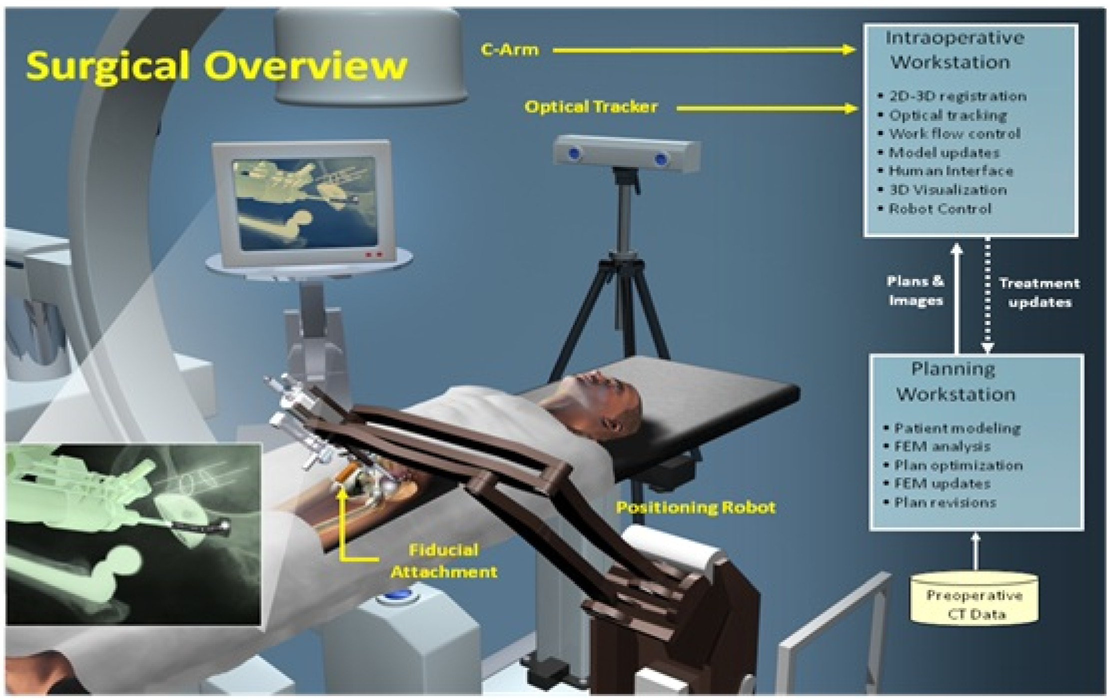
Position Control of BIGSS Lab Snake for Revision Total Hip Arthroplasty (THA) Surgery

600.446 Computer Integrated Surgery II

Project Proposal



Project 6:

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Mentors:

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❖ Summary

Osteolysis is a condition wherein bone breaks down, undergoes resorption, and dissolves into a viscous solution. In less-invasive treatment, the surgeon tries to remove osteolytic defects behind the acetabular cup using conventional rigid tools. However, complete treatment of the lesion cannot be achieved with this method. The BIGSS Lab is developing a minimally-invasive surgical workstation to treat the osteolysis behind the well-fixed cup during revision surgery. They have developed a Dexterous Snake-like Manipulator (SDM) for this purpose. This dexterous manipulator will be an active cannulae for guiding tools in a surgical workstation for the diagnosis, planning and real-time intra-operative treatment of the lesions. This project focuses on integrating the SDM with a 6 DOF Universal Robot (UR5) and position control of SDM inside the lesion.

❖ Background and Specific Aims:

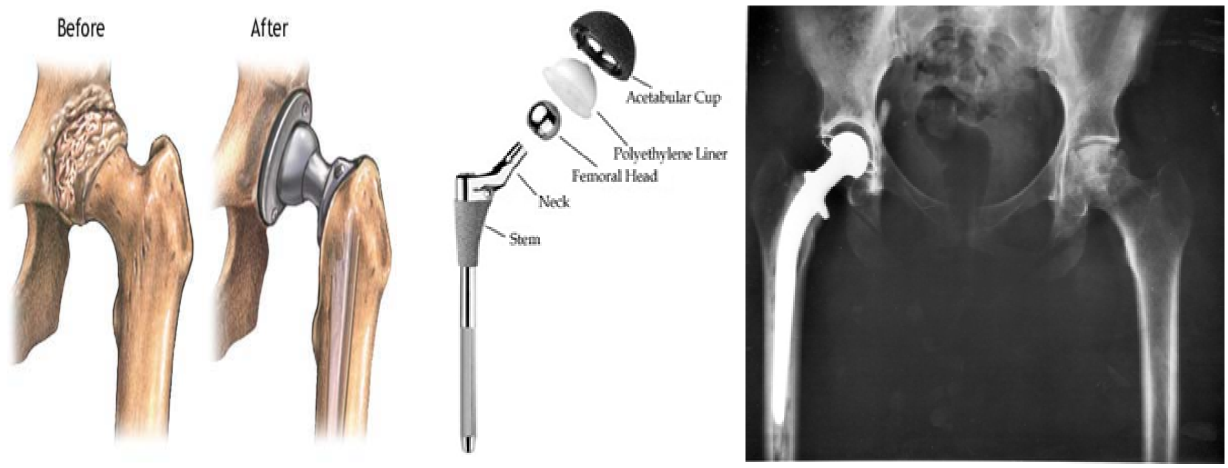


Figure 1. Basic principle of total hip arthroplasty(THA) surgery.

Wear of the articulating components (Figure 2.a) in a total hip arthroplasty (THA) surgery (Figure 1), typically a polyethylene liner, leads to formation of polyethylene particles that cause macrophage activation and osteolysis of the bone surrounding the implant (Figure 2.b). According to Figure 2.c, if this procedure left unmonitored and untreated eventually fracture and component loosening with catastrophic failure will occur.

Diagnosis and treatment of pelvic osteolysis is both challenging and complex, with multiple decision points depending on the extent of lesions and the degree to which the implant is well-fixed. The current less-invasive treatments have been shown to reliably fill less than half of the osteolytic defects behind the acetabular cup (Figure 2.b). Current manual tools are hard to manipulate precisely, and lack sufficient dexterity to permit surgeons reach all the lesion area. This clinical problem motivated the development of a novel system for this kind of surgeries.

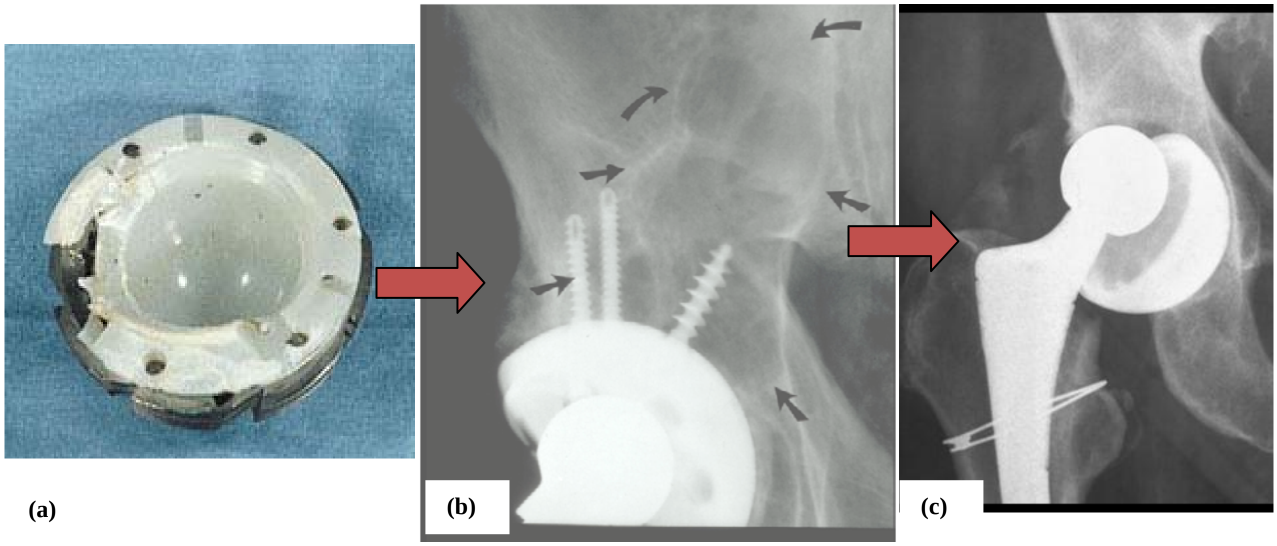


Figure 2. (a)Wear of polyethylene liner in acetabular cup, (b)Osteolysis,(c) failure of implant.

APL has designed a cable driven SDM (Figure 3) to achieve the osteolytic lesions behind the cup without the removal of implants (less-invasive procedure) which has these specifications:

- Planar manipulator composed of superelastic nitinol
- 4mm open lumen for inserting different tools in the SDM
- Designed to fit in a hip implant (6mm OD)

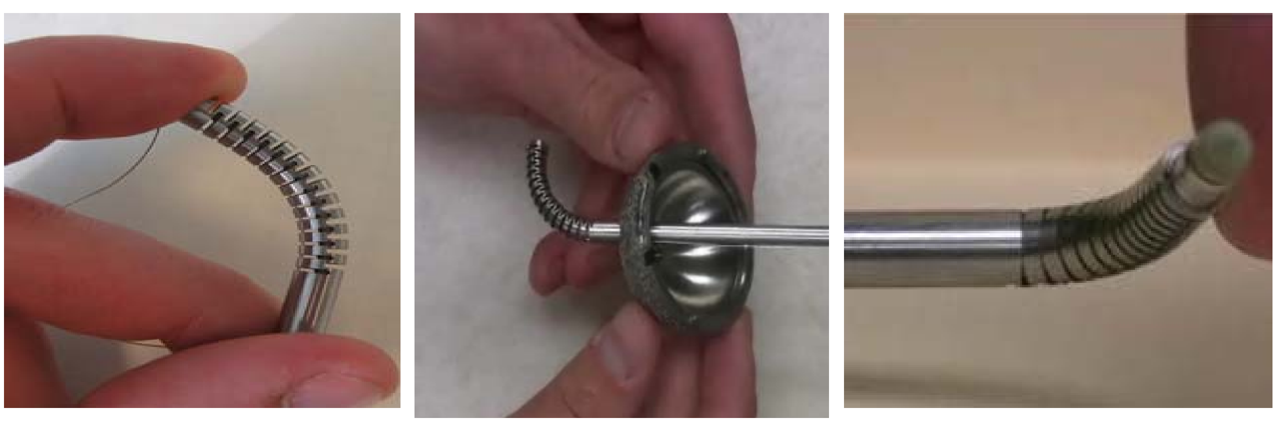


Figure 3. APL SDM specifications.

❖ Overview of Goals

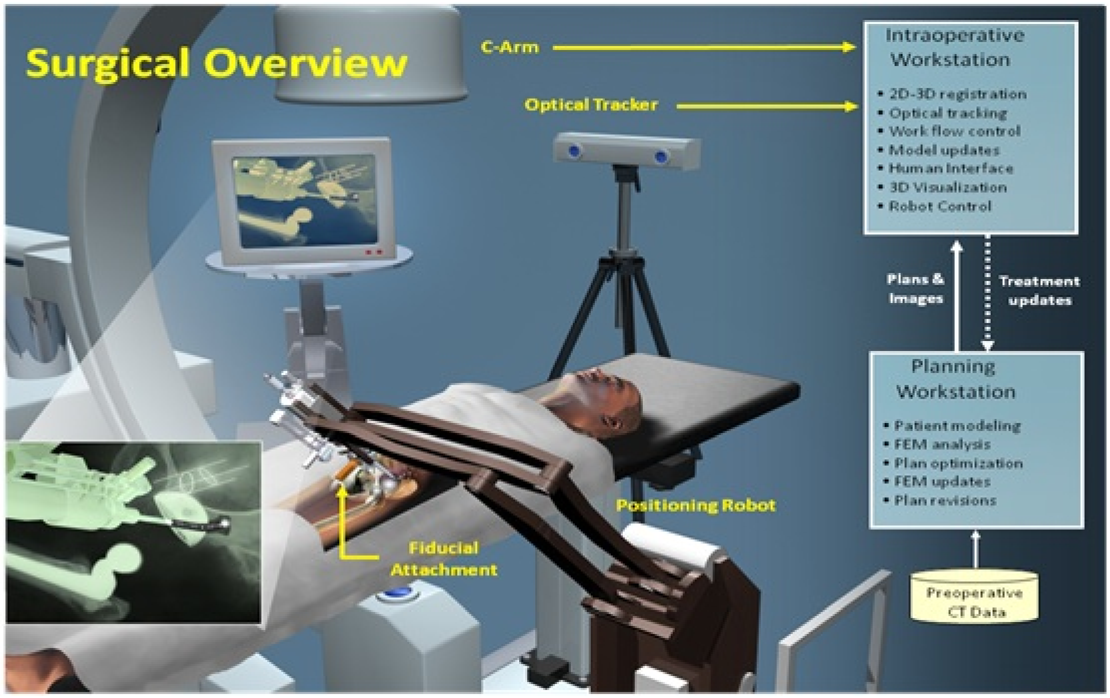


Figure 4. BIGSS lab a minimally-invasive surgical workstation

The BIGSS lab is developing a minimally-invasive surgical workstation (Figure 4) to treat the osteolytic lesions behind the well-fixed cup during revision surgery using the mentioned SDM. This dexterous manipulator will be an active cannulae for guiding tools in a surgical workstation for the diagnosis, planning and real-time intra-operative treatment of the lesions. According to Figure 4, the SDM will be positioned in the workspace by a robotic arm. The focus of this project is integrating the SDM with the robotic arm- which is a 6 DOF Universal Robot (UR5) - and position control of the tip of the SDM inside the lesion area. The SDM and UR5 robot are shown in Figure 5.

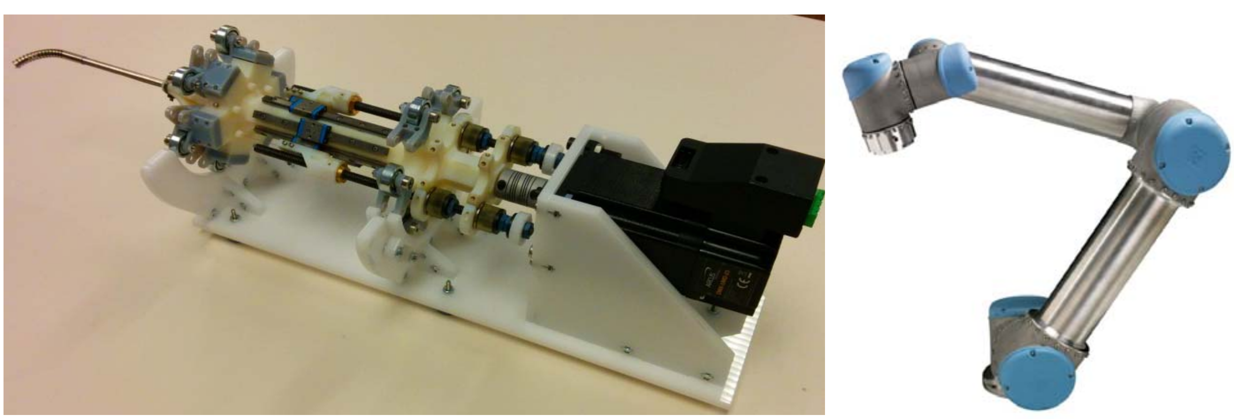


Figure 5. BIGSS SDM (Left) and UR5 robot (Right).

❖ Technical Summary of Approach:

This project consists of four steps (Figure 6):

1) mechanical design for integrating SDM with UR5 robot.; 2) deriving the kinematics and other relevant equations for controlling the robot.; 3) understanding how to control the UR5 through the provided executables and libraries; 4) position control of the snake which is the main focus of this work. We will use the results of other steps in this part. Following the detailed tasks of each part has been mentioned.

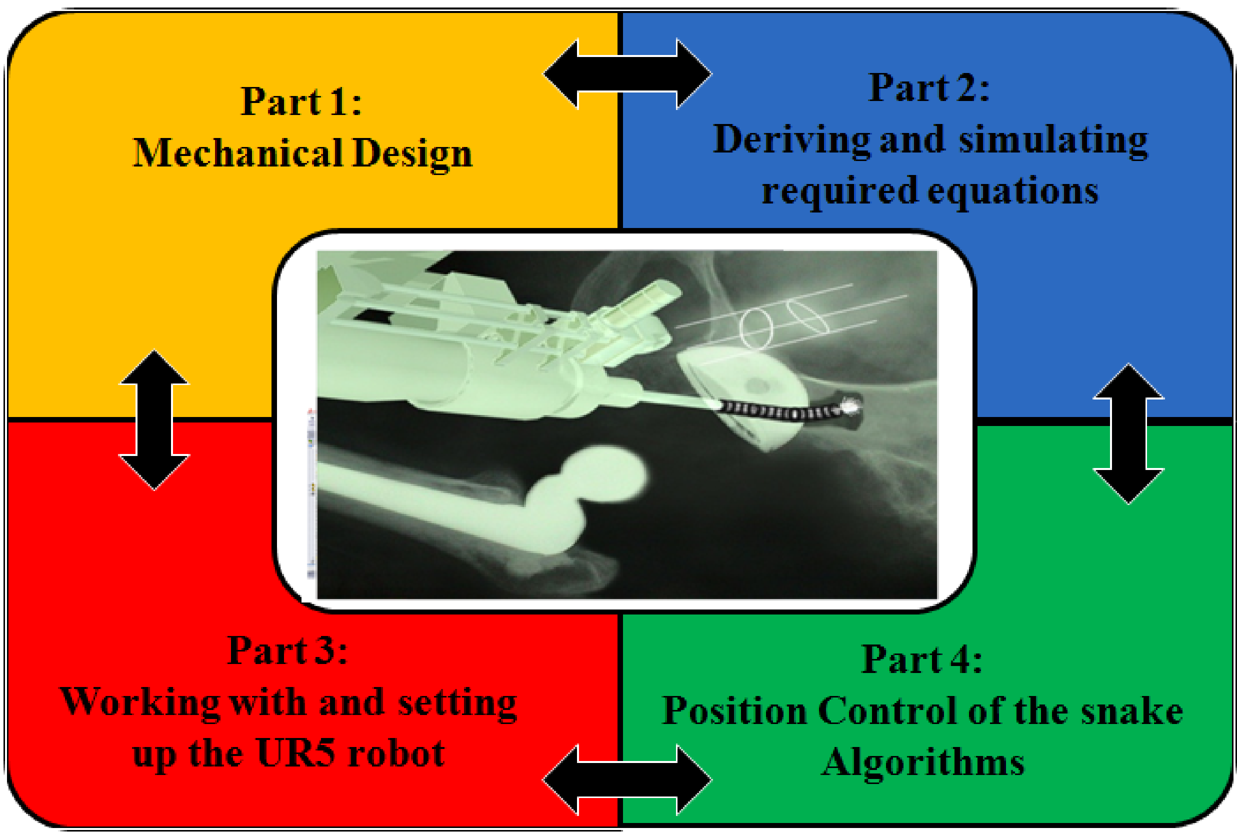


Figure 6. 4 steps of this project.

Part I: Mechanical Design

The main purpose is to interface the SDM with UR5. This task involves:

- ➢ Preparing a 3-D model of the UR5 inside a CAD software
- ➢ Mechanical interface of the SDM to the UR5 considering these limitations:
    - ✓ UR5 has a 5kg load limit

- ✓ SDM lumen should be accessible
- ✓ Modifying existing actuation unit
- ✓ Considering work space of the UR5

- ➢ Fabrication of mechanical parts
- ➢ Assembly

Part II: Deriving and simulation of required kinematic equations of the SDM and UR5 with Matlab- Simmechanics

The Aim of this part is preparing required equation for controlling the SDM and verifying those equations through simulation. We will use SimMechanics for simulation of the robots (Figure 7). This model can be used for implementation of control algorithm before implementation on real robots. The tasks of this part are summarized as:

- ➢ Deriving the Forward and Inverse Kinematics of the UR5 robot
- ➢ Simulation of these Equations in Simmechanics-Matlab
- ➢ Being familiar and working with the available kinematic model of the SDM
- ➢ Simulation of the inverse kinematics of the coupled robots without considering physical limitation

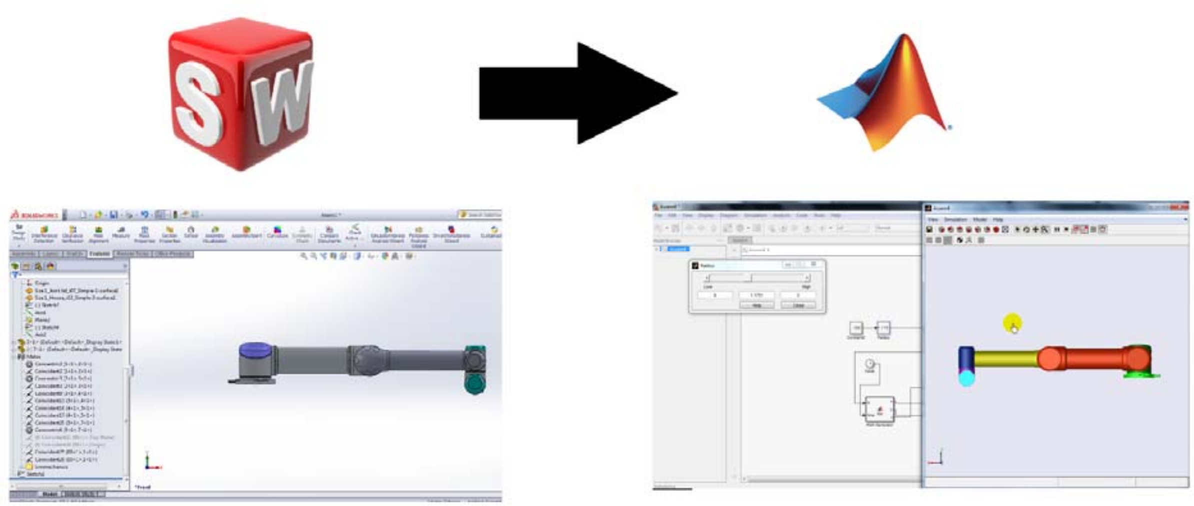


Figure 7. Using SimMechanics for simulation of robots.

Part III: Working with and setting up the UR5 robot

For implementing the control algorithm, we first should be able to work with UR5. Some tasks of this part are:

- ✓ Controlling the UR5 using C or Python
- ✓ Implementation of derived kinematic equations (Forward and Inverse)
- ✓ Controlling the coupled robots without considering the physical limitation of the problem

Part IV: Position Control of the tip of the SDM

The final part and target of this project is controlling the position of SDM. However, for position control we should consider these points:

1. According to Figure 8 SDM entry is through the screw holes of acetabular cup therefore 2 degrees of freedom of the UR5 will be lost considering this constraint

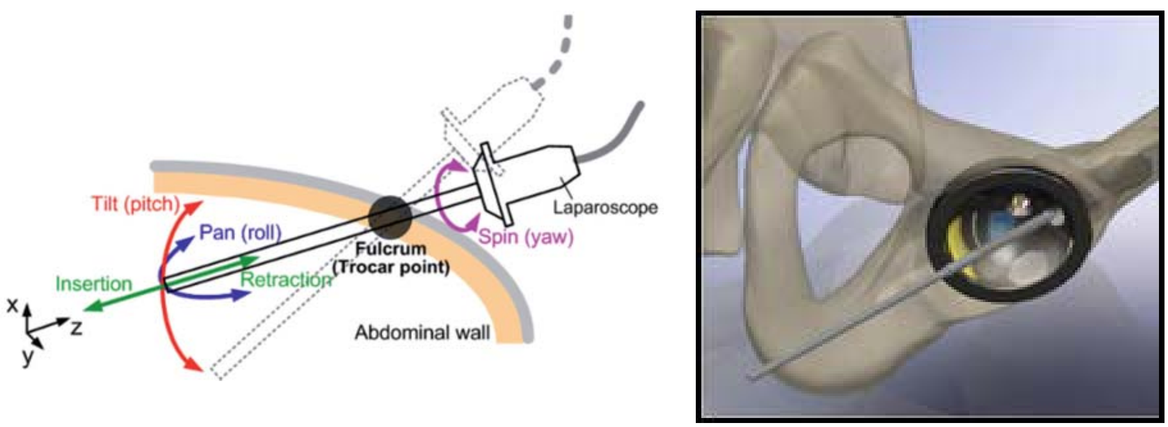


Figure 8. Limitation of the movement of SDM because of its entry.

2. The UR5 robot does not have a mechanical RCM point therefore we should create a virtual RCM point. These RCMs are shown in Figure 9.a which is a work by A.Kapoor [9].

3. There may not be enough space inside the pelvis and behind acetabular cup therefore some parts of SDM may remain outside the acetabular cup during part of the procedure (Figure 9.b). The virtual RCM in this situation would be on the flexible part which is a curve not a line. For this case, we maybe can assume that the RCM is on a rigid body which is along with the SDM base.

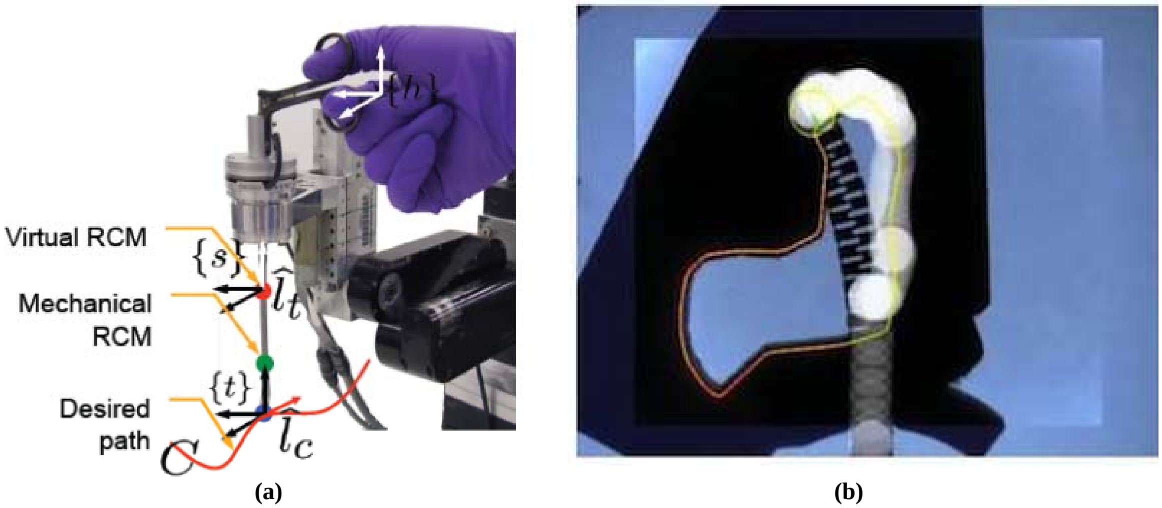


Figure 9. (a)Mechanical and Virtual RCM in a robot [7], (b) Position of the RCM on the SDM.

4. We need the exact configuration of the robot after pulling the cables for controlling and determining the RCM (robot does not have a constant curvature).

5. Lateral forces of the cup may change the derived kinematic equations of the SDM. We assume that there is not any lateral force in this work.

Regarding these assumptions and considerations we should use virtual fixture algorithms to control the SDM [5-9]. We will use optimization to find the joint angles of the actuators regarding our constraints like virtual RCM and limitation on actuators velocities. Figure 10 briefly describes the control algorithm block diagram.

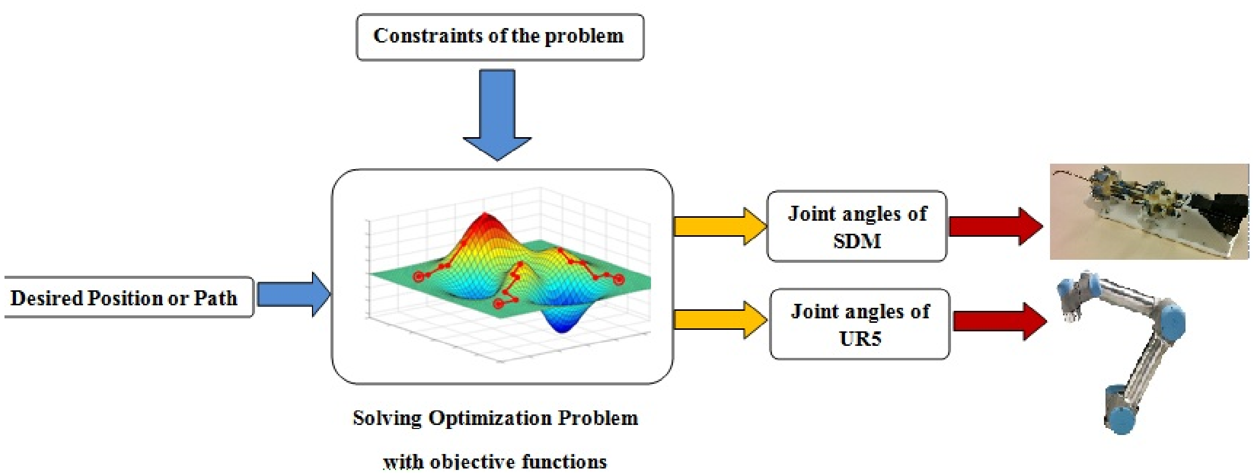
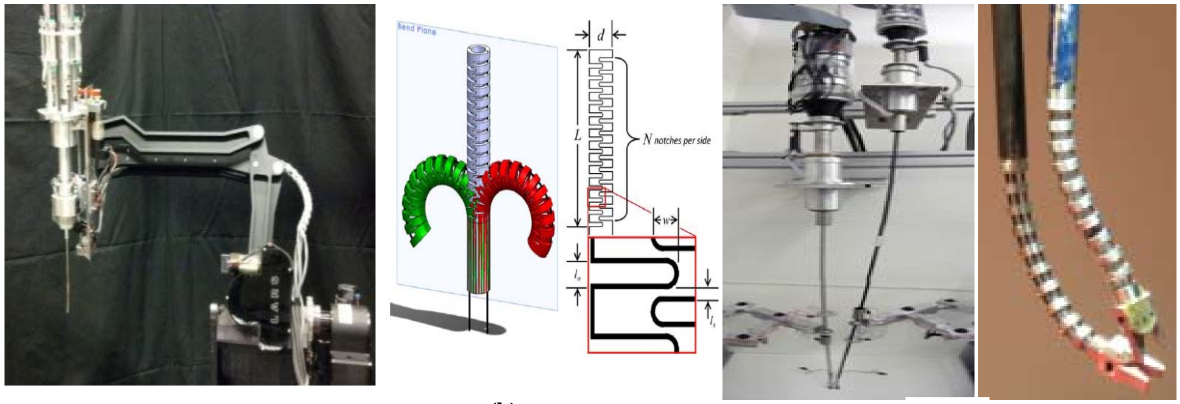


Figure 10. Control algorithm block diagram.

❖ Prior work:



(a) (b) (c)

Figure 11. (a) Interfacing APL SDM to LARS[10], (b) kinematic model of the SDM[4], (c) telemanipulation of snake for minimally invasive surgery of the upper airway[8].

- **On this system:**

1. *Interfacing APL SDM End Effector to LARS Robot , Figure 11.a (Piyush Routray , Ashish Kumar , Spring 2013, CIS II project):*

   ✓ In this work, they had used Lars with a mechanical RCM as the robotic arm.

   ✓ The control of the SDM was separate from the robotic arm. They first controlled the position of the arm then they tried to reach their desired area.

2. *Geometric and kinematic model of the SDM, Figure 11.b (Ryan J. Murphy, Matthew S. Moses, Michael D. M. Kutzer, Gregory S. Chirikjian, and Mehran Armand)*
   They have worked on deriving the kinematics model of the SDM. We will use their result in this project.

- **Similar work**

There are a lot of similar works regarding modeling and control of the morphable or continuum robots. However, we will use the algorithms for creating virtual RCM in robots [5-9] and specifically flexible robots. One of the important works is related to Kapoor, et al [8] for telemanipulation of snake-like robots for minimally invasive surgery of the upper airway (*Figure 11.c*). The difference of this project and the Kapoor’s work is that their robot has a mechanical RCM and all part of the SDM is inside the body and therefore RCM is on a rigid place.

❖ Deliverables:

✓ **Minimum**

- Deriving and implementing the kinematic equations of UR5

- Interfacing the SDM with UR5 (Mechanical design and fabrication)
- Coupled inverse control of robots outside the body

✓ **Expected**

- Controlling the position of the coupled robots using virtual RCM when all of the SDM is in the body (Simulation and implementation)

✓ **Maximum**

- Controlling the position of the coupled robots using virtual RCM when all of the SDM is not in the body (Simulation and implementation)
- Modeling the kinematics of SDM using solid mechanics or beam theory

❖ Dependencies:

✓ **Mechanical design:**

- 3D model of the SDM: Dr. Armand will give me this model.
- Machine shop and 3D printer for fabricating the interface parts: JHU and APL tools can be used using Dr. Armand or Ryan Murphy.

If we cannot access the machine shop or cannot fabricate the part then we should do our works in simulation and Simmechanics.

- **Robots:**
  - UR5 robot: BIGSS lab will buy this robot before March 1.
  - SDM robot: I can use the BIGSS lab 2-D SDM.

If we cannot buy the UR5 then we should do our works in simulation and Simmechanics.

- **Kinematic model of SDM:**
  - ➢ I will use the available model of Ryan Murphy.
- **Access to Mentors:**
  - ➢ Weekly meeting with Dr. Armand and Ryan Murphy
  - ➢ Scheduled meeting with Dr. Taylor as needed

❖ Management Plan: Basics

✓ Weekly meeting with mentors has been considered.
✓ I am planning to spend a total of 35 hrs per week on this project.

❖ Management Plan: Key Milestones

February 16: Simulation of the model in Simmechanics-Matlab

March 09: Mechanical interface of SDM to UR5

March 23: Working with and setting up the UR5 robot

March 23: Fabrication of first coupled robot

April 6: Controlling the coupled robots (**Minimum Deliverable**)

April 20: Simulation of virtual fixture (RCM point is not on the SDM)

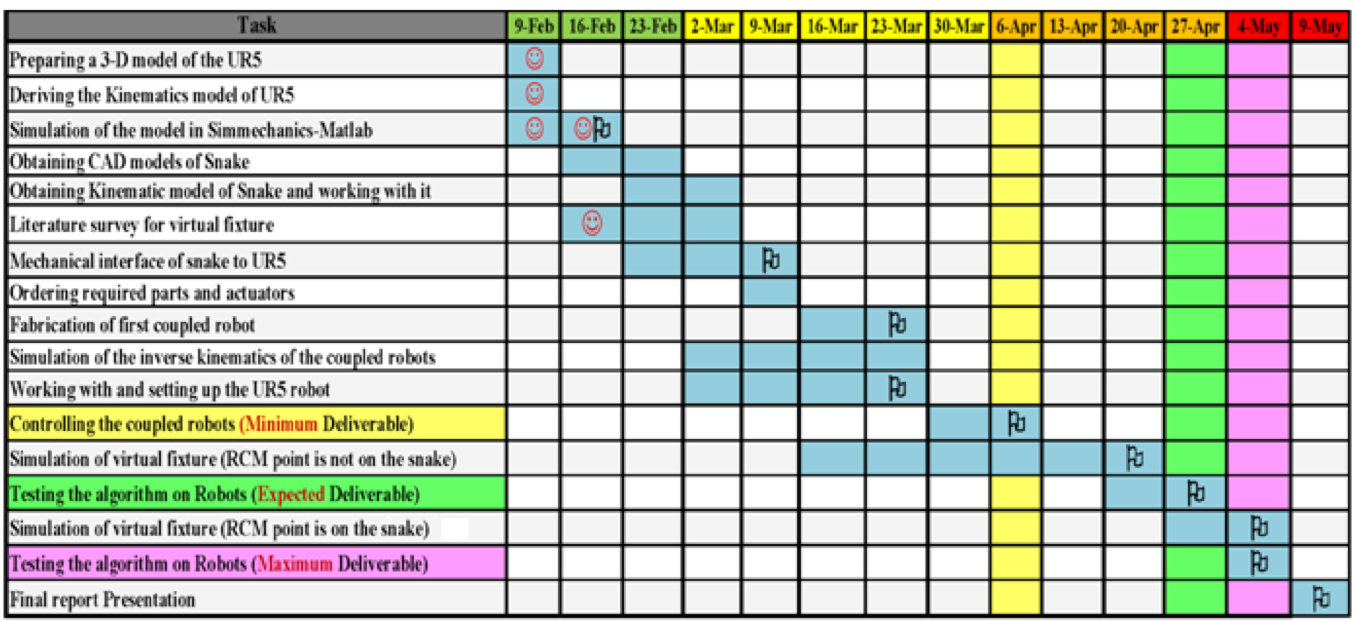
April 27: Testing the algorithm on Robots (**Expected Deliverable**)

May 04: April Simulation of virtual fixture (RCM point is on the SDM)

May 04: Testing the algorithm on Robots (**Maximum Deliverable**)

May 09: Final report Presentation

❖ Management Plan: Detailed Task Schedule



❖ Reading List & Bibliography

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