Surgical robot

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Abstract: The idea of development is to be able to use the robot in MRI (Magnetic Resonance Imaging)-device while taking patient pictures. Equipments used today are not functional while the magnet in MR-imager is turned on i.e. different navigators. Because of very high magnetic forces, smart machines are typically not used. Main reason is electric equipments inside mechatronic systems. There are actually many manufacturers that produce passive instruments for the MR-environment. It is very reasonable to design a smart system working in imaging area. It would possibly save a lot of surgeons and biophysicist time while operating; you don't have to move patient every time away from imager when taking a new picture. In this system it would be also possible to move the instrument while taking pictures so that surgery can see the instruments head in the picture. Pictures are normally taken many in a one operation. In the first step system is thought to use to take samples with a small instrument from a patient, in brain surgeries and prostate surgeries. Advantage should be more accurate sample taking and when only small hole in the patients body is done, healing process is fast. Experts have said that especially in prostate surgeries more accurate system, than human hand, would be a good achievement. Adams-/ Simulink software connection is good help for designing this kind of robot. These softwares can also be used as a part of a user -interface.

Keywords: MRI, surgical robot, Simulink, Adams

1. Introduction

The biggest problem is to make this system work in different MR-environment, in different levels of magnetic fields, because there are magnetic fields used between 0.2 to 3 Tesla (T). /1/ The magnetic field is a reason why there is needed to be found new systems for control equipments i.e. sensors and movement transmitting systems. To make system universal there is tried to find nonmagnetic and non-electric systems. Electrical and magnetic compatibility must be tested in MR-environment. One important test method is to take pictures and see how the system effects to the picture quality. Pictures are very sensitive to external magnetic fields. The other thing is to measure forces from a robot arm with non-magnetic strain sensors. These are i.e. fiber optical sensors. /5/ Forces and moments are coming from MR-devices field.

There are some research done about measuring eddy currents and mechanical forces in MR-environment. /6/ To get pictures with MR-imager there is needed chancing radio frequent magnetic fields and static magnetic field. These fields effect to the instruments used near the MR-imager. /2,3/

Equipments used today are not functional while the magnet in MR-imager is turned on, or they are very hard for the doctors to use. Because of very high magnetic forces, smart machines are not typically used. In figure 1 There is a picture of a 0,23 T open C-type MR-imager where the robot is thought to operate. As you can see from the picture, robots operating space is quite limited.

Fig. 1. 0,23T MR-imager. /2/

2. Mechanical aspects

There are a lot of basic mechanical problems; what should the robots degrees of freedom and dimensions be, and how to do movements transmitting, if the assuming is that normal motors and sensors are denied in imaging region. There are aloud some small currents inside MR-device, but they are different in every imager. A purpose is to test mechanical model with Adams/ Simulink system. You can test straight kinematics and inverse kinematics with that system. Inverse kinematics is needed to be count for the control system. It is possible to simulate control system with Simulink too. Mechanical transmission needs to be tested with different solutions for examples with big forces attached to the instrument.

To make robot MR-compatible, we have to make special solutions. There is designed and tested fibre optical sensor for the robots joint as you can see from the figure 2. This joint is operating in MR-field. There is mounted a fibre optic pulse sensor inside this joint. There is also thought to use fibre optic force sensors in the head of a tool. There are different solutions under development. /4/ Materials in the joints are nonmagnetic; plastic, carbon fibre and aluminium. There are also some parts made of austenitic stainless steel. Force transmitting was first made with belts. Some of the transmission system is already tested and also MR-compatible sensors. After tests they were changed to austenitic steel cables. There also are different constructions under development.

To avoid mechanical play there is also tried to find harmonic drives and ultrasonic motors for the joints. A problem is to find a manufacturers or contractors to make these products. It is also hard to get nonmagnetic ball bearings. There are manufacturers i.e. in Japan for these products, but to get contacts to companies seems to be a problem. Today MR-environment smart tools are becoming more important. With help of piezoelectric motors and optical encoders it comes easier to make system MR-compatible. These applications are used i.e. in Canadian Neuroarm-system /7/. Also many of the Japan surgical robot-research- groups use this technology.

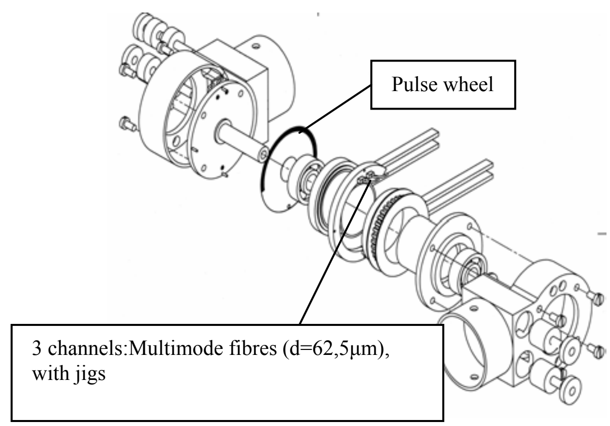

Fig. 2. MR-compatible operating joint.

With Adams it is possible to simulate the robots movements. It helps a designer to check what kind of orientations robot is able to obtain. Also the dimensions of the robot can be tested, if you bring a CAD-picture of the surgical environment to the Adams. Then you can simulate the robot in its real dimensional environment. In figure 3 there is a real dimensional model of the robot-arm.

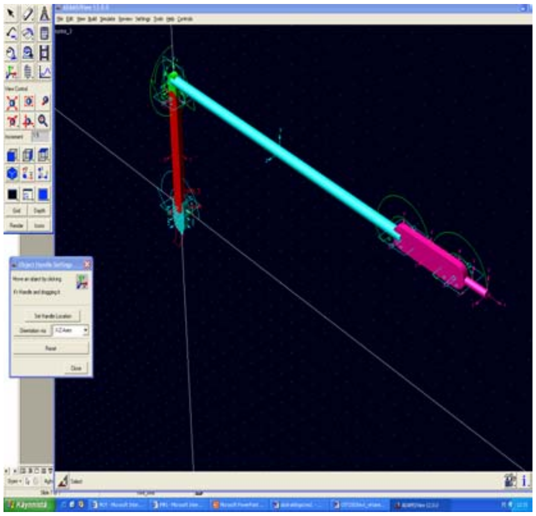

Fig. 3. This is a real dimensional Adams-model of the robot. It is also possible to simulate different control system with Matlab-Adams connection graphically.

In figure 4 there is a robot-model inside a real dimensional, drawn with Ideas-software, MR-environment. Only problem when bringing the environment to the Adams, is systems heavy simulation.

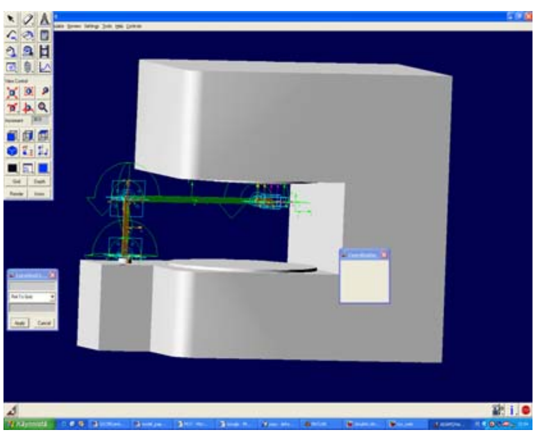

Fig. 4. Robot-model inside MR-imager.

You can also connect the Adams-model to a Matlab/ Simulink software. Now you can use the Simulink as an interface and test different things i.e. control system/ -methods, inverse- and forward kinematics.

It is possible to move the robot from Simulink and get data from Adams to Simulink. In figure 5 there is an example of a Adams-block in a Simulink.

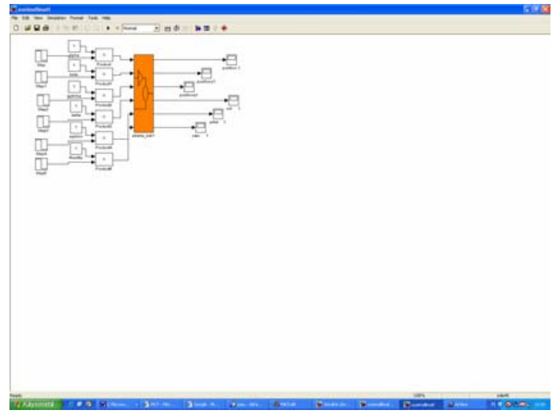

Fig. 5. Adams-block in Simulink.

There is also tested to bring data over the net to the Simulink, so that it is possible to doctor to simulate robots movements in Adams before executing movements in real environment. It is a big advantage for the doctor to see before what the robot is going to do. An aim is to put also the patients 3-D MR-picture (only surgically important area) inside the Adams-model. Then it would be possible to simulate the surgical operation even more sophisticated i.e. like in CNC-systems.

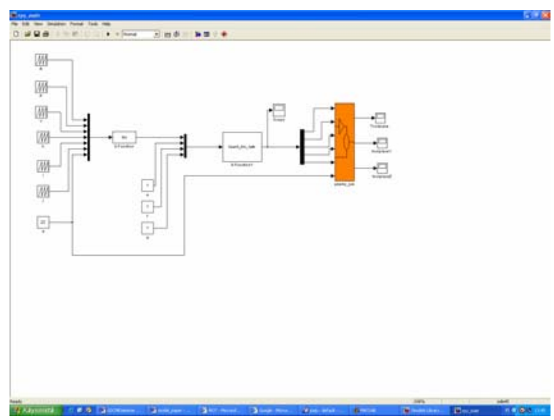

Fig. 6. Inverse kinematics inserted into Simulink with system-blocks (M-code).

In figure 6 there are blocks, which are used to check the inverse kinematics.

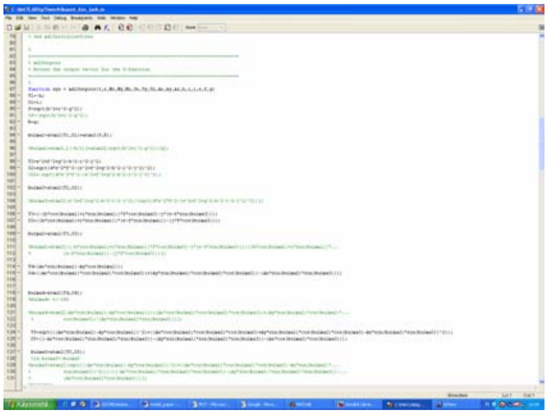

Fig.7. An example about written M-code function (system-block).

3. Other aspects

There are also some totally different problems; how to do the system easily used for the surgeons? Experience is, that if the system is complicated to use, the surgeons will not use it. In test situation there is also one big problem; who takes the responsibility while testing the system? One of the problems is also think, that do we need some kind of force feedback for the surgeon? And there were also one hard design challenge introduced by experts: the robot arm should be able to control as non-motorized arm when needed.

Important parts of the mobile operating room equipment are i.e. the MRI compatible patient and the MRI compatible respirator. Tables, chairs and some of the instruments are also made of MR-compatible material. Experts have said that especially in prostate surgeries more accurate instrument, than human hand, would be a good achievement. Like the other instruments the robot arm has to be MR-compatible too.

4. Tests

Magnetic compatibility can be estimated by measuring forces from different places the robot arm. It could be measured as a sum of these all effects by doing accuracy tests with robot i.e with a chartlike testplate.

Materials and MR-compatibility is important. We have to test manipulator in MR-environment, because also the shape is effective in MRI. There has to be done ESD- and EMC-tests, because of the patient safety. Tests should be done by measuring eddy currents from the robot arm in MR- environment. The effects for the MRI can also be estimate by watching the patient pictures-effects should be clear. /6/

There also have to be done tests for the force transmission in the last non-magnetic, operating link. We already have tried 3 different systems and they have not been good enough-more tests and test results will be done. There has to be used numerical and analytical methods. We have also had to design many of the mechanical parts again.

Of course more detailed tests should be done for the sensor systems too; accuracy and MR-compatibility for pulse and force sensors. The ideal accuracy has to be counted. And different solution must be designed and tried.

We also have to design a user friendly interface for the robot and different instruments that can be used with robot. Actually the whole system has to be estimated by doing different usability tests. For the software there also has to be done component testing, stress testing, performance tests and different communication tests. Mechanical tests have to be done too, because we have to know force limitations for the robot.

Conclusion

In the first step, system is thought to use to take samples with a small instrument from a patient in brain surgeries and prostate surgeries. Advantage should be more accurate sample taking and fast healing process.

Matlab is very functional tool to use with help of surgical tool i.e manipulator design. It can be used to find out right solutions for forward and inverse kinematics, especially with using Matlab/ Simulink and Adams-software combination. It is possible to use Matlab/ Simulink as an interface for the mechanism that is designed in Adams. Controller design is also very easy for the mechanisms, when you can graphically simulate and test the effects of the controller.

vibrations for the robot are problematic, but they can be measured. We try to find methods i.e piezoelectric actuators for damping. There already are some examples about damping in laminate stick vibrations in literature. /5/

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