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

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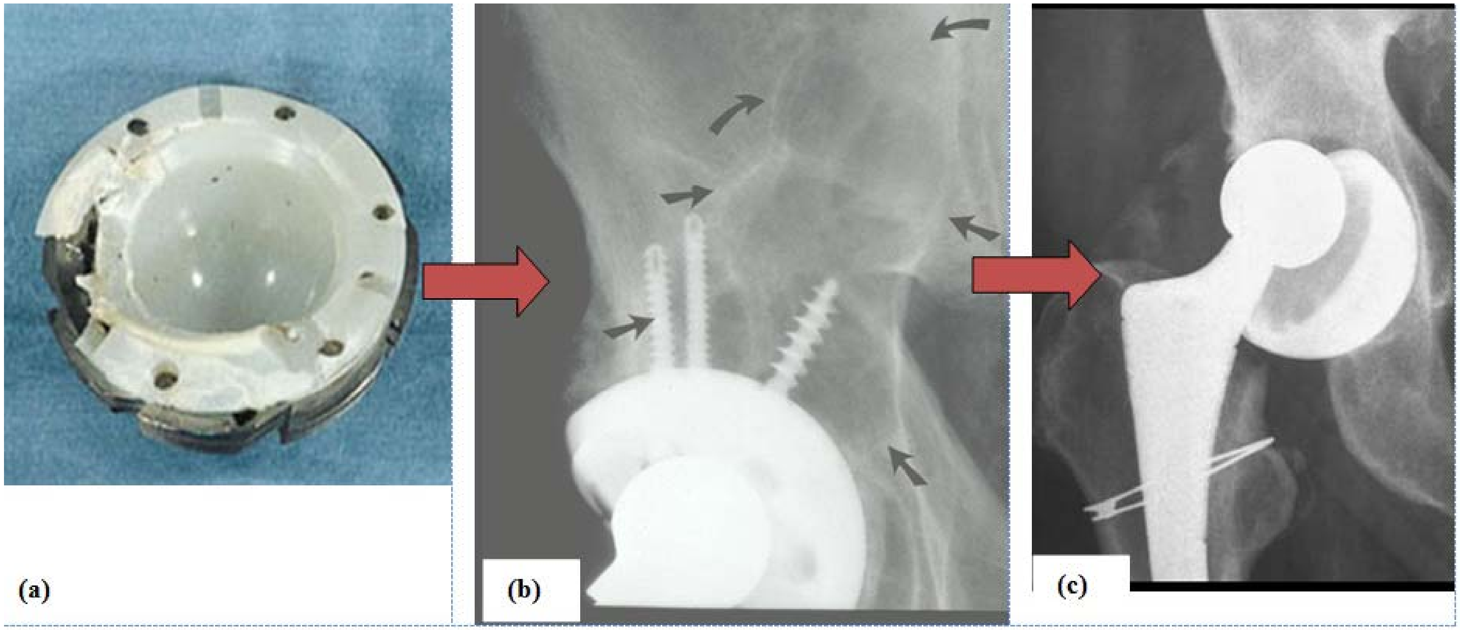
Background and Specific Aims

- The **Total Hip Arthroplasty (THA)** surgery is a medical intervention to restore functionality of the hip joint.

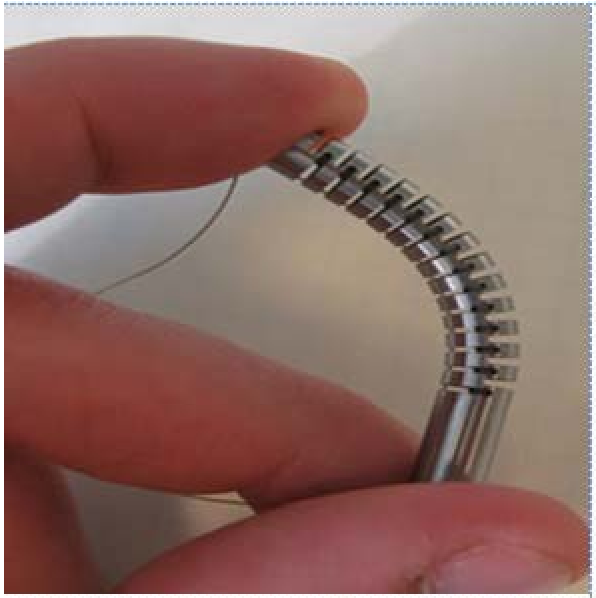
- Wear of the articulating components in THA surgery, typically a polyethylene liner, leads to **Osteolysis** of the bone surrounding the implant.

- If left unmonitored and untreated eventually fracture and component loosening with catastrophic failure will occur.



Background and Specific Aims

- In less-invasive treatment, the surgeon tries to remove osteolytic defects behind the acetabular cup using conventional rigid tools.
- Current manual tools are hard to manipulate precisely, and lack sufficient dexterity to permit surgeons reach all the lesion area.
- BIGSS lab has developed a cable driven **Snake-like Dexterous Manipulator** (**SDM**) to treat the osteolysis behind the well-fixed cup during revision surgery



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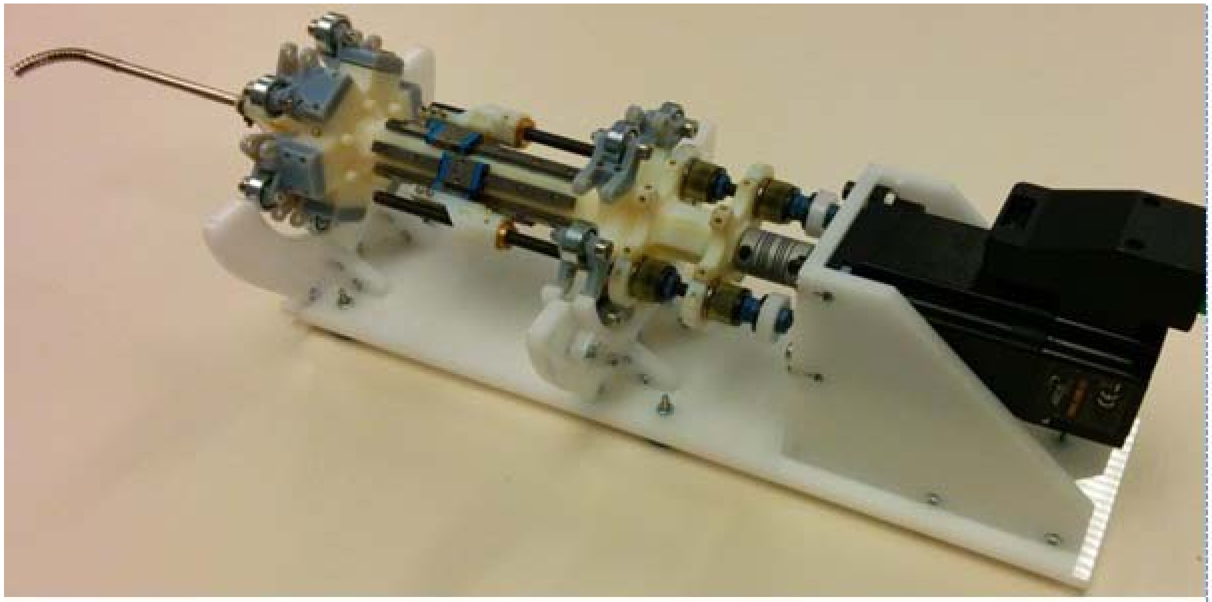
Overview of Goals

- The BIGSS lab is developing a minimally-invasive surgical workstation to treat the osteolytic using the mentioned SDM.

- 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.



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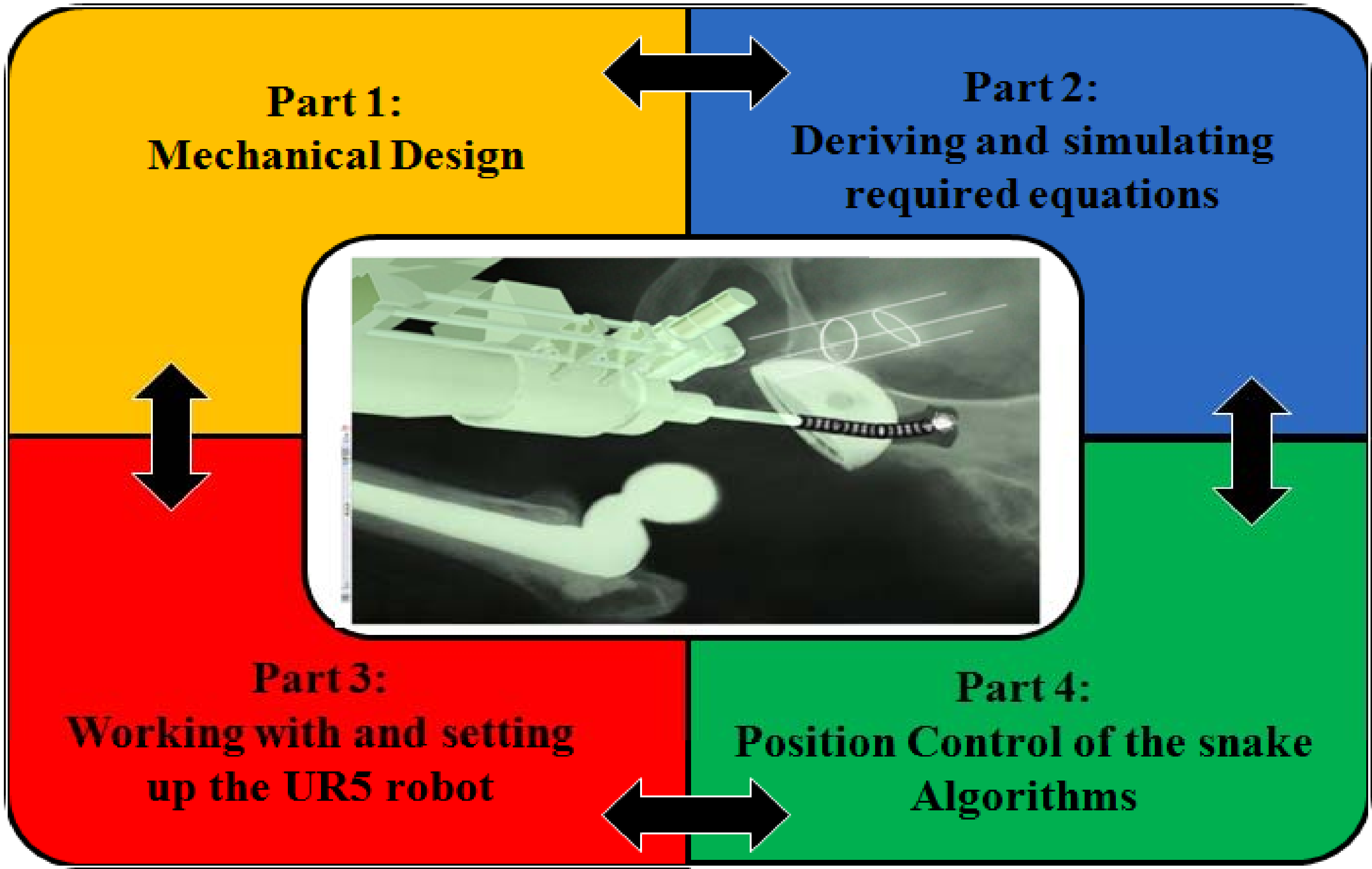
Technical Summary of Approach



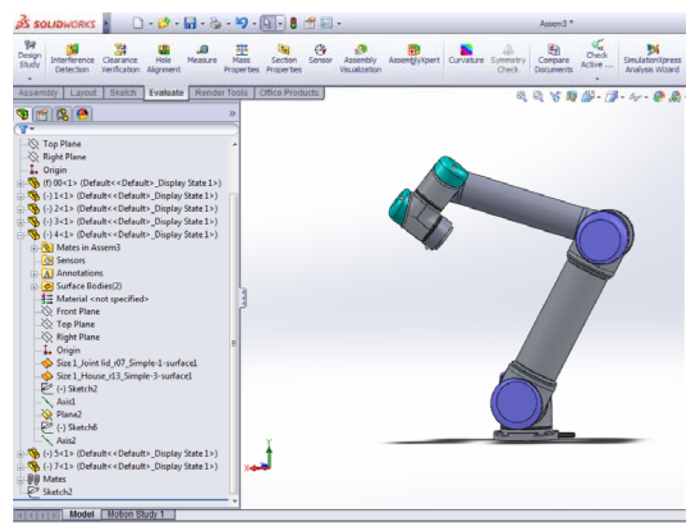
Technical Summary of Approach

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:
  - 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

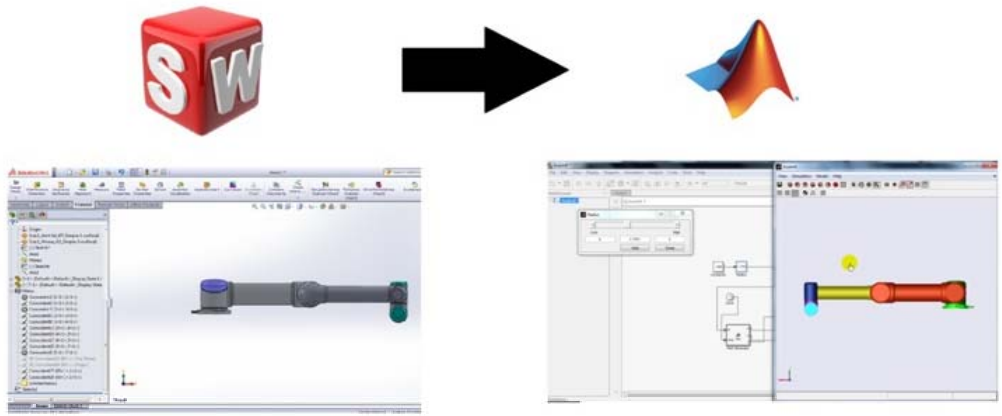


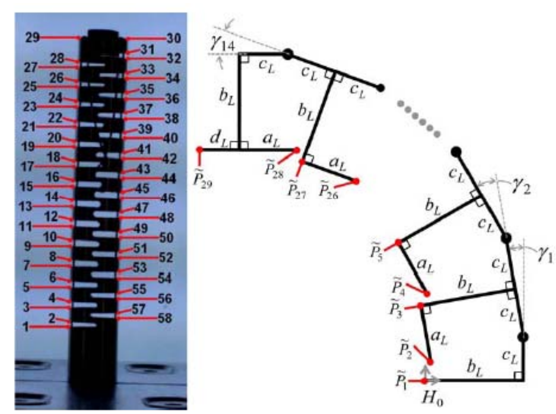
Technical Summary of Approach

***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.

- 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





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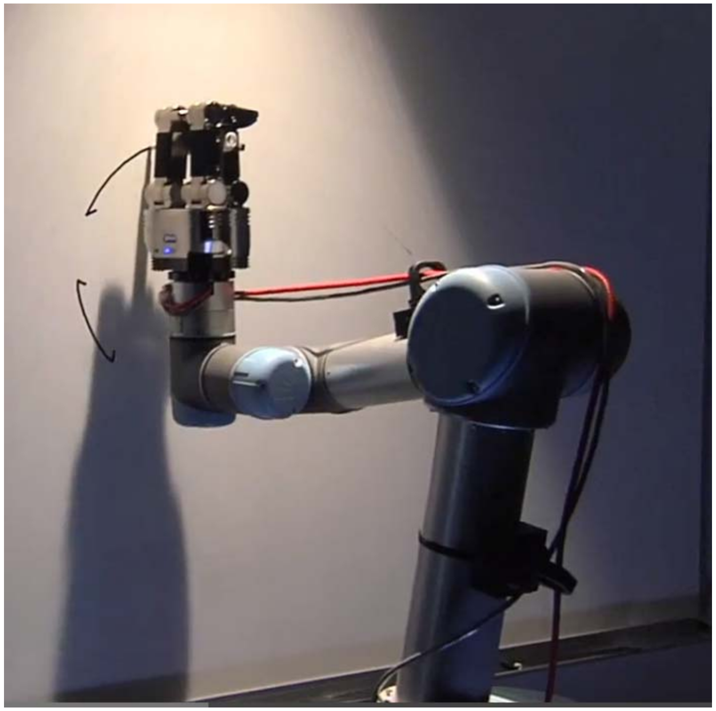
Technical Summary of Approach

***Part III:* Working with and setting up the UR5 robot**

Some tasks of this part are:

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

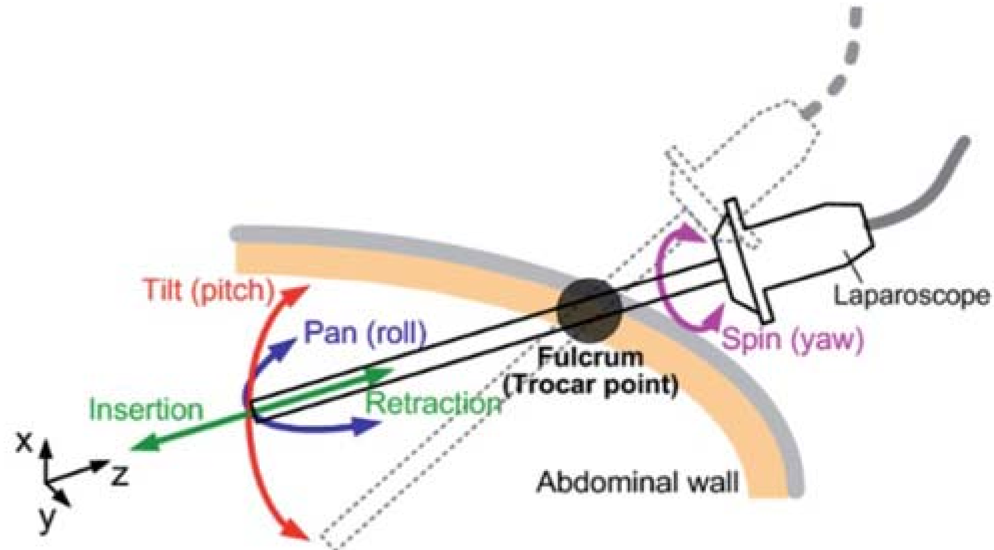


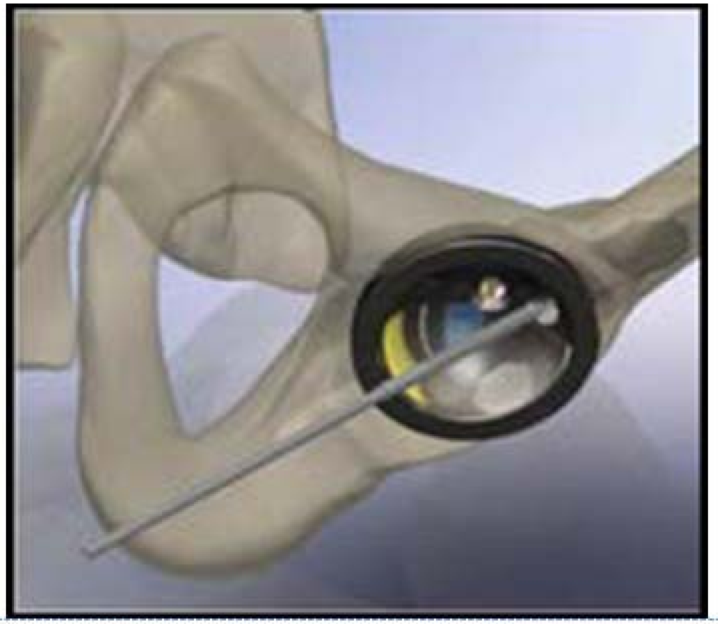
Technical Summary of Approach

Part IV: Position Control of the tip of the SDM

For position control we should consider these points:

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





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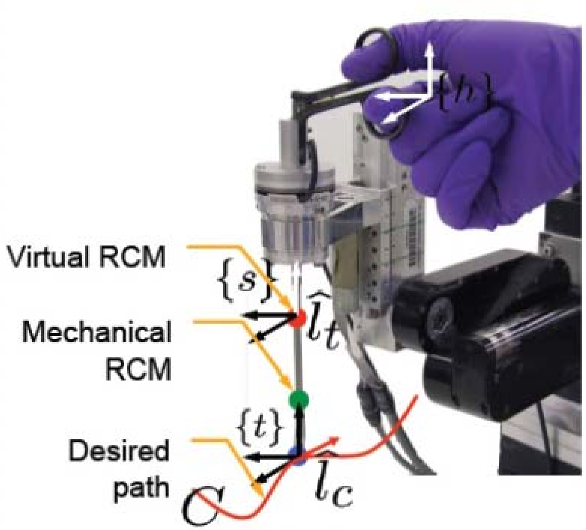
Technical Summary of Approach

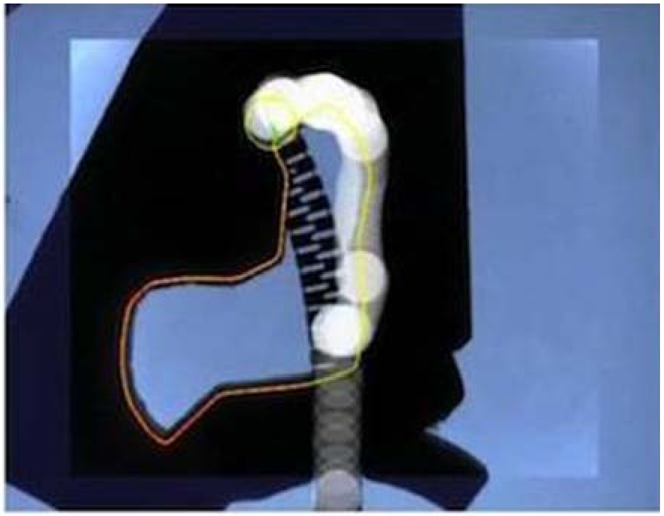
Part IV: Position Control of the tip of the SDM (cont.)

2. The UR5 robot does not have a mechanical RCM point therefore we should create a virtual RCM point.

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 .



(a)



(b)

Fig (a). A. Kapoor, M. Li, and R. H. Taylor “Spatial Motion Constraints for Robot Assisted Suturing using Virtual Fixtures”. Fig (b). Property of BIGSS Lab.

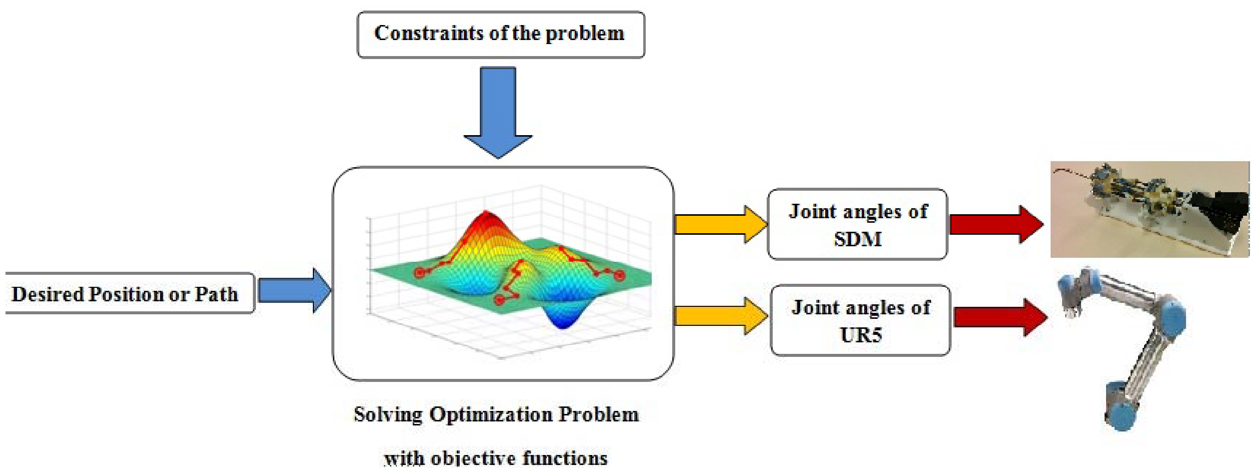
Technical Summary of Approach

Part IV: Position Control of the tip of the SDM (cont.)

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.

Strategy: Using virtual fixture algorithms to control the SDM by UR5



Prior Work

- **On this system:**

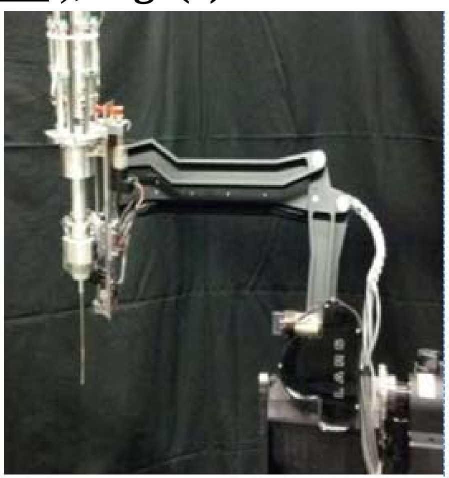
1. Interfacing APL Snake End Effector to LARS Robot , (Piyush Routray , Ashish Kumar , Spring 2013, CIS II project), **Fig. (a).**

2. Geometric and kinematic model of the SDM, (Ryan J. Murphy, Matthew S. Moses, Michael D. M. Kutzer, Gregory S. Chirikjian, and Mehran Armand), **Fig. (b).**

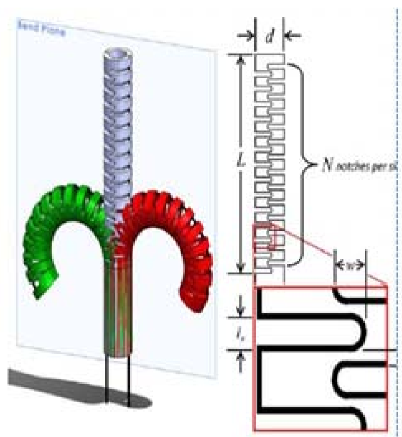
- **Similar work**

✓ There are a lot of similar works regarding modeling and control of the morphable or continuum robots.

✓Telemanipulation of snake-like robots for minimally invasive surgery of the upper airway,(A. Kapoor, K. Xu, et al.), **Fig. (c).**



(a)



(b)

(c)

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.

- **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**

Task	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	9-May
Preparing a 3-D model of the UR5	☺													
Deriving the Kinematics model of UR5	☺													
Simulation of the model in Simmechanics-Matlab	☺	☺⚐												
Obtaining CAD models of Snake														
Obtaining Kinematic model of Snake and working with it														
Literature survey for virtual fixture		☺												
Mechanical interface of snake to UR5					⚐									
Ordering required parts and actuators														
Fabrication of first coupled robot							⚐							
Simulation of the inverse kinematics of the coupled robots														
Working with and setting up the UR5 robot							⚐							
Controlling the coupled robots (Minimum Deliverable)									⚐					
Simulation of virtual fixture (RCM point is not on the snake)											⚐			
Testing the algorithm on Robots (Expected Deliverable)												⚐		
Simulation of virtual fixture (RCM point is not on the snake)													⚐	
Testing the algorithm on Robots (Maximum Deliverable)													⚐	
Final report Presentation														⚐

Reading List & Bibliography

[1] R.J. Murphy, M.D.M. Kutzer, G.S. Chrikijian, M. Armand, Constrained workspace generation for snake-like manipulators with applications to minimally invasive surgery, in Proceedings of the 2013 IEEE International Conference on Robotics and Automation, pp. 5341--5347, May 2013.

[2] R.J. Murphy, MDM Kutzer, SM Segreti, BC Lucas, M Armand., Design and kinematic characterization of a surgical manipulator with a focus on treating osteolysis. Robotica, 2013.

[3] Segreti, S.M.; Kutzer, M.D.M.; Murphy, R.J.; Armand, M. "Cable length estimation for a compliant surgical anipulator," IEEE International Conference on Robotics and Automation (ICRA), 2012, pp.701-708.

[4] M. D. M. Kutzer, S. M. Segreti, C. Y. Brown, R. H. Taylor, S. C.Mears, and M. Armand, "Design of a new cable-driven manipulator with a large open lumen: Preliminary applications in the minimallyinvasive removal of osteolysis," in IEEE International Conference on Robotics and Automation(ICRA), 2011

[5] A. Kapoor, M. Li, and R. H. Taylor "Constrained Control for Surgical Assistant Robots," in IEEE Int.Conference on Robotics and Automation, Orlando, 2006, pp. 231-236.

[6] A. Kapoor and R. Taylor, "A Constrained Optimization Approach to Virtual Fixtures for Multi-Handed Tasks," in IEEE International Conference on Robotics and Automation (ICRA), Pasadena, 2008, pp. 3401-3406.

[7] A. Kapoor, M. Li, and R. H. Taylor "Spatial Motion Constraints for Robot Assisted Suturing using Virtual Fixtures", in Medical Image Computing and Computer Assisted Intervention,Palm Springs, 2005.

Reading List & Bibliography

[8] A. Kapoor, K. Xu, et al. “Telemanipulation of Snake-Like Robots for Minimally Invasive Surgery of the Upper Airway’’.

[9] M. Li, M. Ishii, and R. H. Taylor, "Spatial Motion Constraints in Medical Robot Using Virtual Fixtures Generated by Anatomy," IEEE Transactions on Robotics, vol. 2, pp. 1270-1275, 2006.

[10] P.Routray, A. Kumar, "Interfacing APL Snake End Effector to LARS Robot", CIS II project, 2013.

Thanks for your attention

Questions??