**Motor Choice:**

For the purpose of our project, we created 4 main classifications of motor types which can be used for hard-constraint manipulation. Knowing the range of response speed and holding torque needed, we selected an existing motor for each classification. We then analyzed the advantages and disadvantages of each, and formulated a general idea of which one should be used, and in what orientation and position.

The motor classifications which can be used in this type of application are the following:

* DC Motors (Brush or Brushless)
* AC Motors (Synchronous or Asynchronous)
* Stepper Motors
* Special Purpose Motors

From our previous calculations, we decided that the hard constraint should be able to move at least .5 mm in 990 microseconds. Thus, the required response time in approximated to be 1 millisecond. However, this response time is more dependent on the control system coupled with the motor, rather than the motor itself. With regards to the torque/load, we previously decided, based on our functional requirements, that the hard constraint should be able to hold back a load equivalent to 10 kg (100N).

**DC Motor:**

DC motors are simple and cheap, and are relatively easy to control speed (not critical in our application), and control torque. Furthermore, we can opt for a “high-torque self-starting” gear motor, which are usually strong, quiet, and operate at low speed and high torque. The problem with DC motors is that they are not reliable to control at low speeds, and require higher maintenance than other motors. An example of a “high-torque self-starting” DC motor which is suitable for our application is the following:

* Slow speed and high torque
* DC reversible gear trains
* Motor housing 1-13/16" L x 1-13/16" O.D.
* Steel shaft
* Diameter x 11/16" L.
* Weighs approx. 2 3/4 oz.
* No-load drain Approximately 8mA at 12V
* Continuous run, low temp

**AC Motor:**

Typical AC induction motors (squirrel cage) are very common and cost less than other motor types. They are reliable and can be enclosed in many different environmental enclosures (good for sterilization). However, they are expensive to implement speed control on, and have relatively poor positioning control, coupled with an inability to operate at low speeds. The project from last year uses a typical gear motor which is relatively suitable for small robotics applications.

**Stepper Motor:**

Stepper motors can provide accurate positioning and can be controlled precisely with relatively simple controller setups. Micro stepping can provide smooth and precise positioning, although vibration is usually a problem. The holding torque (detent torque) depends on the size of the motor, but can easily reach the value need in this project (100N). A typical stepper motor which can be used for our application is presented in the following:



• Unipolar [Stepper Motor](http://www.robotshop.us/stepper-motors.html)  
• Voltage: 6vdc  
• Resolution of 1.8 degrees/step  
• Torque of 361 oz/inch  
• Precision of ±5%  
• Single shaft

**Special Purpose Motor:**

An example of a special purpose motor is an ultrasonic motor. Ultrasonic motors use resonance to amplify the vibration of the stator in contact with the rotor. They offer large rotation capabilities or sliding distances, and come in contact and non-contact forms. Ultrasonic motors are difficult to buy and can be relatively expensive, but for purposes of our project, we might find that they are the most suitable.

**Gearing:**

If we go forth with a constant-rotation type motor such as a DC or AC motor, we need suitable gearing setups that will reduce the speed to what’s needed to implement the hard constraint. For the stepper motor, this is not needed.

There is a wide range of gearing possibilities, from traditional and planetary to special gear reduction methods such as harmonic gears. The choice of gearing setup depends on the choice of motor, and in some instances, can actually be chosen in one motor-gear package.

**Traditional Gears:**

Can be oriented in a variety of manners, but need multi-axial systems to function. Provide precise and smooth operation and reasonable reduction rates (20:1 generally being an upper limit). They are cheap to buy and simple to maintain.

**Planetary Gears:**

Advantages of planetary gears are mainly its ability to be used with coaxial shafts, its large reduction capability in small volume, and pure torsional (torsion only) reactions. They are quite complex though and are difficult to access after installation. They also produce higher bearing loads.

**Harmonic Gears:**

Harmonic gears are special types of gears used in applications where high reduction ratios are needed. They have no backlash, are compact and lightweight, have high torque capability, and can operate on co-axial shafts. Their most prominent advantage is their very high reduction ratios, which can reach values of 100:1 in the same volume where a planetary gear would produce a 10:1 ratio)

**Encoders:**

To measure the location of the links at any point in time, typical rotational (usually optical) encoders are used. These can either be relative encoders or ones in need of calibration every time they are activated (absolute). Here, we will not discuss the electronic or control side of the design, but will discuss the location of the encoders’ placement and their effect on the function of the robot.

Since the encoders are rotational, their location is at the rotation joints 1 and 2. There are no translational movements that the robot arm allows, thus, there are no translational encoders to be used. The effect the encoders have on the weight of the device is minimal, compared to the actual weight of the link and the weight of the drive-train setup. However, their size and possible restraining of motion are important to reduce. A large size encoder can impede the view of the surgeon(s) working on the knee, while the wires and connections to and from the encoder can make the link movements harder and rougher. Judging from the size of a typical encoder which can be used for this application (see attached spec sheet), these problems can be avoided in the design.



**Specifications**  
\* Panel Mount; Straight Leads  
\* Input Voltage: 5.0 VDC +/-5%  
\* 30mA max.  
\* Output Voltage: High: 4.2Vmin; Low: 0.4Vmax  
\* Max. Freq. Response: 500 Hz

**Mounting Methods:**

The specific choice of the motor and gear setup used in this project will depend on the technical analysis to be performed on the hard constraint requirements. However, regardless of the motor and gear setup chosen, there remains a dilemma in where to position these two components on the robot.

**Mounting Position 1:**

Since the hard constraint can only act on link 2 in any of the proposed prototypes, the location of the motor and gear setup is effectively restricted to two locations, joint 1 or joint 2. The project from last year successfully implement the hard constraint actuation by positioning the motor and gear setup at joint 2, where they used a motor-gear package mounted co-axially and directly onto the joint. The hard constraint was a pin linked to the output shaft. The system looked like this:

PICTURE OF THE MOUNTING ON JOINT 2 – possible a solid model of it too

Although this system is functional, it poses a number of practical problems. Firstly, it deepens the needs for an effective gravity compensation design on the whole robot, since the motor’s heavy weight acts as a constant unwanted load pulling link 2 downwards. In order to reduce the size and weight of the setup, one must either trade-off the performance of the motor (torque and speed), or significantly increase its price.

**Mounting Position 2:**

To avoid the problem of having a large weight mounted on joint 2, we thought about positioning the motor and gear system on joint 1. Mounting the motor and gear system and joint 1 will allow all the load of the motor to be taken by the rigid bone mount, thus eliminating the need for a high-performance gravity compensation design. However, this design also comes with it’s drawbacks, namely, the need to design a hard constraint which extends to link 2, but maintains the required rigidity to hold back the load, and speed to update to different positions. An example of this system is presented below:

SOLID MODEL OF MOUNTING POSITION 2

**Decision Table:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **DC Motor** | **AC Motor** | **Stepper Motor** | **Ultrasonic Motor** |
| **Traditional Gearing** | Simple motor, simple controls. Unwanted double shaft gearing | Expensive and hard controls for motor. Unwanted double shaft gearing | Very simple motor and very simple control. Motor torque might be a problem. Unwanted double shaft gearing | Complex and expensive motor. Unwanted double shaft gearing |
| **Planetary Gearing** | Simple motor, simple controls. Good co-axial motor gearing | Expensive and hard controls for motor. Good co-axial motor gearing | Very simple motor and very simple control. Motor torque might be a problem. Good co-axial motor gearing | Complex and expensive motor. Good co-axial motor gearing |
| **Harmonic Gearing** | Simple motor, simple controls. Good co-axial motor gearing | Expensive and hard controls for motor. Good co-axial motor gearing | Very simple motor and very simple control. Motor torque might be a problem. Good co-axial motor gearing | Complex and expensive motor. Good co-axial motor gearing |

RED: PROBLEMATIC COMBINATION

YELLOW: REASONABLE COMBINATION

GREEN: GOOD COMBINATION