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COMBINED REGISTRATION OF HUMAN MUSCULOSKELETAL SYSTEM

Goran DEVEDŽIĆ[1], Saša ĆUKOVIĆ[1], Branko RISTIĆ[2], Suzana PETROVIĆ[1], Michele FIORENTINO[3], Tanja LUKOVIĆ[2]
[1]Faculty of Mechanical Engineering, Sestre Janjić 6, Kragujevac, Serbia
[2]Faculty of Medicine, Svetozara Markovića 69, Kragujevac, Serbia
[3]Polytechnic of Bari, Department of Mechanical and Management Engineering, Viale Japigia 182, Bari, Italy
devedzic@kg.ac.rs, cukovic@kg.ac.rs, branko.ristic@gmail.com, suzana.petrovic@mfkg.rs, fiorentino@poliba.it, tanjalukovic_kg@yahoo.com

Abstract: *The need for accurate shape measurement and modeling of human musculoskeletal system appears to be important for both, clinical practice and incorporating emerging technologies to orthopedic and rehabilitation devices and systems. Particularly important emphasis is set on non-invasive, i.e. radiation-free approaches. The contemporary optical and probe-based measurement systems, together with 3D modeling and computer graphics techniques, provide the key platform for methodology development. We present the generic algorithm for reconstruction of patient's back surface from clouds of points in the case of female spinal deformities. Basic registration methods that enable comparative analysis before and after applied therapy are described too. The key benefits of the global and local 3D registration methodology are shown through the matching analysis of the reconstructed surfaces and illustrated by the sample case study of spinal deformity diagnostics.*

Key words: *Complex shape registration, clouds of points, global and local registration, spinal deformity diagnostics*

1. INTRODUCTION

Combined registration of a 2D/3D shapes is critical to various medical imaging modalities and clinical applications. There are numerous shape alignment methods which are proposed to address global and local registration and combination. Also, the registration problems can be under constrained, especially in the case of non-rigid or deformable registration when reliable correspondence is needed in order to determine the local deformation parameters of contours or surfaces [1, 4]. Global registration method is also known as shape alignment. It aims to realize a global transformation that has source image or shape as close as possible to a target one by optimization algorithm (Fig.1) [2, 5].

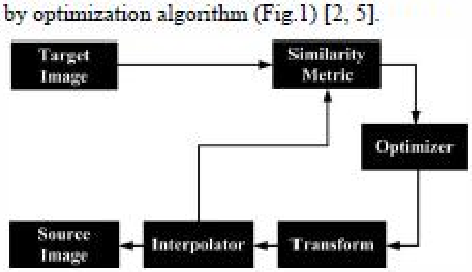


Fig.1. Main components of a 2D/3D image registration framework (adopted from [5]).

Methods of a rigid or non-rigid 2D and 3D registration of pre- and intra- interventional data sets are one of the key technologies for image guided therapies and minimally invasive surgery procedures [3].

Furthermore, non-rigid local registration of the object of interest is needed to achieve appropriate correspondences over the basic deformable elements of shapes, such as points, curves, etc.

2. MEDICAL IMAGING MODALITIES

Modeling of anatomical structures (bones and soft tissues) is a critical component of 3D medical image analysis process. Precise and compact representation that can describe the variation in an anatomical structure of interest across individuals requires establishing local and global correspondences across a set of scans (2D slices). Contemporary medical imaging modalities employ noninvasive methods to retrieve images from inside the human body for diagnosis, to study of normal and abnormal anatomy, and plan therapeutic procedures. Most of these methods involve exposing the patients to harmful ionizing radiation, since the properties of internal structures are inferred from the observed X-rays [3, 5]. The most common types of medical image modalities are:

- Computed Tomography (CT),
- Single Photon Emission Computed Tomography (SPECT),
- Positron Emission Tomography (PET),
- Magnetic Resonance Imaging (MRI),
- Ultrasonography Methods (US).

These modalities record valuable information about the patient's state and they are part of standard daily diagnostic procedures for many fields of medicine. In this paper we present noninvasive optical diagnostic method for patients with scoliosis deformities and introduce methods for 3D registrations.

3. 3D RECONSTRUCTION AND ANALYSIS OF PATIENT'S BACK SURFACE

3.1. 3D reconstruction

In order to create 3D CAD anatomical model of spinal deformities, patients' back surfaces are digitalized using optical 3D measurement system FORMETRIC 3D/4D (Diers, Germany). This optical system is based on the spatial triangulation and rasterstereography principle. As a result of surface scanning, clouds of points, which fully represent deformed shapes, are generated.

Using adequate reverse engineering software (Raindrop Geomagic Studio) and reconstruction algorithms for free form modeling, we have created 3D surfaces (Fig.2). The reconstruction process goes through the following characteristic phases: (a) Acquisition of clouds of points, (b) Generation of a polygonal model, (c) Grid and NURBS (Non-Uniform Rational B-Spline) surface model fitting [7, 8].

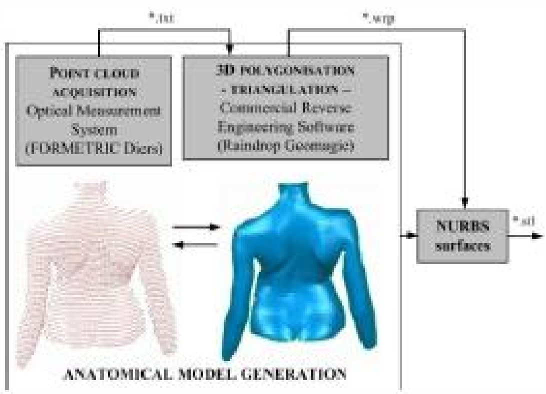


Fig.2. 3D reconstruction of the back shape from clouds of points

3.2. Shape analysis

The aim of the back shape analysis is to obtain relevant parameters of deformities from the reconstructed shape and to relate them to other findings, e.g. x-rays. When the recording and reconstruction are complete, the results are initially available as three-dimensional coordinates (x, y, z) for all the measured clouds of points [6]. There are several reasons why this representation is unsuitable for a direct interpretation and relation:

• The coordinate values are dependent on the random position of the patient relative to the recording system,

• The measurement points are distributed more or less irregularly over the surface of the skin,

• In contrast to the technical objects, the surface of the body has an irregular and variable shape.

The advent of rasterstereography methods, based on Moiré topography and common mathematical principles of surface analysis (e.g. Gaussian curvature distribution), opened a new field in medical diagnosis, which aim specifically lay in the three-dimensional recording of trunk deformity (Fig.3).

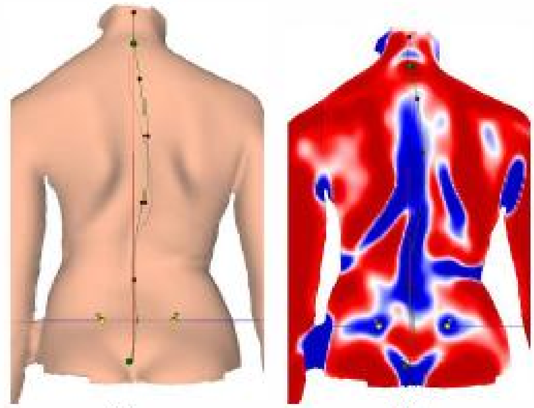


Fig.3. Reconstructed shape: (a) 3D cloud of points of the back shape, (b) medial spinal line created by Gaussian method

In a healthy state the central spinal line has a two-dimensional shape, which is modified into a three-dimensional through vertebral rotations and lateral deviations of the vertebrae, with trunk and back shape asymmetry [9] (Fig.4).

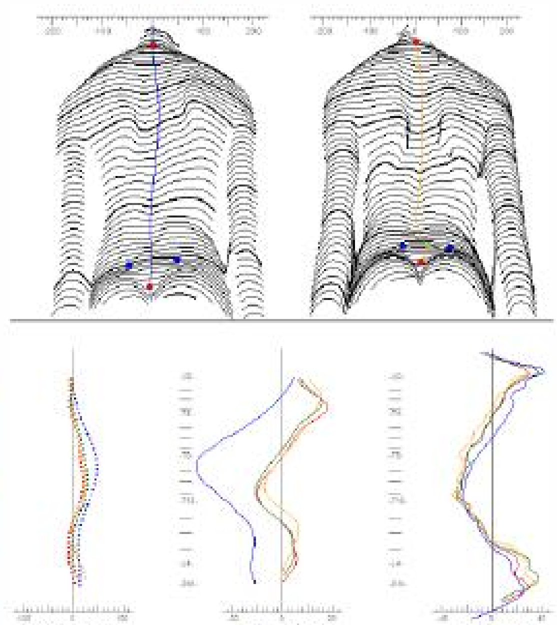


Fig.4. 3D analysis of back shape before and after applied kinesitherapy

In case of spinal deformities, rotational movements of the spinal segments are different from normal range of motion. Such abnormal rotations cause spinal deformity (kyphosys, lordosis and scoliosis) or a combination of these deformities. It is thus desirable to measure and confirm such three-dimensional pathological deformities objectively. Until recently this has been possible only by using supplementary two-dimensional methods (x-rays films on two planes) [9].

4. 3D SURFACE REGISTRATION

4.1. Registration Framework

In a typical image registration framework, it is necessary to define the source images (point clouds as well as polygonal surfaces) as $f(x)$ and the target images as $g(x)$, where x is a current position in n-dimensional space. By considering the registration process as an optimization problem in medical imaging, main task is to find the optimal transformation function, defined as $t(x)$, which matches the source image to the target image.
A similarity indicator is used to measure how well the transformed source image $t(f(x))$ aligns to the target image $g(x)$. Since most medical images have different sizes in discrete pixel space, as well as in the level of voxels, all computation which is performed in continuous space requires some interpolation [5].

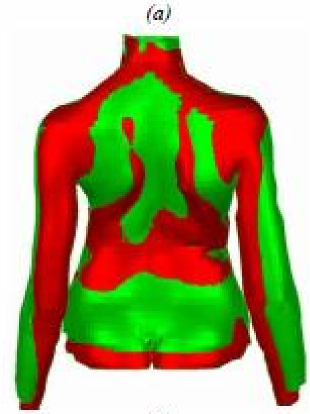
4.2. 3D surface shape registrations

There are innovative tools for registering and merging multiple unaligned clouds of points or polygonal models using a variety of automatic and semi-automatic methods. Surface registration allows easy steps to create a single polygonal model from unaligned scans. It is necessary to perform global, tolerance based alignment to minimize deviation between scans [1, 5, 10]. In the case of spinal deformities, we performed global and local registrations over two polygonal models of back surface of one female patient to determine progress or stagnation of the scoliosis deformity. Second optical scanning is done two months later in the same condition. Figure 5 shows overlay of globally transformed source shape on the target shape.

Fig.5. Global registration using the similarity transformation model

Registration methods have ability to align and merge point data that is tremendous advantage and allows compatibility with any scanner, digitizer or medical image modalities.
Manual registration is done by selecting local anatomical landmarks on target and current shapes (*n*-points registration). In this case we use vertebral prominences and sacrum points, as well as points on left and right patient's scapula.

(a)



(b)

Fig.6. Local registration for 3D polygonal back shape scan data (source and target shapes) using 4 anatomical reference points (a) matching (b) registration

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[1] Goran Devedžić, PhD, Faculty of Mechanical Engineering, Sestre Janjić 6, Kragujevac, devedzic@kg.ac.rs
[2] Saša Ćuković, PhD candidate, Faculty of Mechanical Engineering, Sestre Janjić 6, Kragujevac, cukovic@kg.ac.rs
[3] Branko Ristić, PhD, Faculty of Medicine, Svetozara Markovića 69, Kragujevac, branko.ristic@gmail.com
[4] Suzana Petrović, PhD student, Faculty of Mechanical Engineering, S. Janjić 6, Kragujevac, suzana.petrovic@mfkg.rs
[5] Michele Fiorentino, PhD, Polytechnic of Bari, Viale Japigia 182, Bari, Italy, fiorentino@poliba.it
[6] Tanja Luković, PhD, Faculty of Medicine, Svetozara Markovića 69, Kragujevac, tanjalukovic_kg@yahoo.com

Figure 6 shows that locally deformed source shape after registration overlay on the target establishing point-by-point correspondence between the source and target shapes. The registration process is finished when one of the main conditions is satisfied [10]:

1. The desired tolerance is achieved,
2. The number of maximum iterations is performed,
3. A specified number of iterations are run without convergence.

One of the most important applications of 3D surface registration is for matching a cloud of points acquired at one time-point during a treatment to another one from a different time-point. 2D registration procedures are known as intra-patient registration, which is often used to monitor progress during treatment of non-visible structures. Matching set of images or clouds of points from different patients can be used for generating a model of motion across a population of patients, or to match an image to a PACS atlas. In the case of spinal deformities, registration can be significant to show possible postures and shapes of patients' back.

Having in mind that image registration is the process of transforming different images into a single coordinate space, the data obtained from the different image modalities can be compared by pixel-to-pixel or a voxel-to-voxel level. The most important features to address global registration are:

1. Rigidity (shape translation and rotation),
2. Similarity (shape translation, rotation, and isotropic scaling),
3. Affinity (shape translation, rotation, isotropic or anisotropic scaling, shearing).

Surface registration frameworks feature the choice of best transformation between two anatomical surfaces of the same object and involve spatially transforming the source image to accurately align with the target image. Registration can be performed as a single operation between images from a single-modality or from multiple modalities. The voxel-based registration algorithms have been utilized mostly for the registration of soft tissues images from various medical modalities based on 2D slices.

5. CONCLUSION

Several techniques have been proposed for automatic medical image registration. In this paper we demonstrate a complete application for main types of registration between optical scans of back surfaces. The results demonstrate superior performance compared to surface-based or landmark-based deformable registration methods. We firstly apply global registration to align polygonal model to target one in order to compare progress of deformity. Local registration based on free-form deformations demonstrates non-rigidity of surface registration over common anatomical landmarks. We used single-modality registration method which tends to register optical scans acquired by the same scanner. Further development of the methodology is directed to the multi-modality registration that processes images acquired by different scanners (sensors).

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