THE COLLEGE OF ENGINEERING
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Frameless Stereotactic Navigation

Mid Semester Report
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Table of Contents

Abstract

Stereotactic navigation is a method used in medical procedures to determine the location of an instrument relative to the patient. Dr. Nathaniel Brooks, a neurosurgeon at the UW Hospital, believes that a more affordable version of computerized stereotactic navigation could be created to increase the availability of this technology for a wider range of procedures. Our design team was asked to create a frameless computerized stereotactic navigation system using inexpensive commercial products while maintaining a high level of accuracy. The final design we have chosen incorporates two HD cameras as the image-capturing component. These cameras are used in conjunction with a central computer and a display unit on a portable stand to result in a complete 3-Dimensional stereotactic navigation system.

Problem Motivation

Computerized stereotactic navigation is a system that aids in the precision of certain surgeries, such as neurosurgeries on the brain or spine, which require very accurate measurements. The stereotactic navigation system normally used is extremely bulky and can cost about half of a million dollars. Our goal is to create a much less expensive and more portable stereotactic navigation system using commercially available 3D object tracking hardware and software. This system will track a tool, such as a spinal needle, and project its position in-vivo in real time for the surgeon. In order to display the tool location, its position will be overlaid on x-ray images taken before the surgery which are visible to the surgeon, ensuring accurate tool navigation.

Client Description

The client for this project is Dr. Nathaniel Brooks. He is a neurosurgeon at the UW Hospital who specializes in spinal surgeries. He believes this design would be helpful in a wide range of procedures which do not normally have access to the expensive equipment used in computerized frameless stereotactic navigation.

Current Devices

Stereotactic navigation is widely used today in order to perform minimally invasive surgeries and aid in precision targeting. Companies such as Brainlab and Medtronic currently produce a variety of devices on the market. These devices utilize tracking methods ranging from infrared to RGB in order to accurately visualize the patient. They are very precise and accurate, a test of one machine recording a 97.5% location accuracy rate [1]. However, these devices can cost upwards of $500,000. In most general procedures, the cost of using the equipment would be too expensive, limiting the number of procedures able to use the machine. In addition, current modules can be large and heavy, as seen in Figure 1, and as a result are usually restricted to operating rooms alone. These limitations make it difficult to transport the technology between rooms, preventing full use of the technology.

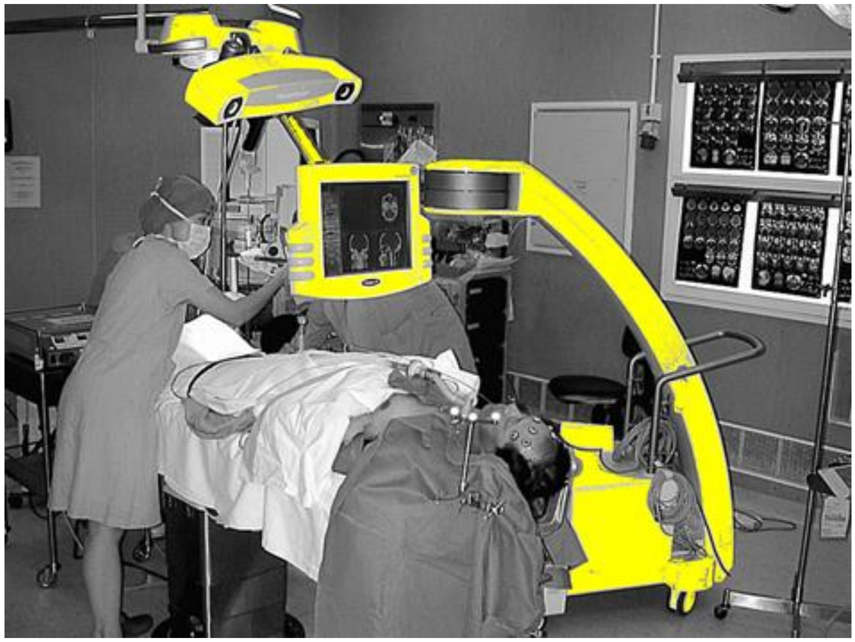

Figure 1: The complete computerized stereotactic navigation system is highlighted in yellow, demonstrating the size and operating conditions of current systems [2].

Design Alternatives

All of the designs that were considered shared the same general physical setup. In each design, the operating room would be equipped with a station on wheels that could be moved between different rooms. Attached to the base of the station would be a 7 foot adjustable stand with a pair of cameras at the top, connected by an adjustable arm. This maneuverable arm would allow a range of views of the patient instead of the limited view provided by a fixed arm. The cameras would additionally be separated by a set distance to maximize the accuracy of the triangulation calculations. Also attached to the stand of the station would be a plate designed to hold the computer that runs the software for the system, along with an adjacent monitor which would display a real-time representation of the surgical tools in respect to the patient's body via the patient’s x-ray. Attached to both the patient and surgical tools would be markers that would be tracked by the cameras for triangulation. Since all of the designs use the same physical setup, it is now possible to discuss the different types of cameras used to track the patient and the tools. A more detailed list of design requirements can be found in the Appendix under the Product Design Specifications.

Design 1: Wii Remote

The first camera that was looked at was the Wii remote, as seen in Figure 2. The Wii remote works by passively reading infrared (IR) light in a room to recognize objects present. It also has the ability to perform object tracking of up to four objects due to an internal processor. In order for the Wii remote to work in this project, the setup would require an infrared lamp to increase accuracy. There would be one Wii remote placed on either side of the IR lamp on the adjustable arm which can be seen in Figure 3.

Figure 2: Multiple views of the hand-held Wii Remote are shown. The location of the IR sensor can be seen in the topmost view [3].

The major benefit of the Wii remotes design is that it only costs $25 for each remote and about $15 for the IR lamp, making the total camera array for this design cost $65, which is well within the budget. Another great advantage of the Wii remote is that there is a large online community of developers who have created software for using the Wii remote for purposes outside of gaming. This would allow for easier program development when trying to perform triangulation and tracking calculations. Additionally, the Wii remote supports a high resolution of 1024x768 pixels at 30 frames per second. It connects to the computer through bluetooth, which allows for an upload speed of 24 megabytes per second. In terms of the accuracy of the Wii remote, it can track a difference in position of one millimeter from one meter away [4]. Unfortunately, this is a little closer than what the general setup for the system would normally be; ideally the system would be at the base of the operating table, which is about one to two meters away from the operating site. The Wii remote meets the requirement for cost, but just barely meets it for accuracy.

Figure 3: The Wii remotes require an IR lamp to increase accuracy. The entire setup, including the central computer and display unit, is shown. One Wii remote is placed on either side of the IR lamp at the top of the apparatus.

Design 2: HD Camera

The second design considered integrated the Replay XD1080 HD Video Camera which is shown in Figure 4. This camera is meant to be used for action videos like skiing or biking, so it is small and light. The camera itself is only 28 mm in diameter and 93 mm in length, making it easy to fit onto the adjustable arm that will serve as its base. The camera is simple to use as it only has two buttons, one for recording and one to switch settings [5].

Figure 4: The Replay XD1080 consists of a lightweight, simple design [6].

The benefit of this camera is that it can capture video at 1080p at 30 frames per second or 720p at 60 frames per second. This will allow for high accuracy while tracking over distances of less than one millimeter, meeting our requirement. It also has the ability to live stream through an HDMI connection at a rate of 480 megabits per second making the video input into the computer almost instantaneous [5]. Two cameras are required for determining depth, the setup being shown in Figure 5. The camera costs $300 per unit, leaving $400 in the quoted budget for the remainder of the project. The major downside to this camera is that there is no community around it for software development. This means that all of the software work needed for the project will have to be created with limited help from outside sources or previous work. The Replay XD1080 HD Camera exceeds the requirement for accuracy while staying inside the budget.

Figure 5: The combination of the two HD cameras provides enough information to determine the 3D location of an object.

Design 3: Bumblebee2

The final design that was brought up for consideration utilized the Bumblebee2 by Point Grey. This camera actually consists of two separate cameras in one box, seen in Figure 6. The Bumblebee2 comes with software for the cameras that already has the ability to triangulate positions in 3-D space. The cameras work at 1032 x 776 pixels at 20 frames per second, giving a high quality picture that allows for a tracking accuracy well within a distance of one millimeter. Another benefit of the Bumblebee2 is that it comes with a kit for software development, making it easy to program the computer for video analysis and tracking. There is also free software development help through Point Grey, if any need was to arise. This camera has also been proven to be reliable and accurate as it has been used by Google in prototypes of their automated-driverless cars [7].

Figure 6: The Bumblebee2 contains two cameras and can accurately determine 3D location without the need for another optical input [7].

The major downside to this design is that the basic Bumblebee2 unit costs $1895. This cost is outside of the budget for the project and would require an increase in budget overall, not even including other component costs of the design. The Bumblebee2 makes the project much more feasible by providing a prefabricated software kit and hardware, but it is outside the budget of this project. The complete setup incorporating the Bumblebee2 is shown in Figure 7.

Figure 7: The spacing between the two cameras in the Bumblebee2 is predetermined. That and its internal processor aids in accurate 3D point tracking.

Design Matrix

In order to evaluate each of the three designs, a design matrix was constructed. Each design alternative was evaluated on the criteria of accuracy and reliability, cost, program elegance, size and portability, ease of use, and safety. The complete scoring breakdown for each design alternative can be seen in Table 1. The HD camera design scored the highest overall, and therefore will be design which we pursue.

Criteria (Weight)	Design 1: Wii Remote 		Design 2: HD Camera 		Design 3: Bumblebee 2 	
Accuracy and Reliability (30)	4	24	4	24	5	30
Cost (20)	5	20	4	16	1	4
Program Elegance (15)	3	9	3	9	4	12
Size and Portability (15)	4	12	5	15	4	12
Ease of Use (10)	3	6	4	8	4	8
Safety (10)	3	6	4	8	4	8
Total (100)	77		80		74	

Table 1: The Design Matrix evaluates the ability of each design alternative to follow the given criteria. The categories and weights were chosen based on their importance to the design and client requirements. The total score for each design is shown at the bottom as a value out of a total of 100 possible points.

Accuracy and Reliability

In accordance with our problem statement and the directed use of our design, accuracy was our most heavily weighted factor in our design comparison. According to our client, the measurements and estimations of tool location in-vivo by our system must be accurate to at least one millimeter. At roughly a one-meter distance from the patient, this level of accuracy was attainable by each of the camera systems proposed. However, due to its existing infrastructure and software design, it was weighed that the tested and verified Bumblebee 2 design would provide the highest degree of accuracy.

Cost

The cost of the device plays a very important role in the design process. One of the main reasons for this design is so that we can create an affordable version of stereotactic navigation using less expensive hardware but still keeping it as accurate as possible. With cost playing such a large part in the final design, it was weighted as 20 in our design matrix to show how imperative it is that the final device be low in cost.

Program Elegance

A large concern with the undergoing of this design was program complexity and elegance. Excluding the Bumblebee 2 design, the systems utilizing HD cameras and Wii remotes would each require a significant amount of software design, requiring greater effort determining the most efficient language and coding practice. The Bumblebee 2 design was excluded from the previous statement due to the fact that the product is pre-programmed to auto calibrate itself and comes included with a programming package. This means that their coding has been tested and backed by the funding of the established Grey Point Industries. For this reason, it received the highest rating in this category.

Size and Portability

Along with the cost and accuracy of the design, it is also of utmost importance that the design be collapsible and light enough to be transported between rooms and environments. The current products are plagued by this flaw, and are limited to being assembled in surgical rooms. A smaller design would provide a larger number of clinicians access to this technology to apply to a greater number of procedures. Due to its flexibility in size and compact design, the HD camera system scored highest in this category.

Ease of Use

While it is extremely important for the device to be accurate and cost effective, it is also important that it be streamlined and easy for a surgeon to use with as little effort as possible. Ease of use is carries a weight of 10 on the design matrix. This is because while the device needs to be accurate and low in cost, it must also be simple and easy to use so that any person would be able to operate it. It may not have a weight as large as accuracy or cost, however simple operation is an important aspect in any interface based system. Ideally, the finished product will be robust and straightforward enough to eventually develop a tablet version to further simplify operation.

Safety

In this case, 'safety' is a more general concern for the maintained well-being of the patient and the surgeon. This factor was ranked relatively low on our matrix due to the systems limited physical contact with the patient in question. The primary concerns of human safety in this project are covered by the reliability of the systems accuracy. This requires considerations as far as the sanitation procedures, production materials, and surgical practices are concerned. The use of hypoallergenic materials is required, and the ability of the practitioner to maintain the device must be considered in designing a device that can accommodate a safe, sanitized environment. The ability of each design to be incorporated with different materials was weighed, and the HD camera system was determined to be the safest due to the system's ability to be customized to different environments.

Future Work

Timeline

Table 2 displays the intended dates of completion for major team objectives. The shaded boxes represent the predicted timeframe, with each "X" indicating progress or completion of the task on that date. At this time, the team has succeeded in being on time or ahead of the projected task schedule in all categories.

Tasks	September			October				November					Dec	
	13	20	27	4	11	18	25	1	8	15	22	29	6	13
Product Development														
Research	X	X	X											
Brainstorming	X	X	X	X										
Design Matrix			X	X										
Design Prototype														
Order Materials														
Fabricate Prototype														
Testing														
Meetings														
Advisor	X	X	X	X										
Client	X		X	X										
Team	X	X	X	X										
Deliverables														
Progress Reports	X	X	X	X										
PDS	X	X												
Mid Semester PPT			X	X										
Mid Semester Report				X										
Final Report														
Final Poster														
Website Updates	X	X	X	X										

Table 2: Displays the projected timeline for the group. Shaded boxes represent the intended timeframe for a task, and a check indicates that the task was worked on or completed.

Software Integration and Physical Setup

After having chosen which design to be pursued, the next tasks for the team include software development and physical setup implementation, which fall under the fabrication category in the previously mentioned timeline. There has been a significant amount of work done in the open-source software community concerning object tracking. Our goal is to find and adjust the most effective previous work to create our own software that will function efficiently with our given design requirements and chosen hardware. The physical setup is also an important part of the fabrication process. This will require developing a method for accurately placing markers on the tools and patient and constructing a portable stand for the equipment to be placed on.

Testing

Because accuracy and reliability are so important to the design, a significant amount of testing will be required before the final product can be considered safe to use. One method of testing will involve using an object of known dimensions. This object will be placed in the working area of our system, and the system will be calibrated. Then, the tool being tracked will be placed at various locations on the object, and the displayed dimensions will be compared to the actual dimensions of the object. Another similar testing method will be necessary to determine the accuracy of the x-ray image overlay once that has been integrated.

Projected Costs

Based on the materials and equipment chosen for the final design, the projected cost for the project is about $800 to $850. The Replay XD1080 cameras can be purchased for about $300 each, our design requiring two. The computer hardware, including display, is expected to total up to about $100 to $150. The remaining materials: equipment stand, patient and tool markers, and mounting hardware, are predicted to cost less than $100 total. The projected cost of $800 to $850 still fits within the team budget of $1000.

References

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Appendix

Frameless Stereotactic Navigation
Product Design Specifications
10/9/13

Group Members: Stephen Monette, Alex Yueh, Matthew Boyer, Jake Levin, Alex Nguyen

Advisor: Dr. John Puccinelli

Function:

Computerized frameless stereotaxy is used routinely for neurosurgical and spine surgeries. This technology makes it possible to determine the 3D location of the surgical tools in relation to the patient, which is invaluable for the removal of tumors or the placement of instrumentation. However, this technology is quite expensive due to its reliance on the use of high definition feature recognition software and hardware, so its application has been limited to expensive, in-patient surgical procedures. Frameless stereotactic navigation could be used to perform smaller interventional radiology procedures and pain procedures if a less expensive alternative could be developed. The goal of this project is to create a frameless stereotactic navigation system using an inexpensive Wii or Kinect system in order to spread the availability of the tool.

Client requirements:

- Design must be accurate up to one millimeter
- Constructed using off the shelf software and hardware (i.e. Kinect, Wii motion software)
- Conformable with pre-existing x-ray prints taken of the patient to track tooling
- Final design should be smaller than existing machine (current are quite large)
- Budget: $1000 (negotiable)

Design requirements:

1. Physical and Operational Characteristics

a. *Performance requirements*: Device must be able to locate the surgeon's tools within one millimeter accuracy on the patient readouts. The stereotactic navigation system must also have a high refresh rate with a minimum of 20 FPS for data acquisition.

b. *Safety*: The end design must comply with medical standards in both sanitation and reliance. It must be able to handle sanitation cycles and be free of unnecessary faces, which facilitate bacterial growth. Any location identifying stickers/markers placed on the patients or tools must also be safe and free of any possible products that may affect the patient (I.E. latex-free, hypoallergenic materials). Stickers/markers must also comply with the data acquisition protocols used in the stereotactic system, i.e. discernible, high contrast colors. Errors in precision may not exceed 1 mm.

c. *Accuracy and Reliability*: The device must have an accuracy minimum of 1 mm, and it must maintain this level of accuracy while the system is anywhere between 1-1.5 m from the patient.

d. *Life in Service*: The life of the product should be 5 years, operating 5 times per week at most for 12 hours at a time.

e. *Shelf Life*: While in storage the device should be kept at normal room temperatures, the device will use power from the computer display.

f. *Operating Environment*: The device could come into contact with small amounts of water or other liquids found in operating rooms, such as blood. It should work at any climate and conditions acceptable for an operating room.

g. *Ergonomics*: The system should not interfere with the surgical process. The locators on the patient should provide minimal discomfort to the patient.

h. *Size*: The device should be able to accommodate maintaining a three dimensional visual field the size of 0.028 m^3 around the surgical site. The system will be designed in order to rest at the foot of the 1 meter high surgical table and extend over the patient lying on the table. As a result, the system will consist of a base, and a collapsible arm with the data acquiring cameras attached. The entire system should be able to collapse down to a carrying case or rolling stand that occupies no more than 0.042 m^3, as specified by the client.

i. *Weight*: The system should be easily transportable between operating rooms with/without the use of a wheeled cart. The total collapsed system should weigh no more than 18 kg.

j. *Materials*: The portion of the device coming into contact with the patient should be easily cleaned or disposable and should not cause harm to the patient.

k. *Aesthetics, Appearance, and Finish*: Because it will be used in the clinical setting, the product must be easy to use, and the display must be easy to read. The system should not be distracting to the patient or surgeon. Focus should be kept on the utility of the design rather than the aesthetics.

2. Production Characteristics

a. *Quantity*: We are designing one system to be used on multiple subjects.

b. *Target Product Cost*: The target product cost is $750.

3. Miscellaneous

a. *Standards and Specifications*: If marketed, the product will require approval from the FDA.

b. *Customer*: The system should be able to track all movements and recognize the instruments being used while taking up minimal room and not interfering with the surgical procedures. The project should be easy to use and inexpensive.

c. *Patient-related concerns*: The information from the fluoroscopic x-rays should be accessed in the system and protected during the procedure, but afterwards discarded. All equipment must be able to be sterilized.

d. Competition: *Brainlab* and *Stealth* are some current models of this technology, but they are too expensive for smaller interventional radiology and pain procedures. Students at the University of Washington have developed a program for the Kinect, which maps the body so that when surgeons use robotic tools they can receive tactile feedback to aid them in navigation.