Telediagnostics of Back Curvature and Posture for Elderly Patients and Remote Access to 3D Data

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***Abstract* — Telemedicine services for the ageing population are expanding recently. Postural screening assessment is usually focused on children and adolescents. Elderly population is endangering on kyphotic deformations due to osteoporotic fractures. Yearly three dimensional (3D) examinations may be applicable to monitor postural deterioration among elderly. Remote assessment of back shape seems to be an option to measure kyphosis angle and postural worsening. The aim of this study is to present the archiving and assessment system and its applicability. The proposed system has two main components: measurement module with data analysis and storage one. The measurement module is based on structured light method. The technique for 3D imaging of back shape is based on temporal phase shifting and Gray codes. Acquired “images” are transferable to Telediagnostic Center. Preliminary analysis was performed on selected cases from database of patient’s cohort. The average age of analyzed patients group was 72 years. Bone mineral density in the analyzed group was below 80 mg/cm3. Kyphosis angle was measured in the range of 32 to 60 degrees, assessed by the clinical team. Shape of the elderly patient’s backs was acquired and sent over the Internet connection. Presented, originally developed system combines postural telediagnostic screening and monitoring. The development of automatic anatomical structures detection shall be able to prompt final diagnostic procedure and make draw of the trend of measured values changes over the time. The safety and procedure of presented examination method was highly accepted by elderly patients.**

Keywords-telediagnostics; posture; kyphosis; osteoporotic vertebral compressive fracture.

INTRODUCTION

Telemedicine services for the ageing population are expanding recently. Postural screening assessment is usually focused on children and adolescents. Among teenagers round back is observed in up to one third of examined population. Elderly population is endangering on kyphotic deformations due to osteoporotic fractures. Yearly three-dimensional (3D) examinations may be applicable to monitor postural deterioration among elderly. Remote assessment of back shape seems to be an option to measure kyphosis angle and postural worsening. The proposed system has two main components: measurement module and data analysis and storage one (Fig. 1). The measurement module is based on structured light method. The technique for 3D imaging of back shape is based on temporal phase shifting and Gray codes. Measurement process consists of projection of sequence of raster images on surface under investigation and their simultaneous acquisition. The hardware components are designed in a way that allows for easy transportation and mobility. Acquired “images” are transferable to Telediagnostic Center. The aim of this study is to present the archiving and assessment system and its applicability.

In the second part of the paper the technology used for capturing 3D shape of human body and flexible data archiving is described. The third part presents how the designed database structure was used in the particular case. Next, the calculation and diagnosis support is covered along with some early results and finally the applicability of the system to the diagnosis of hyperkyphosis and osteoporosis in elderly is presented.

MEASUREMENT SYSTEM

The measurement system consists of four modules which simultaneously measure patient’s skin surface from four directions. Each directional module is an optical full-field 3D scanner based on structured light projection method. The main components of each module are: projection unit, which is a Digital Light Processing (DLP) projector, detection unit which is a Charge Coupled Device (CCD) or a Complementary Metal-Oxide-Semiconductor (CMOS) camera and a PC-class computer. During the measurement

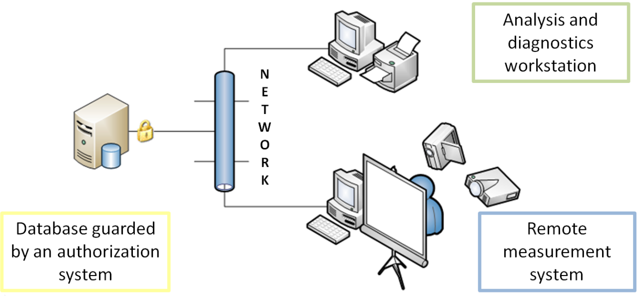

Figure 1. Modular structure of the system

process the patient is placed inside a calibrated measurement volume while a series of patterns is projected onto his or her body surface. These patterns include sinusoidal fringes and modified binary Gray codes. The shape of body surface is calculated based on the raster deformation according to the Temporal Phase Shifting (TPS) method [1]. Dataset produced by the measurement system is in the form of a set of (x, y, z) points that represent the sampled surface of patient's body. The electro-optical hardware setup utilizes TDP-MT700 projectors by Toshiba Corp. and Flea B&W cameras by Point Grey Research Inc. In order to avoid interferences caused by the overlapping of raster images originating from adjacent projectors spectral filters are mounted on projector and detector lenses. This allows projecting raster images simultaneously and conducting measurements using all modules at the same time. Directional point clouds originating from measurement modules are merged automatically basted on a global calibration. The metrological values of the measurement system are as follows:

Measurement volume size: scalable from 1.0m x 1.0m x 1.0m to 1.5m x 1.5m x 2.0m,

Accuracy: 0.2mm to 0.4mm (depending on the measurement volume size),

Data acquisition time: 0.7s (all modules simultaneously), maximum number of points: 4 million.

Depending on the size and position of the calibrated measurement volume the resulting point cloud may represent patient's thoraco-abdominal region or the whole body surface.

Measurement data acquired with use of the measurement system along with patient's textual data are stored in a dedicated database. The database is the heart of the system and serves two main purposes – archiving of data and guarding it from unauthorized access. All operations on the database are performed using a specially designed XML interface, which makes the system independent of the underlying database implementation (Fig. 2). The interface fulfills different functions, including user authentication, data import and user queries. The structure within the database can be in full defined using XML without any necessary knowledge about the system itself and can be extended on the fly in case any additional information or data are required. This database can be seen as a document-oriented one, which is built upon a relational system. The interface thus has to be able to translate the tree structure of the data (described in XML documents) into tables within the actual database taken into account, possibly numerous, changes of the structure definition.

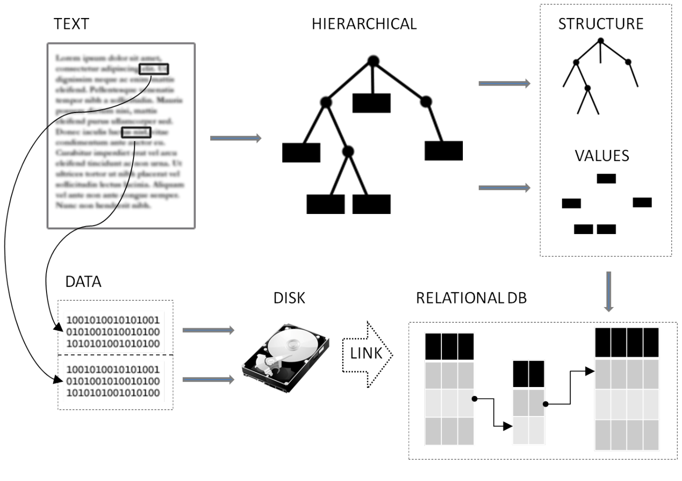

Figure 2. Mechanism of data storage – XML documents translated into records in a relational database

Total dissimilarity of the structures makes it difficult to store the data efficiently – the actual data are kept in the leafs of the XML tree, but still the path to each leaf from the root of the tree is what differs it from other leafs. The solution might be to introduce a separate definition of the structure in the database which is stored only once, keeps the whole tree and can be extended easily, and a separate set of records which store the actual data, at the same time keeping reference to the leaf of the tree which it is representing. The structure should also have the knowledge about types of each leaf in order to be able to perform type checking. One does not have to limit oneself to the types defined within the RDBMS, but can define arbitrary types for the structure intended for the specific application which could be either decomposed into built-in types or validated by some predefined rule. If the structure is broken into separate elements, each of which being a semantic entity, a way to connect elements between each other should be provided. This supplies a robust method of defining complex relationships between elements and creating a hierarchy.

Moreover, the queries system mustn't limit the broad possibilities given by SQL used in the relational database. Such a system has to connect the ease of definition which parts of the structure are the constraints and what type of relation should be applied, and which parts of the structure are requested by the user – this strongly implies that the queries should also be built using XML. Additionally, the system should provide cascade queries in order to facilitate the construction of sophisticated queries and an extra set of constraints concerning the linkage between elements. All these features provide a robust and easily-extendable system of data management. However, if such a system was to be available over the network, some sort of access control should also be given. If the system was used on a larger scale, with a number of users accessing it, a distinction should be made between users that are able to modify the structure within the database, users that are able to import new or edit existing data and ones that have read-only access. Additionally, some elements may be said to be more significant (so shouldn't be modified by the same set of users that are able to modify other data) or confidential (so should be viewed only by certain users). This leads to the conclusion that the authorization system should be defined as access relationship between each element and each user in the database and separated between data and structure access. These features altogether form a complete system which can be securely used over any network, be it a local area network (LAN) or the Internet.

DESIGNED STRUCTURE

Data can be assigned to three main groups – objects, which are the core entities keeping data universal during system's lifetime, data elements, which are supposed to be assigned to each object, keeping information variable in time, and additional elements which are all kinds of data derived from the original data elements. The elements can further be linked with each other in an arbitrary way, thus creating a hierarchical structure. The structure (division into groups and linkage of elements) used in this case is shown in Fig. 3.

Communication between modules is performed over the TCP/IP protocol, incorporating two different channels for each client, dedicated to two kinds of data – text channel, for transmission of the XML documents and binary channel for the transfer of large binary objects, such as clouds of points or photographs. Such a structure is asynchronous and allows performing traffic inexpensive operations such as user logon or querying for text data independently of binary transmission, very costly in terms of network transfer. To further decrease this cost data compression was implemented and was also incorporated in data storage.

The data gathering and analysis module provides a complete interface for the database, allowing the user to manage the information and perform certain operations on the archived measurements. It supports automatic analysis – so called pattern calculation – a series of operations that can be automatically performed on a subset of data according to a predefined scheme. The module is constructed in a way which assures that no data becomes overwritten – any number of derived information can be saved in the database and linked to the parent measurement, thus keeping it consistent and easy to browse. It also makes it possible to compare different measurements, allowing the estimation of patient's improvement in time. This requires good repeatability of measurement and a method to correlate two measurements of the same patient in space. System's vertical, additionally measured for every configuration of the setup and assigned to measurement, and two points within the measurement are sufficient for absolute alignment. Since fine alignment uses two landmarks (dimples of pelvis) for accurate positioning, it is preceded by a coarse operation which detects the general position of the body.

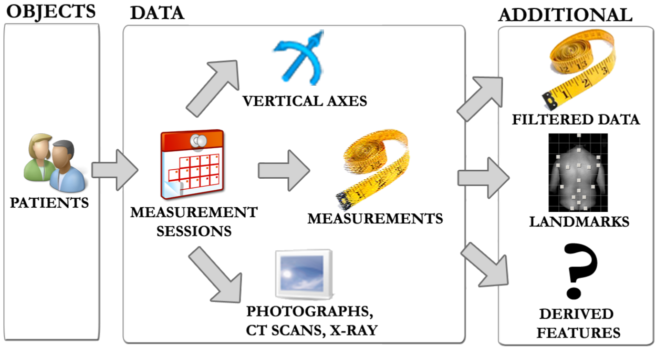

Figure 3. Structure designed within the database

CALCULATION AND DIAGNOSIS SUPPORT

Analysis can be carried out in two ways – discrete, based on a set of landmarks on the surface of the body or on a more global shape analysis. The discrete analysis itself can be performed either using manual indication of points or an algorithm of automatic landmark detection. Such algorithms are currently under development, at the moment the landmarks are acquired from a team of trained physicians, which will help in the development process and provide the assessment of algorithms' reliability. Additionally, the points provide interesting information about the interobserver and intraobserver reliability for evaluated measurements. A preliminary algorithm for automatic landmark extraction is built upon a modified back diagram for a number of predefined landmarks, of which starting positions are pre-calculated using an averaged set of manually selected points, scaled for each measurement with respect to a simple 2D bounding box generated around it. Such a processing path is easily extendable to an arbitrary number of characteristic points, thus providing a versatile detection method.

The method assigns an area to each landmark, within which the exact position of the landmark is searched for. The 3D shape contained in each cell is analyzed based on maps of parameters C1 and C2[1]. These parameters were developed in order to accurately and efficiently describe surface shape of full 3D point clouds [2]. The C1 parameter describes how much the surface in the neighborhood of the considered point deviates from a plane, its values are positive for convex areas, negative for concave areas and zero for planes. The C2 parameter describes the distribution of normal vectors in the neighborhood of the considered point in a way allowing distinguishing areas of unidirectional curvature, such as cylindrical areas, and omnidirectional curvature, such as spherical areas and takes values equal to zero for planes and

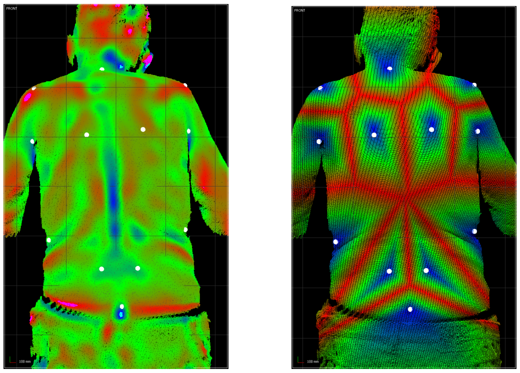

Figure 4. C1 parameter and weights from Voronoi diagram, landmarks shown in white

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[1] Names C1 and C2 must not be confused with the designation of cervical vertebrae

cylindrical surfaces and positive for other surface types. The highest values of C2 are obtained for sphere and for saddle shapes. The analysis of distribution of C1 and C2 parameter values allows discrimination of various surface types in a way similar to used with mean and Gaussian curvatures, yet the former are faster to calculate and more resistant to noise in the analyzed dataset.

Division of the back into subregions makes it possible to avoid global analysis of the back surface. Moreover, the landmarks are in reality not single points, but rather regions on the surface of various scale and as such require computation of the C1 and C2 maps with different input parameters. Each landmark also exhibits specific properties depending on the type of posture which implies the use of different detection paths and an algorithm which would provide some general, coarse information about the posture of the patient, or possibly an adaptive path of detection which would modify its parameters based on some overall properties of the shape of the back. An additional potentially interesting feature is the possibility of comparison of the 3D shape with volumetric data, such as a CT scan. Exemplary map of C1 parameter and weights calculated on the basis of a Voronoi diagram are shown in Fig. 4.

EARLY RESULTS

Clinical evaluation of patients body was performed from August 2008 till march 2009. The average age of analyzed 30 patients group was 72 years. Bone mineral density in the analyzed group was below 80 mg/cm3. Kyphosis angle was measured in the range of 32 to 60 degrees, assessed by the clinical team. Average time for assessment was calculated from logs of user entering the system. Shape of the elderly patient's backs was acquired and sent over the Internet connection. The average 3D image size for each examined patients was 5 MB, which takes about 20 seconds to transfer using a broadband connection. Average time for assessment was estimated to be around 3-4 minutes based on information gathered by the analysis client module. Patients were asked about discomfort during the structural light examination. No patient reported side effect or discomfort during the 3D examination. All patients declared positive attitude towards next follow up 3D examination.

DISCUSSION ON KYPHOSIS

Spinal sagittal curvatures and their deformities are described in relation to the anatomical planes of the body which are the coronal (frontal) plane, the sagittal (lateral) plane and horizontal (transverse or axial) plane (Fig. 5). There are natural curvatures in the sagittal plane. Hyperkyphosis, colloquially called "dowager's hump", refers to excessive kyphotic, or anteriorly concave, curvature of the thoracic region of the spine. A kyphosis angle over 40° - the 95th percentile value for young adults - is currently used to define hyperkyphosis [3]. It is often observed in elderly due mostly to osteoporosis. Most of the studies refer to normal values of kyphosis among older adults at 20% to 40%. Hyperkyphosis is not only a cosmetic back deformation but it may impair pulmonary decreased physical function capabilities, increase risk of future fractures [4-6]. Kyphosis can be measured clinically or from radiographs. Several devices have been developed for kyphosis measurement like Debrunner kyphometer, goniometer, inclinometer, flexible ruler and various optical methods [4,7,8]. Thoracic kyphosis can be measured on lateral radiographs of the thoracic spine globally (T1–T12) and regionally (T4–T9) using Cobb and vertebral centroid angles. Surface topography evaluations utilizing structural light technique was used to evaluate kyphosis angle and lordosis angle. The kyphosis angle was measured from prominent vertebra to lower neutral zone of inclination (VRS method) as described by Weiss and Elobedi [9]. Patient's back surface 3D image was obtained using a high-accuracy optical markerless 3D measurement system for non-invasive, quick and relatively inexpensive assessment of back deformity [10]. Optical methods like photogrammetry and structural light method are currently under development [9]. The second method allows snapping ideal surface shape of the back in digital format. Traditionally, the Cobb angle is measured from standing lateral spine films because measurement in the lying position may underestimate kyphosis. The slight overestimation of Debrunner method versus the Cobb angle was found but the mean difference between the 2 measures was only 4° [4]. Postural changes affecting the cervical, lumbar, and sacral spinal areas and postural flexibility may influence thoracic curvature. The simple method of thoracic kyphosis based on that observation was utilized in cohort Rancho Bernardo studies [11].

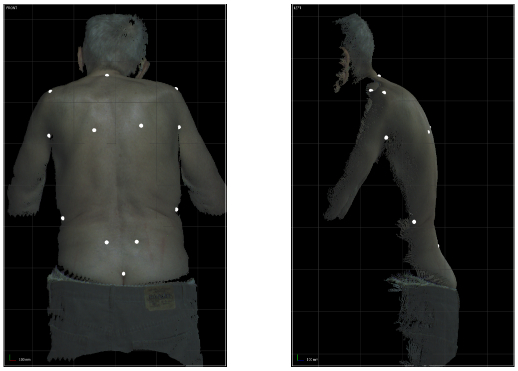

Figure 5. Cloud of points from measurement, frontal and sagittal plane, landmarks shown in white

Osteoporosis and a history of fragility fractures are both associated with age of 75 years and over and thoracic kyphosis. Ettinger et al. [12] measured thoracic curvature, using an architect's flexicurve. Their study suggested that kyphosis is associated with decreased BMD and loss of height but does not cause substantial chronic back pain, disability, or poor health in older women. Only tendencies were confirmed by this study. Ensrud et al. [13] estimated that kyphosis increased by 4.4 per decade of additional age. Milne and Lauder [14] reported a 20% increase in the kyphosis index per decade in women aged 62 to 90 years. In older adults, the mean kyphosis angle rises to about 50° in women and about 44° in men [13,15-17]. In a study by Singer et al. [18] of women aged 50 to 90 years, kyphosis ranged from 40.9 to 57.5° and the highest values were found in the oldest women. In many studies, kyphosis was measured clinically using the Debrunner kyphometer [8] or the flexicurve ruler [14]. In the study by Cortet et al. [18] patient's mean kyphosis was measured 59°. Further studies are needed to determine the correlation between spinal curvatures and spinal bone density measurements to allow physicians to better predict patient's risk of fractures and better plan for surgical or medical intervention.

CONCLUSIONS

Presented, originally developed system combines postural telediagnostic screening and monitoring. The development of automatic anatomical structures detection shall be able to prompt final diagnostic procedure and make draw of the trend of measured values changes over the time. The safety and procedure of presented examination method was highly accepted by elderly patients.

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