Radiotherapy Support Tools, the Brazilian Project: SIPRAD

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Abstract: The radiotherapy planning process (teletherapy) is initially performed by the acquisition of Computed Tomography images of the areas of interest to guide a series of health professionals in the work of vector design of regions of interest for protection (risk organs) and radiation (tumors). All these steps are performed using computational tools that extrapolate measurements and scales in the treatment plan. The efficiency of the treatment depends on the recreation of the patient's positioning on the linear accelerator stretcher with the previously acquired tomography images. For this, in this article, we present three modules of the SIPRAD (Information Systems for Radiation Therapy Planning) project. With the name of Radiotherapy Portal it is able to perform a fusion of planar images of the target region, made on the day of treatment, with the digital recreation (DDR - Digital Reconstructed Radiographs) of this radiograph generated from the Tomography of treatment planning, aiming to improve the reproducibility of the positioning that the radiation dose delivered during all the radiotherapy treatment. The second module named by LYRIA PACS RT provides a client/server architecture for storing, distributing and displaying images from any systems using the DICOM RT Struct, Image, Plan and Dose modes. The third module called Contouring is responsible for the training of new radiotherapists.

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1 INTRODUCTION

There are several difficulties in radiotherapy planning in latin american because few hospitals have solutions that have a complete planning system for the radiotherapy treatment.

In Brazil cancer treatment reality patients who treat in the public system, only 16% start the procedure within 30 days; the average waiting time is 113.4 days. According to the Brazilian National Nuclear Energy Commission (CNEN), there are 371 linear accelerators (LINAC) in operation in Brazil, of which 260 are in the public health network. This means that there is at least a 40% shortage in the supply of machines. 55% of LINACs are located in only 4 states (27 states in all), 70% is the average yield of a LINAC due to a lack of professionals and maintenance and operation processes (SBRT, 2018). Besides the lack of LINACs, another problem is related to a shortage on expert systems linked to the Brazilian reality of treatment.

The patients' positioning and location of the target regions (tumors) at the time of treatment, which is fundamental in the efficacy of the treatment, is carried out in an artisanal manner. In some hospitals (at least 80%), it is attempted to guarantee the reproducibility of the positioning through the use of molds, and ink markings, as a kind of tattoo for temporary marking of the correct region of radiation application. Recently the Federal Council of Medicine has chosen to recommend the use of radiotherapy planning software generating demand for this solution. It was necessary to build a solution to increase the accuracy and improvement of the radiotherapy treatment process in public and private hospitals in Brazil, creating a robust product and cost alternative with the Latin American reality for such systems. The SIPRAD project (Information Systems for Radiotherapy Planning) aims to build a series of software for this urgent Brazilian need to evolve the demarcation process and improve treatment.

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In addition to creating a unique architecture on the regional scene, SIPRAD is interested in building interoperable systems with all linear accelerators (LINAC) in the market as well as its proprietary planning systems. Thus, communication between all the radiotherapy treatment workflow entities are integrated and operating together.

The SIPRAD project is currently in final development, with tests in Brazilian hospitals. Some modules are under analysis by local and international health surveillance certifiers.

Among the SIPRAD solutions that were developed: a contour design application, a PACS RT, a radiological scheduling system integrated to the RRIS radiotherapy and the Radiotherapy Portal.

For a 2D Portal system, the digital radiographic image (portal image) is acquired from each patient before the moment of radiotherapy treatment. The portal image is then fused with a reconstructed digital radiograph from the anterior tomography allowing for corrections of its positioning (Maria Y Law, 2009).

2 SIPRAD

The SIPRAD (Information Systems for Radiotherapy Planning) is a tool for managing and controlling the flow of radiotherapy treatment. Provide an intuitive and efficient way to define all steps of components suitable for a public or private clinic or hospital (Carvalho, 2018).

SIPRAD has access via patient data entry and Computed Tomography scan in the axial plane. The system stores the system inputs and presents specialized interfaces for each type of end user according to their needs. From a computational architecture point of view, SIPRAD can be presented separately as a Client/Server (front end/back end) system. The green parts in Figure 1 represent the back-end (server-side) solutions, while the pink solutions are front-end (client-side) solutions. For each service offered to medical or patient clients, there is a specialized server containing services hosted in clinics, hospitals or data centers (cloud). On the back end side, we have the RIS RT and Lyria PACS RT (Radiology Information System for Radiotherapy) that are directly connected to the workflow module. The 2D Portal and IGRT are fundamental for the improvement of the accuracy/quality in the radiotherapy sessions. The Plotting and Simulation tools are linked directly to the Contours module. The Planning and Management Software is already linked to the planning and management modules respectively. Also, finally, the Onco APP is a way of accessing patients to the critical items of their treatment. The Onco APP is an extension of the workflow module aimed at a restricted view of information within the interest of the user to the type of patient.

The system stores the inputs and presents specialized interfaces for each type of end user according to their needs. To facilitate its interoperability and communication actions the DICOM (DICOM, 1999) standard is used. More specifically the DICOM RT (Maria Y. Law, 2009) standards that are used: Dose, Plan, Image, and Struct.

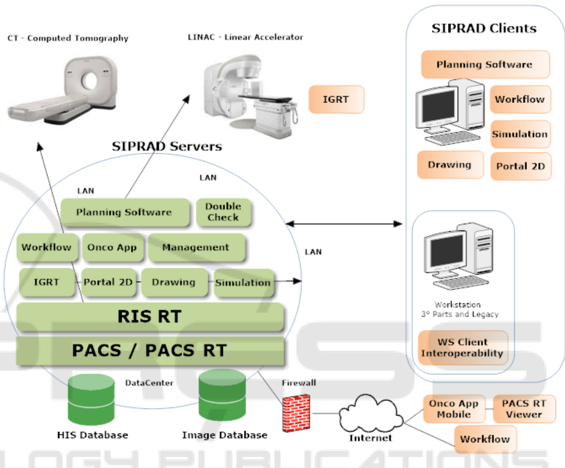

Figure 1: Architecture of SIPRAD.

For better understanding and separation of the DICOM RT storage actions, the SIPRAD was divided into four modules. The four modules of SIPRAD are Workflow, Contours, Planning, and Management. Workflow is the largest module; it is present in practically the entire SIPRAD solution. The Workflow module has the role of extracting the patient data from the Hospital/Clinic worklist by using the Lyria PACS (Carvalho, 2015) worklist solution and creating interfaces of all the system registries, including those of patients. It also monitors the patient during the treatment process at the hospital and brings their agenda of radiotherapy appointments and sessions, also allows patient event logs and reports. Workflow actions are stored in SQL like database.

The Contour module has DICOM with Query /Retrieve communication with Lyria PACS (Carvalho, 2015) and performs Computed Tomography scans (CTs) of the patient making them available, through a specialized interface, the

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contouring of the areas of interest (GTV –Gross tumor Volume, CTV- Clinical Tumor Volume, and PTV - Planning Tumor Volume) and OARs (Organs at Risk). After the delimitation of these important structures for their treatment, the data is transferred to the Planning module.

The Planning module is responsible for the creation of Isodoses, BEV (Beam Eye View), DVH graphs (Dose Volume Histogram), and areas to be irradiated in the radiotherapy treatment. Still, in the Planning module, the user has a friendly interface available that interacts with 3D objects to facilitate the process. It also has the possibility of printing data for the assignment to the corresponding person in charge according to the process of the institution. In Figure 2, you can view the layout of the Contours module.

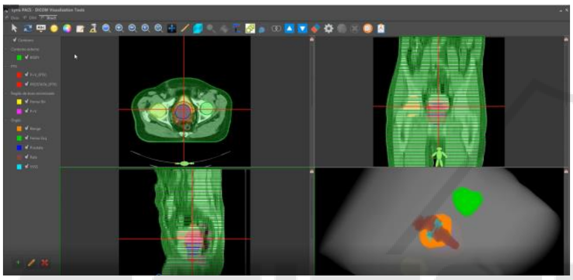

Figure 2: Contours Module Delimitation System.

In Figure 2, we can visualize the interface of the delimitation system; basically, we have a Computed Tomography scan that doctors and physicists perform the generation of contours of areas of interest utilizing specialized delimitation tools which generate vectors. The Management module is responsible for the creation of molds and filters that are inserted in the particle or linear accelerator (LINAC). This module is also responsible for communicating with the linear accelerator to perform the exam. It is also possible to send data to the radiologist technician who performs the treatment session, such as the table position in X, Y, Z, and gantry angle of irradiation of the apparatus.

3 2D PORTAL

3.1 Marking Process

Before and on a weekly basis during the treatment, 2D orthogonal (anterior-posterior and lateral-lateral) radiographic images of the target region are acquired. The images are acquired with Cross-Hair, an accessory that generates a scale with the origin at the center of the target and provides real magnification, recorded with patient information and saved in DICOM format. The same coordinate axis scale is generated digitally in the digital reconstruction of the orthogonal 2D radiographic images (DRR). These scales are of fundamental importance for the process of comparison of the radiographic images, since the coincidence of the origin of the scales, the relative distances of the bone structures with the scales are the same parameters used to confirm the exact reproducibility of the location with the planning, this is maintained during treatment. As the radiotherapy today is mostly isocentric (the target lies in the center of the axis of rotation, and the radiation source is around the patient) the comparison of orthogonal 2D radiographic images with the reconstruction of the same from the planning tomography (DRR), increase the accuracy of planning reproducibility based on bone marking. The overlapping of these images (radiographs and DRRs) through a digital fusion facilitates the comparison of them by the responsible doctor. This analysis is based on the coincidence of the coordinate axis scales, with the DRR being the reference image for the comparison.

The time for demarcation and analysis with this tool facilitated the process and increased accuracy. It is estimated that 28% of the time was gained with a 60% increase in accuracy for testing in 100 adult patients.

3.2 Computer Tool

Initially, for better control of the axial, sagittal and coronal images of the project, it was necessary to implement the MPR algorithm (Multiplanar Reconstruction), enabling the 2D Portal to generate new planes interpolated from the default axial plane from the acquired tomography examination. This computational process of generation of new interpolated planes has algorithmic complexity O (n^3). Thus, it was necessary, the implementation of computational parallelism routines with adapted programs to be processed to user threads in Java.

Once the MPR was stabilized, the stage of fusion of radiological images implemented according to the needs of the medical team was carried out, in order to facilitate the patient's positioning and image acquisition process at the time of planning, thus a specialized interface was developed to perform fusions images (CRs, DRs, and DXs) with Computed Tomography (CTs) images. In Figure 3, we can visualize the interface created for this action; we can visualize in “A” the target with the sagittal

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positioning of a head/neck x-ray with the patient already in the radiotherapy position.

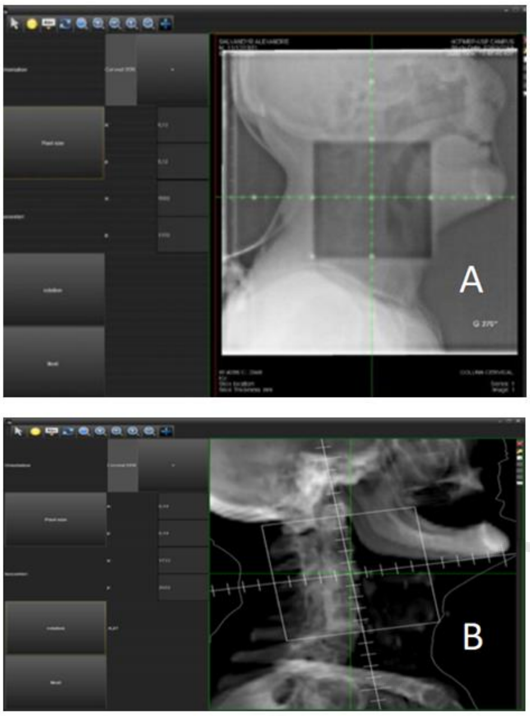

Figure 3: Fusion of X-ray Images and DRR (Computed Tomography).

In "A" of Figure 3, the dark rectangular region corresponds to the holes of the lead block in the positioning present in the gantry of the linear accelerator. In this phase, it is important to calibrate the quantity and pixel positioning of the DRR (Digitally Reconstructed Radiographs) image scale. In "B" of Figure 3, we can see a rotation of the block concerning the sagittal plane. The user can rotate, translate, zoom in and out to make it easier to position.

To facilitate the visualization of two different images in real time, a matrix visualization feature (2x2) was created in which the main or secondary diagonal is chosen to visualize the image that is in the bottom layer; we call this action of "Fusion Division". These options facilitate the change of transparency between the overlaps made in the fusion processes. From the mouse actions, half of the DRR (the lightest region) and the remainder of the standard radiography (darker region) are visualized as shown in Figure 4.

After conferencing this placement, the system reports the differences of distances in millimeters between the (virtual) study model and the (actual) patient at the moment before the radiation. In this way, the technician can adjust the patient in the correct position to be irradiated in LINAC.

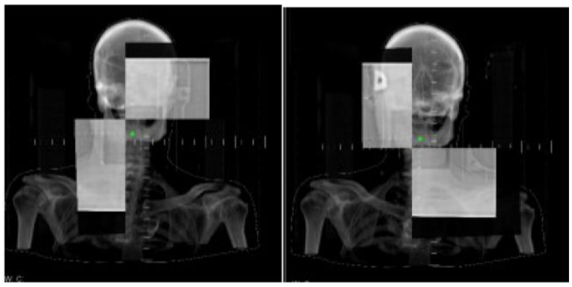

Figure 4: Transparency matrix view for merged images.

4 LYRIA PACS RT

Strong customer demand on the national scene, and not contemplated by any market solution currently, refers to obtaining a PACS RT. This type of system is independent of the architecture acquired by the clinic or hospital that has radiotherapy services, as it does the storage, viewing, and distribution of the examinations of any system brands as long as they work with the standard DICOM RT. More specifically, the Lyria PACS RT (Picture Archiving Communication System for Radiotherapy Planning) is an extension of the Lyria PACS system (Carvalho, 2015) and works on the backend side (server) responsible for the following services:

1. Storage of DICOM RT (Thiruchelvam, 2005) images in magnetic or optical media;
2. Connections for health services and informatics departments (HL7, XML, SGBDs via web services, and others);
3. Recovery of images in the short or long term;
4. Viewing images in remote diagnostic stations; View of DICOM RT (DICOM RT, 1997) structures in a simplified and responsive universal environment, in this case, web.
5. Image-friendly interfaces (Web and desktop clients);
6. Fast and secure communication via computer networks;
7. Patient Worklist Service and communication with other equipment;
8. Interoperability for other systems through the use of Web Services;

The C-ECHO SCP / SCU (ping) and C-STORE SCP / SCU (storage) protocols are obtained directly from Lyria PACS (Carvalho, 2015). Also, it was necessary to extend the DCM4CHEE (Max, 2007) library in the Java programming language by determining a storage hierarchy of the DICOM RT structures of the project on the servers.

The implementation of item 2 was performed via integration with a SQL like database. The creation of the resource of item 3 was done through a service called Query/Retrieve, where we can create DICOM entities called AETitles that have an IP (Internet Protocol) and a port registered in the database. An example of this action can be seen in Figure 5. In this process, the equipment can exchange exams and content information with each other.

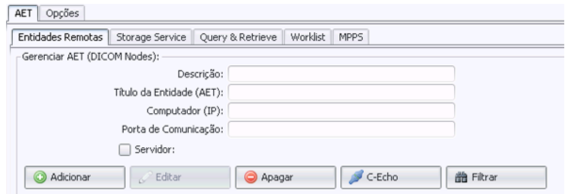

Figure 5: SIPRAD project worklist integrating RIS RT and PACS RT.

The implementation of items 4 and 5 occurred with the integration of the SIPRAD contour interface to search for exams with the DICOM RT protocol (Maria Y Law, 2009). Item 5 refers to the friendly PACS server interfaces, an example of the PACS RT web interface can be seen in Figure 3. This web interface is only for reading and manipulating PTZ (Pan, Translate and Zoom). In Figure 3, it is possible to visualize the main phases of the radiotherapy treatment performed by the VARIAN Eclipse or Aria system. This exam presented in Figure 6 was obtained from the integration with a VARIAN server of the HCRP (Hospital das Clinicas de Ribeirão Preto).

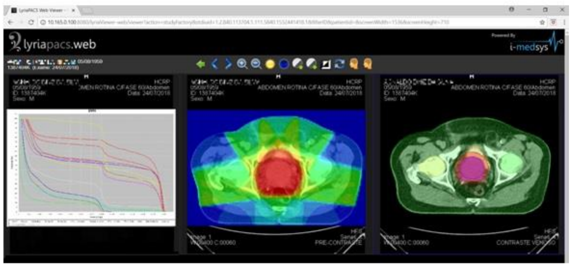

Figure 6: Lyria PACS RT web interface.

In Figure 6, we can visualize on the left side the DVH (Dose/Volume Histogram) graph in the center, a tomography with the isodoses curves and the right the structures plotted on a tomography in the axial plane. To perform the visualization of structures, it was necessary to parser many proprietary tags, in addition to the tags common to the DICOM RT standard. Two examples of proprietary tags from the Finnish company VARIAN can be seen in Table 1.

Table 1: Proprietary tags.

Tag	*VR*	**Data**
(3285,0010)	LO	[0034] [Varian Medical Systems VISION 3285] Private Creator Data Element
(3285,1000)	UM	[0066][\FE\FF\00\E0:\00\00\00\852\10\00"\00\00\00 Varian Medical Systems VISION 3285\852\01\10\08\00STANDARD]

In TCP / IP communication between servers and computers is done using the RESTful API and HTTPS protocols in user authentication (item 6).

Figure 7 shows a complete worklist (item 7) implemented for the HCRP hospital structure, where it is possible to see a list of anonymous patients. This worklist is generated in the morning of the day containing the schedules of patients obtained from the Workflow module. After the list is generated, it is sent to the radiological acquisition equipment and linear accelerators that are registered as DICOM entities. Item 8 refers to interoperable integration with other systems made according to the DICOM standard version 3.0.

This system-to-system communication functionality is paramount for PACS RT testing in clinics and hospitals communicating with RIS and HIS (Hospital Information System) systems.

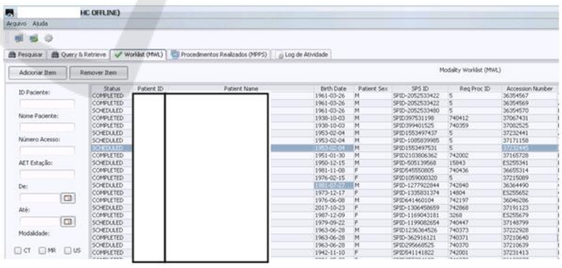

Figure 7: Worklist of Lyria PACS RT.

5 CONTOURING TRAINING TOOL

The contouring training tool is a version of RTPS capable of measuring the degree of similarity between a student and another contour created by an experienced doctor (teacher). Figure 8 shows the process of a typical

test using the Training Contour Tool. In the first step is to teacher choose exams to determine the contours of OARs and TVs. After that, the teacher draws the contours of the answer sheet. In the second step, student's log in the system to create free contours in the axial CT. In the third step, these students create a fill contour for all OARs. In the fourth step, the students create the drawings and fill of the TVs.
In the fifth step, the student analyzes his result in the tool and can improve contours for only 2 times (evaluation rule). Finally, in the last step, the tool will generate students' contours similarities and calculate the student´s grade.

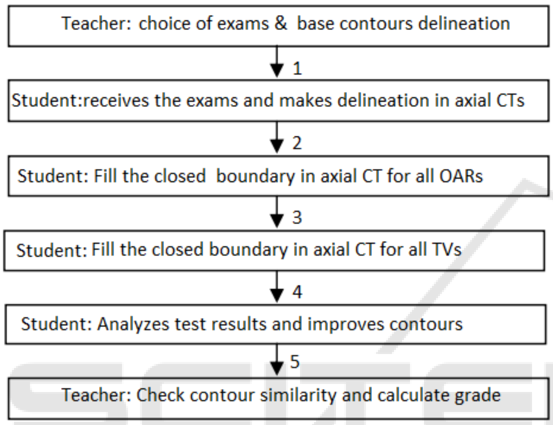

Figure 8: Process Tests Tool Contours.

In the process the Jaccard index is used, also known as the Jaccard's coefficient of similaritiy, is a statistical component to compare similarity and diversity between two sets. The Jaccard index is defined by the size of the intersection of two sets, divided by the size of the union of the same sets (Jaccard, 1901).

In this study it was used a structure (ROI) represented by a set of spatial points (x, y, z). These points are drawn in each axial section of the CT. Each structure is represented by a set of many spatial points, where each subset belongs to each cut of the digital tomography. Each subset is represented by a set of spatial points that form a convex figure representing only the outline of the ROI structure. The Figure 9 presents the Jaccard index in left and the image results in right. The green region refers to the area that the student did correctly, the yellow region refers to the area that the student did not draw. And the red region refers to the area that the student has drawn wrong.

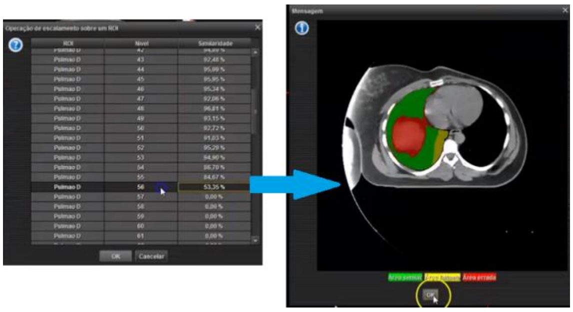

Figure 9: Training Contour Tools Interface.

6 CONCLUSIONS

The 2D Portal SIPRAD demonstrated precision in the determination of the displacements from the fusion when tested at Clinical Hospital at Ribeirao Preto (HCRP-USP), and it found greater agreement among the users on the positioning of the patient when compared to the fusion with visual analysis. Further testing with experts is required to verify the accuracy of the process by comparing the results with the existing models.

The Lyria PACS RT and Training contour tool is currently being tested in two hospitals in the state of São Paulo (INRAD in the capital and HCRP in the interior) and an Australian cancer hospital (Illawarra Cancer Care Center). Both hospitals have equipment and systems from the VARIAN and ELEKTA companies.

The SIPRAD project is currently in final development, with tests in Brazilian hospitals. Some modules are under analysis by local and international health surveillance certifiers.

The cost of SIPRAD will be approximately USD $10.000 for the basic solutions of the radiotherapy planning process according to SUS (Brazilian Public Health System).

In these tests, we will be able to analyze the operational data loads in a real environment to be presented in future work.

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