed in the mouse movement without resorting to using Nintendo's reversed camera-LED system, is to boost camera resolution and frame rate. This will undoubtedly require a more powerful processor, which will also undoubtedly be available in the near future if Intel and AMD continue to follow their projected product roadmaps.

Algorithm-wise, the system can afford to have mathematical approximations rather than precise trigonometric relationships in order to reduce computation time.

4.3 Web camera

Web cameras will definitely be improved as technology progresses. As the resolution and frame rate of capture increases there will be less error to compensate for in our software. Also the distance of operation of our device can potentially be increased significantly based on the web cameras resolution.

4.4 Rechargeable system

4.4.1 Design

In the future we can look into making the USB rechargeable dock have a detachable USB plug to attach onto the SmartPoint device to recharge for traveler's use. We will also be able to change the casing of our rechargeable dock so it will be smaller and more portable.

4.4.2 Circuitry

The rechargeable circuitry can be switched to recharging a Nickel-Metal Hybride battery instead to reduce the cost of a Lithium-Ion battery. The reason for this is because the SmartPoint only requires 10mA of current during normal operation and it does not require an existing battery life of 50 hours since the user can place the device in a charging dock when they are not using it. By using a Nickel-Metal Hydride rechargeable circuit, we can cut the high cost of a Lithium-Ion battery by 50% while still allowing a great performance in the user's perspective.

5. Budget and Timeline

5.1 Budget

The initial planned budget was set at about $320 which also included a contingency cash amount of $100. This contingency cash was to offset any extra cost incurred that we did not foresee as we did not have an exact idea of the specific models and parts we needed to purchase. By the end of the semester, we were on target with our predicted budget and spent slightly over half of the estimated budget, with a total cost of $186.50. This cost was split between the creation of the charging dock, and two prototypes of the controller. Taking into account that the Lithium-Ion battery itself costs $40, the actual cost of creating a controller are significantly less. Furthermore, if we were to take our product into the manufacturing stage, we can further reduce the cost of our device through more optimized design, use of cheaper parts that accomplish the same purpose, and also through the economies of scale. We reasonably estimate that our product can be manufactured at a cost of $25-$30 including the charging dock and Nickel-Metal hydride battery replacement.

5.2 Timeline

The figure below shows our project timeline for this project. Note that since our project idea did change from what we originally proposed, we needed to create a new project timeline. As you can see we started implemented our project using web cameras in the second week of February. The time before that was originally used for researching other potential methods of developing a handheld computer pointing device.

After settling on a method of development the project came along relatively smoothly. A lot of time in beginning to middle of February was spent on learning OpenCV and brushing up on C++ skills. Many different methods of software implementation and hardware design were delegated to each group member and our first milestone was reached near the end of February.

As you can see from the milestone chart tasks were completed on a weekly to biweekly basis until the beginning of April. The last week from April 3rd to our presentation date on April 10th was used for final product debugging and tweaking along with our presentation preparations. Although there are a few things we could modify in our project as listed in our future plans, we were quite happy with our overall project progress.
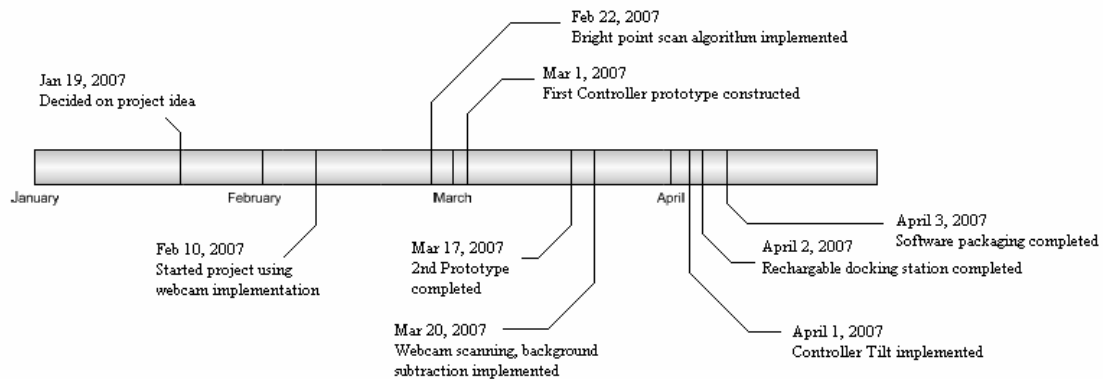
Figure 1: Pointex Timeline (Key Milestones)

6. Personal experiences/reflections

Frank Chen (CEO)
Completing this project has definitely been an extremely rewarding experience. I can still remember the anxiety early on in the semester when we ran into design issues and when we didn't think we could meet the project deadline. After a slightly rocky start, reaching that very first milestone definitely lifted a lot of the initial pressures off my chest. Upon improving on a solid method of development really made me feel like the project was heading in the right direction.

Being a little rusty with programming initially, I really had to pick it up along with doing research for our project. On top of relearning C++, I also learned to implement OpenCV libraries to our project. I also learned a lot about web camera specifications and limitations when it comes to operating as something other than just a camera. My main part in the project involved working on multiple bright point detection, which is the SmartPoint's foundation of operation, and implementing the Drag mode function of our device. A big portion of time near the end was spent on understanding and creating a proper software installation file which could potentially be distributed when we market this product. I believe these software knowledge will definitely prove to be helpful in my engineering career.

Asides from the technical skills, I gained extremely valuable experience when it comes to project planning and delegating tasks within a team. Our team consists of hard working members with different skill sets so they made the task assignment part of my job relatively easy. One very important thing I learned from this project is that it is really hard to put a time frame around research. Sometimes I find that it is a lot of pressure to

need to come up with a solution to a problem in a set project timeline. Running into technical difficulties and device limitations in implementing a solution also puts the project behind really easily. Having gone through all the phases of a project from planning and designing to building and coding, I definitely learned how to make more accurate judgments when it comes to creating a realistic timeframe for project milestones.

Finally I would like to thank all my fellow Pointex members for contributing a great amount of time and effort to this project on top of other school work and obligations. I would also like to congratulate everyone on a job well done. I had a really great time working as a part of this team and I hope we will have more chances to collaborate in the future.

Kevin Yang (COO)
For the past 13 weeks, I have learned how to analyze meaningless image data and to utilize it to accomplish my tasks. My main tasks are: bright point detection, increase the accuracy of the bright point detection, mouse events, and I worked together with Frank on multiple bright point detection and the drag mode.

In addition, I have become familiar with the software program we used for this project. I have become much more familiar with the programming language C++ than I was before, because our project is mainly based on it. Besides C++, we also utilize the OpenCV library to assist us in the image analyzing process.

Interpersonally, I have learned how to work in a group. This group project is much more different than working on a lab in a group. For this group project, it requires excellent communications between every group member. I have learned that communication requires both talking and listening and when you are only doing one, you are not a good communicator. Furthermore, compromising and understanding are also important because everyone is entitled to his opinion and will feel more involved when their ideas are included in the design.

Randall Lim (CFO)
Coming into this semester with very little C++ coding experience, I had learned a great deal about coding both efficiently and correctly in C++ with the use of online tutorials and sample codes. A great part of my learning was being able to understand just how we could utilize an external peripheral device, a web camera in this case, and integrating it with the users input, that being the physical movement of the SmartPoint. For the most part, I was mainly responsible for the background subtraction algorithm, and also the designing of the rechargeable circuitry. Through both of these tasks, I was exposed to both hardware and software details of this project in a very technical manner.

Furthermore, I believe that on top of simply understanding the technical aspect of this project, I managed to gain some soft skills in project management and team development. Since this was my first extensive project that we as a group had to document all our design and even meeting minutes, I found that it showed me a glimpse of how actual

engineering projects are conducted and allowed me to prepare for any type of projects I would undertake as part of my engineering career.

Being able to work in a team and stay focused on our datelines did prove exceptionally hard at times, especially when the coding bugs took very long to be fixed. This has taught me that to simply create a timeline at the start of the semester and sticking to it is much more easily said than done. Being able to do so would require a very detailed understanding of what the outcome of our project would be, as well as all the significant stages of development that the project would go through.

Furthermore, this project did re-affirm my beliefs that if a team has very high involvement between team members and has a strong leadership, then the outcome of the project will only be as successful as the outcome of the team dynamics. Having worked in such a well-cooperated and involved team like this, arguments were at a minimal or otherwise non-existent. Problems were discussed from all aspects and a best solution was made by fully presenting all possible and viable solutions.

Jeffrey Wong (CFE)
I have very little faith in machines. Though an unwarranted sentiment, I admit, this project is no exception to this feeling. Until I actually saw just how fast the average computer processor is able to flip through the pixels of each frame, I had my doubts on whether or not my 2.0 GHz dual-core notebook PC was capable of scanning 1.3 million pixels, locating the centers of the LED "blobs", computing massive trigonometric equations, and controlling the mouse, before the next frame coming from the camera. The end result changed that attitude for the better.

I was in charge of implementing the tilt concept into our project, but also had my fair share of work regarding image processing work. Like my colleagues, I believe this has improved my own programming methodologies.

This course was the closest engineering students will get to a formal project. As such, I learned how to properly document all our activities, how to plot a detailed project plan, and general group dynamics, such as how to behave in a dispute.

Donavan Ho Sui (CHE)
Throughout the process of completing this project, one thing I have learnt is that managing a group as well as working with them can lead to many complications in group position. Confusion in group dynamics can lead to confusion among the ranks, which occurs at the early stage of group development. However, once a hierarchy has been set, and ranks established with a healthy minded leader, team dynamics can ensue, where our group can begin working as a team. Working with friends helped time pass easier, as well as working with many of the members before, we already knew each others strengths and weaknesses. This not only made us stronger as a team, but pushed each of us to rise and become stronger.

Working with new tools, such as the project file, was a definite change in routine and atmosphere where recording the team member's thoughts and ideas can be cause for shyness. None of which was a problem in our group, with such a party-animal type of group, our only problem was bearing those long hours week after week in the lab. With all seriousness, the project file was probably the most important key in keeping with a schedule, keeping our project organized, and making our product possible. Where, without it, design decisions become lost as does important functional information.

Working on the hardware aspects of the project entails ordering parts for use, learning how those parts work, learning how those parts work together, and finally, making a final design which can be realistically accomplished. Most of these issues we were prepared for due to an excellent three years prior of learning and mastering the flows of electronics engineering, where here, we are to show and use our previously learned skills.

I would like to take this opportunity to thank all the members of this group, which this task would not have been completed without them. All their late hours, effort, and thoughts put into the project, while some of us were unwell and incapable, are greatly appreciated. Thanks team!

7. Conclusion

Over the past thirteen weeks, Pointex has successfully completed a prototype to prove the feasibility of the SmartPoint device as an input to a web camera to operate the mouse cursor. Throughout the semester, we have come up with innovative solutions to maximize the utility of our product from a user's perspective. Through some marketing analysis and some product specification comparison to potential competitors in the market, we believe there is huge market for our product if we were to further pursue and develop on this idea.