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THREE DIMENSIONAL IMAGE PROJECTIONS AND ITS MEASUREMENT USING THE VRML TECHNIQUE

Modern digital imaging is used in many areas of human activities. Nowadays, imaging and different human body measurements are also used in medicine, during operation planning by surgeons, dental surgeons, in transplantology, etc. The 3D visualization of human body and some abnormalities of body internal organs can be observed by means of specialized techniques as CT or MRI. During measurements these techniques can present object description by specialized language – VRML (Virtual Reality Modelling Language). Modern VRML browsers offer higher quality visual interfaces for man–computer interaction in real–time environment than ever before. In this paper the simple method of medical images projection and image measurements are presented. Very expensive commercial products can be successfully substituted by means of the computer program proposed in this paper. Proposed approach is based only on VRML and is easy to implement in many programming languages.

1. INTRODUCTION

Observation of the space structures is more attractive if objects can be appropriate displayed. It is especially important in medicine and modern surgery where human body details can be visualised, recognised and measured. It allows surgeons to plane operation or other complicated procedures. Several computer programs realized three–dimensional (3D) visualization, where spatial relations were constructed, transformed, and by means of VRML specification displayed. The VRML is specified by the international standard (ISO/IEC 14772) file format for describing 3D multimedia objects.

Surgeons usually rely on their own understanding of pathological changes base on the two-dimensional medical images produced by computed tomography (CT), magnetic resonance imaging (MRI), digital subtraction angiography (DSA), etc. The creation of traditional operation is deeply associated with personal experiences, and therefore it is difficult to share with each other in the operation group. In many cases it is not enough and difficult, even for skilful operator to perceive the internal human organs before the structures are exposed. The 3D medical images are currently widely available and these

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projections solve many medical problems. Additionally, modern imaging methods will be more widely used for patient diagnosis, therapy, and surgery in the near future [1,2].

Unfortunately in practice, imaging of 3D real objects is very difficult. For this reason very expensive specialised devices must be used [3,4].

2. DATA ACQUISITION

In medical imaging, the two most common systems are used in acquiring detailed anatomical information: Computed Tomography (CT), and Magnetic Resonance Imaging (MRI). Other used systems include, for example, ultrasound and X-rays. The key feature of these imaging technologies is their ability to provide detailed information about the human anatomical structure and abnormalities.

CT uses radiation in the form of a highly collimated X–ray fan beam to slice a two-dimensional image or slice plane. Standard CT scanners can work with resolution of 512×512 elements per layer.

On the other hand, MRI images are obtained based on different tissue characteristics by varying number and sequence of pulsed radio frequency fields in order to take advantage of magnetic relaxation properties of the tissues. MRI differs from CT in at least two key aspects: (1) MRI measures the density of specific nucleus, and (2) the MRI measurement system is volumetric (interrogation of the entire body, within the measurement volume, is done all at one time).

CT and MRI represent the finest resolution capability available in diagnostic systems. During the scanning process, patient body is analysed through the measurement planes, every one with 2–3 mm distance between them. The information from each plane can be put together to create a volumetric image of the structure as well as the size and location of anatomical structures. The scanned model becomes a virtual image that resides in a computer, representing the real image of the patient's body. The virtual image is displayed on screen by formatting the data to create orthographic projections, or by creating a pseudo 3D representation using advanced rendering algorithms.

When the CT images are reassembled to illustrate a 3D presentation of anatomical structures, the medical practitioner can use this information directly and the overall shape of the body structures is clearly understood and visualised.

However, human body visualisation requires good visualisation software, therefore many dedicated software packages have been developed to enhance the visualisation of 3D computer models and enable the surgeon to analyse and observe the particular body details. Software packages take anatomical data from CT and MRI scans and creates computer models of anatomical human body structures. A user can modify the displayed image by redefining various imaging parameters. It allows separating important data from additional, in many cases redundantly information, which can by treated as noise. By combining the data generated with a traditional CAD system, virtual reconstruction of the 3D anatomical shapes and details can be done. When segmentation and visualisation is completed the data can be translated into a special data format VRML. Files with extension wrl (also vrml) store such data. 3D reconstruction of human organ where VRML description is used, can be implemented in many programming languages and specialised programming libraries.

Mentioned approach allows to process data outside expensive medical devices and to use more useful software packages and personal computers.

It should be stressed that in various places many very expensive specialised programs are used, where 3D medical objects can be displayed. For example popular in medical community computer program 3D Doctor costs about 4800$ per licence [1].

The 3D computer–aided diagnose and analyse is useful for medical staff in hospitals. The 3D images with VRML can be used for the 3D medical reconstruction and observation and promising prospect in many fields of the modern medical imaging.

3. MAIN PRINCIPLES OF THE PROPOSED 3D MEASUREMENTS

It is well known, that text format of the VRML includes all information, which allows constructing images in 3D perspective. It has especially significance for medical images. In our case, the 3D VRML datasets are obtained from CT device and are treated as input data. In the next stage, these data are interpreted by means of specialised graphic functions of the OpenGL library. OpenGL is very popular and easily accessible programming environment. By means of simple commands, mentioned library can be included in many program languages. In our case, visualisation and transformation of 3D objects by means of the C++ language were performed.

Additionally, 3D reconstruction from large datasets can work well on PC, and user can control model interaction through different VRML browsers such as Blaxxun (http://www.blaxxun.com), Cosmo Player (http://karmanaut.com/cosmo/player/), Cortona VRML Client (http://www.parallelgraphics.com/products/cortona/), etc. with great convenience.

In the first step, all data described by VRML–type format are normalised by means of the formula:

$$V^{new} = \frac{(V - min)}{max - min} * (new\_max - new\_min) + new\_min \qquad (1)$$

where:
[*min, max*]	– range of the input data,
V	– the normalised value, $V \in [min, max]$
[*new_min, new_max*]	– the new range of data,
V^{new}	– the new normalised value, $V^{new} \in [new\_min, new\_max]$

Because 3D objects (medical images) will be analysed, three-dimensional coordinates system and origin of coordinates system should be defined. Origin of the coordinates system (*a,b,c*) can be obviously freely located. In 3D systems, there are three axes, usually signed as *X*, *Y*, and *Z*. In the VRML standard, the *X*-axis goes from left to right, the *Y*-axis goes from bottom to top, the *Z*-axis goes from the monitor to observers' face (smaller values are "deeper" into the monitor). This is difficult to visualize, because 3D dimensions should be displayed on the two–dimensional monitor surface.

In the described approach, every depth of structure (human's body) and cross–section of structure can be visualised and measured. Different possible measurements of human's body are presented by Fig.1 and Fig.2, respectively. These figures present the same three

layers of the object and principles, how various object measurement can be done. In the Fig.1a the parameters of the hole P_1 are calculated. The hole P_1 passes by layers of the object. The Fig. 1b presents depth values for every layer and simple depth calculation principles. The Fig. 1c depicts layer depth computed and visualised by computer program. All depth values along the axis Z were computed, hence only these values are displayed. Such hole is made from upper surface till bottom surface. The Fig.1b presents normalised depth (thickness) of the layers. All values are located depending on the (0,0,0) reference point, which is located inside of the object. Similar measurement presents Fig.2, where object cross–section is presented. The $A–B$ plane can be freely defined by users.

The Fig.2b presents shape of the cross–section in the given object. It should be stressed that in visualisation and in measurements processes all objects can be re–scaled or rotated around axes.
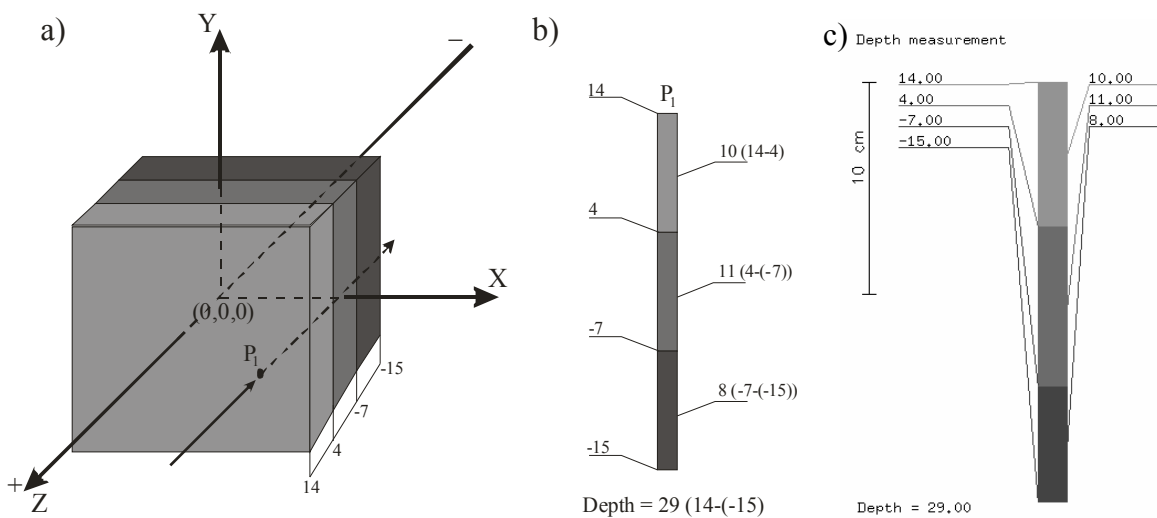

Fig. 1. Measurement of the depth structure: a) object of interesting and axes location, b) depth of object layers object along the hole P_1, c) depth measurement – program application window.
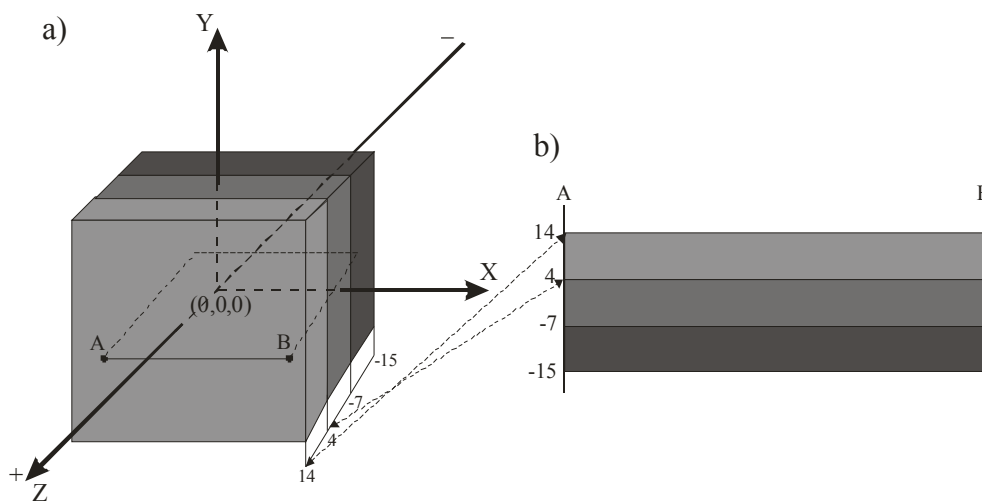

Fig. 2. Object cross-section: a) object of interesting, b) cross-section in the projective plane $A–B$, along the axis Z.

Above presented measurement principles can be applied to real objects, especially to medical imaging, where some important human body measurements can be computed. For this reason very expensive specialised devices can be replaced by relatively simple computer programs and workstations.

4. TECHNIQUE OF THE MEDICAL OBJECTS VISUALISATION

During CT procedures, patient is diagnosed, and images of his body are registered and stored in memory of device. At the moment image description in VRML format can be also produced. Finally we obtain text file, where 3D image description is located. Now, these data are portable and can be treated as input data for simple personal computers, where specialised, but cheap programs are installed.

In standard VRML, among other things, all object coordinates (x, y, z) and connections between them are specified. Groups of specified elements are preceded by markers:

`IndexedFaceSet {}` – after this marker, between parenthesis `{}` object description will be specified.

`coord Coordinate` – after this marker, between parenthesis `{}`, appropriate points coordinates (x, y, z) (are listed inside the marker `point`) are defined.

`CoordIndex` – after marker, between parenthesis `[]`, connection between vertexes are defined. The value –1 indicates termination of the single connection.

Connected points create polygons, which building tree–dimensional objects. In our approach all objects are built by means of triangles. Below, example of cube description in VRML standard is presented.

```
geometry IndexedFaceSet {
  coord Coordinate {
    point [
      -5.0   5.0   5.0,    # vertex number 0
       5.0   5.0   5.0,    # vertex number 1
       5.0  -5.0   5.0,    # vertex number 2
      -5.0  -5.0   5.0,    # vertex number 3
      -5.0   5.0  -5.0,    # vertex number 4
       5.0   5.0  -5.0,    # vertex number 5
       5.0  -5.0  -5.0,    # vertex number 6
      -5.0  -5.0  -5.0     # vertex number 7
    ]
  }
  coordIndex [
    0, 1, 3, -1, 1, 2, 3, -1, 4, 5, 7, -1, 5, 6, 7, -1,
    0, 4, 5, -1, 5, 1, 0, -1, 3, 7, 6, -1, 6, 2, 3, -1,
    0, 4, 3, -1, 4, 7, 3, -1, 1, 5, 2, -1, 5, 6, 2, -1
  ]
}
```

The VRML object description, by means of specialised parser is read and loaded to appropriate class structures, suitable for OpenGL language. Vertexes and connections between them are stored in dynamic table, described by the class object `vector`, from Standard Template Library of C++ language.

```
// Class definition of single vertex representation
class Vertex {
  public:
  double x, y, z;
};
// Class definition of single triangle (any image object is assembled with triangles)
class Face {
  public:
  int  a, b, c;
};
// The object description consists of the colours (iR, iG, iB), vertexes, faces and
// normal vectors to vertexes,
class Object {
  public:
  int              iR, iG, iB;
  vector<Vertex>   aVertex;
  vector<Face>     aFace;
  vector<Vertex>   aVertexNormals;
};
```

In the first step, illumination parameters, and material properties of the object are defined. In the following example the Gouraud's shading was used (the lines 3–5 of the program). In the proposed imaging model the scattered light (`GL_DIFFUSE`), and the environment colour (`GL_AMBIENT`) are automatically selected and depend on the object colour (the lines 9–18 of the program), but user can change these parameters. These properties are the same for all fronts and rears of triangles (`GL_FRONT_AND_BACK`). In the next stage, the function `CalculateNormals()`is called (the line 19). This function calculates the normal vector to appropriate vertex. The normal vectors are needed for colour vertexes establishing when vector's location depending on light source is analysed.

In the last stage, the function `ViewObject()` is called. By means of this function object is displayed on the computer screen.

```
 // Displayed object: here it is bone
 (1) Object  Bone;
 // values,where type of materials were stored
 (2) GLfloat diff[4], amb[4];
 (3) glEnable(GL_LIGHTING);
 (4) glEnable(GL_LIGHT0);
 (5) glShadeModel(GL_SMOOTH);
 (6) iR=Bone.iR;
 (7) iG=Bone.iG;
```

```
 (8)  iB=Bone.iB;
 (9)  diff[0]=iR/255.0;
(10)  diff[1]=iG/255.0;
(11)  diff[2]=iB/255.0;
(12)  diff[3]=0.0;
(13)  glMaterialfv(GL_FRONT_AND_BACK, GL_DIFFUSE, diff);
(14)  amb[0]=iR/255.0;
(15)  amb[1]=iG/255.0;
(16)  amb[2]=iB/255.0;
(17)  amb[3]=1.0;
(18)  glMaterialfv(GL_FRONT_AND_BACK, GL_AMBIENT, amb);
(19)  CalculateNormals();
(20)  ViewObject();
```

Imaging on the screen is performed by the function `ViewObject()`. Imaging procedure are executed by functions of the standard OpenGL language: `glBegin(GL_TRIANGLES)`, `glNormal3f(xn, yn, zn)`, `glVertex3f(x, y, z)`, and `glEnd()`. The function `ViewObject()` is listed bellow:

```
void ViewObject() {
  int       i;
  GLint     a, b, c;
  GLdouble  x1, y1, z1, x2, y2, z2, x3, y3, z3;
  GLdouble  nx1, ny1, nz1, nx2, ny2, nz2, nx3, ny3, nz3;
  for (i=0;i<Bone.aFace.size();i++) {
    a=Bone.aFace[i].a;
    b=Bone.aFace[i].b;
    c=Bone.aFace[i].c;
    x1=Bone.aVertex[a].x;
    y1=Bone.aVertex[a].y;
    z1=Bone.aVertex[a].z;
    x2=Bone.aVertex[b].x;
    y2=Bone.aVertex[b].y;
    z2=Bone.aVertex[b].z;
    x3=Bone.aVertex[c].x;
    y3=Bone.aVertex[c].y;
    z3=Bone.aVertex[c].z;
    nx1=Bone.aVertexNormals[a].x;
    ny1=Bone.aVertexNormals[a].y;
    nz1=Bone.aVertexNormals[a].z;
    nx2=Bone.aVertexNormals[b].x;
    ny2=Bone.aVertexNormals[b].y;
    nz2=Bone.aVertexNormals[b].z;
    nx3=Bone.aVertexNormals[c].x;
    ny3=Bone.aVertexNormals[c].y;
    nz3=Bone.aVertexNormals[c].z;
    glBegin(GL_TRIANGLES);
```

```
    glNormal3f(nx1, ny1, nz1);
    glVertex3f(x1, y1, z1);
    glNormal3f(nx2, ny2, nz2);
    glVertex3f(x2, y2, z2);
    glNormal3f(nx3, ny3, nz3);
    glVertex3f(x3, y3, z3);
  glEnd();
 }
}
```

Above mentioned procedures are used to every object. Generally, proposed approach consists of steps, which are depicted by means of the flow block-diagram in the Fig. 3.
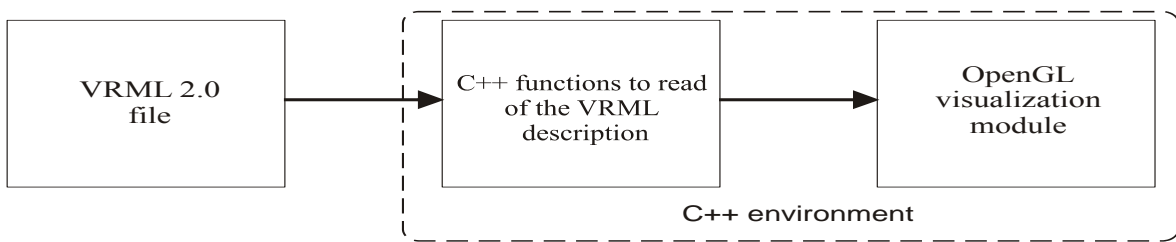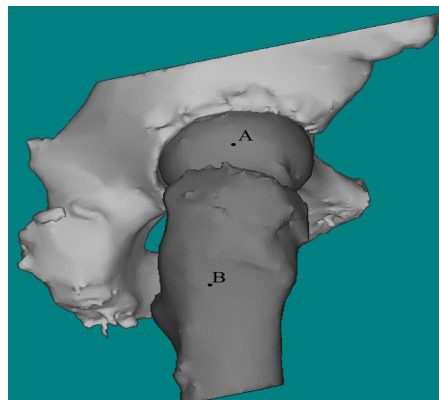

Fig.3. The steps of the retrieving of the VRML–type file in order to 3D image displaying

In practice, proposed method allows users tune visualization results. In particular, colours and projection axes can be modified. Cross-sections can be also freely defined. In the next figures, different options of the human body visualization results have been presented.

5. EXAMPLES OF THE MEASUREMENT AND 3D VISUALIZATION OF THE MEDICAL OBJECTS

The Figs. 4-6 present some human body objects and their measurement details, in accordance with practitioner's requirements.
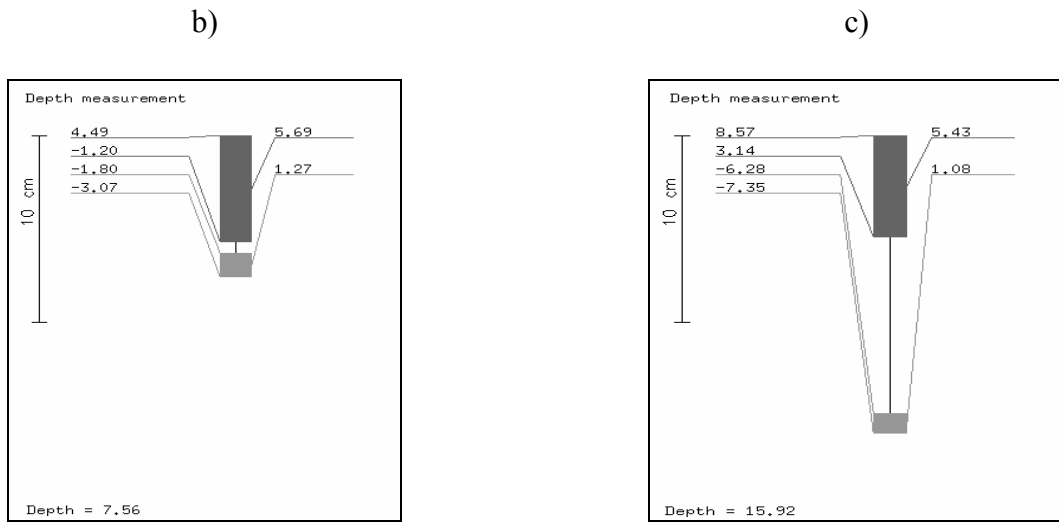
a)

b)

c)

Depth measurement

4.49   5.69
-1.20
-1.80   1.27
-3.07

10 cm

Depth = 7.56

Depth measurement

8.57   5.43
3.14
-6.28   1.08
-7.35

10 cm

Depth = 15.92

Fig. 4. Thickness of the hip joint bone measurement: a) the 3D hip joint model, b,c) depth of the hip in the points *A* and *B*, respectively and dimensions of the body structures.

a)

A   B

b)

Cross-section 1
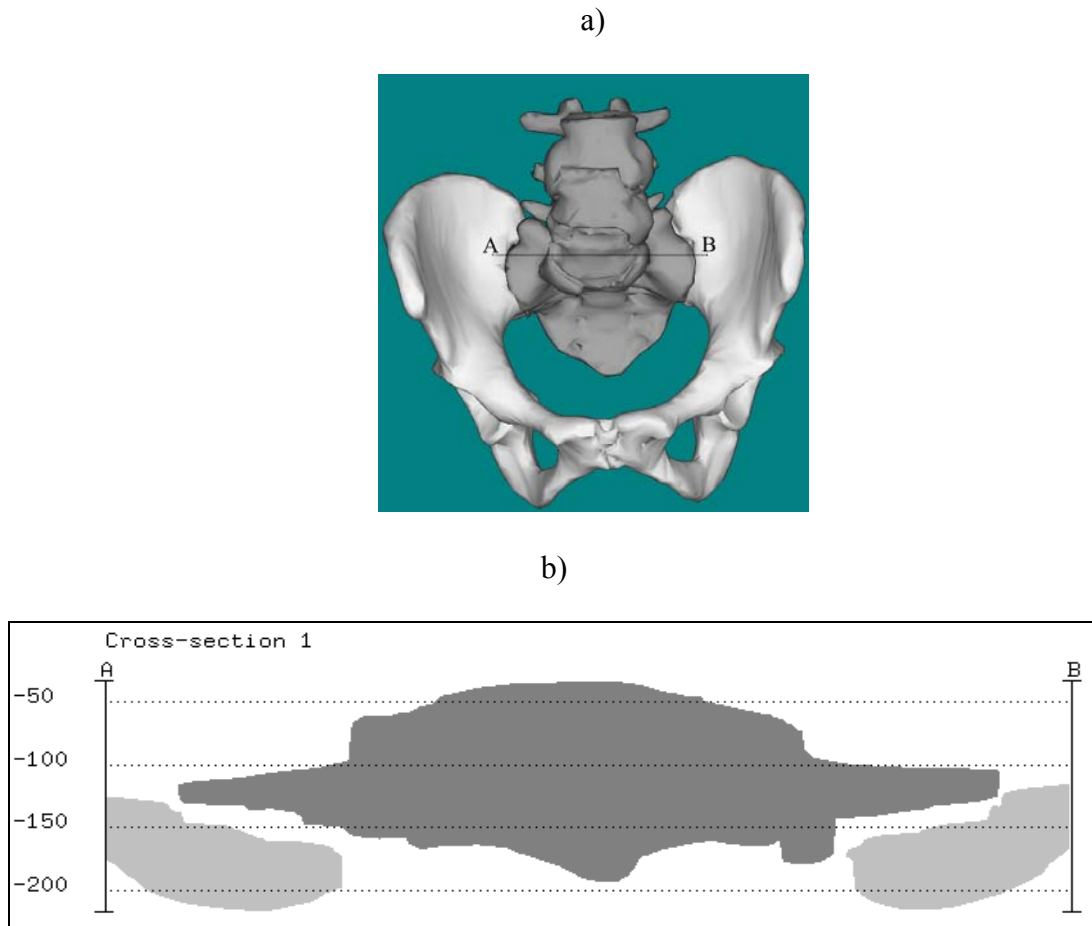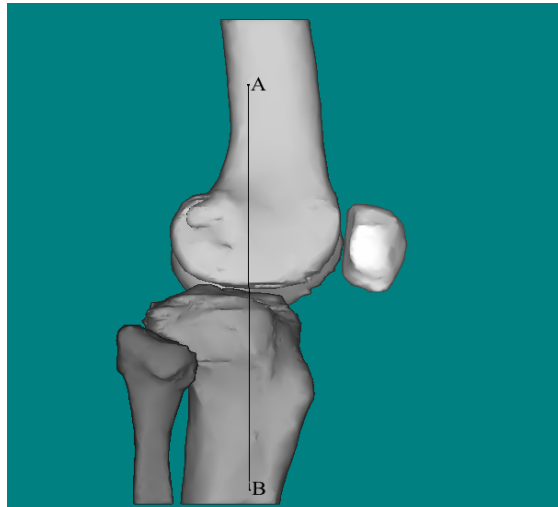
A   B

-50

-100

-150

-200

Fig. 5. a) Three dimensional pelvis model, b) the horizontal cross–section of the pelvis in the projective plane A–B. Note: proportions between pictures a) and b) are not preserved.
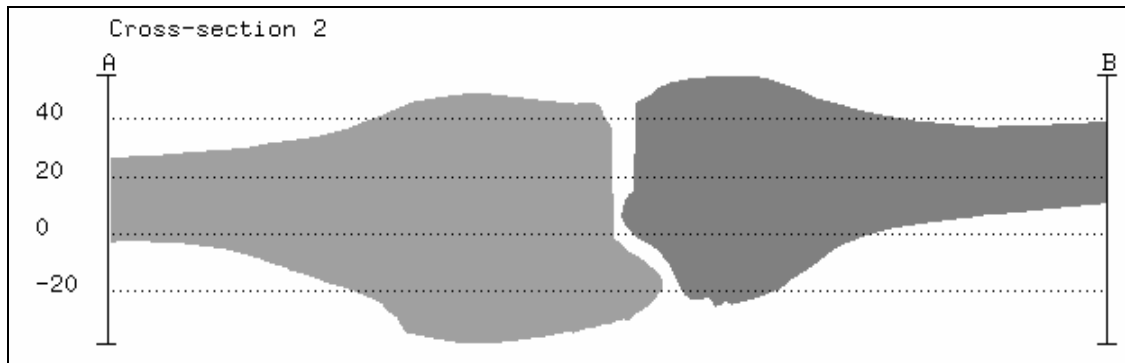
a)

b)

Fig. 6. a) The 3D human bone model, b) the vertical cross–section of the bone with appropriate values.
Note: proportions between pictures a) and b) are not preserved.

6. CONCLUSIONS

Based on VRML model, CT objects (for example Siemens, Sensation Workstation 4mm/layer) 3D visualization can be done. All details can be well dynamically observed. It gives medical staff a vivid and direct image, which is usually hard to seen and understood fully in 2D high–resolution. Proposed computer program can be used in places where expensive devices are not available. In future we are planning development of our software, where additional useful functions will be added.

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