Work Domain Analysis for Designing a Radiotherapy System Control Interface

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With rapid advancements in radiotherapy technology, the complexity of the radiotherapy treatment has multiplied over the past few decades. As a result, it has become increasingly difficult for radiotherapists to have a clear and logical overview of the system state during treatment delivery. Any consequent mishaps may result in serious harm to the patient. To address this concern, a novel radiotherapy control and monitoring interface which visualizes complex relationships and constraints within the treatment system may help radiotherapists understand and address any issues that may arise during radiotherapy delivery. As such, Ecological Interface Design (EID) was applied to redesign the user interface used during radiotherapy delivery. A literature review, ethnographic observations, and domain expert feedback were used to establish a work domain model of the radiotherapy system. From the work domain model, information requirements for interface design were extracted. Some of these requirements suggest the need for novel graphic elements which incorporate multiple treatment parameters for more integrated overviews of the system state. The results from the analysis will be used in the subsequent design phase, which will be aimed at designing a more effective radiotherapy monitoring user interface for improved patient safety.

INTRODUCTION

Approximately 52% of cancer patients require radiotherapy at some point during their treatment (Shafiq et al., 2009). With rapid advancements in radiotherapy technology, the complexity of the radiotherapy planning and delivery process has increased at an unprecedented pace over the past two decades. Generations of new technologies have been incorporated into radiotherapy, including computed tomography (CT), multi-leaf collimators (MLCs), intensity-modulated radiation therapy (IMRT), and volumetric modulated arc therapy (VMAT). These technologies undoubtedly help improve the accuracy of radiation delivery to the tumor by providing greater flexibility in the temporal and spatial arrangements of radiation beams and doses. Nevertheless, such advancements have also increased the complexity of radiotherapy systems, and thus, have made the perception of the system state more challenging for radiotherapists.

Radiotherapists must maintain an accurate and complete understanding of the treatment delivery system state and patient status throughout the treatment delivery process. However, a close examination of the current technology and the context surrounding some recent radiotherapy incidents reveal that existing radiotherapy systems may not provide sufficient support to address this critical need of radiotherapists. Decades ago, radiotherapy delivery only involved a few calculations, which every radiotherapist was capable of understanding, performing and verifying. Modern treatment planning, however, requires medical physicists to use specialized software to perform complex computations. The resulting treatment plan can incorporate a large number of parameters, which are beyond the capabilities of the radiotherapist to easily interpret. The radiotherapy delivery monitoring interfaces, as a result, usually display important treatment parameters in tabular form, showing planned and actual values for the radiotherapist’s verification. What is lost in this process is the radiotherapist’s grasp of the overall picture of treatment delivery, and how the treatment parameters work together to irradiate the tumor. From a human cognition point of view, the current interfaces cannot support such high level knowledge-based reasoning, and thus, do not adequately guide users during active problem solving. Moreover, Chan et al. conducted a heuristic evaluation of the current radiotherapy user interfaces and found 75 usability issues including inconsistency in the design of visual elements and inadequate visibility of information (Chan et al., 2012). Such usability issues aggravate the problem of poor understanding of the system state by making it more likely for important signals to be misinterpreted or overlooked. Not surprisingly, this problem is reflected in recent treatment incidents. The New York Times analyzed radiotherapy treatment records in the New York State and found 284 cases of patient receiving radiation in the wrong part of the body (Bogdanich, 2010). One of the patients with stomach cancer was treated with radiation to the prostate, and another patient with brain cancer received a breast treatment (Bogdanich, 2010). These serious incidents indicate the radiotherapist’s
insufficient understanding of the system state during treatment monitoring. In general, there is an absence of simple visual and radiographic cues to inform the radiotherapist of delivery errors (Marks et al., 2007).

To address this issue, the current study aims to redesign the radiotherapy delivery monitoring interface to better facilitate communication between the radiotherapist and the treatment system for improved understanding of the system state. The interface design method employed is Ecological Interface Design (EID), which aims to create a “transparent” interface where constraints of the work domain are visualized to facilitate problem solving and decision making (Burns & Hajdukiewicz, 2004). The motivation for EID came from problems arising in interface design of complex sociotechnical systems such as nuclear power plants and aircrafts, where operators do not always have complete and accurate mental models of the system and often have insufficient information to handle unexpected situations (Burns & Hajdukiewicz, 2004). System interfaces designed using EID have been proven to consistently improve the operator performance and reduce human errors over the state of the art in industry (Vicente, 2002). It is hoped that the application of EID to radiotherapy will help improve radiotherapy safety by reducing human errors. This article summarizes the first stage in the interface design process: establishing a work domain model and extracting information requirements.

**METHOD**

Multiple sources of information were used for the analysis. A literature review on radiotherapy, accelerator physics, and radiobiology was conducted to understand the fundamental principles and processes relevant to radiotherapy. In addition, ethnographic observations of radiotherapy treatments were conducted at the Princess Margaret Hospital (PMH), Toronto, Ontario, over the course of three weeks (University Health Network REB #08-0300-AE). PMH is one of the largest radiotherapy treatment facilities in the world with 17 treatment suites. A human factors expert observed the radiotherapist was conducted to refine the relationships and components and to identify the most important values and goals governing their actions and decisions during radiation delivery. In addition, an interview session with a radiotherapist was conducted to refine the relationships and elements in the model.

**System Description and Boundary**

The initial step for modeling the system was to clearly define the boundaries of the system under study to avoid inconsistency during the analysis. It is important to note that work domain analysis (WDA) usually does not consider the current interface or sensors as part of the system since including them may constrain the analysis to components in the existing interface.

When the linear accelerator (linac) delivers radiation to the tumor site, the radiotherapist’s decisions and actions are driven by two objectives: irradiate the tumor site as prescribed and minimize unintended harm to the patient (i.e., ensure patient safety). The radiotherapist’s main responsibility is to monitor the linac’s operation and the patient. Since tumor irradiation needs to be highly precise, one of the main aspects of patient monitoring is to watch for patient movement. Thus, immobilization measures and equipment are integral parts of the system. In addition, although imaging components are not operational during beam delivery, they are mechanically relevant, since they rotate about the treatment table and may collide with the patient. Therefore, a system containing the patient, radiation beam, and all the relevant hardware/software systems inside the treatment room (i.e., the linac, immobilization accessories, imaging hardware, etc.) was defined.

**Work Domain Model**

In determining the number of domains to use for the analysis, it was recognized that the patient and the hardware system are very different in nature and may constitute two separate domains. However, all parts of the system including the patient and hardware components work closely together toward the same goals of radiating the tumor and ensuring patient safety. Thus, the patient and the hardware system were combined into the same domain. Consequently, seemingly different components, such as the tumor and the imaging panel, were included in the same hierarchies. Although doing so sacrificed the consistency in the types of elements included, important cross-links between the patient and the hardware system could be preserved.

The work domain model was constructed using two separate but related decompositions of the work domain: a part-whole decomposition and an abstraction hierarchy. The part-whole decomposition (Figure 1) broke down the work domain into three different levels: system, subsystems, and components. The system being defined is the radiotherapy system during beam delivery, which consists of four subsystems: the beam delivery subsystem (linac), the patient subsystem, the imaging subsystem (only mechanically relevant), and the immobilization subsystem.

At the components level, each subsystem was not broken down to its most elemental components. For example, components such as the linac’s magnetron or electron gun were generalized as “beam generating components” in the model. Although these components are part of the treatment delivery process, their performance and specifications are beyond the radiotherapists’ expertise, and are more relevant to service engineers. Thus during a radiotherapy treatment, it may not be necessary to display detailed parameters related to these components. Instead, malfunctioning of any individual component may trigger a warning or an error to instruct the radiotherapist to seek technical support. In the case of the patient subsystem, the patient’s organs such as the heart or liver also have not been exhaustively listed in the model. Specific organs may be relevant for some types of treatments and not others. Due to this variability, the relevant organs
Figure 1. Part-Whole Decomposition of Radiotherapy Delivery Work Domain

Figure 2. Abstraction Hierarchy of Radiotherapy Delivery Work Domain
during a treatment were generalized as the tumor and the surrounding organs.

It is also noted that some components in the patient subsystem may not be physical components. During radiotherapy monitoring, patient wellness is an important aspect. Therefore, ‘soft’ components such as the patient’s speech or gestures were included in addition to anatomical components.

The abstraction hierarchy (Figure 2) describes the system in terms of means-ends relationships and is composed of five functional levels of abstraction: Functional Purpose, Abstract Function, Generalized Function, Physical Function, and Physical Form. The Functional Purpose level reflects the two fundamental objectives of radiotherapy systems: eliminate the tumor or reduce the size of the tumor, and ensure patient safety. At the Abstract Function level, the radiobiology principles, anatomical/geometrical constraints of the tumor and the patient, and patient safety values and constraints were included. The Generalized Function level included the key linac processes in relation to the tumor that allow meeting the radiobiology principles and anatomical/geometrical constraints at the Abstract Function level. Also, the Generalized Function level described patient-initiated processes/actions that allow minimizing collision risks and that signal changes in the patient’s physical and emotional well-being. The Physical Function level described various hardware components of the radiotherapy system (e.g., the couch, gantry, MLCs, immobilization accessories) and components of the patient (e.g., tumor, surrounding organs, and patient’s facial expression) that constitute the processes. The Physical Form level included various properties of the components within the hardware subsystem and the patient subsystem.

DESIGN IMPLICATIONS

The work domain model allowed systematic understanding of the radiotherapy system that radiotherapists work with during beam delivery. Specifically, the model allowed the identification of a number of new information requirements that are currently not available or easily accessible to radiotherapists. Table 1 summarizes the information requirements or variables extracted from the work domain model. The requirements marked with an asterisk cannot be measured by the current technology.

Some of the variables may be impossible to measure in real-time. For example, the effects of radiation on the patient would be an indicator of whether the intended effects of the treatment (i.e., tumor damage) are achieved. However, radiation effects usually become observable at least days after irradiation. Thus this variable cannot be monitored real-time during the treatment.

Some of the patient status indications could not be defined as concretely as other variables. For example, patients’ facial expressions may indicate their physical well-being, and the patient may use hand gestures to convey a message. These variables will likely differ for each patient and cannot be easily quantified or categorized.

Two important variables (underlined in Table 1) may form multivariate visual representations incorporating multiple treatment parameters. The first one is the spatial overlap of radiation beams to the tumor, which is mostly concerned with cancer treatment. During treatment planning, the three dimensional conformation of radiation beams onto the cancerous tissue is calculated and visualized using a planning software system. However, existing user interfaces for administering treatments lack such visualization. A solution may be to visualize the radiation beams in the current closed-circuit-television (CCTV) monitor. The second multivariate constraint is the clearance of the patient from the rest of the system, which is mainly for preventing collision. In the existing treatment technology, the hardware system has interlocks to stop the treatment in case of a collision. In addition, radiotherapists have access to CCTV views of the patient and equipment inside the treatment room. However, the parameters concerning various moving system components are readily available and could be incorporated into the CCTV view for better visualization of the clearance, allowing radiotherapists to prevent collision before it happens.

CONCLUSION

In general, one of the most important design implications from this WDA is that the current CCTV view of the patient in the treatment room may be enhanced to incorporate a number of treatment parameters for more efficient and holistic monitoring. For example, a superimposed image visualizing the radiation beam on the video could help identify treatment errors such as delivering radiation to an incorrect region of the patient’s body.

In the next steps of the study, the information requirements identified will be used to design a novel monitoring interface for radiotherapists. The interface prototypes will be developed and evaluated iteratively through usability testing with radiotherapists. The evaluations will focus on assessing the interface’s ability to help radiotherapists maintain an accurate and complete understanding of the patient and the machine status during radiation delivery.

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<table>
<thead>
<tr>
<th>Level</th>
<th>Information Requirements</th>
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<tbody>
<tr>
<td><strong>Functional Purpose</strong></td>
<td>Amount of radiation damage in cancerous tissue*. Amount of radiation damage in healthy tissue*. Amount of physical harm to patient*. Patient’s identity. Patient’s diagnosis and treatment type. Patient’s immobilization status*.</td>
</tr>
<tr>
<td><strong>Physical Function</strong></td>
<td>Beam on or off. Time since beam on. MLC shape. Wedge presence. Compensator presence*. Tumor at planned position or not*. Surrounding tissue at planned position or not*. Surrounding organs moving or stationary*. Patient moving or stationary. Patient speaking or silent. Signs of instability in patient. Position of patient contour*. Imaging source and panels locations. Couch location. Immobilization accessories presence*</td>
</tr>
</tbody>
</table>

*Cannot be measured with current technology

**REFERENCES**


