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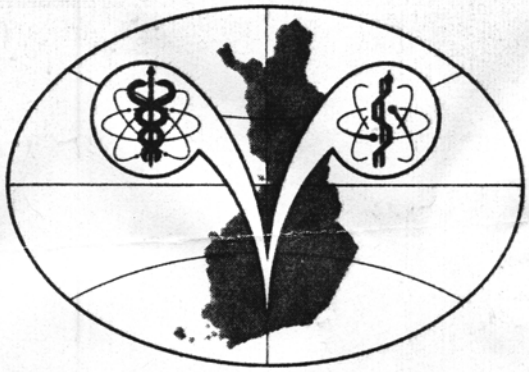

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4.9 A THREE DIMENSIONAL IMAGING SYSTEM FOR RADIOTHERAPY TREATMENT PLANNING

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INTRODUCTION

The integrated three dimensional display of anatomic data sets and dosimetric data can significantly aid the planner in understanding their often complex relationship. Unfortunately, the three dimensional anatomical, physical, and physiologic information now available for radiotherapy treatment planning from CT, magnetic resonance and ultrasound imaging significantly tax our present treatment planning methods. Our approaches to these problems include the reduction of extremely large data sets to their essential qualities (typically surfaces of relevant structures), interactive three dimensional display of anatomical data sets, and superposition of dosimetric data sets in the same space. A prototype of such a system is currently in clinical use at our institution and is undergoing continuing development. This work also includes the development of a set of software tools that use a CT data base to perform the functions of a physical simulator.

SYSTEM FEATURES

The computer used in our Department of Radiation Oncology is a Digital Equipment Corporation VAX 11/750. Magnetic tape and 8" floppy disks currently serve as the image input devices, and a direct link to a radiotherapy based CT scanner is planned. Display processing is done with an Adage 3000 image processor with an internal microprocessor which performs all display transformations, eliminating delays due to data transfer between the image processor and host. Conventional grey scale and color shaded images are displayed on a high resolution raster color CRT. True 3D images are displayed with a vibrating (varifocal) mirror display. Both displays are driven by the Adage 3000 image processor. Image interaction is achieved with knobs, trackballs, and 3D joysticks. A high resolution color ink jet printer and an 8 pen X-Y plotter are used for hardcopy output. Care has been taken to maintain hardware and software compatibility with a larger and more powerful research system based in the Computer Science Department. As software and hardware tools are developed they are transferred from the research system to the clinical system for evaluation and further refinement. Conversely, clinical images and data can be transferred to the research system for investigational work. The two systems are currently connected via a high speed modem but are in the process of being networked using a hybrid fiberoptics/coaxial cable system.

The operating system is Berkeley 4.2 UNIX and most programs are written in the C programming language. The software treats a sequence of tomographic cuts as a single 3D image which is stored in a standard format that allows the image processing programs to handle images of a wide range of sizes and configurations. When a sequence of cuts is first input, user specified options allow for certain operations to be performed on the image prior to display. Options include various types of edge enhancement, and adaptive histogram equalization (AHE), which adjusts the grey scale mapping at each point in an image to the local context, thus achieving good contrast throughout the image. AHE, has produced no perceived artifacts on hundreds of clinical images, and appears to be particularly useful for treatment planning in the thorax since it allows simultaneous display of lung tissue, soft tissue, and bony structures.

At present, structures of interest are identified slice by slice using a combination of automatic and manual edge tracing. The contours are stored and labeled by structure. We are at present working on techniques that work directly in three dimensions rather than slice by slice. When all structures have been so defined (or calculated as in the case of isodose or isoeffect curves), they can then be tiled to produce wire-frame or stick images of each structure. Display and specification of image parameters can be done directly on these line structures, or the tiled images can then be color shaded to produce solid or transparent renditions. At present two qualities of shaded image are in use. In one type, the tiles are clearly visible and only opaque shading is provided but the image may be interacted with (rotation, clipping, etc.) in real time. In the other a smooth shaded image with sophisticated lighting and transparency may be produced, with a very lifelike result. Transparency is proving somewhat effective in allowing the superimposition of anatomic objects and of dose contours on them. The user can also select arbitrary planes in the shaded image for the construction of conventional grey scale slices to inspect isodose curves and/or anatomy in nonstandard planes.

Contouring is not required for the varifocal mirror (VFM) display. The VFM image is a true 3D, self luminous image made up of point "lights" from the point plotting CRT. The light intensity at a point in the image is proportional to the image number at that point. Thus for CT images, bone is light and air is dark. However, intensity windowing, possible in real time, and edge enhancement can be used to make clinical structures of interest more visible. Isodose surfaces can be represented in a variety of ways. One particularly effective method is a web or net that flashes on and off. Near real time rotation, scaling, clipping and other interactions with the VFM images are also possible. The VFM is currently investigational in the clinical setting but shows promise for

aiding understanding of the global relationships of objects that do not have the clearly defined edges required for constructing shaded images.

Aside from their usefulness in aiding appreciation of anatomical and dose structures in three dimensions, three dimensional imaging modalities lend themselves readily to the development of new tools for designing radiotherapy treatments. One major example that is under development is the "virtual simulator". It is our feeling that the physical simulator can ultimately be replaced with considerable increase in functionality by a CT scanner and a set of software tools. The functions of the virtual simulator must include computed simulation films, computed fluoroscopy, display of light fields on the patient's skin (a computed Polaroid picture), localization of brachytherapy applications, and all other functions of the physical simulator. In addition, such functions as design of treatment portals using beam's-eye view perspective, display using transparent shaded displays of the "track" of radiation beams as they traverse the patient's anatomy, computed high energy port films, design of compensating filters based on beam positions and patient surface contours from CT, and numerous others can be added to augment treatment design and, more importantly, to remove most of the burden of three dimensional geometry from the planner.

CONCLUSIONS

A general 2D and 3D imaging system is being developed and used clinically for radiotherapy treatment planning. Even in its early form the system overcomes many limitations of conventional 2D systems for the effective display and fast interaction with complex 3D anatomical, dosimetric and physiologic information now available to modern radiotherapy departments.

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