ON IMPROVING THE ACCURACY OF LENGTH MEASUREMENT IN CLINICAL ORTHOPEDIC

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Lucrarea descrie un sistem de măsurare a lungimii, care este fixat de masa de operaţie sau de patul pacientului şi care asigură măsurarea lungimii membrelor cu exactitate ridicată şi uşurinţă de utilizare în timpul intervenţiilor chirurgicale, şi al cărui palpator poate fi sterilizat.

The paper deals with a length measuring system which is fixed to the operating table or to the patient's bed and assures intra-operative limb length measurement with high accuracy and ease of use, and whose probe can be sterilized.

Keywords: Limb length, Intra-operative measurement, Measuring system, Incremental transducer.

1. Introduction

According to medical statistics, the most used medical devices are orthopedic devices, due to the growing number of accidents involving young people who consequently need reparatory surgeries, and to the growing of life expectancy. This is the reason why orthopedic devices are attentively and consistently studied by medical specialists and engineers.

Manufacturing the prosthesis and the bio-compatible materials which are used are priorities of scientific research in the domain.

The same importance is given to the technologies used during the surgery, one of them being the measuring technology in order to obtain the desired limb length.

The most used clinical measuring methods are the following:

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- measuring with a graduated rule ore tape [1];
- measuring with a linear caliper or with an L-shaped calliper (fig. 1) [2];
- measuring with commercial specialized devices (fig. 2) [3].

These devices are relatively difficult to use and the obtained measuring accuracy is not very good.

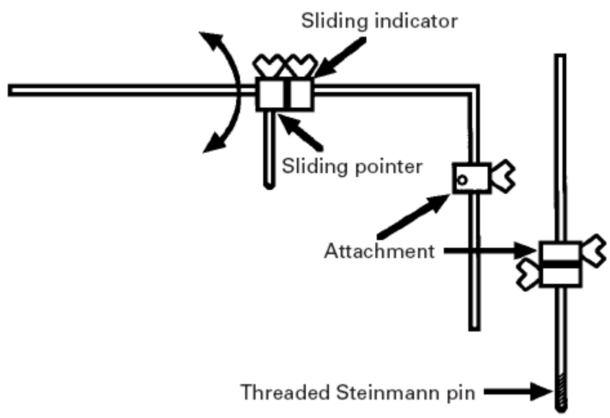

Fig. 1. The scheme of the L-shaped caliper

Fig. 2. Comis leg length apparatus

The paper proposes a length measuring system consisting of three articulated rods which assures the movement of a spherical end probe within a working space, the position of the probe being permanently determined by mean of some angular incremental transducers placed in the articulations and on the rods.

The measuring system is placed on a wheeled rack together with the command computer. The whole assembly can be moved and attached to the patient's bed or to the operating table in order to assure accurate clinical length measurements in orthopedics.

2. Length Measuring System

2.1. General characteristics

The length measuring system (fig. 3) has the following components:

- stand 1, which is fixed to table 2 and allows the rotation of the system in a horizontal plane; this rotation is measured by means of the angular incremental transducer T_1;
- rod 3, which is articulated to the stand 1 and can rotate in a vertical plane; this rotation is measured by means of the angular incremental transducer T_2;
- rod 4, which is articulated to the rod 3 and can rotate in the same plane with it; this rotation is measured by means of the angular incremental transducer T_3;
- rod 5, which is coaxial with the rod 4 and can rotate around its axis; this rotation is measured by means of the angular incremental transducer T_4;
- probe 6 with spherical end, which is articulated to the rod 5 and can rotate relative to it; this rotation is measured by means of the angular incremental transducer T_5.

The counterweight 7 gets back the system to the repose position when the operator releases the probe. The return movement is smooth, without shocks, due to the damper 8 and the friction devices within every joint.

The command computer 9 and the display 10 that shows the result of the measurements are placed on the table 2. The stand 11 supports the whole system and it can be moved by means of the wheels 12. The stand can be fixed to the operating table or to the patient's bed by means of the clamping device 13.

When the operator moves the probe and touches with its spherical end a point of interest on the patient body, the transducers $T_1 \div T_5$ measure the angles of rotation of the system elements and the application software determines the spatial coordinates of the probe sphere in respect to a fixed reference system connected to the operating table. When the probe is moved to the second measuring point, its spatial coordinates are determined and then the distance between the two points is computed, this being the length of the measured segment.

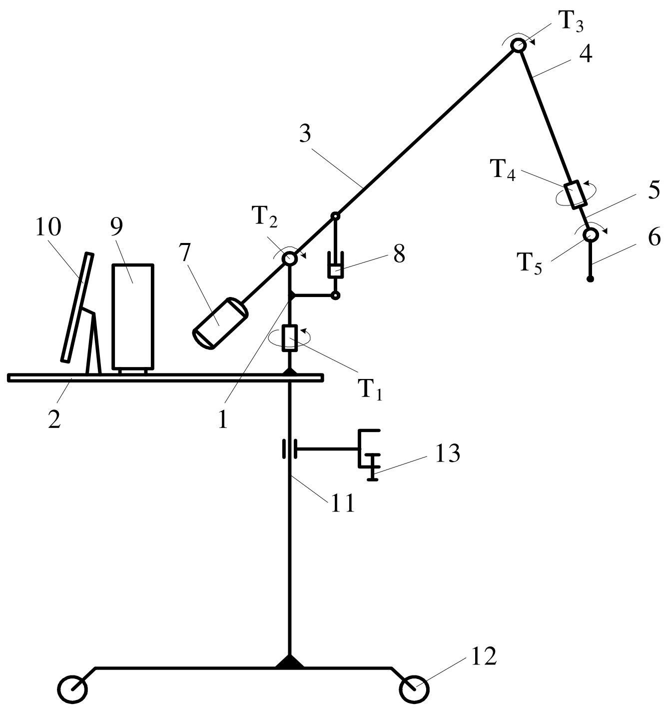

Fig. 3. The general scheme of the measuring system

2.2. The length determining

The coordinates of the centre of the spherical end of the probe are determined dependent upon the lengths of the rods and the angular values measured by the incremental transducers $T_1 \div T_5$ (Fig. 4).

The following notations are used:

- OA=l_1, AB=l_2, BC=l_3;
- α – the angle measured by the incremental transducer T_1, $\alpha \in [0,\pi]$; it represents the first mobility rank of the measuring system;
- β – the angle measured by the incremental transducer T_2, $\beta \in [0,\pi/2]$; it represents the second mobility rank of the measuring system;
- γ – the angle measured by the incremental transducer T_3, $\gamma \in [0,\pi]$; it represents the third mobility rank of the measuring system;
- δ – the angle measured by the incremental transducer T_4, $\delta \in [0,\pi/2)$; it represents the fourth mobility rank of the measuring system;

- ε – the angle measured by the incremental transducer T_5, $\varepsilon \in [0,2\pi]$; it represents the fifth mobility rank of the measuring system.

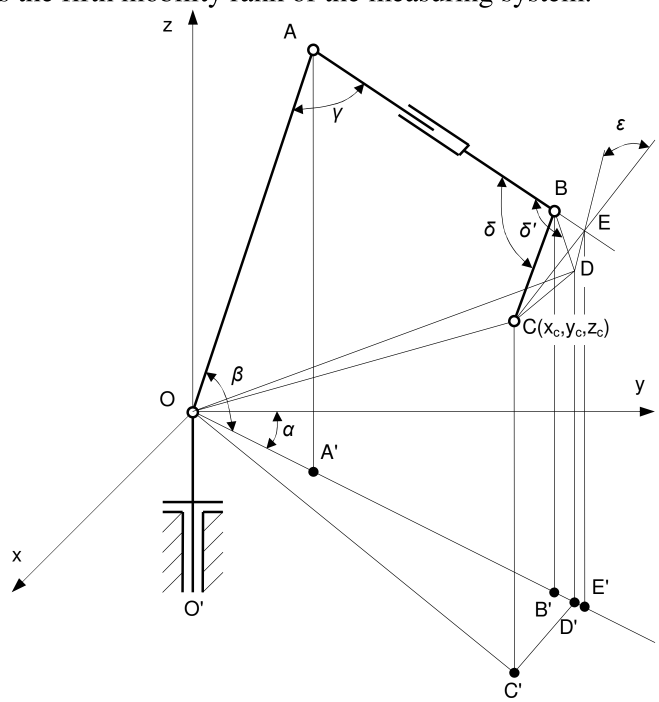

Fig. 4. The coordinates of the probe calculus scheme

The Cartesian coordinates of the centre of the spherical end of the probe are given by:

$$\begin{cases} x_c = OC' \cdot \sin\left(\alpha + C'\hat{O}D'\right) \\ y_c = OC' \cdot \cos\left(\alpha + C'\hat{O}D'\right) \\ z_c = CC' \end{cases} \tag{1}$$

where:

$$OC' = \frac{l_3 \cdot \sin\delta \cdot \sin\varepsilon}{\sin\left(C'\hat{O}D'\right)} \tag{2}$$

$$C'\hat{O}D' = arctg\left(\frac{l_3 \cdot \sin\delta \cdot \sin\varepsilon}{OD'}\right) \tag{3}$$

$$OD' = l_1 \cdot \cos\beta - l_2 \cdot \cos(\beta + \gamma) + BD \cdot \cos(\beta + \gamma + \delta') \tag{4}$$

$$BD = l_3 \sqrt{1 - \sin^2 \delta \cdot \sin^2 \varepsilon} \tag{5}$$

$$CC' = \sqrt{OD^2 - OD'^2} \tag{6}$$

$$OD = \sqrt{OB^2 + BD^2 - 2 \cdot OB \cdot BD \cdot \cos\left(\delta' - A\hat{B}O\right)} \tag{7}$$

$$OB = \sqrt{l_1^2 + l_2^2 - 2 \cdot l_1 \cdot l_2 \cos\gamma} \tag{8}$$

$$\delta' = \arccos\left(\frac{l_3 \cos\delta}{BD}\right) \tag{9}$$

$$A\hat{B}O = \arcsin\left(\frac{l_1}{OB}\sin\gamma\right) \tag{10}$$

The end of the probe is a sphere with the radius R_p, and the calculus of the coordinates of the contact point between the sphere and the patient's body must take into account this radius (fig. 5).

The coordinates of the contact point are given by:

$$BF = l_3 + R_p \tag{11}$$

$$\begin{cases} x_F = OF' \cdot \sin\left(\alpha + F'\hat{O}D'\right) \\ y_F = OF' \cdot \cos\left(\alpha + F'\hat{O}D'\right) \\ z_F = FF' \end{cases} \tag{12}$$

The distance between two points F_1 and F_2 with some positions in space, whose coordinates were determined by two successive measurements is given by:

$$F_1F_2 = \sqrt{(x_{F2} - x_{F1})^2 + (y_{F2} - y_{F1})^2 + (z_{F2} - z_{F1})^2} \tag{13}$$

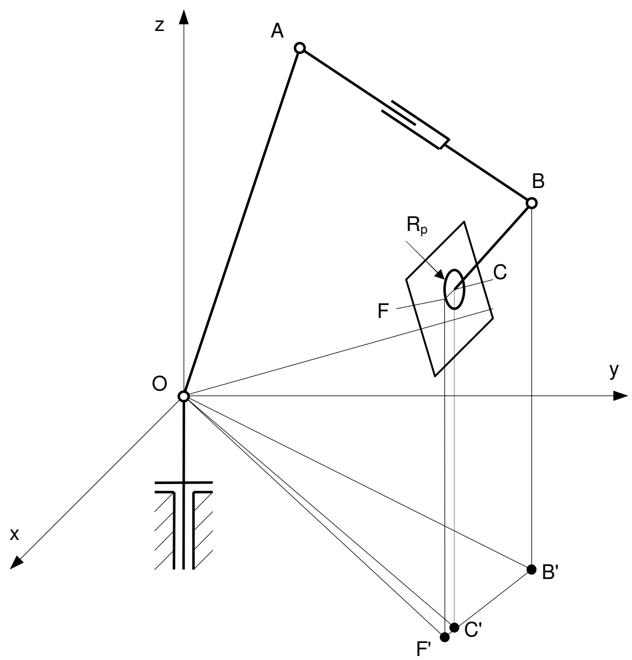

Fig. 5. The influence of the sphere radius

2.3. Discussion on measuring errors

The sources of measuring errors are the following:

- the length errors of the rods;
- the measuring errors of the incremental transducers;
- the mechanical strain of the system;
- the way the spherical end of the probe is positioned against the measured surface.

The length errors of the rods and the measuring errors of the incremental transducers are known and they can be compensated by means of the working software.

The mechanical strain caused by the weight and resistant forces can be minimised by increasing the rigidity of the rods.

The measuring errors caused by the spherical end of the probe and by the way this sphere is positioned against the measuring surface can be minimized by lowering the radius of the sphere and by positioning the probe, for every measurement, as close as possible to a direction perpendicular to the measured surface.

3. Conclusions

The measuring system described in the paper allows ease and accurate length measurements in orthopedics, being useful especially for intra-operative measurements.

The advantages of using the system are the following:

- less radiographies needed, that means less irradiation of the patient;
- the result of the measurement is displayed in real time, as opposed to the radiography, which needs time for processing and calculating the length;
- the system allows accurate measurement of the distance between two points with some positions in space, as opposed to the radiography, which is a projection in plane of the measured points.

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