Surgical table automation with integrated collision avoidance with floor or fixed table parts

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***Abstract* –By adding the hydraulic actuators to movable parts of an manual surgical table, it is possible to support a wide range of surgical procedures. Motion commanding via hand-held unit and automatic positioning may result in a collision between mobile and fixed parts of the table, or with a floor. This problem is solved by integrating a contactless positioning sensor at the last joint of movable part that can hit to constraint. With the knowledge of the geometry of the table and with adding a sensor system for measuring angle and height it is possible to design system which can avoid collision with table and the floor. The paper describes the mechanical design of a surgical table with additional actuators and sensing and control subsystem based on PLC controllers. In particular the spatial positioning algorithm for collision avoidance is explained and verified in practical design.**

Keywords: Robotics, Mechatronics, Automation

I. INTRODUCTION

Modern digital radiography enables high resolution images and a wide range of gray colour which enables its usage in minimally invasive surgery, such as vertebroplasty or stent implants. Therefore, the positions of the digital receiver, as well as the patient that is placed on a surgical table, are of the critical importance. Different surgical tables allow manual positioning of several axes of movement, but the positioning accuracy is brought into a question. The paper describes the automation of a surgical table for precise patient positioning. Existing mechanics of a surgery table, Fig.1, is modified by adding hydraulic actuators. In that way, moving is enabled by setting the movement commands with manual controls. The control system is based on a PLC controller, and the feedback on the level of the table to the floor is performed by using a potentiometer. For measuring the absolute angle between the segments of the table magnetic sensors are used. An interface is developed for voltage adjustment and multiplexing of sensor modules and a PLC controller. Given that carelessness of users can lead to collision with the floor of the table segments, the working areas are defined and the equations are derived that represent the base for implementing the security algorithm on the PLC as the main controller.

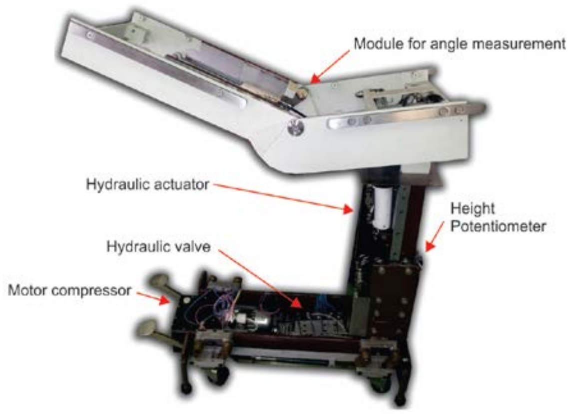

Figure 1. Mechanics of the surgical table in the reconstruction phase

II. BLOCK DIAGRAM OF SYSTEM COMPONENTS

The block diagram of the surgery table, Fig.2, shows the relationship between the system components. The surgical table as such represents a mechatronic system that consists of a mechanical and an electrical subsystem. The mechanical subsystem is shown in Fig.1 while the electrical system consists of a number of distributed modules whose function is coordinated by the PLC controller.

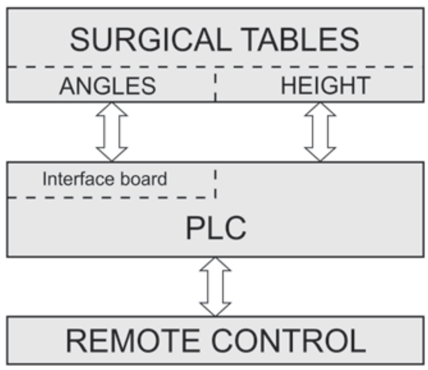

Figure 2. The block diagram of the system components

III. MECHANICAL SUBSYSTEM

The mechanics of the surgery table is shown in Fig.1. To each joint of the table a hydraulic actuator is added and its associated valve. By opening and closing the hydraulic valve the movement of the actuator is controlled, and hence of the corresponding segment of the table to which the actuator is attached. By the mechanical design of the shown surgery table it is possible to perform movements that are shown in Fig.3.

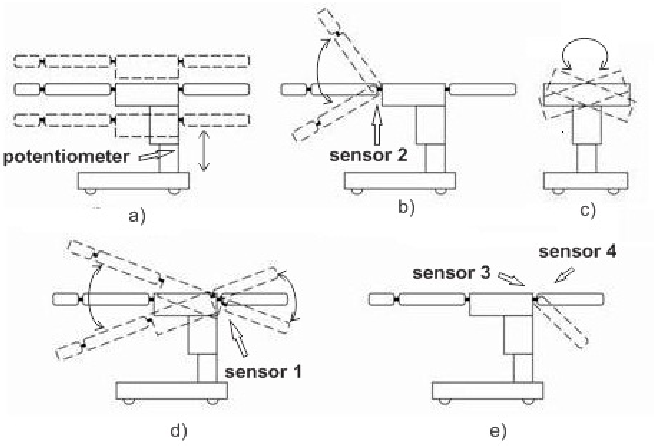

Figure 3. Possible movements of the table segments and locations of the position sensors

By a pulley-belt system a connection of the movable part of the lift for raising the table with a more revolutions potentiometer Fig.3a, and in that way it is possible to measure the height of the table to the floor of the room. To each revolute joint a module for measuring the angle between the moving and stationary segment is assigned. Two modules (sensor 3 and sensor 4) are mounted on the joints of the segments that the patient's legs are relied on, Fig.3e. Measurement of the angle of the segment that controls the position of the body and the patient's head is performed by placing a module (sensor 2) on the joint of the seat and the back, Fig.3b. On the main rotation axis, Fig.3d, a module (sensor 1) that measures the inclination of all segments of the table is set. The restriction of movement on all axes is achieved mechanically by placing an overflow valve, while the information about the overflow is brought into the PLC. The increase in pressure in the system, caused by the boundary position of the segment, will cause activation of the overflow valve and movement termination of the segment that has come to the boundary position. The boundary positions are defined by the mechanical structure of the table.

IV. ELECTRICAL SUBSYSTEM

The electrical subsystem consists of three components:

- the sensor system for measuring the height of the table and the angles between segments,
- the control logic based on PLC,
- the power electronics for energy supplying of compressor engine and other system components.

A. *Measuring of the height of the table in relation to the floor of the room*

For measuring the height of the table the potentiometer with more revolutions is used. By appropriate choice of a pinion mounted on the axle of the potentiometer the measurement of the full range of movement of the elevator is enabled. The potentiometer is connected to the PLC via an input for AD conversion. Nonlinearity which can be caused by imperfections of producing the pinion and the belt can be eliminated by the calibration. The calibration process is performed during the mounting process of each potentiometer. After the calibration each integer value read from the potentiometer is transformed by the implemented algorithm into the position in millimeters.

B. *Measuring of the angle between the segments of the table*

For measuring the angle between the segments of the table a module in the form of a printed circuit boards, which is based on the *Sentronis* 2SA-10 magnetic sensor for measuring angles and the *Microchip* PIC16F684 microcontroller is developed. The 2SA-10 sensor detects the absolute angular position of small magnets which are located above the surface of the sensor. The plate with the sensor is mounted on the stationary part of the mechanism, while the magnet is placed on the rotating part, so the angle of the magnet corresponds to the angle between the segments of the table. The sensor outputs are two linear voltage signals, which are proportional to the sinus and cosines function of the angle of the magnetic field that is parallel to the surface of the chip, as it is shown in Fig.4.

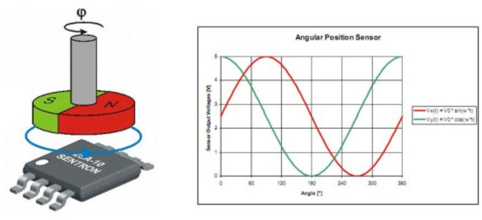

Figure 4. 2SA-10 sensor and its output signals

The sensor provides the absolute angle so the microcontroller program introduces an offset for simplifying the installation and initialization process of the sensor at the zero position. The introduced offset is stored in the EPROM of the microcontroller, so the system is automatically initiated at each next start. The output signals from the sensors are connected to analog inputs of the microcontroller, and after the AD conversion their digital values with the resolution of 10bits are obtained. After calculating the angle of a segment, the region in which the segment of the table exists is coded and the information is sent from the module to the PLC.

The sensor plates are mounted on four joints where it is necessary to measure the angles between the segments, as it is shown in Fig.3.

V. CONTROL OF MOVEMENT AND PREVENTION OF COLLISION WITH CRITICAL POINTS ON THE TABLE

The control of movement and positioning of the table systems is accomplished with the ABB PLC of AC500 series. The motion control of certain segments of the table is done by opening and closing of the appropriate hydraulic valves. The program of the PLC controls opening and closing of the valves, the compressor engine function and processes received data from the position sensor. The user specifies commands by hand control device that is connected to the PLC.

The program of the PLC branches in two modes, the SERVICE and the USER mode. By entering the service mode some privileged functions are allowed, such as the setting of the parameters of the table and the calibration of the sensors. This mode is entered by simultaneously activating the corresponding group of buttons on the hand control device. The user mode is entered at every system start up. In this mode, a lot of prevention procedures are active avoiding collisions which may result during movement of the segments of the table. The algorithm of the program execution on the PLC is shown in Fig.5.

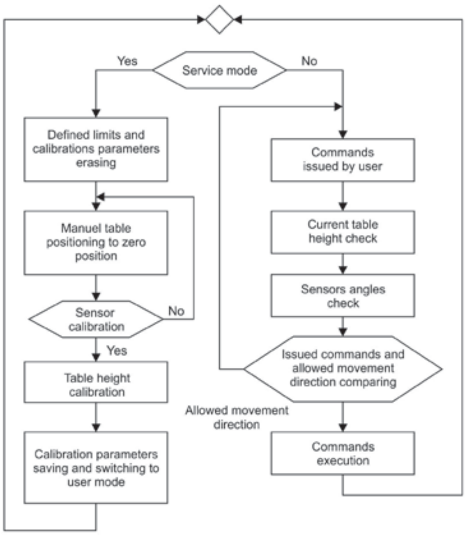

Figure 5. Algorithm of the program execution on the PLC

In order to prevent the collision of the edge of the table with the floor, there is an extra algorithm of the collision protection. Based on dimensions of the table the following equations are derived which calculate the distance of the critical points A, B and C from the floor. Fig.6 shows the geometry of the table with marked dimensions and possible collision scenarios between the edge of the table and the floor.

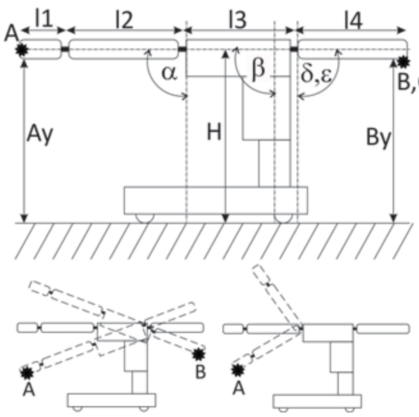

Figure 6. Geometry of the table and critical points

In order to calculate the position of the critical points, the algorithm uses the angles between segments, the height and dimensions of the table. On the basis of these data the algorithm allows or prevents movement at a specific axis, in the case when the collision is predicted.

$$A_y = H - [a \cdot \tan(-\beta - b)] \quad (1)$$

$$a = \sqrt{h_1^2 + \left(l_3 + \sqrt{h_1^2 + (l_1 + l_2 + l_3)^2}\right)^2}, \quad (2)$$

$$b = arc\sin\left(\frac{h_1}{l_3 + \sqrt{h_1^2 + (l_1 + l_2 + l_3)^2}}\right), \quad (3)$$

$$h1 = (l_1 + l_2)\tan(\alpha), \quad (4)$$

$$B_y = H - [c \cdot \tan(\beta + d)], \quad (5)$$

$$c = \sqrt{h_2^2 + \left(0{,}07 + \sqrt{h_2^2 + (0{,}07 + l_4)^2}\right)^2}, \quad (6)$$

$$d = arc\sin\left(\frac{h_2}{0{,}07 + \sqrt{h_2^2 + (0{,}07 + l_4)^2}}\right), \quad (7)$$

$$C_y = H - [e \cdot \tan(\beta + f)], \quad (8)$$

$$h_2 = l_4 \tan(\delta), \quad (9)$$

$$e = \sqrt{h_3^2 + \left(0{,}07 + \sqrt{h_3^2 + (0{,}07 + l_4)^2}\right)^2}, \quad (10)$$

$$f = arc\sin\left(\frac{h_3}{0{,}07 + \sqrt{h_3^2 + (0{,}07 + l_4)^2}}\right), \quad (11)$$

$$h_3 = l_4 \tan(\varepsilon), \quad (12)$$

VI. Conclusion

By implementing control logic and drive units a new surgical table is obtained that can be used in a wide range of surgical procedures. Powerful controllers and precise sensors for achieving the position feedback allow the precise positioning of the table, so the implemented system can be used for the future research in the field of images registration of vertebral osteoporotic by radiography. There are similar solutions, but it is not possible to integrate them into a new experimental system in a way that would meet safety standards.

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