APSC 496

Concept Alternatives Report

Praxim 3D Haptic Hard-Surface Emulator

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*Document Purpose*

*The following document addresses Praxim’s desire to create a 3-dimensional haptic, hard-surface emulating device that will be implemented during total knee replacement surgeries. The following report’s purpose is to detail the design conceptualization process for one of the key functions that the device is required to fulfil.*

*Abstract*

*This report outlines the concept generation and evaluation process completed for the Praxim 3D Haptic Hard-Surface Emulator device. The main goal of this process was to first to categorize the functions the device must perform and identify any critical functions that may have a significant impact on the final design of the device, and then to select a method to fulfil the requirements of this function and create a validation plan.*

*Five important functions have been identified, but the need for the device to stay stationary unless there is input from the user is the only critical function as no similar mechanism is in place in the existing prototype. Five feasible concept alternatives have been assessed and a mechanism incorporating a combination of linear springs, torsional springs and dampeners is believed to provide the best overall performance. Further work must be done to ensure this mechanism can be implemented effectively at two pivots that interact with each other.*

**Table of Contents**

1.0 Introduction 1

2.0 Benchmarking 3

MAKOplasty 4

MBARS 5

Praxiteles 6

PiGalileo 7

3.0 Concept Generation 8

3.1 Function Concepts 9

4.0 Concept Selection 12

4.1 Winnowing 12

High-Friction Joints 12

Dampers 12

Counter Weight 12

Motors 12

Springs 12

4.2 Weighted Decision Matrix 13

5.0 Concept Validation 14

6.0 Conclusions and Recommendations 15

7.0 References and Appendices 16

**List of Figures**

Figure 1- Functional Decomposition Diagram 2

Figure 2- Evaluation Criteria Breakdown 9

Figure 3- Spring Concept 9

Figure 4-Friction Concept 10

Figure 5-Damper Concept 10

Figure 6- Motor Concept 10

Figure 7- Counterweight Concept 11

# 1.0 Introduction

The purpose of designing a 3-D haptic, hard-surface emulating device for total knee replacements is to provide a more precise and systematic method for shaping bones for implant mounting. Currently, the cutting is somewhat methodical in procedure, but depending on certain patient or surgeon conditions, has potential to be very misaligned. This device will take away this uncertainty, provide a less invasive procedure, and damage less surrounding tissue, which decreases recovery time.

Figure 1 on the following page illustrates all functions that must be carried out by the device, as well as the required inputs and final outputs of the device’s operation. The function boxes are coloured in red, light blue, pink or purple (dark blue and orange are inputs/outputs). Red boxes depict general functions that are essentially limited to one method of implementation. The other three colours depict functions who have more than one possible method of implementation, and who require further concept generation to determine the most suitable method for execution; light blue indicates active software-related functions, pink indicates active mechanical functions, and purple indicates passive mechanical functions.

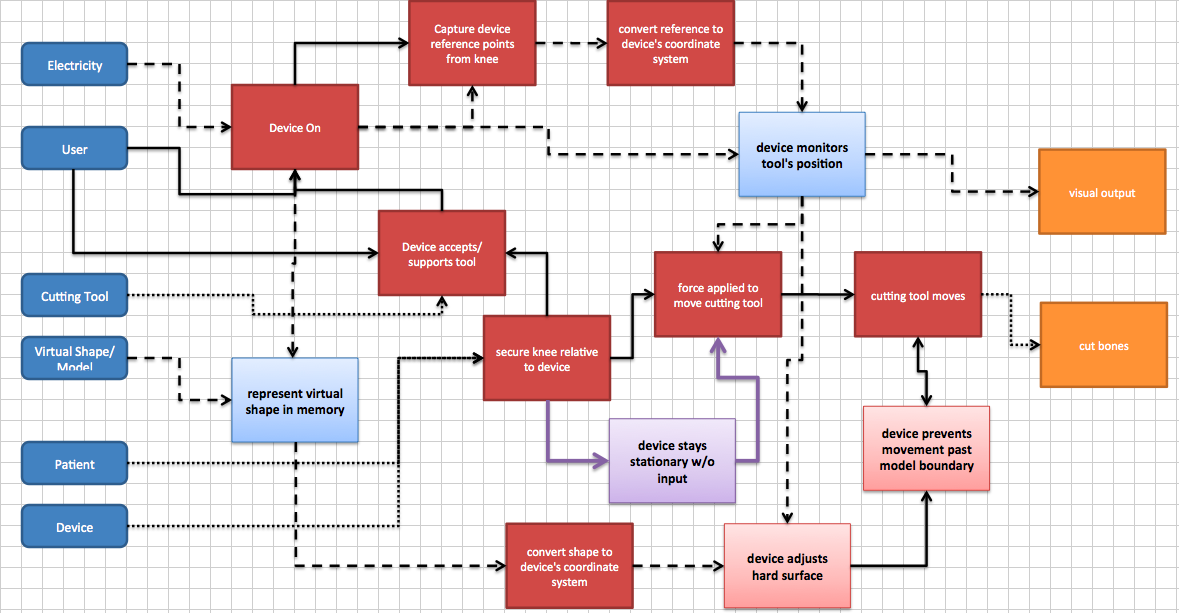


Figure 1- Functional Decomposition Diagram

Box Colours:

Dark Blue- Input

Orange- Output

Red, Pink, Purple, Light Blue- Functions

Line Types:

Solid- Force Transfer

Dashed- Signal Transmission

Dotted- Material Transfer

# 2.0 Benchmarking

There are currently some devices on the market or in prototypical testing phases that are similar in functionality to the scope of this project. Four existing devices have been examined and evaluated, comparing their characteristics to those desired for this project.

The evaluation for each device was based on three separate aspects of the haptic device’s concept: user interaction, autonomous capabilities, and modes of operation. The following table details each function that was evaluated in these three categories.

|  |  |  |
| --- | --- | --- |
| **User Interaction** | **Autonomous Capabilities** | **Modes of Operation** |
| Installation/Mounting | Tool positioning constraint | On |
| Model input | Monitoring/awareness of tool position | Off |
| User connection | Method of providing 3D movement | Idle |
| Tool connection | Conversion of input into traceable surface |  |
| Device motion |
| Sterilization |
| Maintenance |
| Position calibration |
| Positioning awareness/updating |

## MAKOplasty

MAKOplasty is a minimally invasive, partial knee replacement procedure designed to provide quicker recovery and better surgical results for patients with joint degeneration in only one part of the knee. MAKOplasty is unique in its feedback, as it uses an LCD screen to display the knee, with colour-coded areas based on the pre-procedure surgical plan (i.e. areas to be cut are depicted in blue, areas to avoid are depicted in red). (MAKO Surgical Corp., 2009)

|  |  |
| --- | --- |
| **User Interaction** | |
| Installation | Robotic arm acts from a distance; device not mounted directly on patient. Minimally invasive opening made at knee and device operates through here |
| Model input | CT-generated pre-operative planning available on computer (software comes with robot). Surgeon uploads CT scan, plans surgery on computer, and uses the screen during resurfacing to verify correctness |
| User connection | Surgeon moves probe attachment on arm |
| Tool connection | Directly connected to probe that surgeon interacts with |
| Device motion | Full range of 3D motion available; device supports own weight |
| Sterilization | Probe and burring tool are metal and can be sterilized  Robot arm does not contact patient, and is covered with sterile drape |
| Maintenance | No information available |
| Position calibration | Designated reference points are determined prior to procedure to give computer software some bearing |
| Position awareness | Constantly updated—means not available |
| **Autonomous Capabilities** | |
| Tool positioning | Provides hard-surface constraint based on input shapes  Allows 0.5mm deeper cut than hard-surface to prevent tool from ‘bouncing’ off of surface |
| Tool monitoring | Position is constantly updated and displayed on screen |
| 3D movement | Arm has two links and two active connections to control system  Connections seem to be ball-and-socket or U-joint connections |
| Input conversion | Software receives CT scans |
| **Modes of Operation** | |
| On | Present |
| Off | Present |
| Idle | Not present |

## MBARS

MBARS was developed to provide a computer-assisted robotic tool to reduce the invasiveness of a knee joint replacement, as well as provide more bone shaping precision. MBARS attaches rigidly to the bone, and shapes it according to a pre-operative plan. (Wolf, 2006)

|  |  |
| --- | --- |
| **User Interaction** | |
| Installation | Robot mounts on femur, attached by three long metal rods |
| Model input | Information not available |
| User connection | Device is not user operated; cutting is completely automated like a CNC machine |
| Tool connection | Not specified |
| Device motion | Controlled by six separate microcontrollers connected to six actuators; once an applicable bone model is selected, the device plans a path to cut along, and the microcontrollers and actuators are responsible for movement, which is tracked by a notebook computer |
| Sterilization | Not specified, but does not look sterilizable |
| Maintenance | Not specified |
| Position calibration | Surgeon pilots robot equipped with a force sensor along patellar tracking line on femur—robot then automatically traces the bone surface with the sensor to build a model |
| Position awareness | Tracked/assumed with microcontroller/actuator pairs |
| **Autonomous Capabilities** | |
| Tool positioning | Unclear from photos—tool may be permanently mounted |
| Tool monitoring | Does not appear to monitor position save for beginning calibration |
| 3D movement | Six separate actuator/microcontroller pairs located circularly around tool |
| Input conversion | No input, other than calibration tracing—device uses this path to select appropriate model for cutting/shaping from an internal library |
| **Modes of Operation** | |
| On | Yes |
| Off | Yes |
| Idle | Not specified |

## Praxiteles

Praxiteles is a 2-dimensional cutting guide for total knee replacement surgery. A guide jig is positioned by the robot that allows the surgeon to make planar bone cuts to shape the bone for implant mounting. (Plaweski, 2007)

|  |  |
| --- | --- |
| **User Interaction** | |
| Installation | Robot mounts on femur via 2 pins |
| Model input | Praxim’s bone morphing technology is used, which takes input from reference points on bone, and uses this data to morph pre-existing bone models to suit the patient |
| User connection | Surgeon cuts the bone using cutting jig that has been positioned by Praxiteles |
| Tool connection | Tool is not attached, but guided by jigs |
| Device motion | Has two degrees of freedom which allow jig to accommodate all positions required for planar cuts |
| Sterilization | Drive unit can be removed during sterilization |
| Maintenance | Not specified |
| Position calibration | Not specified |
| Position awareness | Position of cutting jig is tracked, but surgeon is responsible for cutting tool’s position |
| **Autonomous Capabilities** | |
| Tool positioning | Constrains tool movement by positioning cutting jigs |
| Tool monitoring | Aware of jig position, but not of tool position |
| 3D movement | Two rotational axes allow for accurate positioning of jig |
| Input conversion | Input via Praxim’s bone morphing technology |
| **Modes of Operation** | |
| On | Yes |
| Off | Yes |
| Idle | Not specified |

## PiGalileo

PiGalileo is a navigational system used in total knee replacement procedures. PiGalileo uses a computer-assisted cutting guide to execute cuts based on alignments from input data. The input data is captures using optical alignment tools and an infrared camera. The computer controls a cutting block with slots that the surgeon can put the cutting tool into, and restricts movement. (Smith&Nephew, 2008)

|  |  |
| --- | --- |
| **User Interaction** | |
| Installation | Cutting block mounted on bone using pins |
| Model input | System is imageless—reference points captured from cameras and projected onto generic bone models |
| User connection | Surgeon uses robot as a cutting guide |
| Tool connection | Robot positions the cutting block, and the surgeon inserts tool into slots in block |
| Device motion | Device allows only planar cuts, restricted by cutting block |
| Sterilization | Appears to be fully sterilizable |
| Maintenance | Not specified |
| Position calibration | Performed by palpating anatomical landmarks using optical apparatus |
| Position awareness | Not specified |
| **Autonomous Capabilities** | |
| Tool positioning | Slots in cutting block restrict the saw—positioning can shift in 0.5mm steps |
| Tool monitoring | Position is constantly updated and displayed on-screen |
| 3D movement | Robot has two joints that allow planar cuts in 2-dimensions |
| Input conversion | Input is only used to position cutting block |
| **Modes of Operation** | |
| On | Yes |
| Off | Yes |
| Idle | Not present |

# 3.0 Concept Generation

The function that was selected for detailed concept analysis in this report is that “The device stays stationary without input”; this means that when the surgeon releases their hold on the cutting tool, the supporting arm remains in position, and does not move under the effects of external forces (primarily gravity). This function was selected as it has been previously determined that user satisfaction is most prominently influenced by device weight and ease of manipulation; the chosen function has the most influence on these attributes. This function is illustrated in purple in Figure 1. Concept requirements for this function are outlined below.

Functional:

* Prevents cutting tool from falling towards the knee when robot lacks input
* When input is present, concept allows robot to emulate 3D haptic interface.

Interface:

* Can be sterilized without component or capability deterioration
* Any non-sterilizable components must be completely sealed and contained in a sterilizable encasement

Ergonomics:

* Must be light-weight, weighing less than 3 lbs (total robot weight should be < 10 lbs)
* Must have a size less than 25% of the link or robot arm it will be mounted on/in.
* Must add a resistance to user-directed movement that is less than a force of 5N (as total resistance of device should be ~10N)

There are no numerical evaluation criteria for this function, as it is simply a yes/no question in terms of performance. What will be considered instead is how the passing concepts affect simplicity, cost, and feasibility.

Evaluation criteria for the concepts are illustrated below:

|  |  |
| --- | --- |
| Criterion | Relative Importance |
| Weight addition | 25% |
| Resistive force addition | 20% |
| Size increase | 20% |
| Feasibility/simplicity | 15% |
| Ability to be sterilized | 15% |
| Cost (predicted) | 5% |

Figure - Evaluation Criteria Breakdown

## 3.1 Function Concepts

|  |  |  |
| --- | --- | --- |
| **Type** | **Diagram** | **Description** |
| Spring | D:\Dave\Dave's School\Current Semester\Praxim\Conc Alt\detail spring concept.bmp  Figure - Spring Concept | Using energy stored in springs, force of gravity is opposed. Concept can be implemented by using a single spring in each joint, or a combination of springs on each joint. |
| Friction | C:\Users\davychiu\Desktop\2009-11-05\Image0001.JPG  Figure -Friction Concept | Joints in linkages are made of materials with high coefficients of friction to prevent device from falling under its own weight |
| Damper | C:\Users\davychiu\Desktop\2009-11-05\Image0001.JPG  Figure -Damper Concept | Hydraulic dampers attached to linkages resist force of gravity by damping motion around joint |
| Motor | Motor.jpg  Figure - Motor Concept | Senses the link’s free-falling movement when user removes opposing force—motor activates to provide appropriate torque to resist motion. Torque can be transmitted via clutch or brake mechanism |
| Counter weight | Counterweight.jpg  Figure - Counterweight Concept | Rotary and/or linear links can be mounted with counterweights to provide constant countering force to gravity—weights would be equal in mass to cutting tool plus arm mass |

# 4.0 Concept Selection

## 4.1 Winnowing

The purpose of winnowing is to remove invalid/impractical concepts that are not worth pursuit.

### High-Friction Joints

The greatest issue with high friction is that the user must continuously apply extra force to overcome friction. This is especially problematic when the user is moving the tool up and away from the joint, as friction and gravity both must be opposed. For this reason, this concept will be deemed as not worth pursuing.

### Dampers

This concept would likely need to be incorporated with another concept to achieve required results, which is a possible option. For example, dampers could be included in a spring-based concept implementation to reduce unwanted oscillation and help to control tool speed when released by the user. This concept will not be further evaluated individually, but instead kept as an option to assist another concept.

### Counter Weight

The primary flaw with this concept is that it adds significant weight to the device, which opposes an elementary goal of the design. Although this is undesirable, this concept will still be considered in later stages of evaluation.

### Motors

Complexity is a significant issue in the implementation of this concept. To facilitate its execution, more information and research is required, however it is seen as a very feasible option. For this reason, the motor concept will be evaluated further.

### Springs

The use of springs is a highly desirable concept that is lightweight and simple, as well as being highly adjustable. For this reason the spring concept will be developed further. (Barents, 2009)

## 4.2 Weighted Decision Matrix

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Wt** | **Counterweight** | | | **Motor** | | | **Spring** | | |
| Score  (/10) | Weighted Score | Reasoning | Score (/10) | Weighted Score | Reasoning | Score (/10) | Weighted Score | Reasoning |
| **Weight Addition** | **25** | 1 | 25 | Additional linkages nearly double weight of device | 4 | 100 | Motor masses will significantly impact overall device weight | 6 | 150 | Weight is related to weight of linkages, but adjustable |
| **Reposition Force Required** | **20** | 5 | 100 | Additional inertia must be overcome due to added mass | 4 | 200 | Does not change reposition forces, but user must resist gravity when system is inactive | 8 | 160 | Additional forces to overcome as user moves farther from datum |
| **Size Addition** | **20** | 2 | 40 | Extra linkages increase size | 4 | 80 | Two additional motors will impact size | 7 | 140 | Size req’ments depend on total device weight, minimal impact on total size |
| **Feasibility/**  **Simplicity** | **15** | 10 | 150 | Passive concept that can accept a variety of tools | 1 | 15 | Complex coding required; motor position may interfere with encoder placement | 7 | 105 | Passive concept but adjustment options add complexity |
| **Sterilizable** | **15** | 8 | 120 | Extra linkages do not reduce ease of sterilization, but limit autoclave capabilities | 3 | 45 | Increased complexity of sterilization procedures due to motors | 6 | 90 | Must be able to withstand autoclave temp. |
| **Cost (Predicted)** | **7** | 10 | 70 | All required components are passive and negligible in cost | 2 | 10 | Motors/ controllers are relatively expensive | 5 | 50 | Potentially costly in order to meet design criteria |
| **Total** |  | 505 | |  | 450 | |  | 695 | |  |

# 5.0 Concept Validation

For this application, the best method of concept validation is to physically test the concepts, as the criteria are generally qualitative concepts, with minimal quantitative analysis required.

The best way to validate a concept would be to develop a quantitative experiment to measure the performance of the concept. The function that these concepts have been developed for primarily has a qualitative component to it (does the device move without input?); however, the overall performance of the concept can also be measured quantitatively (How much force is required to move the device?). So the experiment used to validate a concept should consist of two parts. The first part to test whether the device remains stationary without input in multiple different orientations and the second part to measure the force required to move the device to predetermined orientations.

In order to simplify the experiment, only two degree of freedom motion needs to be considered (the linear slide is parallel with the ground, so it does not need to be considered). Even though this concept could be proven using just one link, both should be considered to ensure that there are no unwanted coupling effects between the two links.

Evaluation criteria, such as, the total weight of the concept and the concept's ability to be sterilized should also be used to validate the concept.

# 6.0 Conclusions and Recommendations

Reviewing the final three concepts evaluated in section 4.2, above, it can be deduced that the spring concept is the most fulfilling for the application. The design is not yet completely understood/conceptualized, however the concept ensures little complication, easy replacement, and quick adjustability for accommodation of a series of tools. Prototypical analysis will be used to ensure that the concept delivers desired results without any major complications, specifically the interaction between linkages and their springs.

# 7.0 References and Appendices

# Works Cited

Barents. (2009). Spring- to-Spring as Energy-Free Adjustment Method in Gravity Equilibrators. *ASME 2009 International Design Engineering Technical Conferences.*

Barrett, A. R. (2007). Computer-assisted hip resurfacing surgery using the Acrobot Navigation System. *Journal of Engineering in Medicine* , 773-85. .

Fabris, S., Oskui, A., Pak, A., Roger, B., Sajadian, S., & Siddiqui, A. (2009). *Three-Dimensional Haptic Emulation of Hard Surfaces with Applications to Orthopaedic Surgery.*

Hungr, N. (2008). *Haptic Emulation of Hard Surfaces with Applications to Orthopaedic Surgery .*

MAKO Surgical Corp. (2009). *Mako Surgical Corp. Physicians*. Retrieved November 2nd, 2009, from Mako Surgical Corp.: http://www.makosurgical.com/physicians/

Plaweski, S. (2007). *PRAXIM ACL Navigation System using Bone Morphing.* SpringerLink.

Smith&Nephew. (2008). *Smith&Nephew Orthopaedics Europe*. Retrieved November 2nd, 2009, from Knee Navigation: http://www.plusorthopedics.com/produkte\_liste\_en,861,1018,navigation.html?ordner\_id=1018

Wolf, A. (2006). MBARS: Mini Bone Attached Robotic System for Joint Arthroplasty. *Biomedical Robotics and Biomechatronics* , 1053-1058.