Application of computer aided surgery in cranio-facial area and orthopaedy

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Abstract

Application of computer aided surgery has become a practical attitude to provide high precision, safety, individual anatomy analysis, low invasiveness and what is important in economical sense: short hospitalization and rehabilitation time. The surgery in cranio-facial area is very demanding procedure because of presence of critical structures such as nerves and blood vessels. The precision is a factor of highest interest. The limb correction surgery demands high precision because of influence of resulting limb geometry on biomechanical conditions. In the paper two developed systems for computer aided surgery are described. First system is a 3D free-hand sonographic system applied in measurement of tissue geometry, planning of limb corrections and aiding of surgery. Results of tests in laboratory tests on phantom and clinical tests are described. The second part of paper describes the concept of new system to design a tumour resection surgery and support real resection procedure.

Keywords: biomechanics, optimization, programming, software, computer aided surgery, free-hand sonography

1. Introduction

Computer aided surgery concerns application of tracking systems often supported by imaging techniques. Application of these advanced techniques enables customization and planning of surgery and follow up the implementation. First of all support of the surgery can improve the safety of vital structures, high precision of surgical instruments positioning on the medical images background and reduce the invasiveness of treatment. Computer aided surgery benefits are indisputable in the treatment of orthopedic, oncology, neurosurgery, etc. The paper describes the new tools developed to assist orthopedic surgery and cancer resection in the craniofacial area.

2. Material and Methods

2.1. 3D freehand sonographic probe system

A new system of 3D freehand sonographic probe has been developed. The system consists of computer navigation (infrared camera Spectra Polaris, NDI, Canada) and ultrasound machine with linear probe (EchoBlaster128, Telemed, Lithuania). An original software has been created to define templates of measurement, bone surface reconstruction, handling of ultrasound measurement according to self-defined templates, virtual planning of bone correction, supporting of osteotomy and bone segments reposition.

2.2. Matrix transformation and calibration of ultrasound probe

Both devices are controlled by PC. To analyze the acquired data, the algorithm of matrix transformation was implemented. The camera tracks the position of ultrasound probe and the reference coordinate system. Using matrix equation the transformation between coordinate system of ultrasound probe and reference frame is calculated. The transformation distinguished with green colour (Calibration US Probe – US Image) (Fig. 1) is a calibration matrix specific for an ultrasound probe and mounting of rigid body on probe.

To define the calibration matrix the wire-phantom with five levels of double N structures. The simplified project of N wire phantom was applied in work of Kozak [2]. The phantom contains own reference frame defining coordinate system. Basing on the distribution of wires in the reference coordinate system and distances between echoes of wires measured on ultrasound scan, the position of the echoes in the phantom coordinate system can be calculated. Using optimization algorithm the calibration matrix providing the smallest sum of distances between the proper and calculated positions of echoes in phantom coordinate system was defined.

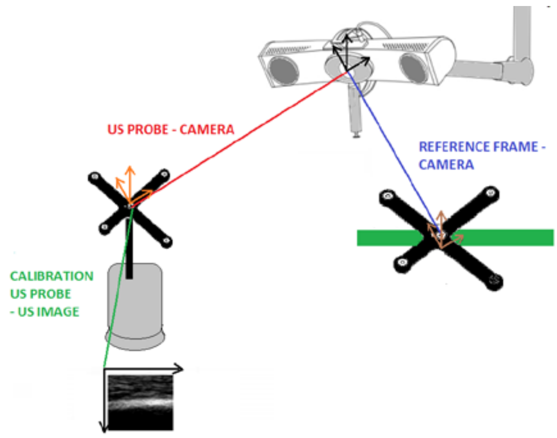

Figure 1: Algorithm of matrices transformation

2.3. 3D measurement of bone geometry using ultrasound

The developed system provides measurement of geometric parameters of tissues according to the self-defined templates. The templates are designed on virtual skeleton. Using a virtual probe the User defines the positions of scans and on virtual scan (containing observable in these conditions contour of bone) the positions of markers are designed. The User specifies also the

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parameters: lengths, planes, angles, projections which are automatically calculated as soon as the data is recorded.

The developed system provides also the possibility to reconstruct shape of the bone using an algorithm for bone tissue identification and 3D modelling based on cloud of points. On the reconstructed shape the surgery can be designed and the changes of parameters during the reposition of bone segments is controlled. To support the surgeon in virtual planning the system enables analysis of contact forces in joints basing on changing positions of anthropometric points.

The aiding of intraoperative osteotomy is realized using the Kirschner's wires navigated with a guider. To apply the designed scenario of surgery it is crucial to define the transformation between preoperative and intraoperative coordinate system. The procedure is called matching and calculates a matrix providing smallest sum of distances between measured and calculates location of landmarks or corresponding points of surface. If the navigated bone segments are moved, the software calculates the changes of real parameters.

2.4. System for aiding tumour resection in cranio-facial region

The second developed system is applied for virtual planning of tumour resection in cranio-facial region, project of individual scaffold to reconstruct the bone, tissue engineering using patient cells and growth factors, aiding the real resection (Fig. 2) and dental implants location. The accuracy is crucial for the surgery for safety of vital structures in the operation field.

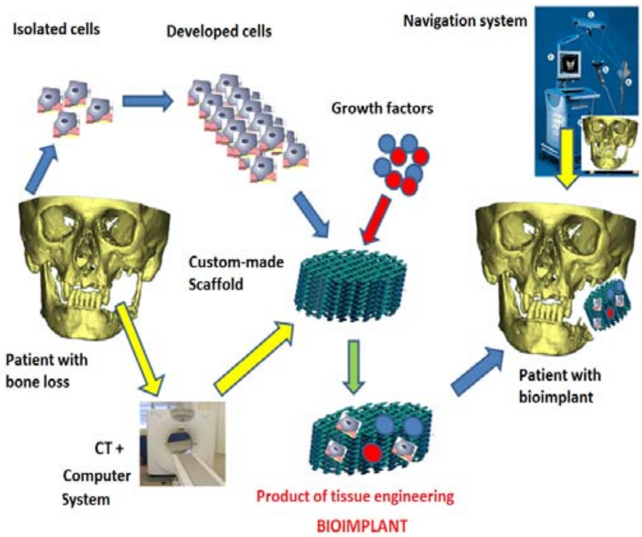

Figure 2: Scheme of project for individual bioimplant and computer aided bone reconstruction

2.5. Virtual planning of resection and design of bioimplant

The developed system enables so far the manual identification of tumour on the 3D dataset from Computed Tomography. The surgeon has the ability to design the cutting. The precise geometry of scaffold may be also determined using Mimics Materialise software. The scaffold is produced according to the project using the rapid prototyping technique.

2.6. Aiding of resection

To follow the surgery scenario intraoperatively a system with optical and electromagnetic navigation is designed. Electromagnetic navigation allows the user to track tools without the need to maintain eye contact between them. However the drawbacks of this method is a small range of work and the need for non-magnetic tools. Metallic and ferromagnetic objects disrupt the magnetic field. Hybrid (optical and electromagnetic) application helps to use advantages of both techniques at the same time.

2.7. Aiding of prosthetic implanting

To restore the chewing function it is crucial to apply prosthetic implants in a proper axis. The prosthetic treatment is also a two-stage process. First of all it is necessary to design the implant geometry, the axis, depth and location of implant of selected type. The second stage is the real implantation. State of the art in computer aided prosthetic treatment is to design and produce the individual stereolitographic template which is mounted on bone, other teeth or mucosa membrane. In case of mandible reconstruction there are no other teeth in the operating area. Mounting on the bone is risky because of possible infection. The accuracy of the implantation using the prosthetic templates is limited to ca. 3 mm. A system to support implanting the prosthetic implants is developed to provide higher precision than applying the templates.

3. Results

The developed ultrasound system has been tested in clinical conditions throughout the comparison to the results of measurements on Magnetic Resonance Imaging. The deviations between the parameters calculated using sonography and MRI methods were estimated at 0.42-4.33 mm and 2.5 degrees and the correlation coefficient was 0.99 [1]. Additionally tests on 3D ultrasonic phantom were performed. The deviations between measured and nominal geometrical parameters of calibrated objects were estimated at 0.2 - 0.8 mm [3].

The system for aiding cranio-facial cancer resection is in developing phase. The accuracy of electromagnetic navigation Aurora from NDI is 0.9 mm (according to the technical specification [4]). It encourages to apply this type of navigation to track the position of surgical instrument for cancer resection and prosthetic implant guider.

4. Acknowledgement

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5. References

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