ROBIN HEART SYSTEM MODELLING AND TRAINING IN VIRTUAL REALITY

Received 15th February; accepted 28th February.

Zbigniew Nawrat, Marek Koźlak

Abstract:

Paper presents prototype surgical robot Robin Heart. It is computer-controlled and based on EON reality software. The structure, control and motion possibilities of the robot are shown. Then its working in virtual reality environment is described. For less invasive surgery 3D issues are crucial.

Keywords: *surgical robot, virtual reality, control*

1. Introduction

Due to a technology progress, usage of surgical robots (telemanipulators) in surgery treatment increases radically the quality of the minimal invasive surgery. Currently there are two different robotic systems designed for a cardiac surgery: clinically working da Vinci offered by Intuitive Surgical (since 1998) and a Polish prototype Robin Heart (RiH). Both da Vinci and the RiH systems are computer-controlled tools, located between surgeon's hands and the tip of a surgical instrument. Polish system named Robin Heart was constructed as a result of work on several prototypes. The project was carried out by wide area of specialist (Technical Universities in Łódź, Warszawa, Gliwice) under the leadership of Foundation for Cardiac Surgery Development (FCSD) in Zabrze. Launching of the first clinical Robin Heart application is planed by 2009.

Efficiency of using robotic equipment in endoscope's procedures significantly depends on both a precise tools manipulation and a proper surgery procedure planning. Accurate arrangement of setting up the robots arm with reference to surgery table, positioning the trocars location and right choice of a correct tools, makes the surgery procedure much more safe and harmless. Using a virtual reality technology, based on EON Reality interactive software, we plan all those important steps, increases effectiveness in non-invasive surgeons training and helps to verify the benefits of using robotic systems in a various surgery treatments.

2. Conception of construction

The main assumption that makes Robin Heart 1 useful is construction of double closed loop, which provides point constancy between laparoscope instrument and patient tissue. This approach complicates the construction of the mechanism, but has some benefits.

The total structure of the robot (Fig.1.) was divided to 15 separate and independent parts that can move relative to each other, and all those parts were fixed to a massive non-movable base of the robot, which might be manually adjusted on several levels. In surgical treatment, based on robotic system, it is very important to fix the point of introducing the laparoscope's instruments into the human body all the time while the robot moves (*constant kinematics point*). Da Vinci system ensures this rule using an opened loop mechanism with advanced steering algorithms for a three independent servomotors [1]. To optimise this type of construction, Robin Heart structure was based on a double closed loop mechanism, which provides constancy of a point outside the robot structure. In this way, only one reliable servomotor is used with a simple steering algorithm.

To identify the constant *kinematics point* and to explain the necessity and the principle of working this type of structure, a separate simplified model was created in a CAD program (Fig.2.). The model represents all joint axes. The stationary point was found as the intersection of dashed line (parallel to vertical elements, determined by two utmost joints) and the continuous line (axis of laparoscopic instrument symmetry). The same localization was verified by putting together two of all of the final robot positions. Transforming this point into the three-dimension area, the conclusion is that the intersection point is placed on the second element symmetry line.

Overlapping all final position of the Robin Heart 3D model, the geometric position surface of laparoscopic instrument was described in geometry and dimensions.

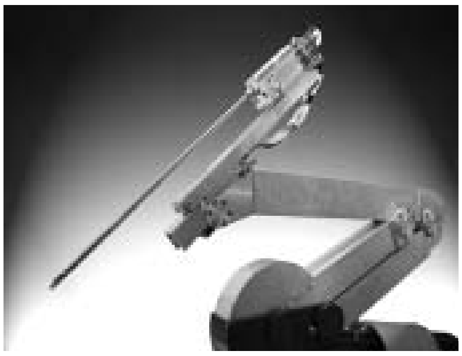


Fig.1. Robin Heart 1 with a docking base.

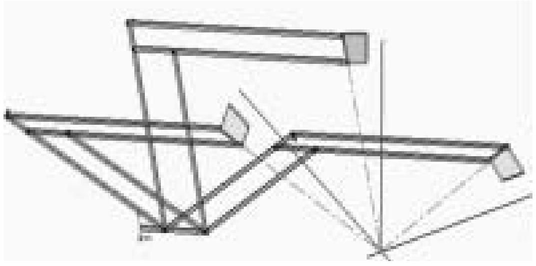
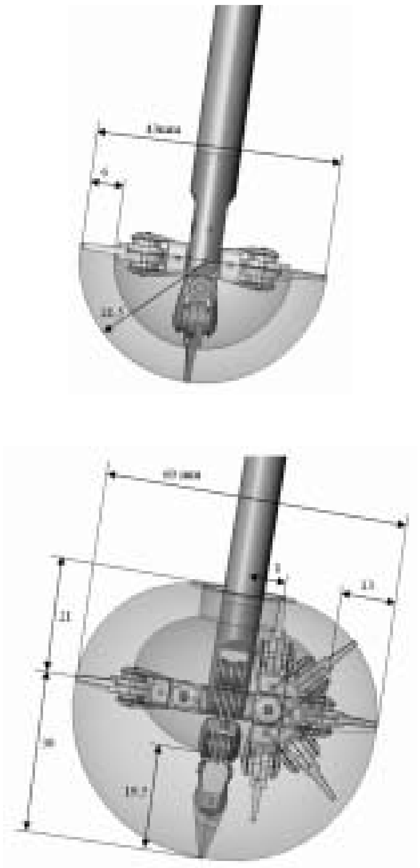


Fig.2. Simplified kinematical model of Robin Heart 1 structure.

To provide all necessary functionality of modern laparoscope's devices, robot Robin Heart gives user a three degrees of freedom to orientate in space, fourth one is responsible for opening and closing jaws of the tool and the fifth one increases the manipulation skills to avoid obstacles, or like Robin Heart allows to work "backwards". Standard laparoscope's device has got a limited mobility and does not offer very sophisticated types of movement that are provided by a robotic systems. To see the differences in mobility between two various Robin Heart instruments, a tool workspace was calculated for a robot equipped with a standard laparoscope's device and a more advanced robotic instrument (Fig.3.). If one have a workspace sphere calculated for all of the robot instruments, it is very easy to verify the goal of using a suitable device for a proper surgery treatment.

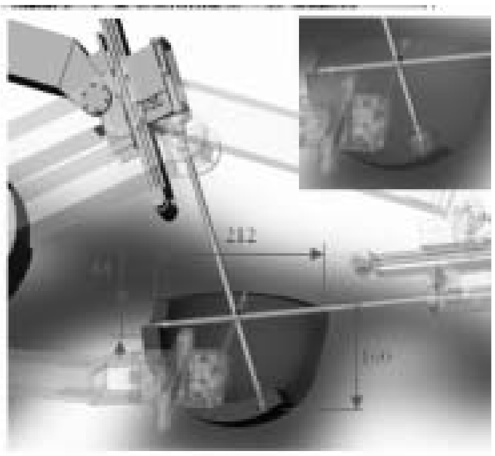


a)

b)

Fig.3. Instrument workspace: a.) standard laparoscope's tool, b.) Robin Heart 1 instrument.

a)



b)

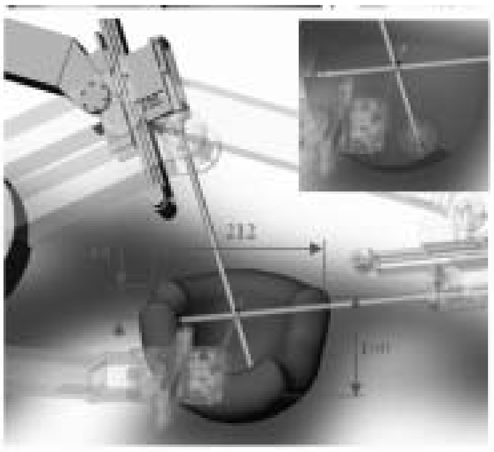


Fig.4. General rage of robot mobility equipped with: a.) standard laparoscope's tool, b.) Robin Heart 1 instrument.

Combining this workspace with a geometric position surface, we were able to calculate the total range of movement for both robotic instruments inside the patient body (Fig.4.). Although the external borders are same for both tools, it can be easily seen that the thickness of more advanced instrument sphere is over two times bigger.

3. Multibody system dynamic modelling

The numeric model of Robin Heart structure was prepared in Matlab software using rigid body dynamic methods. The main aspect in rigid body approach is not the actual shape of each element of the system, but the connectivity between them. Total robot structure was divided into a fifteen rigid bodies, defining their mass properties and setting new local coordinate systems in their mass centres. Elements were connected together using a sixteen rotary and two linear joints in respect to the local coordinate systems (Fig.5.). Three constrain equation (1) are written as a vectors equation with assumption that the both s_i^p, s_j^p vectors in local coordinate systems have constant value. To fully describe a revolute joint on a Fig.5, we need to write a five equations describing one DOF.

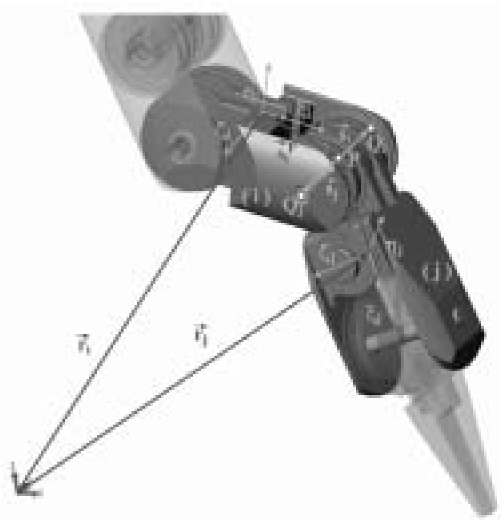


Fig.5. Multibody system structure for Robin Heart revolute joint.

Last two equations are using two extra points arbitrary chosen on the joint axis. It is clear that vectors s_i, s_j must remain parallel. Transforming a local vector into the global coordinate system and adding a transformation matrix *A*, we can write the final constrain equations formula for two exemplary robot elements (2).

$$\vec{r}_i + \vec{s}_i^{P} - \vec{s}_j^{P} - \vec{r}_j = 0 \tag{1}$$

$$\begin{cases} \Phi^{(3)} = r_i + A_i s_i^{\prime P} - A_j s_j^{\prime P} - r_j = 0 \\ \Phi^{(2)} \equiv \tilde{s}_i s_j = s_i \, x \, s_j = 0 \end{cases} \tag{2}$$

A – rotational transformation matrix for body *i*.

Assume that constrain equations are _($\underline{q}$,t)= 0, than we simply create kinematics velocity matrix by calculate the first derivative $\frac{d\underline{\Phi}}{dt}$ (3), and similarly we calculate the kinematics acceleration matrix from the second derivative (4).

$$\frac{d\underline{\Phi}}{dt} = \frac{\partial \underline{\Phi} d\underline{q}}{\underbrace{\partial \underline{q}}_{\underline{\Phi}_{\underline{q}}} \underbrace{dt}_{\underline{\dot{q}}}} + \underbrace{\frac{\partial \underline{\Phi}}{\partial t}}_{-\underline{\nu}} \longrightarrow \begin{cases} \underline{\ddot{\Phi}} = 0 \\ \underline{\Phi}_{\underline{q}} \underline{\ddot{q}} = \underline{\gamma} \end{cases} \tag{3}$$

ν – vector of independent coordinates

$$\underline{\gamma} = \frac{d\underline{\Phi}\underline{q}}{dt} \dot{q} + \frac{d\underline{\nu}}{dt} \longrightarrow \begin{cases} \underline{\ddot{\Phi}} = 0 \\ \underline{\Phi}_{\underline{q}} \underline{\ddot{q}} = \underline{\gamma} \end{cases} \tag{4}$$

γ – vector of right hand side of acceleration equation

The following approach was used to receive the multibody dynamic equations of Robin Heart system. A structure mathematic model of robot was created. In a several computer simulations, information about translations velocity and accelerations were received for each element of the robot. Testing the feedback for a several different external driving signals, we received a set of data that describes the behaviour of Robin Heart. This data was used to prepare a computer animation of a robot movement. Visualization of movement was prepared in Matlab graphic interface and in virtual reality software.

4. Virtual Reality modelling

To be up to date the part of Robin Heart system research and the modelling work is using an EON Reality Virtual Reality latest technology. Because VR is a very intuitive solution this type of modelling gets much more popular nowadays helping surgeons and even patients to understand very complex procedures much more clear and efficient. Moreover, it becomes a demand from a patient to comprehend future treatment. Methods like CT (computer tomography) and NMR (Nuclear Magnetic Resonance) gives a very precise 3D geometry of patient organs, but on the other hand although the geometry is very accurate there is a leak of any interaction between the model and a user needs. Also new and less invasive surgery methods drastically limits the viewing area during the treatment, so the need of detailed 3D visualization is getting much more crucial. In this case we have an option to transfer the picture from endoscope's camera as a regular video, or we can prepare a stereoscopic signal which might be seen on a special shutter glasses or autostereoscopic screens. This type of data after recording and adding some additional information and instructions might be treated as an educational tool. After combining them with a virtual reality modelling methods we can get a system, which allows us to interact, train and plan. This type of intuitive understanding of virtual objects was used by FCSD to create a several training station that helps us better to see the benefits of robotic surgery and how to use a robotic system during the surgery treatment. Nowadays in a RiH project VR technology is implemented in a four different areas: - as a training station in surgeon education process, - as a tool used for a surgery treatment procedure planning with a step by step briefing, - in an advisory voice operated system with an external database, - to verify a different construction versions in aspect of ergonomic and functionality.

5. Training and planning of surgery treatment

The first structured surgical training program in the United States (based on clinical service with subjective feedback from mentors (apprenticeship)) was created by Dr. William Halsted [2]. This concept was prevailed for most of the 20th century. Currently, economic constraints have focused more attention on the efficacy of surgical education [3].

According to surgeons and device executives, surgeon training is the key to the future success of the robotics industry. “Any kind of new technique takes a while to catch on”, says Peter Schulam, MD, chief of the division of endourology and laparoscope's surgery at UCLA Medical Center (Los Angeles). Such new techniques commonly encounter resistance until surgeons are shown how the systems can make their jobs easier. Falk reported [4] the successful application preoperative planning for by-pass procedure. The regions of interest (i.e., heart, ribs, coronaries, internal thoracic artery) were segmented semi automatically to create a virtual model and algorithms for weighing visibility, dexterity, and collision avoidance were calculated after defining non-admissible areas using a virtual model of the manipulator. He concludes that more complete understanding of the surgical decision process is required to better formalize the planning algorithms.

The surgical procedures with the robotic device (e.g. daVinci) takes 40 to 50 minutes longer than standard laparoscope's surgery, this is attributed, in part, to lack of surgical experience with the new technology. Intuitive Surgical is developing a training program for surgeons, in collaboration with FDA. Currently for clinical use of the da Vinci surgical system, the FDA requires a 2-day training course to understand the set-up, maintenance, and applications of the surgical system, in addition to animate laboratory training. Each of the device manufacturers has training programs in place to advance the skill sets of both new and established surgeons.

In this manner, FCSD has used a Virtual Reality technology to create several training station that helps user better to understand the benefits of robotic surgery and how to use a robotic system during the surgery treatment. The total impression of immerse in a computer world was emphasized by using a special active stereoscopic projector and a shutter glasses. All of the virtual Robin Heart robots were connected to the native wireless controllers, so having true joysticks in your hands user can manipulate and stand next to the robots that actually do not exist. A virtual copy of those robot prototypes is able to perform all of the movements and provides the same behaviour as the origin Robin Heart. Possibility of interaction between all of the three robots and the surrounding virtual objects is a great chance of an advanced training for young surgeons but also gives an opportunity to plan (or even practice) surgery procedures that have to be perform in the real world by a professionals. The total Virtual Reality scene was completed with a three separate Robin Heart robots that can be manipulated realistically with all of their functionality. The endoscope's camera viewport displayed in a PIP technology (picture in picture), human model with basic organs which might be exchanged to ones from a patient CT or NMR; surgery room with a surgery table, lamps and all the basic equipment.

Prepared VR model and a Robin Heart training system was created in an EON Professional, and fully supports real time rendering with advanced graphic effects, contact between the objects, friction, gravity and a mass properties. Foundation for Cardiac Surgery Development uses the virtual model: to verify the choice of using a specific instrument inside the surgery area by comparing the size and the shape of the different workspaces; to plan and simulate the surgery treatment with step by step instructions; for a surgery room choreography optimising the position of each robot arm for different procedures; to set the correct trocar ports between the patient ribs; to educate how to use an endoscope's camera during the surgery procedure. Virtual Reality modelling examples listed above are the most important factors of creating computer model, but not the only ones.

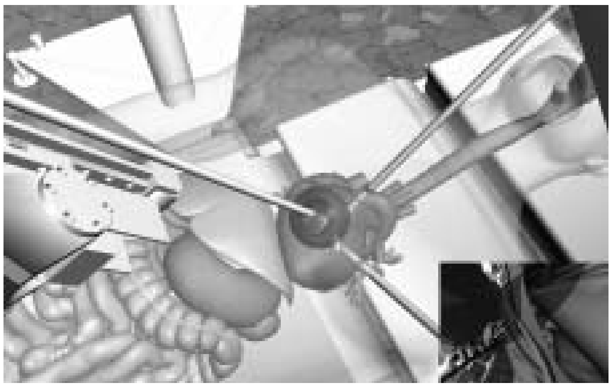


Fig.6. Robin Heart surgery scene planning inside the patient body.

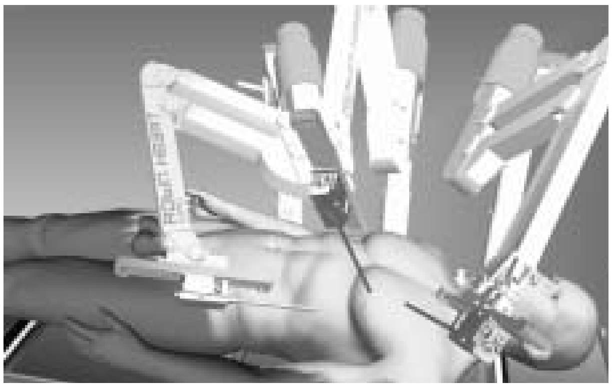


Fig.7. Robots choreography planning and training.

6. Summary

There is a few very important factors influenced success of modern tool in a surgery treatment. The most important one is the cost, which is quite a big expense in case of daVinci system. In this way the polish robotic surgery setup named Robin Heart will be a device that is much more affordable for most users both in purchase and maintenance. Using a Virtual Reality technology an interactive model of surgery room equipped with a Robin Heart system, we have a possibility to test the solution in a prototype phase. Computer modelling methods allows for advance procedure training and will be used as a low cost training station for surgeons in the future. The link between this type of modelling and a Computer Aided Design

Fig.8. Wireless controller for virtual model steering.

Fig.9. Constant point position planning between patient ribs.

(CAD) techniques is using an accurate CAD robot models in a VR software together with a precise reflection of workspace geometry. This approach gives a surgeon easy and intuitive way to understand technical information and use it to optimise and plan medical process. The next step in FCSD research work will be a leadership in establishing the surgery workshops based on the newest technology, and some new projects of affordable semi-automatic robotic tools. Presented model of Operating Room in Virtual Reality environment has been successfully used during Surgery Workshop in FCSD.

AUTHORS

Zbigniew Nawrat – Foundation for Cardiac Surgery Department, Zabrze, Poland,& Medical University of Silesia, Katowice, Poland, e-mail: nawrat@frk.pl
Marek Koźlak* – Silesian University of Technology Institution, Gliwice, Poland, e-mail: marek@eonreality.com
* corresponding author

References

[1] Available online: www.intuitivesurgical.com
[2] Halsted W.S., “The training of the surgeon”, *Johns Hopkins Hosp. Bull.*, 1904, no. 15, pp. 267-75.
[3] Debas H.T., “Impact of managed care on funding of surgical residencies”, *Arch. Surg.*, 1995, no. 130, pp. 929-30.
[4] V. Falk, F.Mourgues, L.Adhami, S.Jacobs, H. Thiele, S.Nitzsche, F. W. Mohr, E. Coste-Maniere, “Cardio Navigation: Planning, Simulation, and Augmented Reality in Robotic Assisted Endoscopic Bypass Grafting”, *Ann. Thorac. Surg.*, 2005, no. 79, pp. 2040-2047.