Mechanical and Aerospace Engineering

DESIGN OF A 2-DEGREE-OF-FREEDOM UTERUS MANIPULATOR

by:

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1. Abstract

The following report describes the designing process of a two degrees of freedom parallel manipulator, which was designed and introduced as a new alternative for surgeries involving uterus manipulation tasks. Apart from providing two degree of freedom movement, it was also tried to develop a system that allows to omit the intervention of an assistant surgeon. This omission is supposed to be made thanks to the use of a robot, which would allow the main surgeon to manipulate the mechanism by himself.

Although the 2-dof mechanism was designed and is thoroughly described below, there was no solution found during the development of the research to the robot design, but key requirements and guideline for further works are mentioned below.

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2. Background

Hysterectomy is the most commonly performed gynecological operation worldwide. In fact, approximately 600,000 operations of such type are made every year in the United States alone, making it the second-most common surgical procedure performed on women in this country. Hysterectomy basically consists of the removal of the uterus or part of it due to various reasons, which could involve among many others:

- Menstrual disorders
- Pelvic pain
- Fibroids
- Endometrial diseases.

A common approach for hysterectomy is laparoscopic hysterectomy (LH), which offers the advantage of a short recovery time when compared to the alternatives. This method involves the uterine manipulation through the insertion of a device through the abdominal cavity, which allows a notably reduced blood loss during the operation, less damage to the surrounding organs and less postoperative infections among other advantages.

Apart from hysterectomies, there are between 1 and 1.5 million surgeries each year that require the use of a uterus manipulator. These operations also involve in any way the movement of the uterus to a more convenient part of the body.

Due to the extremely high volume of surgeries of this kind performed every year, a wide variety of uterus manipulators can be found in the current market, but in this study some steps forward are going to be made by firstly developing a mechanism that adds an extra degree of freedom during the manipulation and then attempting to implement an upgrade that allows the omission of an assistant surgeon as the operator of the mechanism.

3. Objectives

An ideal device for laparoscopic hysterectomies should meet the following requirements:

a) Ease of assembly and convenience of use.
b) Inexpensive cost, no matter if the device is disposable or reusable.
c) Easy appliance to the cervix and stability through the procedure.
d) No chance of destructibility during its operation.
e) Allowance to move the uterus as much as possible, in order to make the laparoscopic hysterectomy intervention simpler.
f) Offer the possibility to inject solutions.

These are the key requirements that a basic uterus manipulator must meet, but in this study, a few more constraints are going to be applied. These new constraints appeared following the introduction in the 2000s of the DaVinci system, which allows the performance of robot-assisted surgeries, including among others the laparoscopic hysterectomy mentioned above. During these robot-assisted LHs, two surgeons are involved: the primary surgeon, which controls the robotic arms located at the patient's bedside from the console; and the assistant surgeon, which assists the other by operating the uterus manipulator.

The main purpose of an all-new uterus manipulator should be to omit the necessity of an assistant surgeon, allowing the primary surgeon to operate the device according to his needs. This omission can lead to a more precise performance of the intervention and would eliminate the fatigue that the assistant surgeon present while holding the manipulator, which usually decreases the quality of the procedure and eventually threaten the patient in some extreme cases. To omit the necessity of the assistant, a robot should be designed, which key requirements are basically:

1. Securely hold the manipulator.
2. Ability to use the manipulator as an assistant surgeon does.
3. Ability to receive commands from the primary surgeon and translate them to an accurate movement.

4. Current options

The current options available in the market present many drawbacks still to be solved. According to a study conducted by the University of Utah Medical Center, which compared the commercially available uterus manipulators, there is no current device which allows both lateral and vertical manipulation combined. As a visual reference, in *Fig 1* two examples of the most commonly used currently uterus manipulators are presented.

Figure 1. Braun (left) and SecuFix (right) Uterus Manipulators.

Another major disadvantage of current options relates with the length and control mechanisms, which in many cases do not allow the surgeon to remain in an upper position at the abdomen of the patient, which is the common thing during LH interventions. This leads to a failure while satisfying the determination of cervical landmarks and could increase the cost because of the increase of usage of disposable equipment.

5. Discarded designs

The mechanism was designed always bearing in mind the basic idea of transmitting the exact input motion made by the surgeon to the output, with two degrees of freedom in this movement. For this purpose, a first design iteration involving two spherical joints was created, which was later discarded as it will be explained below. After this mechanism was discarded, a Preliminary Design Review of a different design was made.

The first iteration consisted of a spherical joint based mechanism. Its main advantage relates with its simple structure, which basically consisted of two joints *(Fig 2)* connected by four links. Every movement made in the input handle is transmitted to the output platform through the joints. This system of joints and links is completely contained in a case, which is fixed to the ground in order to provide an extra degree of freedom through the addition of rotation.

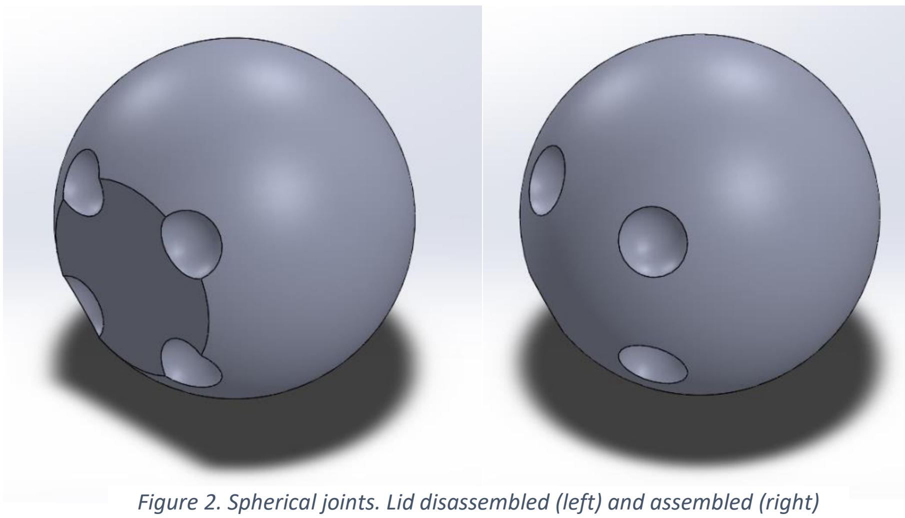

Figure 2. Spherical joints. Lid disassembled (left) and assembled (right)

An important detail about these spherical joints is that they have a detachable 'lid' that makes the assembly of links way easier. In *Fig 2*, a representation of the joint with the lid and without it assembled can be observed.

In *Appendix I*, a raw sketch of the complete mechanism is attached, with the nomenclature of each of the components.

Despite its simplicity of functioning and low number of parts, this design iteration was discarded due to its low maximum manipulation angle. The spherical joints are not as manageable as the mechanism which will be presented right away.

6. Preliminary design review

A more complex design was thought up after discarding the one described above. Despite its higher complexity, it can provide a greater manipulation angle in both planes of movement. A preview of the complete assembly aspect can be found at *Fig 3*, and a brief explanation of the functioning of the mechanism is provided below. Please note that in this representation, the dimensions of the manipulator are just a mere reference to preview the essential functioning principles of the device, and the definitive measurements should be studied if any prototype of the mechanism is intended to be developed.

The mechanism of this uterus manipulator also involves the use of a cover *(Fig 4),* which is fixed to the ground. Inside this cover, two lanes are embedded. These lanes are created to serve as guide for one of the wheels of the wheel subassembly presented in *Fig 5*. This wheel subassembly is probably the key part of the mechanism, as it is the responsible of ensuring that the gears rotate inside the case with no misalignment. There are four wheel-subassemblies mounted in the device.

There are two of these mentioned gears *(Fig 6)*, with the particularity that they have also one circular lane carved in their faces. These lanes serve as guide to the other two wheels of the wheel-subassembly. A detail of this subassembly with all its connections is represented at *Fig 7*. The gears are connected to each other by a toothed belt, which has not been represented in the model to simplify the visualization of the mechanism.

The two big holes in the gears are used to connect them to the input handle *(Fig 8)* in one of them, and to the output piece *(Fig 9)* in the other; and the smaller center hole houses a link *(Fig 10)* that connects both gears to each other, providing extra robustness to the mechanism.

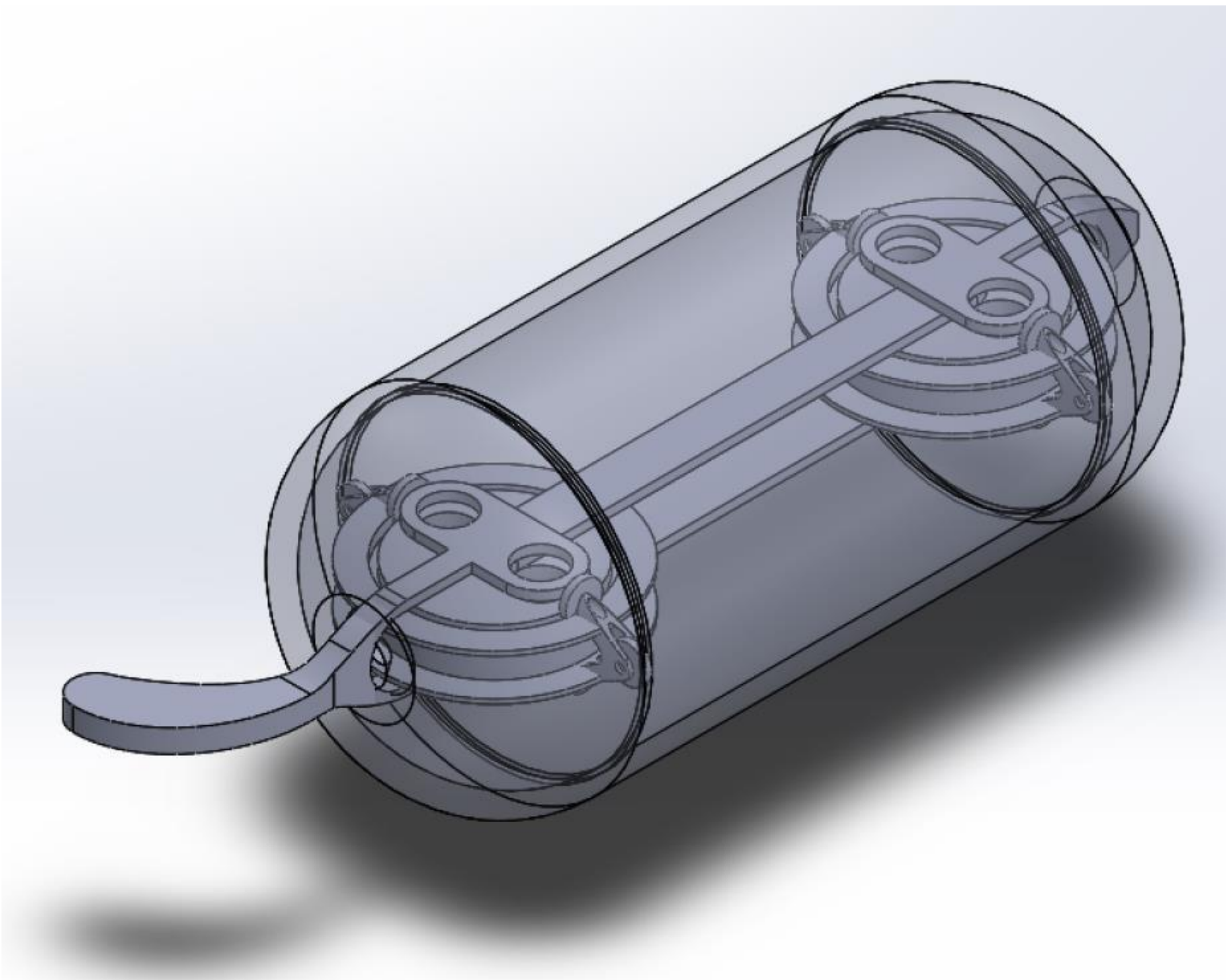

Figure 3. Overview of the complete mechanism of the manipulator.

The handle and the output platform work synchronized, making possible that any input movement introduced to the handle will be transmitted through the toothed belt to the output platform. The subassembly represented in *Fig. 5* makes it possible to rotate the handle and adds an extra degree of freedom.

Although the description of the mechanism may look a little messy at a first glance, once the functioning is understood it is quietly intuitive. The surgeon manipulates the handle platform, and he can transmit any movement required to the output platform. The movements that he can perform to use the device are basically two:

1. A wrist flexion or extension performed in the handle would lead to an equivalent upward or downward movement in the output.
2. A forearm rotation in any direction would provide a rotation movement to the output platform, adding an extra degree of freedom.

Figure 4. Cover part

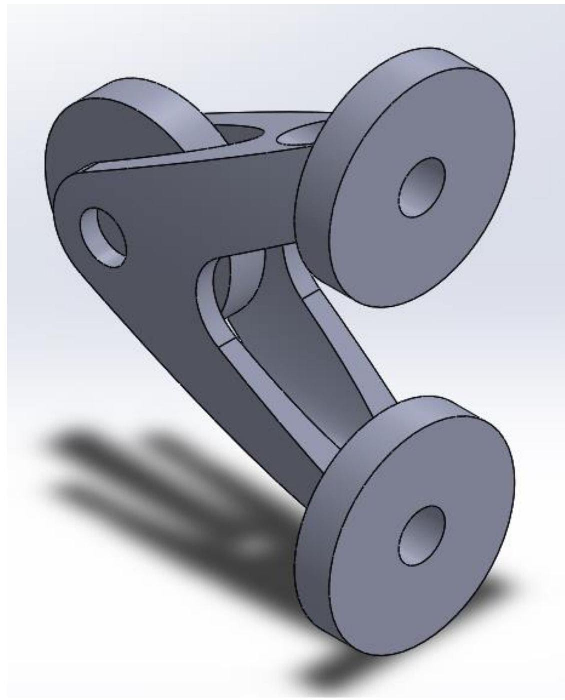

Figure 5. Wheel subassembly

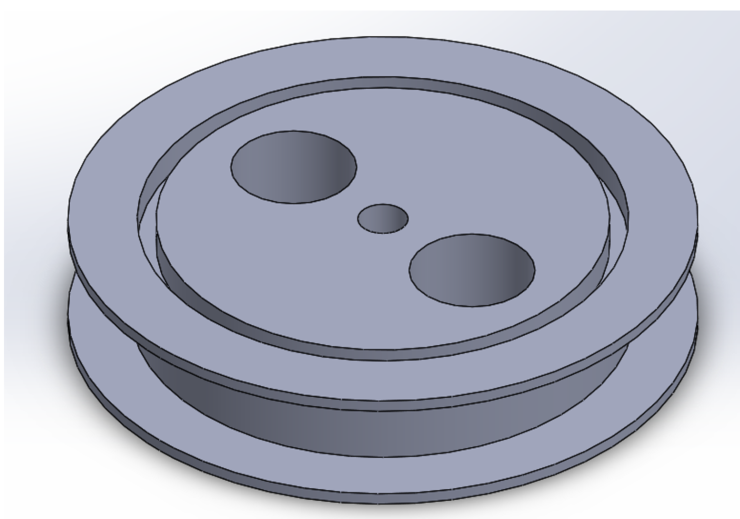

Figure 6. Gear part. The lateral face would have guides for a toothed belt.

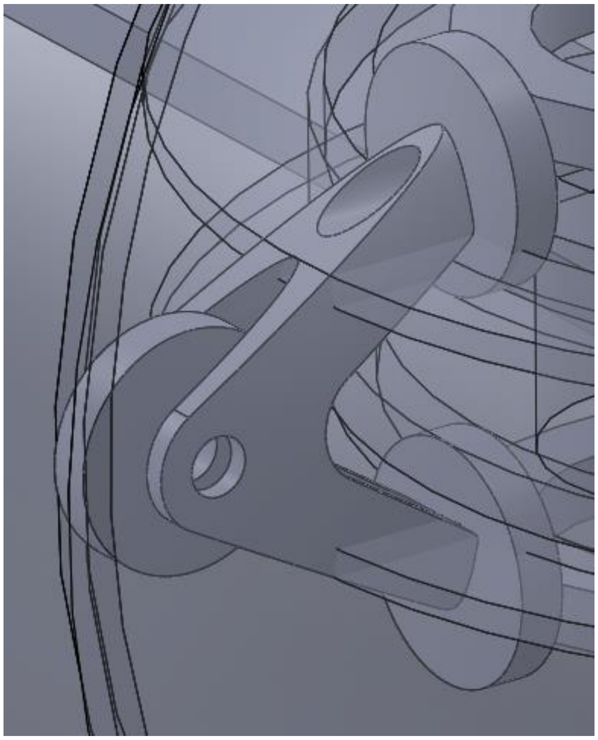

Figure 7. Detail of the wheel subassembly connections

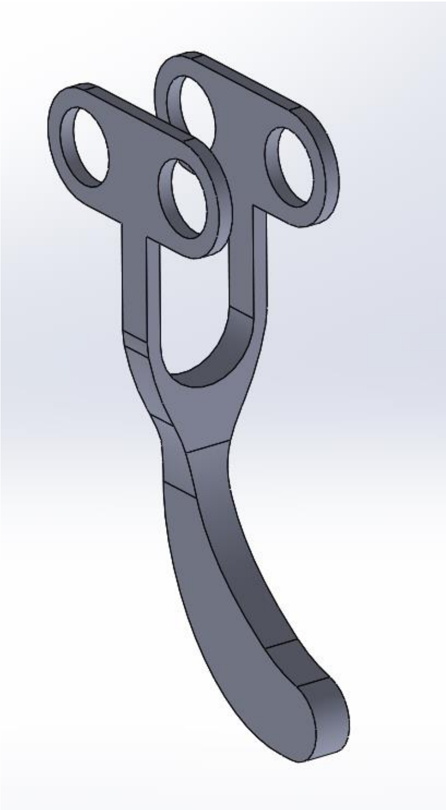

Figure 9. Handling platform

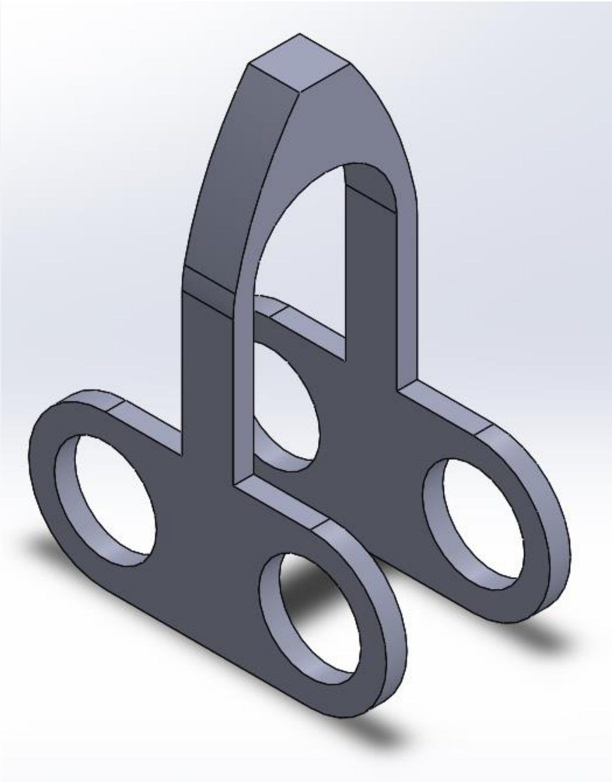

Figure 8. Output platform.

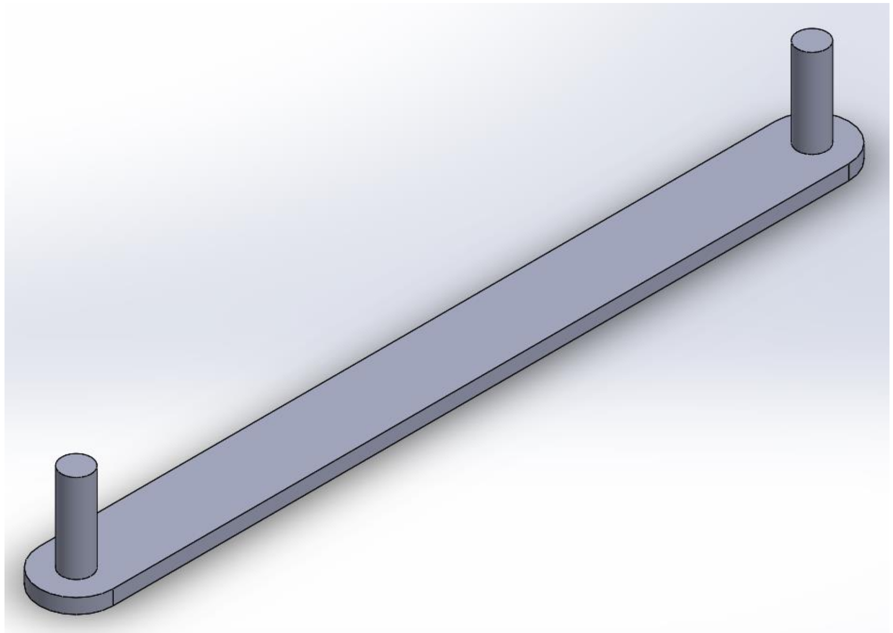

Figure 10. Connecting link. The two vertical cylinders go through the small hole in the gears.

How can it be made possible to get rid of the assistant surgeon?

The next step once this device idea has been modeled implies the development of a mechanism which allows that the movements mentioned above can be performed by a robot. Despite coming up with a few ideas, any of them turned out to be feasible, and the problem was definitely a little headache without any solution found during this semester. A raw sketch with some of the ideas generated during the brainstorming moments is attached in *Appendix III*. All of these satisfy the manipulation of one of the movements but would eventually fail when implying the other degree of freedom.

7. Further work

As it could have been appreciated in the previous figures, some interferences between the components are presented. These interferences should be corrected before proceeding with the prototyping part.

A prototype assembly would be the next step in order to check if the mechanism works as expected and would be of countless help for determining which materials are the most suitable to be used in the device. This prototype can be developed with any of the currently available 3D printing technologies that support the materials desired. In the prototypes assembled in the reference texts, a common material used is Polylactic Acid for the moving pieces. Obviously, the cover around the mechanism should be made out of stronger materials such as stainless steel.

The most crucial task to be completed is the design of the handling mechanism. If this task is successfully completed, it would mean a breakthrough advance not only in surgery equipment, but also in the robotics industry. Anyway, the presented mechanism can be manipulated by the surgeon with the handling piece in *Fig 9*.

Another task to be done, as mentioned above, is to establish which would be the most suitable dimensions of the manipulator. For this purpose, the simulation of a real-world environment would be needed in order to experiment the relationship between the patient and the machine.

Lastly, an economic feasibility study is an essential task during the development of this kind of mechanisms, as it has some non-reusable parts.

8. Conclusion

Despite this study did not achieve the objective of providing a solution that could enable the omission of an assistant surgeon, it attempted to provide an interesting design explanation of an all-new 2-degree-of-freedom mechanism that could have appliances beyond the gynecological procedures.

Some further steps should be done in order to move forward in the development of the device, though; and they are described in the *Further Work* section. The author of this report also raise an invitation to anyone interested in continuing with this development to do such thing, and if any further questions raise, to contact with him by any of these means:

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Thank you for reading this Report.

9. References

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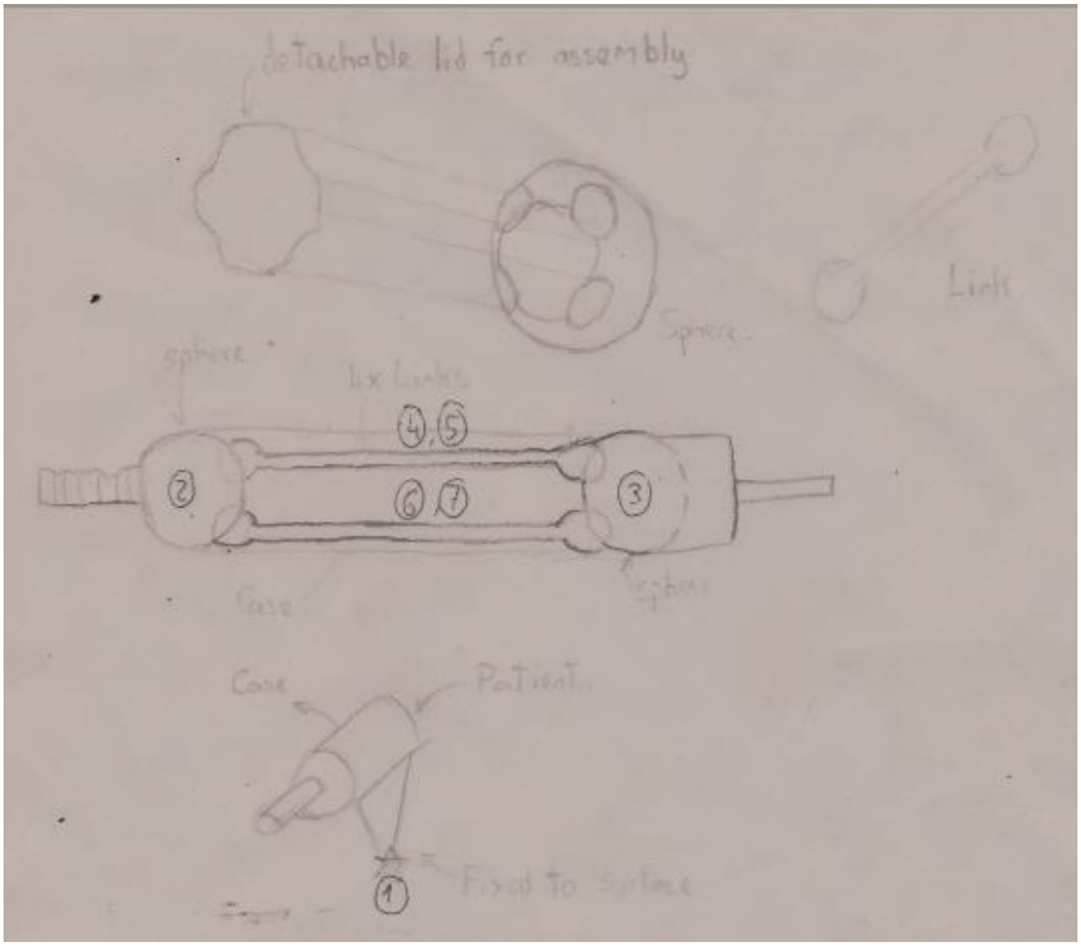
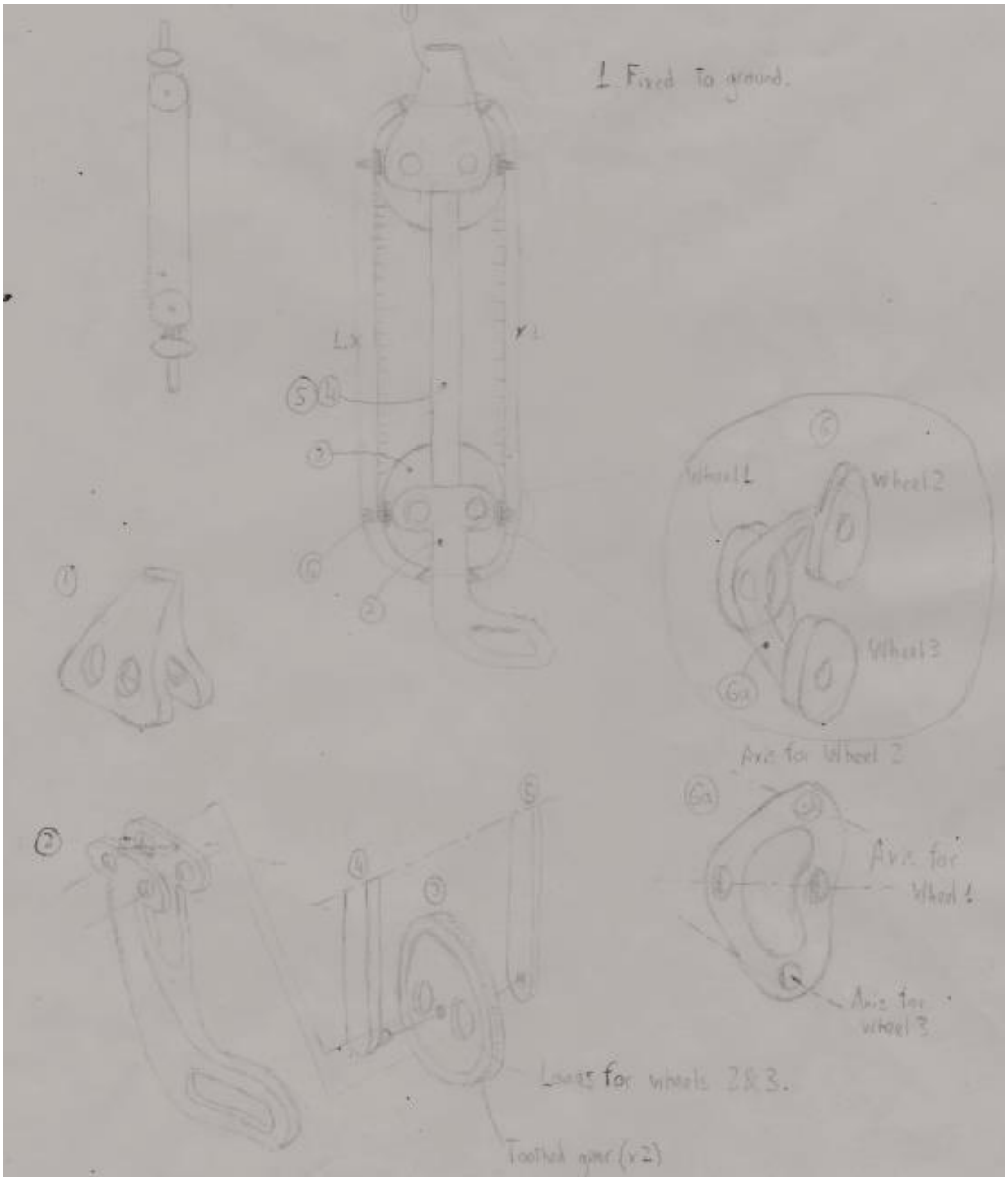
Appendix I: Discarded Design Sketch



Appendix II: Preliminary Design Sketch



Appendix III: Robotic Manipulation Ideas Sketch