APSC 496

Critical Function Prototype Report

Praxim - Surgical Robot

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# 1.0 Introduction

# 2.0 Critical Function

The critical function evaluated is this document is the “cutting tool moves” function identified in the functional decomposition. The ability for the user to move the cutting tool in 3D space is essential to the ultimate project goal of generating a 3D hard surface and interfaces with other functions that have significant impact on the design – these include the mechanism used to implement and move the hard surface, how the device is secured to the knee and the types of shapes that can be created. This function also has a direct impact on many of the design requirements. The mechanism selected will set limitations on the size and weight of the device due to the type of joints used in the design, as well as motor speed and accuracy requirements and how the user interacts with the device. As a result, it is important that these effects are considered early, before the interfacing functions are developed further.

From this analysis completed in this report we plan to finalize the mechanism that allows the cutting tool to move in 3D space and assess the impact of link lengths on the envelope of the device.

# 3.0 Description of Prototype

The prototype developed to assess the critical function is based on a previous prototype used to evaluate the feasibility of the entire concept in 2009. This existing prototype implements a three link mechanism consisting of two rotational joints and one linear joint. The drawback with this link arrangement is the size and weight of the linear joint, and through concept generation and evaluation of this function all linear joints have been removed.

The portion of the existing prototype used for the critical function prototype is shown in . The motor and encoders were removed from linkage 1 and linkage 2 leaving only the mechanism developed by Nikolai Hungr. Based on Hungr’s analysis the ideal lengths of linkage 1 and linkage 2 are 5 cm and 4.5 cm respectively. The critical function prototype developed, however, uses link lengths of 5.5 cm and 6.0 cm. The project team felt that these lengths would be the maximum lengths allowed to maintain the size and weight requirements, but the analysis would provide insight into the possibility of a multiple lobe envelope.

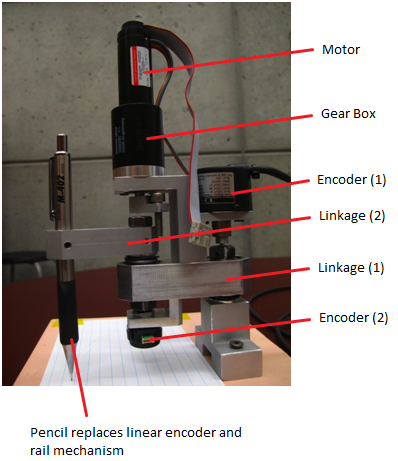


Figure – Dynamic Physical Constraint mechanism used in existing prototype

## Prototype 1

Prototype 1 consists of three rotational joints at positions 1, 2 and 4. Bearings have been used at joints 1 and 2 while link 4 is allowed to rotate by a set screw held in place by a setscrew. Link 3 is a kept stationary by a setscrew and is not allowed to rotate. The link 3 has been designed to be repositioned depending on the experimental requirements. Link 4 has also been designed to vary in length from 3 cm to 6 cm in increments of 1 cm, but will be set at 6 cm for Prototype two. Figure 2 provides an overview the Prototype 1 mechanism. The figure highlights the relationship between Link 3 and Link 2 and the position of Link 4 and the cutting tool because they cannot rotate with respect to each other.

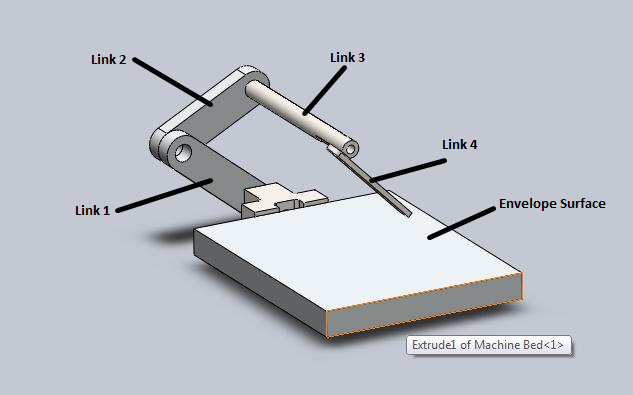


Figure – Model of prototype 1

Table – Prototype 1 link lengths

|  |  |
| --- | --- |
| **Link** | **Length [cm]** |
| Link 1 | 5.5 |
| Link 2 | 6.0 |
| Link 3 | Variable |
| Link 4 | 6.0 |

## Prototype 2

Prototype 2 consists of four rotational joints at positions 1, 2, 3 and 4. Bearings have been used at joints 1 and 2 while link 4 is allowed to rotate by a set screw held in place by a setscrew. Link 3 is a kept allowed to rotate by loosening the setscrew but a stopper is placed at the end to stop translation. Link 4 will be set at 6 cm for Prototype 2. In model of Prototype 2 – shown in Figure 3 – Link 3 can rotate with respect to Link 2 and Link 4 can always be oriented towards the envelope surface as a result.

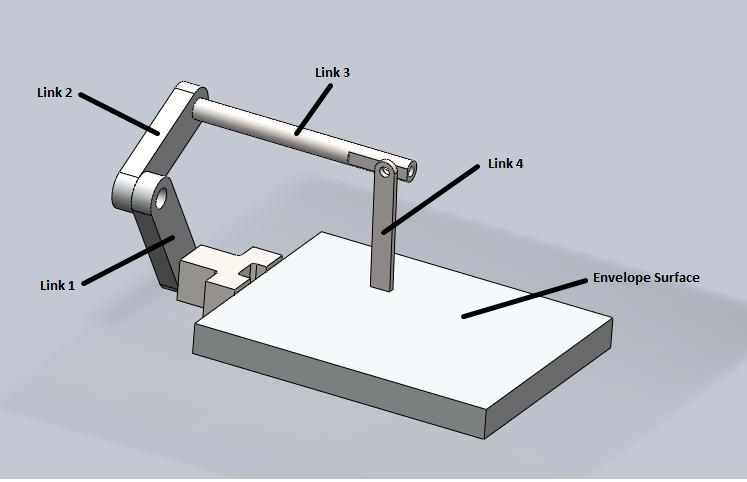


Figure – Model of Prototype 2

Table – Prototype 2 link lengths

|  |  |
| --- | --- |
| **Link** | **Length [cm]** |
| Link 1 | 5.5 |
| Link 2 | 6.0 |
| Link 3 | Variable |
| Link 4 | 6.0 |

# 4.0 Experimental Method

**Testing Protocol**

The purpose of the testing protocol is to see if the desired range of motion is achieved with the rotation-rotation-rotation joint configuration design within the specified requirements. In order to complete Unicompartmental Knee Replacement Surgery the tool must have access to both femoral lobes. This can be achieved in two ways; (1) a linkage mechanism with a range of approximately 16 cm - equivalent to the entire knee - or (2) a linkage mechanism in which linkage 3 is adjustable to allow operation on individual lobes using the same mounting position.

**Max range/volume**

This test is to determine the feasibility of two design types; (MODE 1) four link mechanism with rotational joints at positions 1, 2 and 4 and (MODE 2) four link mechanism with rotational joints and positions 1, 2, 3 and 4. Steps will be taken to access the effectiveness of both designs with respect to the entire knee from one position design and the individual lobes design discussed above.

Assumptions/Requirements:

1. Device is fixed to femur (no play in the bone mount)
2. Link 2 can never be perpendicular to the generated surface
3. Link 4 has a maximum angle of 45 degrees from the vertical position
4. Link 4 cannot come into contact with the support structure
5. Entire knee envelope has a radius of 8cm
6. Single lobe envelope must be 16cm by 8cm
7. Lateral deflection cannot occur
8. Linkages cannot transfer between right and left orientation
9. Link 4 length is 6cm

Method:

1. Setup up mechanism in MODE 1
2. Position mechanism in right orientation
3. Set reference point to the position where link 4 is perpendicular to surface and in line with the axis of the mechanism
4. Position tool (end of link 4) along the surface of the support structure at a edge of the envelope – on the verge of lateral deflection
5. Moving the tool along the surface and maintaining near lateral deflection position, map out the envelope of the current setup moving link 4 from +45 degree to -45 degree position
6. Maintain -45 degree position keeping tool on the surface, map out the envelope generated until link 1 is perpendicular to the surface
7. Moving the tool along the surface and maintaining link 1 perpendicular to surface position, map out the envelope of the current setup moving link 4 from -45 degree to +45 degree position
8. Maintain +45 degree position keeping tool on the surface, map out the envelope generated until mechanism reaches the lateral deflection position
9. Repeat for all steps for MODE 2

Questions:

* Is the workable area sufficient?
* Are there any areas where the tool cannot be oriented?
* Note: max range should be before lateral deflection occurs (when link1 is almost 90 degrees)

# 5.0 Analysis of Results

After completing a physical prototype of the robot’s new linkage system, the critical function was preliminarily examined with a series of basic tests. The main feature we tested for is the range of workable area the linkage allows for.

At first, our shaft link (3rd link from the bone mount) simply acted as an offset for the system, as it was rigidly fixed against movement with a set screw in its joint with the second link. All three other links were allowed to rotate in their respective planes. Although this set-up provides an easier task for hard-constraint calculations and control, since you need 1 less encoder and a less intensive mathematical calculation, the workable range provided is greatly lacking. Effectively, with the link sizes of the prototype we tested (15 cm shaft and 6 cm tool link), the area was a triangle with a height of merely 3 cm and a base length of about 5 cm.

We decided to test whether the range from the previous set-up would be improved if the 3rd shaft link was allowed to rotate about its axis. The change was immediate and obvious. The rotation of the shaft link effectively allowed the projection of its rotation angle to be added to the range of the workable area, thus greatly increasing it. With the same link sizes used for the first testing set-up, this added degree-of-freedom to the third link allowed us to work on a square area with a side length of 6 cm (???what I remember I’m not sure???). That being said though, implementing this extra DOF requires an additional encoder and a more intensive mathematical and computing process for hard surface control.

# 6.0 Future Steps and Updated Timeline

# 7.0 Conclusion