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The internet and medical collaboration using virtual reality

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Abstract

Computed Tomography (CT) provides a large amount of data but the presentation of the data to a physician can be less than satisfactory. Ideally, the image data should be available to physicians in interactive 3D to allow for improved visualization, planning and diagnosis. A virtual reality representation that not only allows for the manipulation of the image but also allows for the user to, in effect, move inside the image remotely would be ideal. In this paper the research associated with virtual reality is discussed. A formalism is then presented to create, from the CT data, the virtual reality world in the Virtual Reality Modeling Language. An implementation is described of this formalism that uses the Internet to allow for users in remote locations to view and manipulate the virtual worlds.

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Keywords

Medical informatics

Internet

World wide web

Virtual reality modeling language

Computed tomography

Nomenclature

[ ]

subset

[ ]c

critical points subset

[ ]s

segmentation points subset

{ }

set

*Fi*

a polygon

*Ki*

knowledge constraint *i*

*O*

region of interest

*Pr*,*s*,*t*

user-specified centroid of *O*

*Px*,*y*,*z*

candidate point with coordinate *x* and *y* in slice *z*

*S*2

a 2D segmentation design model

*S*3

a 3D design model

*V*

objective function, where *V*=*f*(*S*2) or *V*=*f*(*S*3)

1. Introduction

Two dimensional (2D) images require that the physician mentally determines 3D images from 2D slices, and this is difficult and error prone, particularly for more complex structures such as the lung [[1]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB1), [[2]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB2). 3D image-based displays of radiological data avoid this problem by explicit representing the data in 3D, literally improving the interpretation of the images [[3]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB3), [[4]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB4), [[5]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB5). However, the fundamental problems with current approaches to 3D display of scans are that they are not interactive once reported, and that they can only be viewed from an angle chosen by a technician or the primary reporting radiologist [[3]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB3), [[6]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB6). This is not ideal as the images frequently raise as many new questions as they have answered. If there are changes required in presentation or interpretation of the images, then this requires time on the part of the physician or surgeon to visit the radiology site, and, together with the technical person operating the computer, refashion the images. This process is time consuming, and is often difficult to organize effectively.

We, therefore, have a situation where 3D visualization of data is of limited use since there is little interactive capability in the present systems and where such 3D visualization is difficult and time consuming. Ideally, the image data should be available to physicians in *interactive* 3D to allow for improved visualization, planning and diagnosis. The generation of interactive 3D images is a challenging research task especially when it is borne in mind that there are substantial advantages to be gained if physicians can be remotely located from the image analysis technologists, or from other physicians that they may wish to consult.

Users need to be able to see the imaging data and this visualization is preferably in interactive 3D so that the users can move or manipulate the image in order to improve viewing the data. Ideally, what is required is a vehicle for visualizing data that is platform independent, is low cost, allows for interactive 3D and is computationally efficient. Virtual Reality Modeling Language (VRML) is a prime candidate for such an application. VRML, introduced in 1995, is a language for describing multi-participant interactive simulation. VRML is capable of creating virtual worlds networked via the Internet. The aspects of virtual worlds, including display, interaction, and Internet working, can be specified using VRML.

In this paper a formalism is presented to address this fundamental research task. Given this formalism, the question remains of how can this be implemented? Certainly, it can be implemented on a single machine. However, such an isolationist approach ignores the geographic distribution of medical staff. To address these aspects, an Internet-based implementation of this formalism is described that uses the Internet to support activities so that physician can readily interact with 3D images over a computer network, and where they can coordinate activities with other medical personnel and with the image analysis technologists. A full experimental evaluation of the formalism is beyond the scope of this paper, rather this paper aims to show the structure of the formalism. The format of this paper is as follows. First the research associated with virtual reality is discussed. A proposed formalism for the generation of virtual reality worlds from medical imaging data is then detailed. The implementation of this formalism using the Internet and VRML is then described. Some initial results are then presented.

2. Virtual reality

A successful data collection visualization should satisfy a set of many requirements: unification of diverse data formats, support for serendipity research, support of hieratical structures, algorithmizability, vast information density, Internet-readiness, and other. Recently, virtual reality has made significant progress in engineering, architectural design, entertainment and communication [[7]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB7). There has been an increased interest in the exploration of virtual environments for a wide range of applications such as environmental planning and management, urban planning and design, landscape visualization, and education and training. Among these applications, virtual reality technology offers new and exciting opportunities for users to interact visually with and explore 3D geo-data [[8]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB8). Nevertheless, the combination of the VRML and the World Wide Web (WWW) getting focused as it has the potential to radically alter the way in which computers interact, and the way in which complex systems are conceptualized and built. The application of VRML in the virtual reality environment has been mentioned in recent research. Campbell (2000) has investigated the use the VRML in the production and communication of construction documents, the final phase of architectural building design. A prototype, experimental Web site was set up and used to disseminate design data as VRML models to the design client, contractor, and fabricators. Shen et al. create a virtual shopping mall environment, simulating most of the actual shopping user interactions [[9]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB9). The virtual mall brings together the services and products of various vendors. Users can navigate through the virtual shopping malls, adding items of interest into a virtual shopping cart, and perform searches. In the research, a VRML and Java3D-based prototype is presented, which permits users to navigate around virtual e-commerce worlds and perform collaborative shopping and intelligent searches with the assistance of software agents, in order to find the products and services of interest to them. Huang reports a web-based framework-CyberReview—a central portal for supporting collaborative product design review, which provides the virtual reality design process [[10]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB10). Craig and Zimring also develop an asynchronous collaborative system, called the Immersive Discussion Tool (IDT), is introduced as a means for supporting productive design exchanges [[11]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB11). IDT allows collaborators to reason about 3D models over the Internet using view -dependent and view-independent diagrammatic marks, dynamic simulations, geometric design surrogates and text annotations. Brodlie et al. briefly review work on the use of computer graphics and virtual reality to create realistic training environments for surgery [[12]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB12). And they suggest that many of these require sophisticated and dedicated equipment. Although some initial work on using VRML for medical imaging has been reported [[13]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB13), [[14]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB14), [[15]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB15). However these works is primarily focused on manual VRML generation. To our knowledge, this paper is the first to examine the semi-automatic generation of VRML images from CT data.

3. The generation of virtual reality worlds from radiology imaging data

Our aim in this paper is not for completely automated segmentation; since the complexity of the problem and the variability between patients mean that it is unlikely that a reliable completely automated segmentation method is viable, at least in the near term. Semi-automated interaction techniques are important for this task due to limitations of automated processing [[16]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB16). Rather, this paper is concerned with semi-automated segmentation, where automated segmentation methods are used but where these methods are monitored and manually altered, where necessary. In this paper, we consider the data from CT in the form of slices made up of an array of voxels. The proposed formalism has three main steps:

1.

*Boundary identification or 2D segmentation*, which involves the evaluation of the data points in the original CT data set and the determination of 2D objects and 2D object boundaries.

2.

*3D segmentation*, which involves extending the 2D object boundaries, obtained from the previous step, into 3D.

3.

*Virtual reality world creation*, which involves taking the 3D object boundaries and creating a virtual reality world.

3.1. Boundary identification (2D segmentation)

The proposed approach for boundary identification (2D segmentation) is based on thresholding, boundary finding, and region growing [[3]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB3), [[4]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB4), [[17]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB17), [[18]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB18). The proposed approach first identifies objects by threshold using the gray levels. For example, lung airways, provided that they are not too narrow, have a confined gray range and are in high contrast to the airway walls, thus they can be readily identified [[3]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB3), [[4]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB4). Seeded region growing [[19]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB19), [[20]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB20), [[21]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB21), [[22]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB22), [[23]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB23) is then proposed to identify the main structures. The problem addressed is that of *boundary identification* (BI), which can be described as follows:

There is a set of candidate points, {*Px*,*y*,*z*}, from which a subset is to be selected which satisfies a set of knowledge constraints {*Ki*} while minimizing (maximizing) an objective function *V*, where *V*=*f*(*S*2).

A 2D segmentation model (*S*2) is the representation of an artifact to be segmented. For a BI process then

S2=[Px,y,z]

*S*2 therefore represents a model that consists of points, each being selected from the set of candidate points, {*Px*,*y*,*z*}.

3.1.1. Grouping analysis

Let the location of the user-specified centroid be *Pr*,*s*,*t*, and this is assumed to lie within the object. Along a direction *X*, example values of pixel are shown in [Fig. 1](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "FIG1). The boundary points are in the slope areas in the two ends, where there is a significant change in the value of the pixel.

1. [Download full-size image](https://ars-els-cdn-com.erl.lib.byu.edu/content/image/1-s2.0-S0895611103000429-gr1.gif)

Fig. 1. The value of pixel in *X* direction.

Since there is an underlying noise in the values of the pixel, it is necessary to have an algorithm to identify boundary points. To identify the boundary point, we propose the following objective function *Vx*

Vx(Px,y,z)=ABS((MEAN(Px−p,y,z,…,Px−2,y,z,Px−1,y,z)−MEAN(Px+1,y,z,Px+2,y,z,…,Px+p,y,z))

where

ABS gave the absolute value of the brace

MEAN is the average of the values

The boundary points should have the maximum objective function. To use the average of the previous *p* pixels instead of using one pixel is to reduce the noise (note that the larger the value of *p* is, the more the noise is reduced, but that a higher value may start to be affected by other boundaries).

3.1.2. Boundary identification (2D segmentation) algorithm

This section describes a proposed algorithm for BI. The algorithm consists of five steps, with Step 2 containing six sub-steps, Step 3 containing six sub-steps, and Step 4 containing eight sub-steps.

*Step 1 (Identification of ROI)*

1.1

According to knowledge constraints {*Ki*}, refine the set of initial slice points {*Px*,*y*,·} into an subset points [*Px*,*y*,·], which includes the region of interest (ROI) *O* which is a matrix of size *m*×*n*.

1.2

Define the user-specified centroid, *Pr*,*s*,·.

*Step 2 (Scanning Y direction critical points)*. This step involves determining the critical points, where each point satisfies the objective function

Vx(Px,y,·)=ABS((MEAN(Px,y−q,·,…,Px,y,−1,·,Px,y−1,·)−MEAN(Px,y+1,·,Px,y+2,·,…,Px,y+q,·))

2.1

Find the *Vy*(*Px*,*y*,·) of all the points in [*Px*,*y*,·].

2.2

Start from *i*=0

2.3

Add 1 to *i*, If *i*>*m* then go to Step 3.

2.4

Find the maximum *Vy*(*Px*,*y*,·), which lies between *Pi*,1,· to *Pi*,*s*,·, add *Px*,*y*,· to the critical points set [*Px*,*y*,·]c

2.5

Find the maximum *Vy*(*Px*,*y*,·), which lies between *Pi*,*s*+1,· to *Pi*,*n*,·, add *Px*,*y*,·to the critical points set [*Px*,*y*,·]c

2.6

Go to 2.3.

*Step 3 (scanning X direction critical points)*. This step involves determining the critical points, where each point satisfies the objective function

Vx(Px,y,·)=ABS((MEAN(Px−p,y,·,…,Px−2,y,·,Px−1,y,·)−MEAN(Px+1,y,·,Px+2,y,·,…,Px+p,y,·))

3.1

Find the *Vx*(*Px*,*y*,·) of all the points in [*Px*,*y*,·].

3.2

Start from *j*=0

3.3

Add 1 to *j*, If *j*>*n* then go to Step 4.

3.4

Find the maximum *Vx*(*Px*,*y*,·), which lies between *P*1,*j*,· to *Pr*,*j*,· add *Px*,*y*,· to the critical points set [*Px*,*y*,·]c

3.5

Find the maximum *Vx*(*Px*,*y*,·), which lies between *Pr*+1,*j*,· to *Pm*,*j*,·, add *Px*,*y*,·to the critical points set [*Px*,*y*,·]c

3.6

Go to 3.3.

*Step 4 (Identify 2D segmentation boundary points)*. This step involves determining the segmentation boundary points, where linking these points can clearly identify the object.

4.1

Let *j*=0 and start from *Pr*,*s*+*j*,·

4.2

If *Pr*,*s*+*j*,·∈[*Px*,*y*,·]c, add *Pr*,*s*+*j*,· to the segmentation boundary points set [*Px*,*y*,·]s and Go to 4.5.

4.3

Find the nearest point *Px*,*y*,· to *Pr*,*s*+*j*,· where *Px*,*y*,· is ranged from *Pr*,*s*+*j*,· to *Pm*,*s*+*j*,· and ∈[*Px*,*y*,·]c. Add *Px*,*y*,· to the segmentation boundary points set [*Px*,*y*,·]s.

4.4

Add 1 to *j* and go to 4.2

4.5

Let *i*=0 and start from *Pr*+*i*,*s*,·

4.6

If *Pr*+*i*,*s*,·∈[*Px*,*y*,·]c, add *Px*+*i*,*y*,· to the segmentation boundary points set [*Px*,*y*,·]s and step 5.

4.7

Find the nearest point *Px*,*y*,· from *Px*+*i*,*y*,· where *Px*,*y*,· is ranged from *Px*+*i*,*y*,·to *Px*+*i*,*n*,· and [*Px*,*y*,·]c. Add *Px*,*y*,· to the segmentation boundary points set [*Px*,*y*,·]s.

4.8

Add 1 to *j* and go to 4.6

Note that the algorithm (step 4) described above only aims to identify the segmentation boundary points of the lower right quarter of the whole area. However, the same procedure can be applied to the other quarter areas. In step 5, we assume all the segmentation boundary points [*Px*,*y*,·]s. have been obtained.

*Step 5 (Detailed segmentation)*. Use the segmentation boundary points [*Px*,*y*,·]s, now we can transfer the object representation or, if possible, consider other domain knowledge, and manually refine the segmentation.

3.2. 3D segmentation algorithm

After we identify the boundary for each object in each 2D slice, we now need to build a 3D model of the object considered. The problem addressed is that of *3D Segmentation* (3S), which can be described as follows:

There is a set of candidate coordinate points, [*Px*,*y*,*z*]s, which were obtained from the previous 2D segmentation algorithm, from which a subset is to be selected, which satisfies a set of constraints {*Ki*}, to form *Fi* while minimizing (maximizing) an objective function *V*, where *V*=*f*(*S*3).

The 3D design model (*S*3) is made up of an assembly of polygons:

S3=∑Fi

If we use polygons with *w*-side, the 3D shape can be built from the 2D slices using the algorithm for generating 3D polygons shown in [Fig. 2](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "FIG2).

1. [Download full-size image](https://ars-els-cdn-com.erl.lib.byu.edu/content/image/1-s2.0-S0895611103000429-gr2.gif)

Fig. 2. Algorithm for generating 3D polygons.

In some parts of the anatomy, additional rules have to be used. Consequently, the above 3D segmentation algorithm can be supplemented with a knowledge rule-based approach. The rule-based aspect consists of a number of rules of the form:

If *antecedent* Then *consequent*

Three rules for lung airway segmentation are, for example [[3]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB3), [[4]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB4):

*region*=*backgroundIF*((*region\_size*>*max\_vessel\_size*)

*OR*(*region\_size*>*max\_airway\_size*)

*OR*(*max\_airway\_gray*<*region\_brightness*<*min\_vessel\_gray*))

*region*=*vessel IF* (*region\_gray*>=*min\_vessel\_gray*)

*region*=*airway IF* ((*region\_gray*>*max\_airway\_gray*)

*AND* (*region*<=*is*−*adjacent*−*to vessel*)

*AND* (*region NOT is*−*adjacent*−*to big\_vessel*))

Such a rule can be thought of as a logical implication connective constraint with an associated truth value of true, false or unknown. For such an implication sentence, if the truth value of the antecedent is *true*, then the truth value for the whole sentence is the same as the truth value of the consequent. If the truth value of the antecedent is *false*, then the whole sentence has no truth value and it can be regarded as ‘inapplicable’. If the truth value of the antecedent is *unknown*, then the whole sentence is *unknown*. If either antecedent or consequent has no truth-value, then the whole sentence has no truth-value, and the logic sentence is ‘inapplicable’. The application of such a rule-based approach allows for the inclusion of domain specific knowledge into the segmentation algorithm to allow, for example, the inclusion of knowledge about airways following the path of blood vessels. 3D skeletonization can then be used to construct the detailed trees identified [[3]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB3), [[4]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB4).

3.3. Virtual reality world creation

The 3D model *S*3=∑*Fi*, is expressed as an assembly of polygons. These now need to be mapped to the 3D graphical representation and the mapping methods will be highly depend on the syntax of the representation tool and is difficult to generalize. In this paper, we will use VRML as the representation tool, and the mapping details are discussed in [Section 4](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "SEC9).

4. Example illustration

[Section 3](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "SEC3) has described a formalism that can be used for the creation of a virtual reality world from radiology imaging data. As indicated in [Section 1](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "SEC1), given this formalism, the question remains of how can this be implemented? In this section, an Internet-based implementation of this formalism is described that uses the Internet to support activities so that a physician can readily interact with 3D images over a computer network, possibly while also coordinating activities with other medical personnel and with the image analysis technologists.

4.1. Virtual reality modeling language—VRML

VRML can be viewed at a high level of abstraction as a collection of objects that are called nodes. These objects, or nodes, are defined for 3D graphics. Nodes are arranged in hierarchical structures called scene graphs, which define an ordering for the nodes. The scene graph has a notion of state, so that nodes earlier in the world can affect nodes that appear later in the world. For example, a rotation or material node will affect the nodes that appear after it in the world. A mechanism is defined to limit the effects of properties (separator nodes), allowing parts of the scene graph to be functionally isolated from other parts. Applications that interpret VRML files need not maintain the scene graph structure internally; the scene graph is merely a convenient way of describing objects.

A description of the methods to formulate objects in VRML to be used can be found in Refs. [[24]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB24), [[25]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB25), [[26]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "BIB26). Free-formed surfaces, such as that arising from imaging, are not included in the VRML specification. Therefore, a set of polygons should approximate to a free-formed surface or curve. For the purpose of rendering and shading the created polygons, their normal vectors are calculated and given to the respective polygons.

Some initial work on using VRML for medical imaging has been reported [[13]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB13), [[14]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB14), [[15]](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#BIB15). However these works is primarily focused on manual segmentation methodologies and manual VRML generation. To our knowledge, this paper is the first to examine the semi-automatic generation of VRML images from CT data.

4.2. Example—lung imaging

In the following example, the CT image was scanned in 3 mm thick into 28 slice data sets from a pig's lung. Images were then reconstructed into a 200×200 matrix for each slice and image analysis was done in 8-bit gray-scale resolution. This provides the CT data input to the proposed formalism. The process is conducted, as described above, in three main steps: *Boundary Identification or 2D Segmentation*, *3D Segmentation*, *and Virtual Reality World Creation*.

4.2.1. Boundary identification (2D segmentation)

The 2D segmentation algorithm is used as follows:

*Step 1 (Identification of ROI)*. According to knowledge constraints {*Ki*}, refine the set of initial slice points {*Px*,*y*,·} into subset points [*Px*,*y*,·], which include the region of interest (ROI) *O* as a matrix of 31×43 and define the user-specified centroid, *Pr*,*s*,· ([Fig. 3](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "FIG3)).

1. [Download full-size image](https://ars-els-cdn-com.erl.lib.byu.edu/content/image/1-s2.0-S0895611103000429-gr3.gif)

Fig. 3. An example region of interest (ROI) and centroid, *Pr*,*s*,·.

*Step 2 (scanning Y direction critical points)*. This step involves determining the critical points along the *Y* direction. We use three points (*q*=3) to reduce the noise, and the resulting objective function is

Vy(Px,y,·)=ABS((MEAN(Px,y−3,·,Px,y−2,·,Px,y−1,·)−MEAN(Px,y+1,·,Px,y+2,·,Px,y+3,·))

Using the procedure described previously, the critical points set [*Px*,*y*,·]c can be determined.

*Step 3 (scanning X direction critical points)*. This step involves determining the critical points along the *X* direction. We use three points (*p*=3) to reduce the noise, and the resulting objective function is

Vx(Px,y,·)=ABS((MEAN(Px−1,y,·,Px−2,y,·,Px−1,y,·)−MEAN(Px+1,y,·,Px+2,y,·,Px+3,y,·))

Using the procedure described previously, the critical points set [*Px*,*y*,·]c can be determined

*Step 4 (Identify 2D segmentation boundary points)*. This step involves determining the segmentation boundary points, where linking these points can clearly identify the object. An example segmented ROI is shown in [Fig. 4](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "FIG4). (The value of 255 indicates the boundary points).

1. [Download full-size image](https://ars-els-cdn-com.erl.lib.byu.edu/content/image/1-s2.0-S0895611103000429-gr4.gif)

Fig. 4. The final segmented ROI.

After continuing the procedure with all 28 slices, we now have approximate 2000 boundary points in [*Px*,*y*,*z*]s.

4.2.2. 3D segmentation

Based on the boundary points in [*Px*,*y*,*z*]s, we can use triangle-polygons (*w*=3) to build the 3D shape from the 2D slices using the algorithm for generating 3D polygons shown in [Fig. 5](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "FIG5), which itself is derived from [Fig. 2](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429#FIG2).

1. [Download full-size image](https://ars-els-cdn-com.erl.lib.byu.edu/content/image/1-s2.0-S0895611103000429-gr5.gif)

Fig. 5. Using triangle polygons to generate a 3D model.

The result of this procedure is that a 3D design model (*S*3) is produced as an assembly of approximately 4000 triangle polygons. A partial visual representation of a 3D design model is shown in [Fig. 6](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "FIG6).

1. [Download full-size image](https://ars-els-cdn-com.erl.lib.byu.edu/content/image/1-s2.0-S0895611103000429-gr6.jpg)

Fig. 6. The partial visual representation of the 3D design model, *S*3.

4.2.3. Virtual world creation

The 3D model *S*3=∑*Fi*, is expressed as an assembly of polygons. These now need to be mapped to the VRML representation as follows:

S3⇒{Ni}

where {*Ni*} is a set of nodes expressed in VRML.

For polygons, the VRML 2.0 node predominantly used will be that of IndexedFaceSet. The IndexedFaceSet node represents a 3D shape formed by constructing faces (polygons) from vertices listed in the coord field of the node. IndexedFaceSet is specified in the local coordinate system and is affected by parent transformations. The mapping between {*Fi*} and {*Ni*} is 1:1. That means each polygon *Fi* can be expressed as a node in VRML. If *Fi* is a *w*-sides polygons with member of point *j*,*j*+1,…,*j*+*w*−1,*Ni* can be shown in follows:

*IndexedFaceSet* {

*coord Coordinate* {

*point*

[0.0400.21, //*coordinateX*, *Y*, *Zof j*

0.0300.2, //*coordinateX*, *Y*, *Z of j+1*

⋮

−0.0100.17] //*coordinateX*, *Y*, *Z ofj*+*w*−1

*coordIndex*

[0,1,2,…,,*w*−1,−1]

}

}

After defining the 3D model *S*3=∑*Fi*. Each polygon *Fi* is now can be 1:1 mapped to the VRML representation {*Ni*}, where {*Ni*} is a set of IndexedFaceSet nodes expressed in VRML.

To illustrate the resulting VRML image, example computer screens are shown in [Fig. 7](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "FIG7), using a web-browser with a VRML plug-in. The user, by manipulating the mouse, can rotate the image about any axis and can focus in on a particular area of interest. In this way, the system will add improved visualization, while, at the same time, each user can make full use of the network connections to access data or to communicate with others, thereby reducing the substantial time taken at present to move data and information through the chain of users.

1. [Download full-size image](https://ars-els-cdn-com.erl.lib.byu.edu/content/image/1-s2.0-S0895611103000429-gr7.jpg)

Fig. 7. Example screens.

5. Implementation

Example architecture for the implementation of the interactive 3D visualization system is shown in [Fig. 8](https://www-sciencedirect-com.erl.lib.byu.edu/science/article/pii/S0895611103000429" \l "FIG8), where the main facilities and personnel can be in remote locations, linked together with a network. The process envisaged is as follows:

1.

The patient is scanned using a CT scanner.

2.

The scan is examined and a radiation treatment plan is produced.

3.

This is sent to the server, which uses the algorithms (described above) to produce 3D segmented data and then to produce 3D interactive images.

4.

The radiation treatment plan, together with the 3D interactive images, is then sent to the Radiation Oncologist for approval.

5.

The Radiation Oncologist uses the interactive 3D images to help in evaluating the radiation treatment plan.

6.

The approval, interactive 3D images, and the radiation treatment plan are sent to the treatment technologist who can prepare and use the radiation treatment equipment to treat the patient.

1. [Download full-size image](https://ars-els-cdn-com.erl.lib.byu.edu/content/image/1-s2.0-S0895611103000429-gr8.gif)

Fig. 8. Example operational architecture of interactive 3D visualization system.

This process can be carried out with the patient, treatment technologist and radiation oncologist being in a site remote from the radiation planning. This compares with the present situation where much time is spent hand carrying documents, and in communication, between the sites. Operating the proposed system, data will be obtained from the patient CT database at one site and communication will be over the network. Also, semi-automated 3D segmentation, described above, can improve the visualization of CT data for each user.

6. Summary and conclusions

The aim of this paper is to address the research issue of developing a suitable formalism for the creation of virtual reality worlds from medical imaging data, specifically CT data. In this paper, the research associated with virtual reality is discussed. A formalism is presented to create the virtual reality world in the VRML from the CT data. An implementation is described of this formalism that uses the Internet to allow for users in remote locations to view the virtual worlds. A full experimental evaluation of the formalism is beyond the scope of this paper, rather this paper aims to show the structure of the formalism. The aspect that is most useful is the virtual reality world creation and the use of VRML as a representation tool. This formalism for creating the virtual reality world from medical imaging data, of interactive 3D images over the Internet, goes beyond the current image presentation approaches to allow users to manipulate interactive 3D images remotely. Furthermore, it is thought that the 3D semi-automated segmentation algorithm presented can be mapped to other medical data, such as MRI data, so as to develop a virtual reality world from these different data sources. However, further research is needed into this mapping and also into a full testing of the formalism on a variety of data.

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