THE ROBIN HEART VISION, TELEMANIPULATOR FOR CAMERA HOLDING – PRELIMINARY TEST RESULTS

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Abstract:

This paper presents the general information of mechanical structure, control system and preliminary technical evaluation results of the new polish telemanipulator for camera holding Robin Heart Vision®, belonging to the family of robot arms to support the minimal invasive cardiac surgery. It has four degrees of freedom with the interface for quick endoscope fixing. It was designed and carried out as a standalone robotic assistant for manual laparoscopic surgery or to operate together with the tool arms Robin Heart®.

Keywords: *Surgery robots, Minimal Invasive Surgery, Telesurgery*

1. Introduction

In medicine and more specifically surgery, robotic technology has become a viable surgical alternative to provide minimally invasive surgery with the advantages of traditional open surgical techniques. Robotics has a role in the surgical training by increasing the precision and accuracy of the learning process. Robotics may also allow for telementoring and telepresence surgery facilitating global access health care. For future role of robotics the most important now is to solve the economic, cost-effectiveness problem.

An application of teleoperation allows to remove the tremor and to introduce the scaling of hand movement range via interface of manipulator on properly exact movements of tool inside the body and as a result - improves the ergonomics and precision. Supervision is held using optical observation via voice or manually controlled endo-camera (2D or 3D). American cardiosurgical robots have been produced by two, currently merged, companies, Computer Motion® (Computer Motion Inc. of Goleta, Calif., CM), and Intuitive Surgical® (Intuitive Surgical, in Mountain View, Calif., IS) firstly clinical used in Europe. First on world mechanical assistant of surgeon - voice controlled endoscope positioner AESOP 1000 (Auto Endoscopic System for Optimal Positioning) - was introduced by firm CM in 1994. In January - May 1998 a French team in Paris and German group from Leipzig performed using da Vinci (IS) telemanipulator first in the world endoscopic operation of single coronary bypass and mitral valvuloplasty. In summary, about 1000 surgical and endo-camera robots were installed in clinics many counters (also in Poland, Katowice) till now used for more than 130,000 minimally invasive procedures across a broad range of surgical applications such as general surgery, gynecology, spinal, urology and cardio thoracic [1][4][5].

In 1999, The Zeus surgical system made history in the world's first robotic-assisted beating-heart bypass surgery, by Douglas Boyd, MD. In 2001, the first trans-atlantic telesurgical procedure was performedusing the Zeus system. The doctors in New York removed a gallbladder of a 68-year old patient in Strasbourg, France, and the procedure was reported successful with no complications.

The Foundation of Cardiac Surgery Development (FCSD) in Zabrze began in 2000 the grant for realization of the prototype of a robot useful for cardiac surgery. The multidisciplinary team including specialists in medicine and techniques during three years prepared two families of robot prototypes named Robin Heart [1].

Presented work describes the Robin Heart Vision for endoscopic camera holding telemanipulator preliminary testing results. It has four degrees of freedom with the interface for quick endoscope fixing. It was designed and carried out as a standalone robotic assistant for manual laparoscopic surgery (similar to AESOP camera holder in ZEUS system) or to operate together with the tool arms Robin Heart. Because this is first pre-animal stage of Robin Heart Vision development the general information of its mechanical structure and control system are presented.

2. Surgery telemanipulators for camera holding

In traditional laparoscopic surgery the operating surgeon does not have direct visual control of the operative field due to manual camera control by assistant. Ideally, the surgeon should have full control of operative instruments and the operative field. The ***endoscopic cameraholding telemanipulator*** return camera-control to the surgeon and to stabilize the visual field during minimally invasive procedures. The active and passive camera holders offer the surgeon an alternative and better tool for control of the operating surgeon's direct visual field.

One of the first, active teleoperated robots introduced into clinical practice was produced by Computer Motion (US) company. In summary over 1500 of Computer Motion's robotic systems (AESOP, ZEUS) are in use worldwide in 900 hospitals by over 3000 surgeons in 32 countries. The ZEUS System consists of three robotic arms mounted onto an operating table. Two arms hold surgical instruments, and the third arm holds and positions the endoscope via voice control. All three arms are connected to a master console where the surgeon telemanipulates the arms. The handles used to control the movement of the surgical instruments are similar to the instruments used in conventional surgery. The surgeon's manual movements are filtered and scaled for the slave instruments to perform precise microsurgery. The ZEUS system can be used in combination with an independent 3-D visualization system (AESOP).

More than 300,000 surgical procedures have been performed with Computer Motion's robotic systems assistance. The AESOP (Automated Endoscope System for Optimal Positioning) system is both CE marked and FDA approved and has been used in over 100,000 laparoscopic and endoscopic procedures. The duration of several types of endoscopic surgery was reportedly faster using AESOP, with voice control felt to be more efficient and faster than either the foot or hand control.

The robot is attached to the side of the surgical table and can grasp any rigid laparoscope. The advantage of AESOP was demonstrated by Kavoussi et al. [2] (in a comparison of robotic vs. human laparoscopic camera control. In 11 patients requiring bilateral procedures, robotically controlled camera positioning was used on one side and compared to traditional hand control on the contra lateral side. They found robotically controlled positioning was significantly steadier with similar operative times.

Disadvantages for AESOP include the constant voice commands, which may be distracting. In addition, the voice control is slower compared to the rapid camera movements achieved by an experienced assistant. AESOP is intended to facilitate solo-surgeon laparoscopic procedures; however, the surgeon may still need an assistant for control of the fourth laparoscopic port.

The Intuitive Surgical Inc, (US) da Vinci telemanipulator consists of three or four robotic arms in one set fixed on one common column, placed near the operating table. In opposite to AESOP system da Vinci arm for camera holding is integrated with all robotic arms. Today approximately 400 da Vinci Systems have been installed worldwide, its application have been described in thousands of scientific publications and presentations. It is CE marked and FDA approved and used in over 300 hospitals in America and Europe. The da Vinci was used in at least 16,000 procedures in 2004 and sells for about 1.3 million dollars.

In Europe the Armstrong Healthcare Ltd (UK) produced telemanipulator EndoAssist. A robot system EndoAssist holds a conventional laparoscopic telescope and camera, coordinated by the surgeon's head movements. EndoAssist (CE marked and cleared by FDA) has also been used in telesurgical applications with control via a joystick communicating with the robot over a telephone line. In comparison with AESOP is rather not popular about thirty systems installed worldwide now and has been used in several thousand clinical procedures.

3. Robin Heart Vision Descripton

Mechanical construction of RH Vision (Fig.1a) is based on the prototype surgery telemanipulator Robin Heart® developed and tested in FCSD between 2000-2005 (Fig.1b) [4],[5].

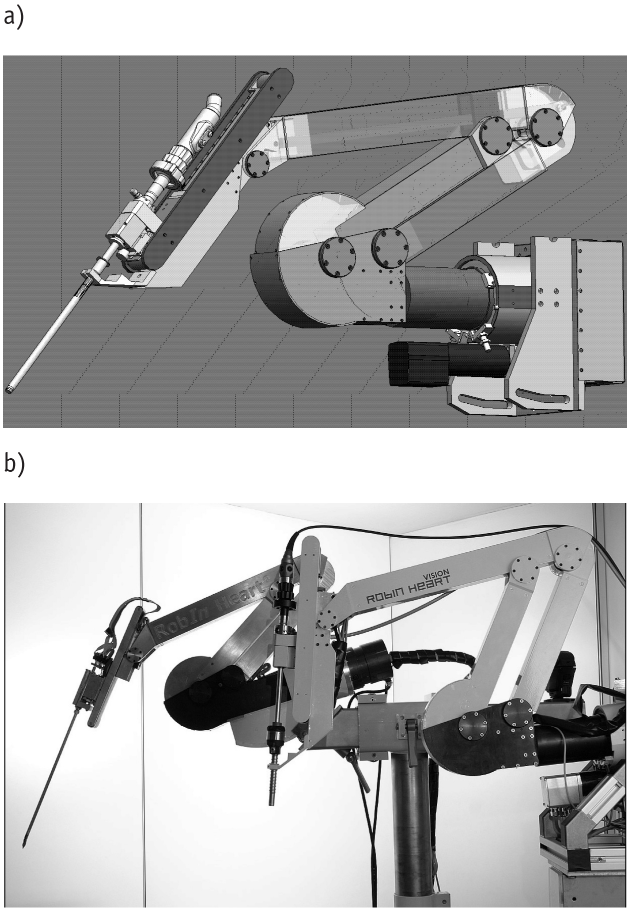


Fig.1. The Model of Robin Heart Vision (a) and the picture of real arm RH Vision in the foreground together with Robin Heart prototype in background (b).

Basic idea of the manipulator Robin Heart consists of mechanisms realizing fixed in space 'constant point', composed of two closed kinematics' chains [4],[5]. The first loop is in fact a typical parallelogram mechanism, used as a transmission mechanism coupled with the second one realized inverse mechanism. By special connection of two rotations coupled by constant angle internal link, the mechanism can change external angle to approximately 150 degrees. The first degree of freedom (DOF) is driven by electric, brushless motor integrated with planetary gear. The second (range up to 120 degrees doubled system of parallel mechanisms) and third DOFs (the parallel mechanisms eliminates the necessity of using a linear slideway) are driven by brushless motors, roller screws and system of strings. All four DOFs uses Maxon® DCBL motors with hall sensors and digital encoders as a control loop position sensor. The construction makes possible fast and not complicated disconnection the drive part of the bunch from the manipulating part.

Simultaneously to works on mechanical construction the surgery procedure planning with the application of RH Vision took place. Choreography of whole robotic surgery set including tool arm (RH) and endoscopic channel holder (RH Vision) placed next to surgery table was performed both in created in our team virtual environment (Fig.2a) using EON® software and in real condition (Fig.2b).

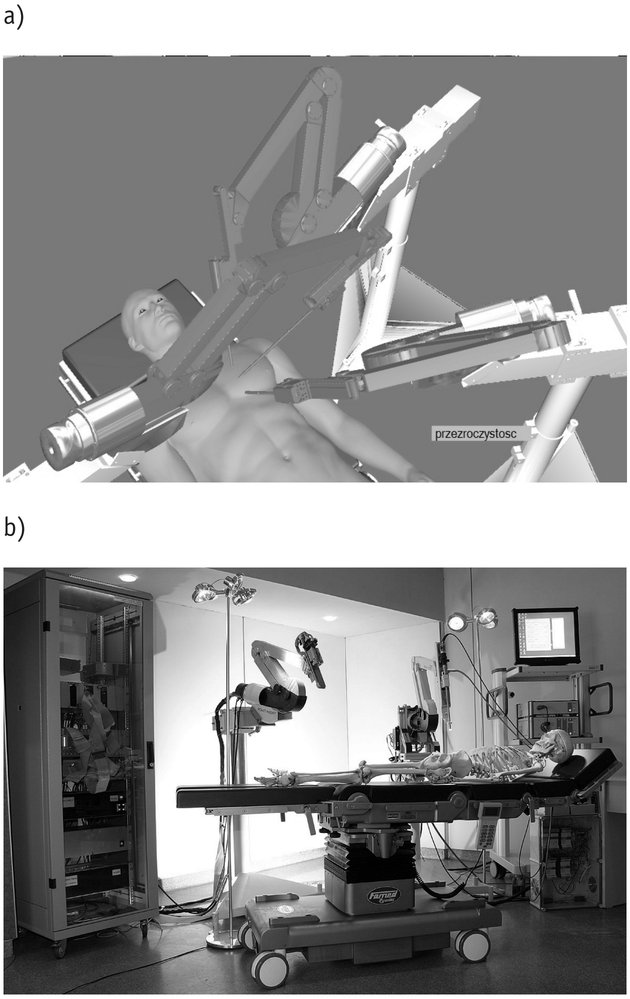


Fig.2. 3D model of virtual operation room with RH & RH Vision robots (a) and real training set up with RH1 & RHVision prototypes (b).

Control system of Robin Heart Vision.

The main idea of control system is common for all described cardio-surgical systems (including Zeus and daVinci systems). The main task of Master-Slave teleoperator is reliable mapping of surgeon hand movements (temporal values of position/velocity/acceleration or other physical quantity) onto the movements of tool arm, through calculation of control signals for its motors.

Technical requirements of Robin Heart surgical telemanipulator control system could be listed below:

- frequency of updating signals in the main control loop for translating the Master arm commands into the Slave arm movements, which ensures fluent work should be at least 1000 [Hz],
- satisfactory precision of surgery procedures, taking into account the small sizes of anatomical objects (e.g. 1 mm diameter of coronary vessels) should be guaranteed by the positioning accuracy and resolution equals at least 0.2 [mm],
- delay between Master and Slave arm movement should be lower then acceptable limit : $T_{DEL\_MIN} = 50$ [ms],
- possibility of scaling the movements between the operator and the arm with surgical tool,
- an introduction apart from position surgeon commands (by means of master arm) also other forms of communication with system (e.g. voice control), to increase the comfort and ergonomy of the user interface,
- elimination of surgeon hands tremor,
- optional possibility of the 'mirror' movements effects reduction,
- hardware and software movement limit detection on particular axis,
- communication with host computer (RS, Ethernet) to change work parameters and monitor current state of the system,
- optionally, introduction of force feedback with the possibility of scaling of the force (or others: audio-visual, termical or mechanical - vibrations) sense, passing to operator.

System of motor (Maxon DCBL motors, EC&ECPowerMax family) drivers has a distributed structure, where every motor unit assigned to particular DOF has its control PID unit with very advanced communication and safety systems (EPOS®, Maxon) placed next to it. All driver units are connected in serial CAN bus.

Mentioned above assumptions were fulfilled in implemented control system based on digital signal processor (DSP) specialized for motor control, working as central unit (Fig.3). Main parts of Robin Heart Vision control system are following:

a) ***Master tool interface.*** Depending of type of Master tool (see below) signals from digital encoder sensors (A,B,I) or analogue voltage output (anal. gyroscopes) are translated to common, universal SPI serial bus. In case of Master tools cooperating with PC (joystick and voice recognition system) USB bus is used as a communication channel to system.
b) ***Central unit.*** Input signals acquired and translated from Master tool are processed, where several control algorithms are implemented:
    - forward kinematics of Master tool,
    - options: scaling, tremour removing,
    - inverse kinematics of Slave arm.
c) ***Communication unit.*** Control system is an autonomous module working in real time system. Communication with host industrial PC realized by USB, Ethernet or BlueTooth protocol is applied only for system parameter changing and monitoring.

Designed structure of control system is planned to be redundand, where apart from basic information channel the second one for safety improvement is added. Pararelly two control channels compute the same required data but using different/doubled sensors (both of Master and Slave tool). In every iteration cycle two groups of computed data are compared and in case of difference greater then set limit, immediate stop command with the highest proritet is send to all motors to detect and prevent possible emergencies.

Several Master tools for endoscope manipulator were developed to test different ways of introducing command to system by surgeon/operator:

a) manually controlled tool base on classical laparascopic structure with relative encoder sensors,
b) head movement command interface by means of MEMs

gyroscope sensors and digital output (SPI) MEMs accelerometers,

c) voice control commands (on current stage using PC software for speech recognition),
d) PC based wireless joystick.

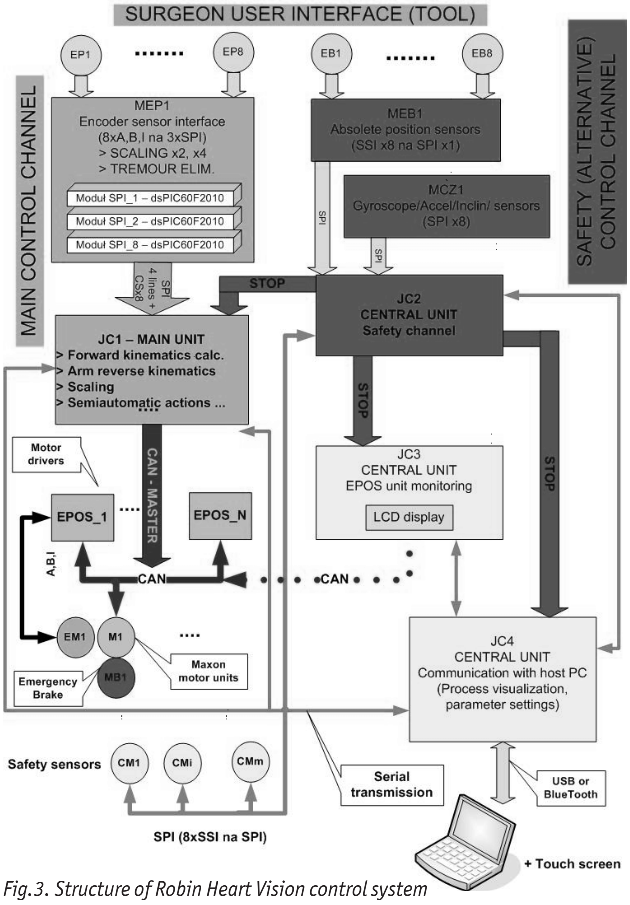


Fig.3. Structure of Robin Heart Vision control system

4. Test results

Preliminary tests carried out for Robin Heart Vision consisted on several stages, where using different methods the external displacement and trajectory of the arm was recorded and evaluated by the comparison with required data. In this paper we present two testing procedures.

4.1 Technical evaluation of Robin Heart Vision by means of digital micrometer fixed to prepared testing stand.

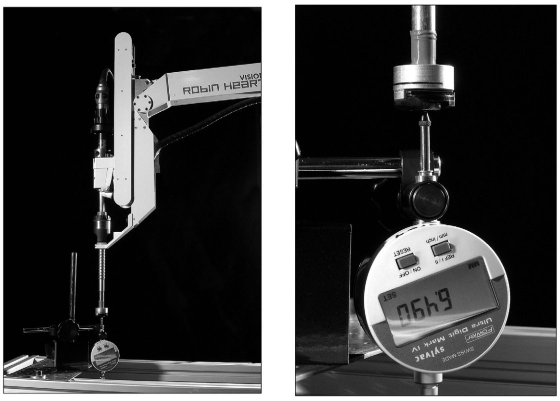


Fig.4. Movement range measurement stand by means of digital micrometer with PC communication

4.1.1 Verification of the movement range for particular DOFs:

Range of movement	DOF1 [deg]	DOF2 [deg]	DOF3 [mm]	DOF4 [deg]
	187	117,5	Effect. range: 165 Max. range: 400	350

4.1.2 The assessment of arm positioning resolution:

	DOF1 [mm]	DOF2 [mm]	DOF3 [mm]	DOF4 [mm]
Resolution	0.2	0.2	0.1	0.1

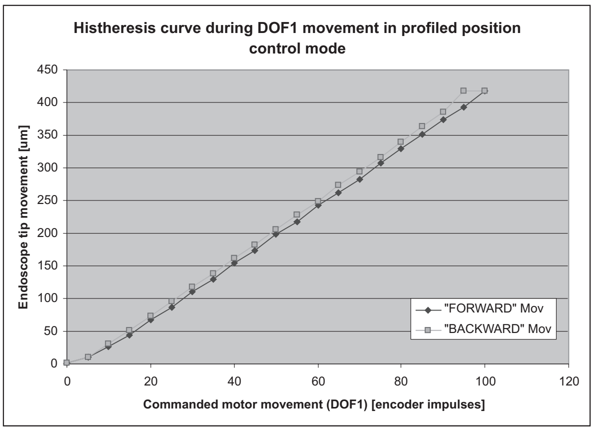
4.1.3 The test of arm precision during the repeat test registration of the real external trajectory for every of n=100 constant position movements.

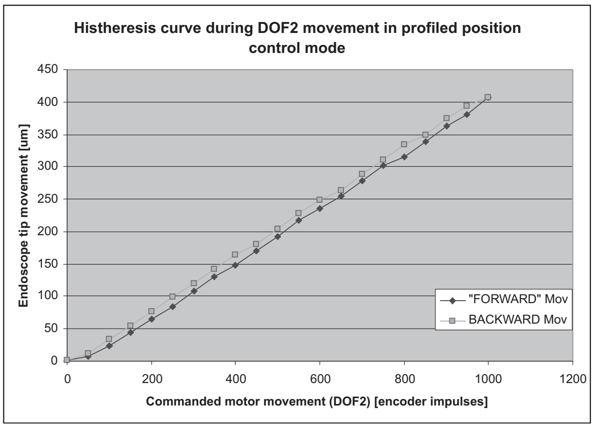
	DOF1	DOF2	DOF3	DOF4
Max [mm]	12,486	8,672	9,844	3,157
Min [mm]	12,466	8,625	9,791	3,024
Mean [mm]	12,473	8,668	9,820	3,109
Std. dev. [mm]	0,0054	0,0075	0,013	0,021

4.1.4 Histheresis test

Consecutive n movements with incremented (1. phase) and decremented (2. phase) commanded position (x_i) during 'forward' and 'backward' phases (1):

$$x_i = x_0 + i * step\ ;\ i = \{1..n..1\}\ ;\ x_0, step \in Z \qquad (1)$$





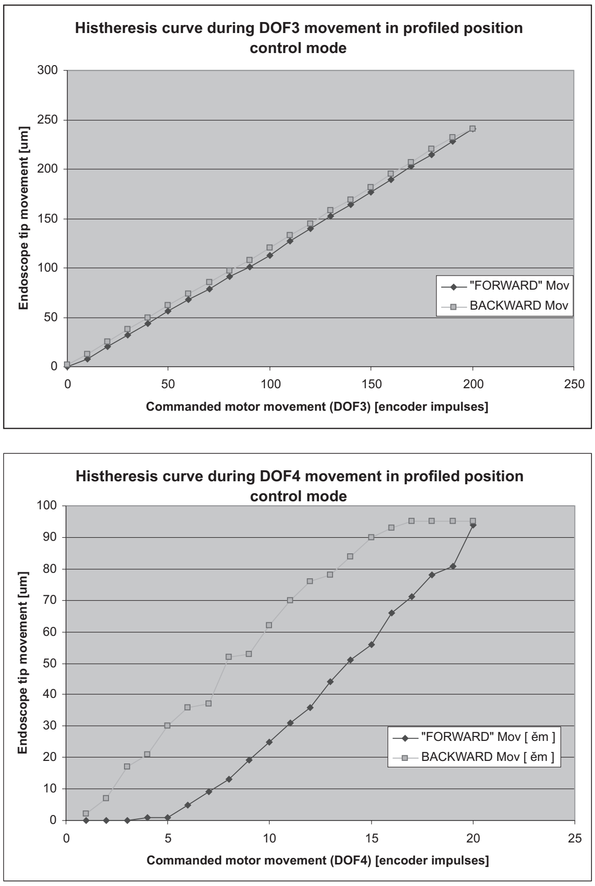


Fig.5. Results of histheresis tests for DOF1-DOF4.

4.2 Visualization tests.

System of three digital cameras synchronize record the movement of robotic system with special markers fixed to its characteristic points (mainly joints and linear movement parts) (fig.6). Trajectories recorded from different cameras are combined and analyzed in specific image analysis software to compute real external trajectory of robot arm.

Synchronize recording of 'Slave' arm movements, reflecting operator command movement using head movement interface was also performed and trajectories for both 'Master' and 'Slave' tools are presented (fig.7).

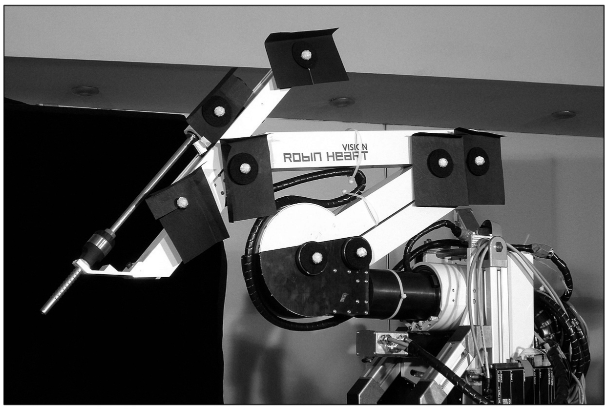


Fig.6. Robin Heart Vision prepared for visualization test. System of external trajectory recording using several digital cameras, markers and image analysis methods.

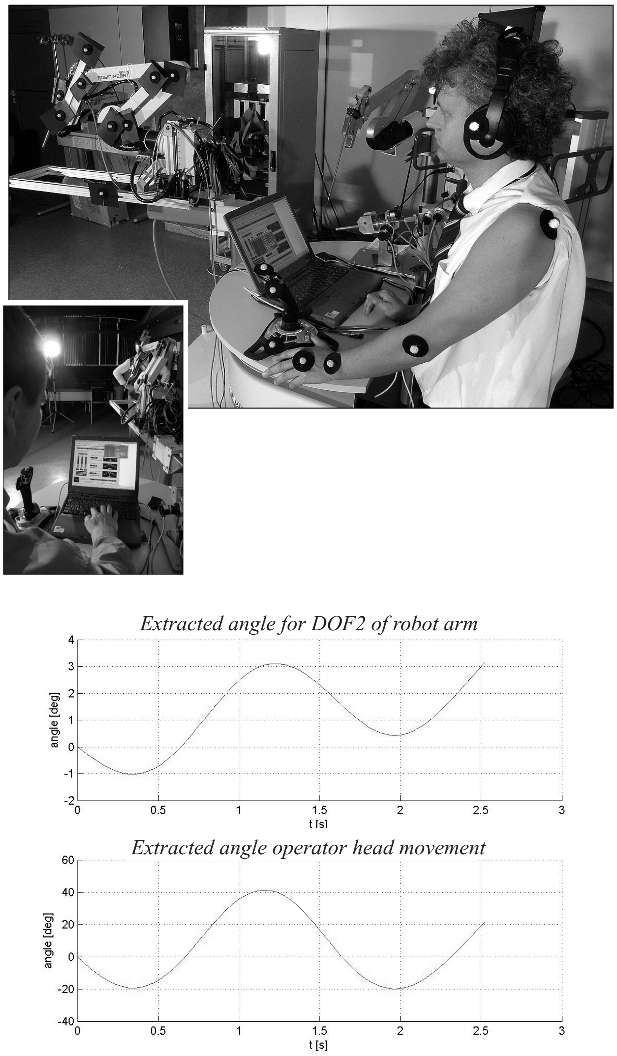


Fig.7 Testing stand and extracted results for the synchronized movement of operator head (Master) and camera arm (Slave) during head movement control mode in visualization test with the movement scaling clearly seen.

5. CONCLUSION

Preliminary tests stage allowed to verify the functional and technical assumptions of the project and to reveal some defects, which currently are removed.

The future of robotic surgery has significant potential what verified in many clinical applications. The procedure completed without the need for an additional assistant is called as 'solo surgery'. Robotic assistance has enabled a solo surgery approach [6]. The most popular, over 130,000 application, was the voice controlled robotic arm (AESOP-Automated Endoscope System for Optimal Positioning) provided a stable and precise video image with excellent exposure of all valvular and subvalvular structures, heart and vessels. This factor enable also the decreasing of surgery time.

Semiautomatic controlled telemanipulator for camera holding during minimal invasive surgery will be in closest years, one of the necessary equipment reducing the operation costs (in relation to conventional operation) and shortening of time of hospitalization directly after operation and above all with diminution of number of surgical complications.

The project of robotic endoscopic camera RobIn Heart Vision is the consequence of successfully finished of research project led by FRK in years 2000-2003. Tested in laboratory our robots they showed correctness of construction and control. We have agreement of ethical committee onto first experiments on animals now. Planned start of experiments is the summer of 2007. According to a plan the first arm for animal experiment will be just the RHVision for camera holding.

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