Management information services for enhancing interoperability in radiology through segmentation techniques

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Abstract

An efficient information sharing environment can enhance interoperability within any organization. Healthcare organizations and hospitals, in particular, are no exception. Indeed, managing hospital processes, through the appropriate techniques, may provide the basis for designing information services that can support healthcare provision. Radiology information services aid in exploding imaging modalities, generate views from different anatomical structures contained in CT data sets and perform treatment plan techniques. Important issues for the design of such information services include a) the extraction of the corresponding data from the image and b) accurate definition of the target volumes as well as organs at risk for the treatment outcome. Implementation of this radiology information could be achieved by using simulators, which are medical devices used in the oncology clinics to perform the simulation for the external beam radiotherapy treatment. Virtual Simulators in particular offer a excellent cost benefit ratio for a clinic and further assist physician to detect the tumor site from different viewpoints to design orientation, to evaluate treatment, to calculate the dose distribution around tumor and finally to design an effective planning. The implemented high-end visualization techniques allow the users to simulate every function of the real simulator, including the mechanical component movements, radiation beam projection and fluoroscopy. In this work, a hospital process map is provided and a twofold study is conducted: A. Information management for supporting the interoperability of hospital processes; and B. Design radiology information services through image segmentation techniques. Thus, we present a process that can be used for the accurate semi-automatic segmentation of the important target in use organs (like skin, lungs, spinal canal, and bronchus) in three dimensions from CT images. Our clinical experience is described using patient example (breast cancer). The advantages of virtual simulation system over classical simulation would be presented, and the clinical effectiveness would be emphasized.

Keywords: Information services, management, hospital interoperability, radiology, image segmentation.

1. Introduction

The hospital operational environment is information and technology intensive. Managing hospital processes may provide the basis for designing information services that can enhance interoperability and support healthcare provision. Novel evidence-based healthcare services, including the radiology area, require both modern equipment and information availability. An efficient information sharing environment can indeed augment interoperability within the hospital. Radiology is a rapidly advancing area of healthcare practice, heavily based on information interchange as well as information and image technologies. The process that separates an image into its important features (primitives) so that each of them can be addressed separately is called image segmentation. Image segmentation in radiology aid in exploding imaging modalities, generate views from different anatomical structures contained in CT data sets and perform treatment planning techniques. Humans may perform this task using complex analysis of shape, intensity, position, texture, and proximity to surrounding structures. Hence, screening the final results is an effective way to solve clinical problems through imaging techniques, as well as documenting the presence or absence of a disease or condition, and managing the next planning/decision considering medical conditions. Important issues for the design of such information services include a) the extraction of the corresponding data from the image, and b) accurate definition of the target volumes as well as organs at risk for the treatment outcome.

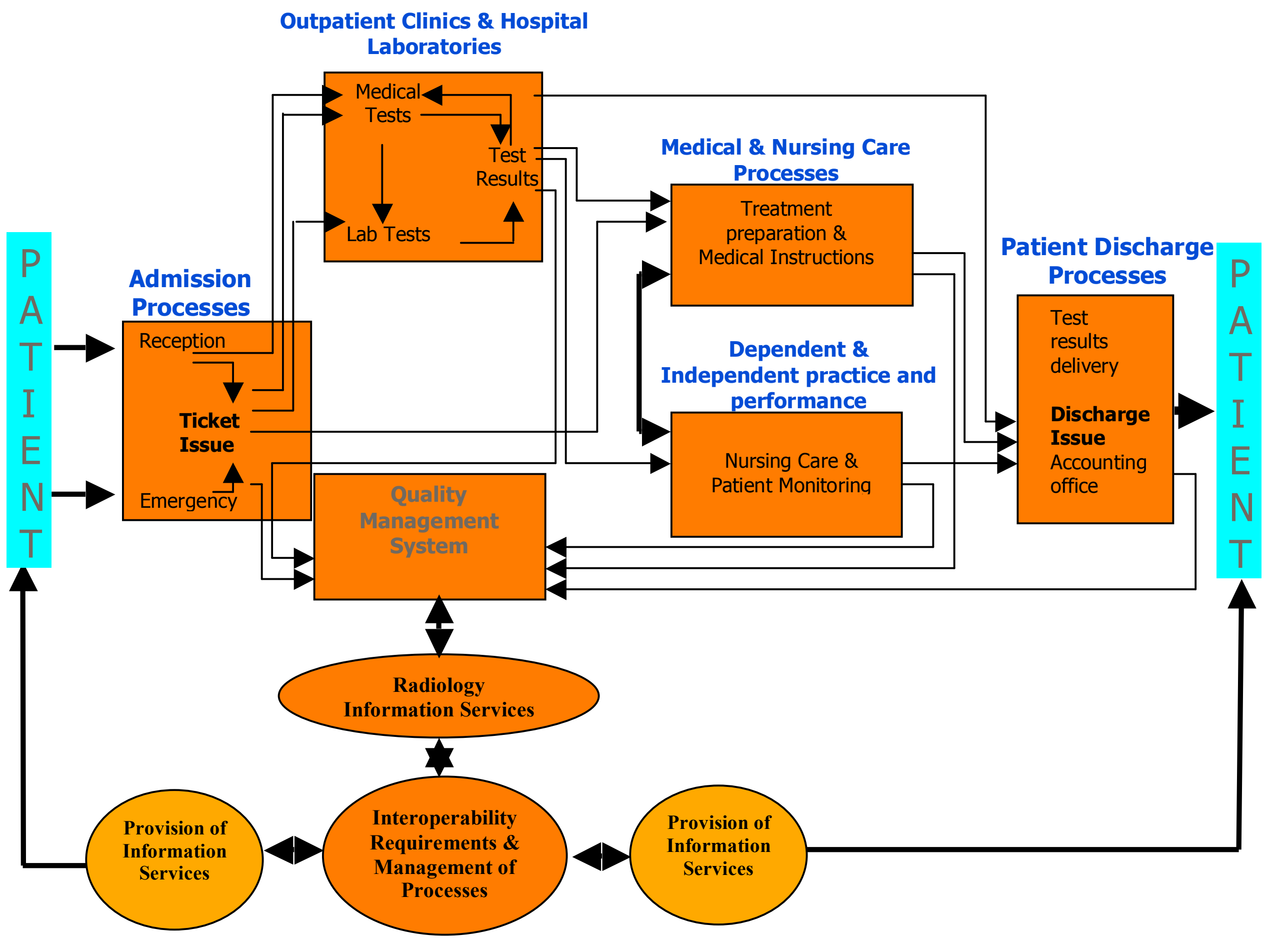
Implementation of this radiology information could be achieved by using simulators, which are medical devices used in the oncology clinics to perform the simulation for the external beam radiotherapy treatment. Unlikely for a clinic to obtain a real Simulator is a high investment in terms of money, space and personnel. The alternative here can be a Virtual Simulator (VS), similar to the simulator EXOMIO employed here. The implemented high-end visualization techniques allow the users to simulate every function of the real simulator, including the mechanical component movements, radiation beam projection and fluoroscopy. In this work, a hospital process map is initially provided for supporting information sharing thus enhancing the interoperability of hospital processes; and then a detailed example of clinical radiology services through imaging segmentation techniques is provided. The method employed is basically composed from an edge detection algorithm, which is applied on the original, axial CT images. The implemented method is based in 2D boundary tracking (BT) algorithm, and it works at one image level at the time. In the case of the CT modality, the algorithm is applied on the original (axial) cross section images. Our clinical experience is described using patient example from breast cancer. The advantages of virtual simulation system over classical simulation would be presented, and the clinical effectiveness would be emphasized.

2. Managing hospital processes for improving interoperability

Hospital information systems (HIS) aim at the formation of a secure and reliable framework within which the involved parties of the hospital have access to information they need, whenever they require it. HIS further should be able not only to access-use services provided by others but also to re-use their functionality (Apostolakis & Valsamos, 2005), thus, they should integrate information sharing including different sources and different types of information (Mercer, 2001). The above, face a series of difficulties originating from the nature of healthcare information (Apostolakis & Valsamos, 2006). Management however of the hospital processes may provide a pathway incorporating usage and re-usage of information within a wide framework (Snyder et al, 2005). Our approach is based on mapping the hospital processes in order to establish information requirements for the two (2) levels of interoperability, defined in Apostolakis and Valsamos, (2006), i.e. functional/syntactic (e.g. the radiology information system may exchange information with other hospital systems, witch is machine readable/processable) as well as semantic (e.g. the ability for information shared by systems to be understood at the level of formally defined domain clinical radiology concepts through the image segmentation techniques on CTs, so that the information is machine understandable). For example, information may be organized to support medical diagnostic procedures so that when a doctor is considering doing blood tests to investigate a patient's symptoms, he is linked to the hospital laboratory information subsystem to guide him with his choice of investigations and subsequent interpretation of the results.

Figure 1 provides a user-centered hospital operations process map for service integration and application reuse. Data and information related to hospital processes are important resources for healthcare providers. In Figure 1, the starting and finishing point (on the left and right of the figure, respectively) is the patient. The key hospital operational processes include: a. Patient admission; b. Outpatient clinics and laboratories; c. Treatment preparation, medical examination and patient instructions; d. Nursing care and patient monitoring; e. Patient discharge. Each of these hospital operational processes receives inputs (arriving arrows) and produce outputs (outgoing arrows). Information service interoperability is introduced within all the distinct operations within the hospital environment. The HIS provides a medium for data and information interchange. Furthermore, recent developments and the availability of digital library technologies may enhance the role of hospital library in designing information services in the hospital (Kostagiolas et al. 2007). In this way, distinctive operational data and information units are not isolated, but are managed within a holistic patient-centred information services environment. Inevitably specific technologies and hospital processes may find this model of more relevance than others.

Figure 1. A user-centered hospital operations process map for information service integration and application reuse (modified from Kostagiolas et. al., 2007).



One hospital service where we believe it may be particularly beneficial is Radiology as illustrated by the following examples. Especially designed information services may be used for increasing interoperability between the radiology department and the overall HIS, as well as of the presentation of the medical results using computer assisted image diagnostic tools. Such an approach involves information services based on the principles of diagnostic imaging and interventional radiology fields (Hillman, 2000). Also involves the judicious use of external evidence and objective information, which are integrated with clinical expertise and patient-specific preferences to make decisions regarding the care of an individual patient. Hence, the use of radiology information services might be important because (Bui, et al. 2002):

1. **Increase information availability:** Information about the reference textbooks available in many radiology libraries and other information providers are often out of date.

2. **Increase information interoperability:** Electronic databases with patient data deign scattered across different data sources (e.g. radiology information systems [RIS], picture archive communication systems [PACS]), make it difficult to provide quick, simple, effective and comprehensive consults for reporting the imaging results.

3. Radiology information services through image segmentation techniques

Screening the final results is an effective way to solve clinical problems through imaging techniques as well as documenting the presence or absence of a disease or condition and managing the next planning/decision considering medical conditions. Radiology information services can be used either for diagnostic imaging or screening. Both cases are important for the investigation and the final decision of a medical problem. For the first direction, radiologists can apply diagnostic methods considering either statistical techniques or image analysis techniques or a combination of both. The main task is the investigation of a medical problem after considering a couple of testing rules. Considering the second direction, screening is the most important part for checking the outcome of a disease. That can be done either by representation of important statistical measures, or by computer assisted medical tools.

Standard radiotherapy techniques as well as the modern 3D treatment planning techniques, like intensity-modulated radiotherapy, aim to maximize the dose delivered to the target while minimizing the exposure of the dose-sensitive structures to high dose, thus increasing tumor control probability without increasing normal tissue complications. Calculation of the irradiation field position, orientation and size is done based on the shape and location of the target volume and the surrounding organs at risk. In addition to the geometric parameters that are calculated based on the Volumes Of Interest (VOIs), the calculation of the dose distribution is directly related to the characteristics of the VOIs. Accurate segmentation is required for volume determination, 3D rendering, radiation therapy, and surgery planning. Once an accurate segmentation is obtained, an information service may provide evidence to be used by the radiologist in order to compare a) the volume and morphology characteristics of each region against known anatomical norms, and b) the volume and morphology characteristics of each region in the same image set. In many cases, especially in Radiotherapy Treatment (R.T.), reconstruction of a 3D shape of the particular organ must be applied for the benefit of cancer treatment. Illustration of the organ involves an anomaly, clinical problem or general artifacts. Visual representation of the particular organ, in addition to clinical examinations, could be a powerful tool to the doctors for diagnosis, medical treatment or surgery.

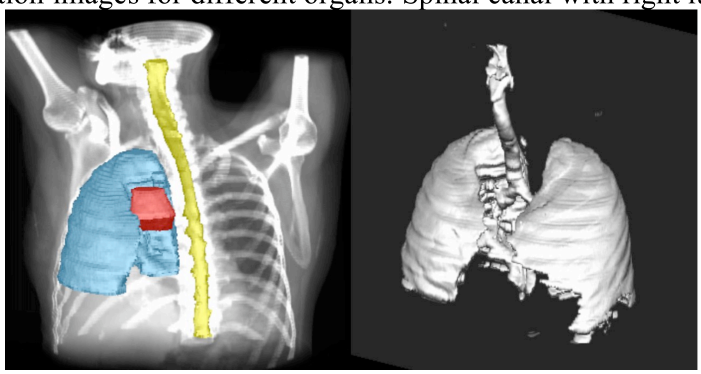
3.1 A radiology image segmentation information system

Image segmentation is currently used in several medical imaging applications that involve diagnosis or treatment. Among several treatment applications, radiation therapy treatment of cancer is an area where segmentation of anatomical volumes is an essential procedure. Physicians have to deal daily with large amounts of data and information that must be segmented accurately and within a reasonable time frame. Substantial computational and storage requirements become especially acute when object orientation and scale have to be considered. Overall, image segmentation approaches may be performed in one of three ways: (1) manually, in which the user specifically selects pixels to be included in the region of interest, (2) automatically, in which a computer selects pixels based on a previously determined set of rules and (3) semi automatically, in which both manual and automatic methods are used in combination. The differences in these types of interaction are the amount of time and effort required, as well as the amount of training required by the operator. Even automated segmentation methods typically require some interaction for specifying initial parameters that can significantly affect performance.

Computer tomography (CT) has become an important clinical diagnostic tool in radiography. Information services including the employment of computer graphics and advanced rendering algorithms may support the quality of radiography. In order to reduce the investment of time and effort by the radiation oncology staff, several image analysis tools are integrated. In medical images, a human expert has traditionally involved in segmentation process. Even with the aid of image processing software, manual segmentation of 3D CT images is tedious time-consuming, and thus impractical, especially in cases where a large number of object must be specified. Traditionally, image segmentation denotes the technique of extraction of image entities or structures (regions or objects), so that the outlines of these structures will coincide as accurately as possible with the physical 2-D object outlines (Haralick & Shapiro, 1985; Gonzales & Woods, 1992; Pal & Pal, 1993). An object region is a set of image pixels, which are similar with respect to a homogeneity criterion such as texture.

Regarding segmentation techniques, several contour and region based approaches have been proposed. The former, while being generally more computationally efficient, are often less robust and more sensitive to noise and variability of data. Improvements have been introduced by techniques for segmentation based on data-driven elastic models such as snakes (Kass, et al. 1987) and deformable surface models (Terzopoulos, 1987), which have also been applied to the field of medical imaging (Eviatar & Somorjai, 1996). These models can be 2D image curves or 3D polygon meshes, which are adjusted from an initial approximation to the image or volume features by a movement caused by simulated forces. Image features provide the so-called external force. An internal tension of the curve resists against highly angled curvatures, which makes the Snakes movement robust against noise. After a starting position is given, the Snake adapts itself to shape by relaxation to the equilibrium of the external force and internal tension. Snakes have been proven efficient and fast for a number of applications in medicine involving different imaging modalities (Grosskopf et. al., 1998).

Figure 2: 3D segmentation images for different organs: Spinal canal with right lung and tumor.



A radiology image segmentation information system allows the user to draw contours around the tumor, target, and normal tissues on a slice-by-slice basis and provides, at the same time, a cross-reference to planar images. A function that significantly accelerates the contouring process is the linear interpolation between the original key-contours. The same principle can be applied for defining structures in both planar planes, sagittal and coronal. The contour edit functions allow the user to move, scale and rotate an entered contour in addition to providing tools for rapid contour corrections and copying to inferior and posterior slice. Organs with large differences in their intensities can be segmented semi-automatically. In terms of user effort the only action required from the user is the selection of an initiation point for the algorithm on the original axial slices. The complete 3D geometry of the organ will be traced automatically. Some of the common organs with high sensitivity factor and vital importance are the lungs, the spinal cord and the trachea (26-30). In addition to those organs, the external body contour can be extracted in a similar manner. The contours that are generated semi-automatic can be manipulated and modified at the same manner as those defined manually. The user has the possibility to reconstruct the segmented organs as volumetric structures (Karangelis & Zimeras, 2002A; Karangelis & Zimeras, 2002b; Zimeras & Karangelis, 2001). Figure 2 illustrates different 3D reconstruction examples of segmented structures. In practice, the system is capable to interface any CT scanner devise and any treatment planning system through DICOM communication protocol. The DICOM protocol handles security issues and is employed for communicating digital images from the medical imaging modalities.

3.2 Radiology image segmentation information system performance

The system is installed in the clinic of Offenbach, and a large number of patients have gone through virtual and real simulation. For 80 patient cases, we performed time measurements on the real Simulator and on virtual simulator system (EXOMIO). The different patient's cases are shown in Table 1.

Table 1. Patient simulation cases.

Patient Case	**Number**
Head & Neck	10
Thorax *Includes breast, lung, sternum and clavicle cases*	34
Pelvis *Includes prostate, rectum, vegina, penis cases*	29
Abdomen	7
Total	**80**

For each case we measure the time spent for the patient, for the medical-technical assistance (MTA) and for the physician. The results are shown in Table 2. If one examines Table 2 may notice that the total time needed for a real simulation is near to 30 minutes. It is interesting to notice that the physician spends most of his/her time on documenting the patient case. The measurements recorded using EXOMIO are shown in Table 3. In the case of virtual simulation no MTA is involved. In this case the patient has to go only though the CT device (Karangelis & Zamboglou, 2001).

Table 2. Time needed, for patient and personnel, while performing simulation using real Simulator.

Person	**Process**	**Mean time in min.**
Patient	Waiting	27,7
	Simulation	31,1
Total		**58,8**
MTA	Positioning	2,9
	Fluoroscopy	5,0
	Develop X-ray	4,1
	Patient Marking	3,8
Total		**15,8**
Physician	Documentation	15,5
	Fluoroscopy	5,0
Total		**20,5**

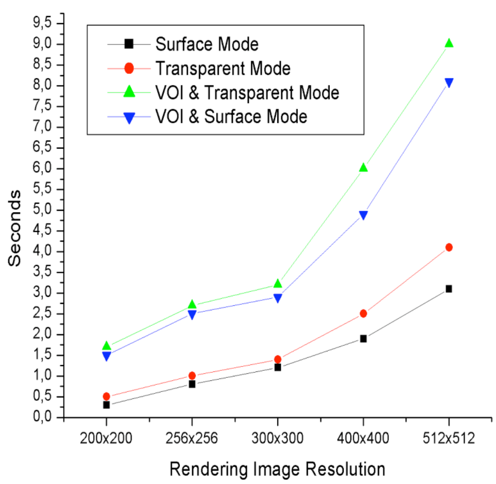
The physician on the other hand spends most of his time on preparing the patient plan. She/he has to perform the structure definition on the EXOMIO console. As mentioned in the system features, one can define structures in any orthogonal slice direction. In addition the existing contour interpolation techniques are tools that accelerate the laborious contouring process.

Table 3. Time needed, for patient and physician, while performing simulation using EXOMIO.

Person	**Process**	**Mean time in min.**
Patient	Waiting	20,5
	CT scan	12,8
Total		**23,3**
Physician	Structure definition	6,5
	Field placement	3,0
	Documentation	3,0
Total		**12,5**

3.3 Volume rendering performance

The EXOMIO uses two different views that involve volume rendering: the BEV where perspective projection is used and the OEV where parallel projection is used. The experiments are performed on a double processor (2xPentium III 450MHz) PC with physical memory 512Mb. For each view we performed time measurements for several rendering image sizes using different data resolution. The goal of this experiment is to examine the volume rendering interactivity as well as to prove the effectiveness of the system for large amount of data.



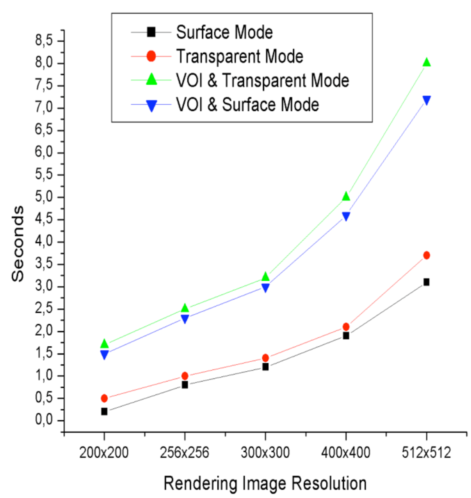


Figure 3a: Volume reconstruction times for the Figure 3b: Volume reconstruction times for the

perspective projection parallel projection

The first series of experiments (Figure 3a, b) involve the use of CT volume with resolution 84x512x512 and 256 gray values. For both views we define and reconstruct the same volume of interest (VOI). The time needed for reconstruction is very similar for both views. In general using a rendering resolution 200x200 and 256x256 the reconstruction time needed starts from 0.6 seconds for the surface mode and up to 1.3 second for the transparent mode. The reconstruction time is almost duplicated in case of VOI's reconstruction. Figure 4a illustrates the reconstruction time relative to the amount of data used. For these experiments we maintain a constant rendering resolution of 256x256 pixels, which is very common in practice. A comparison for the system memory relative to different amount of data is presented in Figure 4b. The results suggest a linear increase in required memory as it was expected. Important is that a PC with 512MB physical memory can manipulate up to 300 slices with a rendering speed for transparent mode between 1.2 and 1.8 second and for the surface mode between 0.6 and 0.9 second.

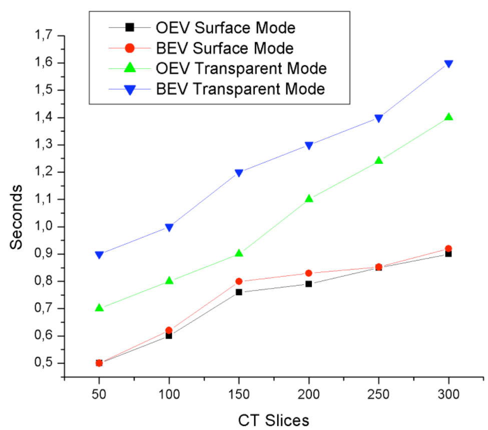


Figure 4a: Volume reconstruction times relative CT slices with rendering image resolution 256x256 pixels

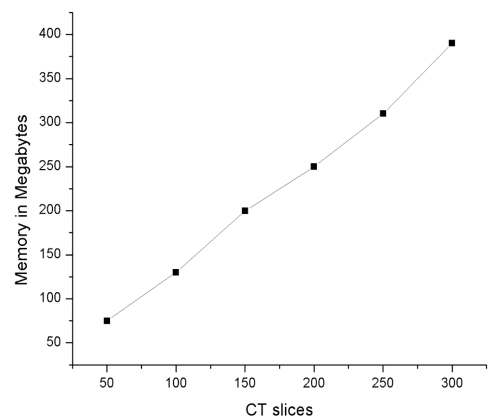


Figure 4b: The system memory cost in the loaded MB relative to the loaded amount of CT slices

3.4 Clinical material

One example of the use of EXOMIO in clinical practice is presented. The patient is a 58 year old patient with stage pT2pN1Mo carcinoma of the breast. The patient received radiotherapy of the left breast and the supraclavicular region after breast conserving surgery and adjuvant chemotherapy. The radiation fields cover the entire prostate gland, which includes safety margins. For this case, CT slices of 3mm thickness and 3mm slice distance have been reconstructed using spiral CT acquisition from a 512x512 pixel matrix where a total of 119 slices were needed. For the breast case, three radiation fields were used. Figure 5 shows the planning procedure for two tangential, opposing, asymmetrical 6 MV photon fields for the treatment of the left breast region. Individual blocks have been used to protect the lung tissue. Figure 6 shows how the radiation of the supraclavicular region was applied using an anterior half field. All fields have a common isocenter. Setup of the patient during CT acquisition and treatment was done in supine position with the arms located up over the head (see Fig 7). The size of the CT gantry opening (70 cm on the Siemens Somatom CT) was not critical for the right positioning of a female patient.

Figure 5. Planning procedure for two tangential fields for the treatment of the left breast region. (Top left) 3D room view of the virtual simulator and patient. (Top right) Digital reconstructed radiograph (DRR) for the 309° field with the individually designed block. (Bottom left) Axial plane at a level where lungs and heart are visible, showing the 309° field configuration. (Bottom right) Observer eye view (OEV) showing the patient with the light field projection on the skin for the 309° gantry position.

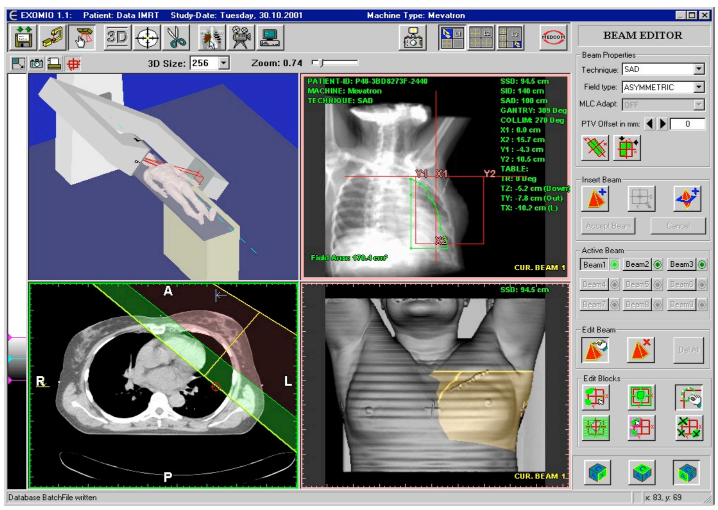


Figure 6. Planning procedure for anterior field for the treatment of the supraclavicular region. (Top left) 3D room view of the virtual simulator and patient. (Top right) Digital reconstructed radiograph (DRR) for the 0° field. (Bottom left) Sagittal view with the anterior field. (Bottom right) Observer eye view (OEV) showing the patient with the light field projection on the skin for the 0° gantry position.

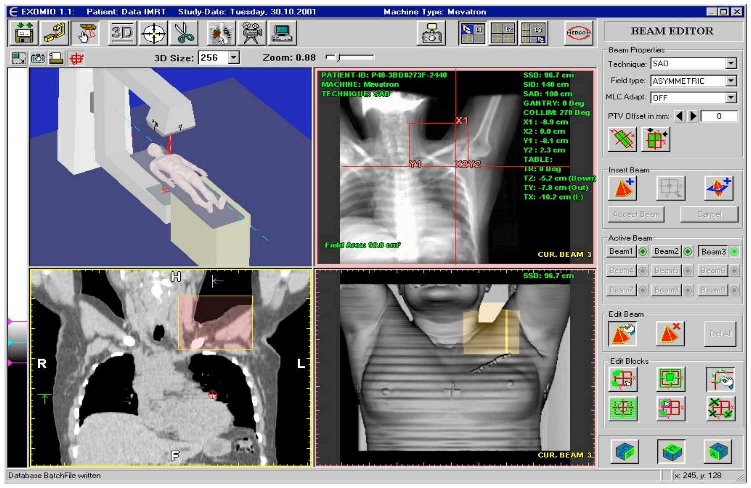
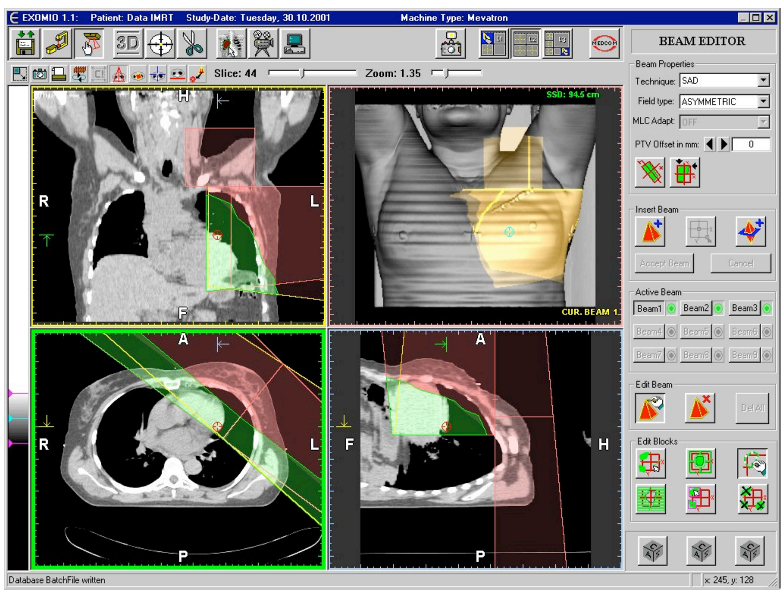


Figure 7. Planning procedure overview. (Top left) Coronal plane with the two opposing tangential fields and the anterior field. (Bottom left) CT slice at the thoracic region with the two tangential fields. (Bottom right) Sagittal plane with the two opposing tangential fields and the anterior field. (Top right) OEV showing the patient with the light fields projections on the mask and skin for all fields.



4 Conclusions

Over the past decades advances in information and communication technologies significantly contribute in a) improve the quality of the provided healthcare services and b) constantly improve the hospital operations. Interoperability is indeed a very important issue. The primary goal is to extract the highest quality images that provide the most accurate diagnostic information, depending on experience, previous available medical cases and computer assisted visualization tools. Based on the previous statement, radiologists need to evaluate during the medical process a large system of clinical target RT images with the main purpose being to maximize their medical decisions based on the parallel clinical investigation through diagnostic imaging results. At the same time, new medical cases must be included for the benefit of the doctor's decisions into medical database. Information and quality in healthcare are indeed two interrelated concepts (Kostagiolas, 2006).

Implementation of this radiology information could be achieved by using simulators, which are medical devices employed in the oncology clinics to perform the simulation for the external beam radiotherapy treatment. Unlikely for a clinic to obtain a real Simulator is a high investment in terms of money, space and personnel. The alternative here can be a Virtual Simulator (VS). The implemented high-end visualization techniques allow the users to simulate every function of the real simulator, including the mechanical component movements, radiation beam projection and fluoroscopy. In this paper, a hospital process map is provided in order to manage radiology information services, study interoperability of hospital processes issues and finally design radiology information services based on image segmentation techniques. Furthermore, we present a process that can be used for the accurate semi-automatic segmentation of the important target in use organs (like skin, lungs, spinal canal, and bronchus) in three dimensions from CT images.

The method employed is basically composed from an edge detection algorithm, which is applied on the original, axial CT images. The implemented method is based in 2D boundary tracking (BT) algorithm, and it works at one image level at the time. In the case of the CT modality, the algorithm is applied on the original (axial) cross section images. Our clinical experience is described using patient example (breast cancer). The advantages of virtual simulation system over classical simulation would be presented, and the clinical effectiveness would be emphasized. The model and examples presented in this paper demonstrate how information services can play a fundamental role in healthcare. Novel services which are based on information management may be introduced within hospital process and thus significantly contribute to both the quality of the provided healthcare services. A significant step is the concept of an integrated hospital process-based management for information interoperability purposes. Innovative information services let not only to access-use information for diagnostic, treatment and research purposes but also to re-use their functionality, e.g. the radiology information services.

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