APSC496

Project Report

**Praxim Surgical Robot**

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# Abstract (NICHOLAS)

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# Introduction (NICHOLAS)

* General overview of project and how it came to be – include Nikolai and MECH 457 2008
* List different parties involved – Chris (praxim), Tony (UBC), Team
* Arthroplasty surgery background and value product brings to patients and surgeons

# Project Background (NICHOLAS)

* Introduction to haptic surface emulation and potential use
* Brief review of existing technologies (not as long as benchmarking)
* More complete review of PREVIOUS MECH 457 Prototype
* Highlight failures of existing devices, specifically MECH 457

# Project Scope (NICHOLAS)

* Relate failures of other devices to the objectives/scope of current project – general final state to where the project will get to (Device suitable for Cadaver testing of parameters related to performance and to user interface).
* Design objectives: List of specific evaluation criteria and requirements (cleanable, total error, user feel….)

# Work Completed

* Overview of structure of focus and areas that will be presented in document

## 4.1 Mechanism Selection (?)

* Diagrams of mechanisms reviewed
* stand out features of each design
* brief description of methods used to evaluate each design
* single table summarizing results
* Overview of passive hard surface implementation methods (not entirely sure where to put this as seems suited to objectives section – perhaps do not include at all?)

## 4.2 General size and weight optimization (IBRAHIM)

The operating workspace and total weight of the device are two critical characteristics that will ultimately determine the overall success of the design. Analysis has been completed to maximize the potential workable area of the device by adjusting link lengths, while maintain the total weight of the device with the design requirements. There are two critical parameters that must be maintained, minimum workable area with a diameter of 63.5mm and a maximum total device weight of 5lbs, and any increase in workable area or decrease in the total weight of the device is beneficial to the design of the system based on user satisfaction criteria. The final link lengths shown in Table 1 have been determined by maximizing the total allowable workable area maintain the weight of the links at approximately 2lbs.

Table : Final design link lengths

|  |  |
| --- | --- |
| Link | Length [cm] |
| 1 | 7 |
| 2 | 7 |
| 3 | 5 |
| 4 | 5 |
| 5 | 7 |

Table : Joint operating range

|  |  |
| --- | --- |
| Joint Angle | Range [degrees] |
| **Ɵ12 min** | 30 |
| **Ɵ12 max** | 120 |
| **Ɵ54 max** | 45 |
| **Ɵ3** | 20 |
| **Ɵ135** | -15 |

With these link characteristics the device has a workable area of 90mm. This range has been optimized based on the user requirements determined early in the project, and ensure than there is no intereference between any of the links involved – specifically joint 1 on the primary links. Prototype testing will assess user feel to further develop the user requirements of the device based on weight and may require a reduction in the potential workable area, to improve the user performance.

## 4.3 Gravity Compensation (NICHOLAS)

One of the primary focuses of the new design is to improve the user feel of the device. A critical aspect of this is the weight of the device and tool the user must support when the tool head is away from the hard surface. Gravity compensation mechanisms can be implemented to transfer this load from the user to the support structure and bone mount. Two type of gravity compensation were considered;

* **Rotational gravity compensation** that counteracts moments produced about the bone mount due to the weight and position of the device.
* **Linear gravity compensation** that resists motion towards the bone mount that causes the radial link system to collapse.

A technical assessment of rotation gravity compensation suggests that for the theoretical design weight of the device rotational gravity compensation is not necessary, and no rotational gravity compensation mechanism has been design as a result. This assessment must be verified with user tests of a complete prototype.

A simple position adjustment mechanism coupled to the rotating base will be used to optimize the tension in a linear spring used for linear gravity compensation. The spring extends along the secondary support links of the radial link system causing a moment about the joint between secondary link 1 and secondary link 2 that counters the force of gravity on the links. User tests of the prototype will be user to optimize the spring tension for the desired operating range.

## 4.4 Joint Design (DAVE)

The detailed design goals for the mechanical design of the device have been driven by the need to create a device that is light and small enough to provide adequate user feel and minimize the force exerted on the bone as well as ensure the device meets performance goals. As a result the joints have been designed using minimum constraint theory and measures to ensure the joints do not become loose overtime. This section will discuss the major functions for each of the design components and provide an overview of the design for each of the components.

### Bone Mount Axle (BMA)

Functions: The bone mount axle must attach to Praxim’s adjustable bone mount and allow the rotating base to freely rotate around it. The axel must be rigidly coupled to the encoder shaft that determines the orientation of the rotating base with respect to the bone.

Design Goals:

* The bearings for the rotating base spaced as far apart as possible to minimize play in the joint
* Recess caps to minimize the size

Design:

**Rotating Base (RB)**

Functions: The RB acts as the base attachment for the device. The RB couples the primary and secondary links for the radial linkage system to the BMA and secures the hard constraint motor and BM encoder.

Design Goals:

* Design to be as easy to manufacture as possible
* Remove unnecessary weight

Design Features: Link axles are designed to be threaded in to the RB in order to avoid a press fit into the RB. The attachment points for the links are perpendicular to each other and angled 45 degrees away from the BMA to minimize interference with the soft tissue around the knee.

Recommended Improvements

Casting this part would allow for a more complicated geometry, which, in turn, could reduce the total amount of material required to accomplish its required functions; therefore, reducing the weight of the part.

**Primary and Secondary Links (PL1 and PL2)**

Functions: The primary and secondary links combine to generate a radial link system that constrains the upper connection block (Link 3) to move linearly with respect to the RB. The primary links facilitates the physical constraint preventing motion past a defined linear distance between the RB and link 3.

Design Goals:

* Minimize the size and weight of the links
* Facilitate hard constraint at primary link 1 (PL1) and shape to simplify the motor positioning function.
* Minimize the size of the joints between the two primary links and the two secondary links.

Design Features:

*Link Size*

The physical constraint function is simplified by keeping the primary links equal. 70mm links provide the necessary operating envelope and reduces the possibility of collisions between the primary link encoder and the and the physical constraint motor.

*Link Profile*

All of the links, except PL1, have a peanut shape in order to reduce the weight of the links. PL1 has the peanut profile on the top half of the link; however, the bottom half of the link is a straight edge in order to provide an edge for the physical constraint to act on.

Recommended Improvements

An area for improvement lies in the joint design. The joints have been designed to be a small as possible while still providing minimal play. A possible improvement to the design would be to simplify the machining process for the links as much as possible. Simplifying the joint design could lead to a much easier and faster assembly of the device, and reduce critical tolerances by minimizing machining error.

* Specifics of Bearing and encoder selection/design WRT to overall size of device.
* Specifics relating to looseness
* Specifics relating to manufacturing

## 4.6 Error Minimization (IBRAHIM & DAVY)

* Mechanical hardware selection
* Electrical hardware selection
* Software design

# Conclusions

The Praxim haptic surgical aid aims to assess two major concept goals necessary to implement an effective device to facilitate knee surgeries.

1. Device Performance: Does the device do what it should be able to do?
2. User Interface: Is the device user-friendly? How well does the device interact with the user?

Tests have been designed to evaluate the prototype design based on these goals.

## 5.1 Device Performance Tests (Nicholas)

The device performance tests determine whether the device will provide the precision and accuracy necessary to be considered an acceptable surgical aid. Concept specifications require that the hard surface constraint is physically imposed within 0.5mm of the desired model surface. This means that the device must recognize the current position of the tool to within a 0.5mm total displacement based on all encoder readings and play in linkage joints. The device must also provide a total work space to implement a common uni-compartmental implant. This has been approximated as a circle with a radius of 63.6mm.

### Precision, accuracy and workable area testing

In order to assess the precision of the device the position of a number of points must be known to a greater accuracy the required precision of the device. This can be achieved by using a mill with a known accuracy of +/-0.05mm to locate and mark four calibration positions on a piece of carbon steel with a coefficient of linear expansion of 13.0E-6 m/m K. Allowing for a 100K temperature variation the mark positions will be known to within +/-0.05mm. The device accuracy can be determined by comparing the device location with the actual position of the milled marks.

|  |  |  |
| --- | --- | --- |
| Step | Task | Comments |
| 1. | **Mill Calibration Positions**   |  |  | | --- | --- | | 1. | Clamp an approximately 6cm by 6cm by 1cm piece of scrap carbon steel in the mill vice. | | 2. | Use edge finder tool to position the mill at a corner of the steel. Replace edge finder with a 0.2mm drill bit and reposition the z-coordinate at the surface of the device. Zero all dimensions. | | 3. | Use the mill to make holes 1mm deep holes at four positions [(40mm, 40mm); (40mm, 10mm); (10mm, 40mm); (10mm, 10mm)] | | 4. | Clamp steel in a vertical orientation and complete steps 1.2 and 1.3 at [(5mm, 10mm); (5mm, 40mm)] | | Try to drill each hole quickly and use coolant to avoid heating metal excessively. Actual position of calibration points may vary. Record any changes on the testing procedure. |
| 2. | **Create holes for bone mount**   |  |  | | --- | --- | | 1. | On a flat surface of the steel create two 5mm holes 10mm apart using a 2.5mm drill bit. | | 2. | Tap the holes using a 3.3mm tap | |  |
| 3. | **Device Precision**   |  |  | | --- | --- | | 1. | Connect device to carbon steel piece designed above through the bone mount using two m3 screws | | 2. | Connect a pin to the tool end so that the pin head is positioned at the centre of the radius of curvature of the tool. | | 3. | Place the tool at the calibration corner of the steel piece and record the encoder determined position. | | 4. | Place the tool at the marks located at [(40mm, 40mm); (40mm, 10mm); (10mm, 40mm); (10mm, 10mm)] and record the encoder determined position. | | 5. | Place the tool at the marks located at [(5mm, 10mm); (5mm, 40mm)] in the vertical plane and record the encoder determined position. | |  |
| 4. | **Device Accuracy**   |  |  | | --- | --- | | 1. | Repeat step 3 five times | | 2. | Graph the actual mark positions as well as each test position. | |  |
| 5. | **Workable Area**   |  |  | | --- | --- | | 1. | Position tool at the calibration corner with a piece of paper positioned below the steel piece. | | 2. | Trace the tool head through each of the steel marks and ensure the tool head does not leave the surface of the steel piece. Can this be completed effectively? | | 3. | Move the tool head towards each of the corners of the piece of paper. Record the device reach to each of the corners on the piece of paper. | | 4. | Keeping the x and y coordinates the same as step 5.3 record the highest possible vertical position. | | This test does not determine the volume of the device, but provides a basic footprint range and will verify that the device will be effective for the implant sizes considered. |

### Instability

Tests of previous prototypes identified the presence of instabilities at corner positions. The hard surface position and any potential instability can be determined by tracing the surface of various hard surfaces.

|  |  |  |
| --- | --- | --- |
| Step | Task | Comments |
| 6. | **Hard Surface**   |  |  | | --- | --- | | 1. | Clamp a piece of foam to the steel testing piece created in step 1. | | 2. | Implement four models into the system (flat, spherical bulge, cone and pyramid) | | 3. | Slowly trace the surface of the foam for each of the shapes, removing excess material and revealed the implemented shape. Not down any positions where the tool head penetrates the hard surface | | 4. | Place the tool head at any corners. Access the stability of the tool at these locations. | | Tool should not penetrate the hard surface. |
| 7. | **Instability**   |  |  | | --- | --- | | 1. | For each of the shapes implemented above place the tool head at any corners. Access the stability of the tool at these locations. | | Tool instability should be maintained to within +/- 1mm. |

### Results

Testing has not been completed

### Verification Testing

* Device positioning code based on encoder values – hand calcs
* Tests that ensure encoders read position properly
* Test setup

## 5.2 User Interface (Nicholas)

The user feel of the device is essential for wide spread acceptance and has been a major focus of the current design. Previous prototypes confirmed that 3D haptic surfaces could be implemented effectively, but proved hard to control due to a resistance to user movement termed “virtual weight”. User based tests will be used to determine the effectiveness of the device as a bone sculpting tool.

### Virtual Weight Assessment

|  |  |  |
| --- | --- | --- |
| Step | Task | Comments |
| 8. | **Virtual Weight**   |  |  | | --- | --- | | 1. | For each user: Setup device using foam and implement a hemi spherical hard surface. The foam must be cut to within 5mm of the hard surface prior to testing. | | 2. | With a black pen, place point pairs 5cm apart in a zigzag pattern at 1 cm intervals and mark transition paths across the surface points – use a total of 10 points. | | 3. | In an orientation perpendicular to the step 8.2, repeat step 8.2. | | 4. | Position user 45 degrees from the bone mount position and a line connecting the hip and the knee. | | 5. | Make user follow the zigzag paths described in 8.2 and 8.3, pausing at each point for 5 seconds. Each transition should take between 3 and 5 seconds. | | 6. | Ask user to rate the device performance based on the scale shown in step 8 comments. | | 7. | Ask user to provide general comments on the perceived effectiveness of the device for high precision cutting applications. | | 8. | Measure and record the maximum error between the cut path and desired path. | | Testing using foam will not provide the same resistance as a bone, but be used to assess the effects of the weight of the device on the user in different orientations while performing surgical type operations. The user assessment scale is based on the user’s perceived control over the position of the device and the user’s ability to maneuver the tool along a specific path.   |  |  | | --- | --- | | Rating | Description | | 1. | Device is uncomfortable to hold, will not follow desired path and requires excessive effort to maintain position | | 2. |  | | 3. | Device is uncomfortable to hold, somewhat follow desired path and requires effort to maintain position | | 4. |  | | 5. | Device is uncomfortable to hold, follows desired path and requires effort to maintain position | | 6. |  | | 7. | Device is comfortable to hold, follows desired path well and can maintain position with limited input | | 8. |  | | 9. | Device is comfortable to hold, follows desired path well and can maintain position without user input | | 10. | Device does not affect user control of the tool. | |
| 9. | **Accessibility**   |  |  | | --- | --- | | 1. | For each user: Setup device using foam and implement a hemi spherical hard surface. The foam must be cut to within 5mm of the hard surface prior to testing. | | 2. | With a black pen, place point pairs 5cm apart in a zigzag pattern at 1 cm intervals and mark transition paths across the surface points – use a total of 10 points. | | 3. | In an orientation perpendicular to the step 8.2, repeat step 8.2. | | 4. | Position user 45 degrees from the bone mount position and a line connecting the hip and the knee. | | 5. | Make user follow the zigzag paths described in 9.2 and 8.3, pausing at each point for 5 seconds. Each transition should take between 3 and 5 seconds. | | 6. | Ask user to rate the device performance based on the scale shown in step 9 comments. | | 7. | Ask user to provide general comments on the perceived effectiveness of the device for high precision cutting applications. | | 8. | Measure and record the maximum error between the cut path and desired path. | | This assessment should be completed by experienced surgeons.   |  |  | | --- | --- | | Rating | Description | | 1. | Device is does not provide access critical locations | | 2. |  | | 3. |  | | 4. |  | | 5. | Device is allows access the all critical locations, but requires undesirable repositioning of hand | | 6. |  | | 7. |  | | 8. |  | | 9. |  | | 10. | Device provides comfortable access to all desired areas. | |

# Recommendations

User tests and performance evaluations have not been completed because the prototype is not yet fully functional. Basic performance tests have been used to evaluate the encoder performance based on the update speed and the consistency of each reading, and the software has been verified using hand calculations. The majority of the mechanical aspects of the design require user tests, but an evaluation of the manufacturing techniques can be provided based on machining and fabrication analysis. Once prototype construction and user tests have been completed, a review of the prototype will be presented to the client and a formal list of recommendations will be compiled from the findings.

### Encoder Performance

The encoders pick up 100% of repositions and position the tool within 0.17mm of the desired position if mechanical play is ignored. This allows for 0.3mm of additional error from the bone mount joint, play at the links and software rounding errors. The design uses relative encoders and the total performance maybe limited by accuracy of the calibration position as a result. The calibration position accuracy will not be known until the prototype has been completely manufactured.

### Software Positioning Error

The software designed takes encoder input and computes the desired user position. Related error occurs due to rounding in the position identification and bugs in the software the computer the wrong position in certain circumstances. No errors have been found in current version of the code and all variables maintain 16 decimal places, so there is negligible error in the software as a result.

### Link Joint Play

Manufacture of the prototype has been rushed resulting in a significant increase in play in the joints. An assessment of the maximum in the primary, hard constraint, joints shows a play in the joints of approximately 5 degrees, amounting to +/-6mm of error. Combining the primary and secondary links to create the radial link structure reduces the error to 1mm; however this error is unacceptable for surgical purposes. Manufacturing techniques must be considered further to ensure the desired tolerances for critical components can be met.

### Manufacturing

Manufacturing of the prototype has been completed using a combination of water jet cutting and machining. The complexity of the links necessary to reduce the overall weight of the system makes accurate machining difficult. As a result, a combination of casting and CNC is recommended for additional devices. Casting should be used for the rotating base and the tool mount while minor changes made to the current design could allow for complete manufactured using water jet and CNC.

**6.0 References and Appendices**

**6.1 References**

1. Mech451/2 Praxim Project Final Report, 2008

2. Haptic Emulation of Hard Surfaces with Applications to Orthopaedic Surgery, Nikolai Hungr, 2008