Screen Pointer for Laparoscopic Surgery

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Abstract

Laparoscopic surgery can be described as a surgery that is performed in the abdomen by making micro incisions to insert tools and a camera. Typically, one surgeon is responsible for the camera and while another handles the tools. This surgical procedure has been incredibly useful in modern society because it eliminates the need to make large incisions in the abdomen, which greatly decreases the time it takes patients to recover [1]. One area where laparoscopic surgery can fall short, however, is in the communication between the surgeons responsible for the surgery. As of right now, surgeons must rely on verbal commands to communicate with one another, which can often be misinterpreted or misunderstood. In order to solve this problem, the video signal from the camera will be intercepted with an electronic box that is capable of superimposing a video pointer over the image and this signal will then be sent to the monitor for the surgeons to view. The video pointer will be controlled by a trackball, which is mounted to the camera. This screen pointer will allow the surgeon holding the camera to point things out to the other surgeon, which will essentially solve communication issues within the operating room.

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Introduction

Problem Statement

This project aims to improve a surgeon's ability to teach and complete laparoscopic surgery. Current surgeries require two surgeons, one to hold the instruments and the other to hold the camera. The image from the camera is then transmitted to a TV. When a resident and an attending perform this surgery, the attending holds the camera and directs the resident through the surgery. Often times, the attending wishes to clarify what he says by pointing at various objects on the screen but cannot complete such a task because his hands are occupied. It is our aim to install a screen pointer that can be operated from the camera, allowing surgeons to point out various structures during surgery without the need to move their hands.

Background

Laparoscopic surgery, also called, minimally invasive surgery (MIS), is surgery performed in the abdomen in which only small incisions are made [2]. Through these incisions, doctors place operating tools and an operating camera. The camera is used to give a view of the area in which the surgery is being performed [3]. Its signal is transmitted to a high definition monitor, which is what the surgeons use to see what they are doing.

A typical laparoscopic surgery involves two surgeons. The first surgeon is responsible for positioning the camera in a way that allows the second surgeon to complete the operation. Often times, the surgeon holding the camera also utilizes another tool with which he can use to assist the other surgeon. A typical setup for a laparoscopic surgery is shown below in Figure 1.

Figure 1: A typical laparoscopic surgery. This picture shows how the surgeons involved often have full hands during surgeries [4].

One of the negatives associated with laparoscopic surgery is that the surgeons must have excellent communication with one another. It is imperative that the surgeons who are operating work well with one another and that they are on the same page at all times. Unfortunately, with current laparoscopic surgeries, surgeons must rely strictly on verbal communication. This can cause issues when one surgeon wishes to point something out to the other, but can only describe what he is talking about. In many cases, the surgeon receiving the information misinterprets or misunderstands it.

The problem with miscommunication is especially apparent when training residents. In typical training procedures, the attending surgeon is in charge of holding the camera and directing the resident when (s)he needs guidance. If communication breaks down in one of these procedures, the attending surgeon needs to put down any tools he is holding, walk over to the screen displaying the surgery, and physically point out what he is talking about. This is largely inconvenient and sometimes even dangerous.

In order to solve these problems of miscommunication, the video coming from the camera will be intercepted by an electronic box, which superimposes a cursor on the video. The cursor will be controlled by a trackball that is mounted to the handle of the camera. This solution will enable the surgeon controlling the camera to manipulate the cursor in order to point out exactly what (s) he is talking about to the other surgeon. This will eliminate any need for the surgeon to drop tools and physically point out information on the monitor.

Current System

The current system that is used in the operating room consists of a camera, a camera processing unit, a high definition monitor, and the cables needed to connect them. A diagram of this system is shown below in Figure 2. The camera directly connects to a processing unit (shown in Figure 3), which further connects to a TV monitor (see Figure 4).

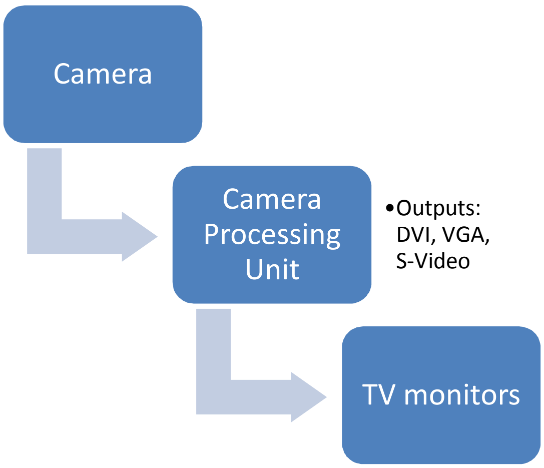

Figure 2: Model of the current system used in operating rooms.

Figure 3: Camera control box outputs. Digital outputs are limited to DVI, while analog outputs may be S Video or BNC

Figure 4: Operating room screen video inputs

Design Criteria

To accomplish the client's goals, this device should integrate with the existing technology in operating rooms, be intuitive to operate, and should not interfere with surgery or cause harm to the patient in any way. Thus, the design must meet the following criteria.

First, the device must integrate with the current system in use in the operating room. Currently, a video signal is taken from the DVI port of the camera processing unit, converted to VGA, and then sent to the HD TV screens. To function in this system, the device should take VGA or DVI input from the camera processing unit and use VGA or DVI output to the TV. There are also a number of different video outputs from the camera-processing unit, including BNC and S-Video ports, so these could potentially be used as inputs to the screen pointer device if needed.

Another important aspect for integrating with the current system is that the pointer controller, which will be a separate unit from the main video processing unit, must integrate with the handheld camera. The controller, which will likely be a small trackball or joystick, must be able to attach to the camera handle without interfering with the surgeons ability to operate the camera. This controller should be intuitive to operate so that the surgeon will not be distracted during surgery.

Since the device will be operated in a surgery setting, safety is of utmost importance. One aspect of safety is that the device should not interfere with the surgeon's ability to operate the tools.

Another aspect is that the video signal should not be damaged or delayed. The video signal is extremely important, because it is the only way the surgeons can see what they are doing, so if the signal is delayed it could be incredibly detrimental to the operation, which may put the patient in danger. Obtaining a real time video with absolutely no delay may not be possible, in which case a delay of less than 50 ms will suffice.

There are a number of more specific criteria that are important for the success of the design. The device must fit in the operating room equipment tower, meaning that it should be no larger than a standard laptop. The weight of the controller should be less than one pound, so that it does not burden the person holding it during surgery, and the weight of the video processing unit should be less than twenty pounds. The connection from the pointer controller to the main video processing unit could be either wireless or wired, but if it is wired it should be sufficiently long to reach from the center of the operating room to the equipment tower (20 feet should be long enough). The device should be powered from a standard outlet, using the 120V AC power supply, and should be able to operate throughout the duration of a single surgery. A full list of design specifications can be found in the Product Design Specifications in the appendix.

Design Options

Our team came up with three different design options: the video pointer, the laptop interceptor, and a custom designed device. The video pointer and laptop interceptor utilize existing, off-the-shelf, devices to meet the design criteria; thus, they should be relatively easy to construct. The custom designed device, on the other hand, uses just the necessary components, which are programmed specifically for this design, making it a much more elegant solution.

Design Option 1: Video Pointer

The main component of this design is a video pointer, a device that takes a video signal input, adds a cursor to it and outputs the signal. A picture of a video pointer is shown in Figure 5 [5]. These video pointers are relatively old technology, dating back to at least the 1980s, and there is a variety of video pointers available for purchase. Most of them cost around $1000 or more; however, a used video pointer could be purchased for about $50 from online sources (such as Ebay). The main problem with video pointers is that the joystick that controls the location of the cursor is located on the video pointer box. In order to use this design, we would have to remove the joystick and make it attach to the handheld camera. Furthermore, the video input/output ports are analog, as opposed to DVI, and are not usually VGA, so the video signals may need to be converted to integrate with the current operating room equipment.

Figure 5: Example image of video pointer.

Our team has obtained an old video pointer, which could be modified to fit the design criteria. The video pointer has BNC jacks for video input/output. Fortunately, the hospital's camera processing unit has a BNC output, so that could go directly into the video pointer. However, the BNC output from the video pointer must be converted to a VGA signal to integrate with the hospital's system, which would require another converter unit. A BNC to VGA converter would cost over $100 and would introduce another bulky box into the design, with its own set of cables. A flow chart to illustrate the video signal path is shown in Figure 6.

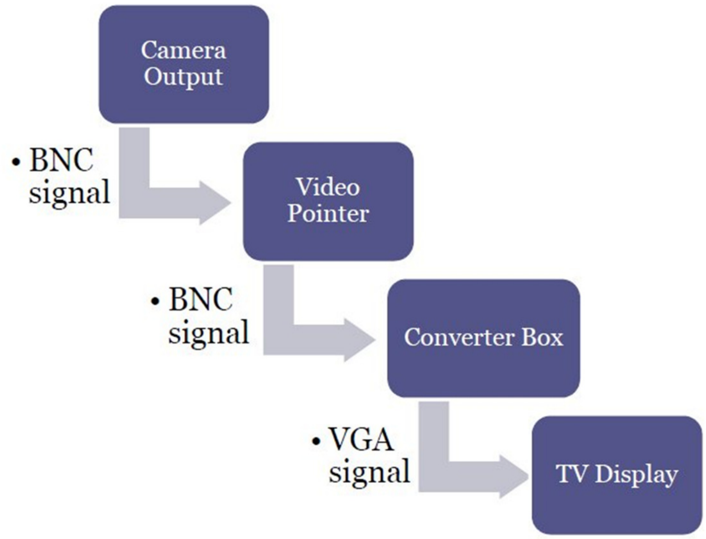

Figure 6: Flow chart of video signal connections for the video pointer design option.

Another aspect of this design option is that the joystick in the video pointer must be removed and made to attach to the handheld camera. Upon inspection of the circuitry inside the video pointer, it was seen that the joystick would be very easy to remove and attach to longer wires. This joystick could then be attached to the camera via a rubber strap.

One advantage to this design is that it is very simple to construct, the only additional component needed is a BNC to VGA converter. It is also relatively cheap if a used video pointer is utilized. The disadvantages to this design are it would be difficult to reproduce on a large scale and it would have many components and cords, which would look unprofessional in the operating room and would clutter the equipment towers.

Design Option 2: Laptop Interceptor

This design would utilize a laptop as the main component. The laptop would be able to obtain both a video signal and a mouse signal through USB ports, and then it would send out the video through the VGA output. A flow chart illustrating this design is shown in Figure 7. In this case, the S-Video signal would be taken from the hospital's camera processing unit, and this signal would go into a USB video capture device. These video capture devices are designed to input video signals into computers to electronically store and edit videos, and cost between \$50 -\$150[6]. This device would bring the video signal into the laptop, where it can be displayed in full screen mode. A standard mouse can be used to put a cursor on the video signal, and this video can then be sent out the VGA port using the presentation mode standard in most laptops. The mouse used in this design must be suitable for attaching to the camera handle. One option is to purchase a mini trackball mouse, pictured in Figure 8, which could potentially be modified to fit on the camera handle.

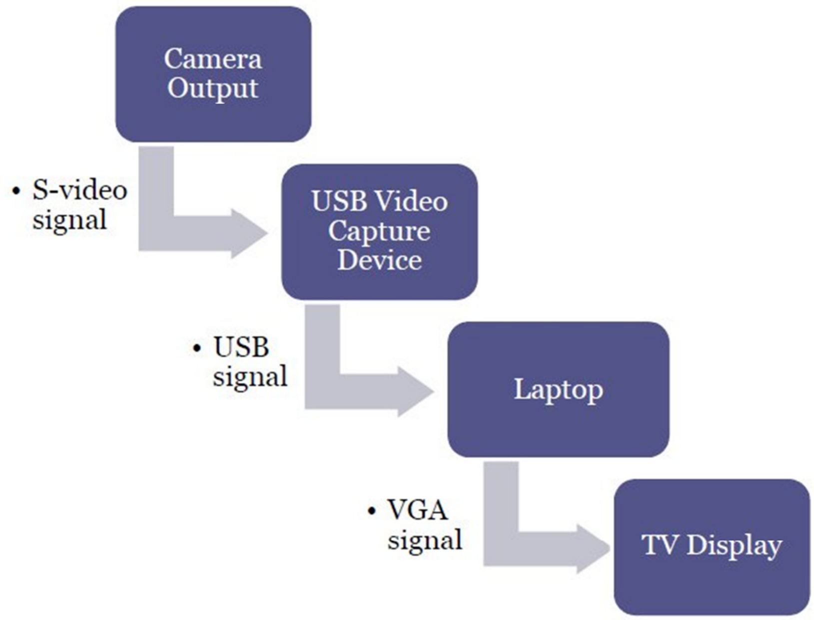

Figure 7: Flow chart of video signal connections for the laptop interceptor design option.

Figure 8: Mini trackball mouse, suitable for use with the laptop interceptor design [7].

Some advantages of the laptop interceptor design are that it utilizes existing off-the-shelf products to manipulate the video signal and that it could be reproduced if needed. Disadvantages include that it may be very costly, considering that, it needs a laptop computer, and that it may look unprofessional to have both the laptop and video capture system in the operating room. The surgeons would also have to run the software on the laptop to prepare it for use, so there is extra user input required. Overall, this design makes a good prototype, but it is not an elegant solution to the problem.

Design Option 3: Custom System

As we advanced with design one and two, each choice had some good positives, but some obvious negatives, such as the bulk associated with each. Design one has significant converters and extra wires, while design two essentially places a laptop computer in each room exclusively to set a pointer on a screen. At this point we came up with design option three as a custom built circuit that would be a significant decrease in size as well as be simpler to recreate on large scale, offering Haggi the most return on investment.

Initially the focus of this area began with some DVI in and out boards that are offered by the company AMD, advanced micro devices. A few video cards from the 4800 series ATI Radeon offered high quality video cards that we could integrate with another development board to add our own mouse signal. Unfortunately, these options offered by AMD required elite programming experience and a development board that we would have to integrate with to program with Linux; looking into further options after this we had similar problems with the medically approved video technology offered by NVidia. They were requesting between $10,000 and $30,000 for a few of their higher quality boards.

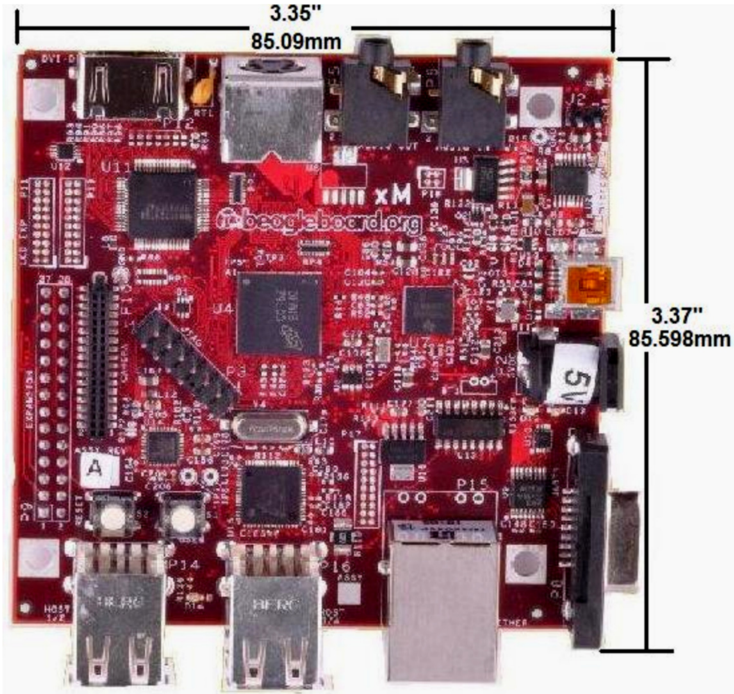

Figure 9: BeagleBoard [8]

The next goal of the custom design circuit began to focus on FPGA boards or field programmable gate array boards. Essentially these are single or multiple panel computers that one can programmed with Linux in a similar fashion to the standard PC. These chips are smaller and do not have the memory and processing functions of laptops, but they serve other functions very well. A few of the FPGA's we were looking into were around $1000 to $5000, which is expensive to have one of these in 24 operating rooms in one hospital. Luckily, we found a FPGA board called BeagleBoard, figure 9 above, that offers us a programmable circuit that can receive and output high quality video and integrate the mouse cursor data. BeagleBoard-xM system is the system that we wound up choosing as our circuit, which is shown in Figure 9. The BeagleBoard is designed specifically to address the Open Source Community. It has been equipped with a minimum set of features to allow the user to experience the power of the processor and is not intended as a full development platform as many of the features and interfaces supplied by the processor are not accessible from the BeagleBoard. By utilizing standard interfaces, the BeagleBoard is highly extensible to add many features and interfaces. The BeagleBoard has USB input capabilities for us to input our USB mouse signal as well as a simple VGA to USB converter to import the video. The board offers us a DVI-D output, which the exact output is found at the hospital. In addition, we can fairly simply program this board using Linux system [8].

Decision Matrix

Criteria		Possible Designs		
Considerations	Weight	Video Pointer	Laptop Interceptor	**Custom Designed**
Safety/ No time delay	35	32	25	**29**
Feasibility	10	9	9	**5**
Reproducibility	25	12	20	**24**
User Simplicity	10	1	7	**9**
Cost	15	13	11	**13**
Originality	5	0	0	**3**
Total	100	67	72	**83**

We constructed our decision matrix focusing on six different goals: safety, feasibility, reproducibility, user simplicity, cost, and originality. The groups of safety and reproducibility received the highest weight. Safety is the most important factor as any video delay is extremely detrimental to surgery. The laparoscopic surgeon has to see the video in real time. Reproducibility is important because Haggi's goal is to have each laparoscopic surgery tower equipped with this technology, so this is where design one and two become less appealing than the custom circuit, as the custom circuit offers the shortest time delay and is the most reproducible. The groups cost, feasibility and user simplicity were weighted each significantly less than the safety consideration, but were still important. The user simplicity of each design is relatively equal for the three designs, as no design offers complicated procedures to use. In addition, the feasibility of each design is standard across the board. The custom designed board and design one are similar in price, while the laptop is more expensive. Lastly, Haggi would like an original option that offers him the most return on investment. The only option fulfilling this is the custom designed BeagleBoard.

Final Design

We chose our third design option involving the implementation of the BeagleBoard to pursue as a final design. The BeagleBoard is a fully programmable Single Board Computer (SBC) with an Altera processing chip that links the hardware. The unit can thus be programmed using Linux. A simple diagram depicting the hardware layout and schematic of the board can be seen in Figure 10. We took advantage of the board's four USB hubs and plan to utilize one USB port for incoming video and another for signals from an external user interface device. Aside from video cards, we were unable to find any device that contained both incoming and outgoing VGA ports. These devices, however, cost thousands of dollars and thus are not a feasible option. Consequently, we determined that the best way to introduce video to a SBC was through USB, and the BeagleBoard xM offers the ideal setup of multiple USB ports and a VGA output. SBC boards are only capable of interpreting input data streams from USB, and we therefore require a VGA to USB converter. Using the converter, we are therefore be able to create USB programs that read both the incoming video and external interface signal from their respective ports on the hub. The program then has to overlay both signals into a single video signal, and output this through the VGA output. In addition to the software, we will also modify a USB capable trackball interface device (such as the one shown in Figure 8) and alter it to fit onto multiple laparoscope designs.

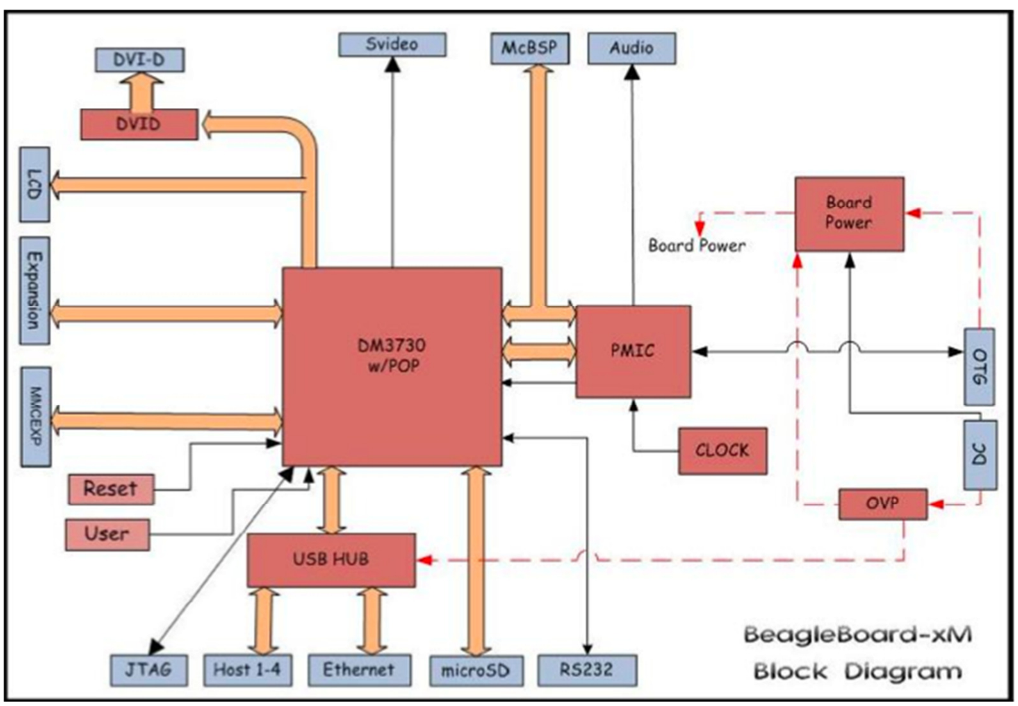

Figure 10: Block diagram of the BeagleBoard xM [8]

Future Work

Once we obtain the BeagleBoard, we must program it to accept both input signals and convert them into a single video output. This can be done on a Linux platform. We must then obtain a VGA-USB converter and a trackball with USB output. The VGA-USB converter will convert VGA video input signal into USB compatible signals. The trackball device must also be USB compatible. After we program the board, the incoming video signal on VGA will be converted to USB and condensed with the trackball signal. The two will be programmed to converge as a single signal, and then sent out through the VGA port. Consequently, our next steps involve obtaining the proper hardware (VGA converter and trackball) and programming the SBC. Afterwards, we must test the unit on a system that exports VGA signals. Finally, we must develop a method for attaching the trackball to the laparoscope and transmitting this signal to the SBC.

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[8] “BeagleBoard-xM Rev A2 System Reference Manual” July 7, 2010.

Appendix

Project Design Specifications

February 1, 2011
Function:
This project aims to improve a surgeon's ability to teach and complete laparoscopic surgery. Current surgeries require two surgeons, one to hold the instruments and the other to hold the camera. The image from the camera is then transmitted to a TV. When this surgery is performed by a resident and an attending, the attending holds the camera and directs the resident through the surgery. Often times, the attending wishes to clarify what he says by pointing at various objects on the screen but cannot complete such a task because his hands are occupied. It is our aim to install a screen pointer onto the TV, that can be operated from the camera, allowing surgeons to point out various structures during surgery without the need to move their hands.

Client Requirements

- Design a pointer controller that attaches to a wide variety of laparoscopic camera handles, the system will be detachable as well
- Design a system to embed a pointer onto the signal going to the HD TV screen
- The device should not hinder the image or ability to hold and operate the camera
- The pointer controller should be wireless

Design Requirements

1. **Physical and Operational Characteristics**
    - **a.** Performance Requirements: The device must function in a surgery setting without hindering the process or damaging the signal. It must also apply a cursor that can be positioned intuitively without blocking the image.
    - **b.** Safety: The device should not disable the video feed. The attached pointer on the camera should not damage the operator in any possible way.
    - **c.** Accuracy and Reliability: The overall camera system should not go through extensive processing to delay the signal. The system should maintain power throughout surgery. The pointer should be fine so that the users can see what is being pointed out, not too fine so that it is difficult to see. The pointer should move in a relatively smooth and controlled fashion.
    - **d.** Life in Service: Should last a comparable length in time as the camera that are used during surgery.
    - **e.** Shelf Life: Must withstand operating room conditions and should be built to last. Should last until the next generation of human sub species.
    - **f.** Operating Environment: The environment of this device is the operating room. Potential exposure to bodily fluids for the pointer attachment.
    - **g.** Ergonomics: The device must be comfortable for the user and in no way inhibit his ability to operate the camera.
    - **h.** Size: The camera mounted controller should be smaller than the standard track ball for a standard computer mouse. If there is a cord it should sufficiently long to go the length of the operating room. The interceptor box should be smaller than a standard laptop.

- **i.** Weight: The controller should be less than one pound, the interceptor box should be less than twenty pounds.
- **j.** Materials: Should be able to be sterilized by operating room standard room standard cleaning equipment. The controller should be a durable plastic that will hold up over time.
- **k.** Aesthetics, Appearance, and Finish: The device will be used in an operating room setting, so it should look professional.

2. Product Characteristics

- **a.** Quantity: One testing unit is necessary, and possibly multiple prototypes
- **b.** Target Product Cost: This has not been determined

3. Miscellaneous

- **a.** Standards: If we are successful with our prototype testing, we will attempt to implement with one of Dr. M's surgeries, if that is successful, we will then attempt to attain a patent.
- **b.** Customer: Hospitals around the world that perform laparoscopic surgeries.
- **c.** Patient Related Concerns: This device must be able to be sterilized and must maintain an instant video feed for the duration of the surgery, overall the pointer controller will not interfere with the patient directly.
- **d.** Competition: None