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Models of Surgical Procedures for Multimodal Image-Guided Neurosurgery

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Abstract

Improvement of image guided surgery systems requires a better anticipation of the surgical procedure. This anticipation may be provided by a better understanding of surgical procedures and/or the use of information models related to neurosurgical procedures. We are introducing a generic model of surgical procedures in the context of multimodal image-guided craniotomies. The basic principle of the model is to break down the surgical procedure into a sequence of steps defining the surgical script. Each step is defined by an action; the model assigns to each surgical step a list of image entities extracted from multimodal preoperative images (anatomical and/or functional images) which are relevant to the performance of that particular step. The model has been built in two phases: creation and consolidation. Besides, a planning software prototype based on the generic model has been built. The resulting generic model is described by an UML class diagram and textual description. Some initial benefits of this approach can already be outlined: improvement of multimodal information management, enhancement of the preparation and the guidance of the surgical act.

Keywords:

Surgical procedures models, UML, Multimodal image-guided surgery.

1. Introduction

Image guided surgical systems have now become the standard for cranial neurosurgical procedures. The improvement of such systems notably requires the development of visualization and validation standards, real-time visualization and ergonomic human-machine interfaces [1]. To improve the ergonomic aspect, these systems need to better use and manage the multimodal data, to plan the whole surgical procedure, to add to the planning stage a simulation step based on the patient data, and to take into account of the technical and haptic constraints of the procedure.

Most of research on simulation of surgical procedures are focused on realistic rendering or on simulation of biomechanical reality more than on understanding surgical procedures. However the need for models derived from behavioral modelisation and task analysis has been clearly outlined during the conception of surgical simulation systems [2]. The added value of surgical procedures models has been underlined for robotic systems or minimally invasive procedures [3]. As neuronavigation procedures need to deal with complex multimodal information, modelisation should improve the management of this information, specially for systems based on microscope with augmented reality.

In this paper, we propose a generic model for neurosurgical procedures [4]. In this model, the procedure is broken down into main steps, each step being characterized by an action and its attributes. To each step is associated a list of image entities (extracted from preoperative multimodal images) considered by the surgeon as relevant for the performance of the step. We studied three types of neurosurgical procedures : surgery for supratentorial intra-parenchymatous tumors (SSIT); surgery for supratentorial cavernomas (SSC) and selective amygdalo-hippocampectomies for medically intractable partial epilepsies (SAH). In this paper, we present the two stages of our method of model construction : a creation stage starting with 12 clinical cases, then a consolidation stage upon 29 clinical cases. Afterwards, we discuss the relevance and the interest of such a modelisation.

2. Methods

The model breaks down the surgical procedure into a sequence of major steps defining the surgical script. The model assigns to each step a list of image entities extracted from multimodal preoperative images (i.e. anatomical and/or functional). These image entities are considered as relevant for the performance of the step. The role of each image entity in the step is identified from a list of predefined values: target area (e.g. tumors, malformations), area to avoid (e.g. high risk functional areas, vessels), reference area (e.g. cortical sulci, vessels, anterior and posterior comissures) or surgical approach (e.g. a sulcus used as a surgical path to the target).

For the first phase of model construction, we analyzed the description, made by neurosurgeons, of the three types of procedures listed above (i.e. SSIT, SSC and SAH). These descriptions were either generic, referring to standardized procedures and expressed as a generalization of several clinical cases, or specific, derived from the analysis of clinical cases, studied during and after surgery on video tapes (6 SSIT, 3 SSC and 3 SAH).

Then, we formalized the decomposition of these procedures into an UML class diagram [5], describing the main entities and their relationships. The formalization was drawn from the methods used in cognitive psychology, in terms of behavioral modelisation [6]. The model has been iteratively refined through the instantiation of the clinical cases into UML object diagrams.

In the second phase of model construction, we have strengthened the model through its systematic instantiation from 29 clinical cases (21 SSIT, 4 SSC and 4 SAH). To decrease the subjectivity of the results, four different neurosurgeons took part in the study.

We developed a planning software based on the generic model. For each surgical procedure, this software allows the definition of the number of steps; then, for each step, the neurosurgeon describes the corresponding action and selects the relevant image entities among the preoperative multimodal patient data. The surgeon then assigns to each image entity a role in this step. The software allows to save the broken down surgical procedure into a structured form (XML file defined by a DTD). Visualization parameters (e.g. color, transparency) can be defined for each image entity within each step. For each step, a 3D scene including all the selected 3D entities is generated and saved into an XML file and Vtk files (VisualToolKit), according to the orientation and the point of view defined by the neurosurgeon, and corresponding to the view of the future operating field. The surgeon is then able to play the procedure step by step and visualize it by displaying each 3D scene.

3. Results

3.1 Model of surgical procedure

Figure 1 presents the generic model as an UML class diagram. The major conceptual entities and relations are the following. The *SurgicalProcedure* concerns one or more

Targets and comprises one or more ordered *Steps*. These *Steps* are either steps defined during the planning *(PlanningStep)* or steps realized during surgery *(RealizedStep)*. This allows to differentiate the procedure that has been planned from the procedure that has been realized (e.g. planned step not realized, addition of an unplanned step).

In multimodal image-guided surgery, a procedure may require several *ImageEntities* corresponding to 3-D image entities (i.e. points, surfaces or volumes) extracted from anatomical or functional preoperative images. A *Target* may have an *ImageEntity*, as its graphical representation segmented from preoperative images. Each *Target* has properties (e.g. size, orientation and amplitude) and is located within the right and/or left hemisphere (*Side*). More precisely, a *Target* can be located in one or several anatomical structures (*AnatInstConcept*) such as a gyrus or a lobe. A *Target* is represented by a pathological characterization (*PathoInstConcept*), such as cavernoma, glioma or epileptogenic focus.

A *Step* aims at realizing a single *Action* (e.g. incision of the dura mater). An *Action* acts upon a pathological, functional or anatomical structure (*InstanciatedConcept*). This *Action* is characterized by an *ActionModel* and may be described by one or several *ActionAttribute*. For instance, an *ActionModel* may be a graphical representation of the action to realize, such as the contours of a craniotomy, or a line representing the surgical approach to a cavernoma. An *ActionAttribute* provides more details on the action: e.g. the surgical tools needed, the incision shape, the patient position.

A *Step* comprises an *ImageEntList*, listing all the anatomical and/or functional *ImageEntity* relevant for the performance of this specific *Step*. Each *ImageEntity*, referring to a specific *ImageEntList*, has a *Role* representing the use anticipated for that instance in that *Step*, such as target area, area to be avoided, reference area or surgical approach. Each *ImageEntity* refers to one anatomical, pathological or functional structure *(InstanciatedConcept)*, characterizing the information about anatomy, function or pathology that the *ImageEntity* carries.

The model distinguishes the anatomical, pathological and functional structures that are patient-specific (*InstanciatedConcept*, used as *AnatInstConcept*, *PathoInstConcept* and *FunctInstConcept*) from the anatomical, pathological and functional generic concepts

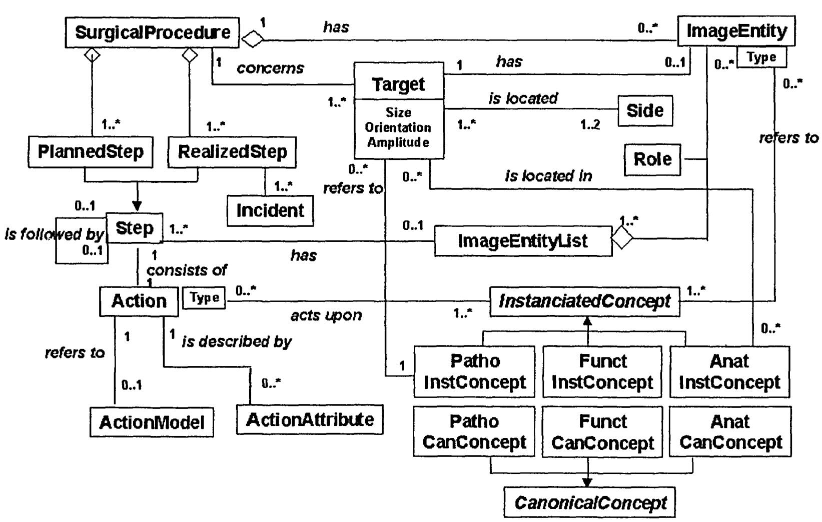

Figure 1 : UML Class Diagram

(*CanonicalConcept*, used as *AnatCanConcept*, *FunctCanConcept*, and *PathoCanConcept*), referring to existing generic knowledge [7].

3.2 Model consolidation

Results of the study upon 29 clinical cases did not question the model structure but raised problems, related to the cardinalities of the relations between classes and related to the values used to instanciate the classes. The model main objective was to break down the surgical procedure into steps defined by a single action and illustrated by a single list of image entities. The relevance of this decomposition has been confirmed by the neurosurgeons; moreover, they have noted that it would be interesting to define exactly when each step starts and finishes. They underlined the importance of the *ActionAttribute* to describe the surgical tools needed or to detail the action (e.g. the skin incision shape).

The model constrained the action to act upon only one patient-related structure (*InstanciatedConcept*). In four cases, we have realized that this cardinality has to be extended to one or more patient-related structures. For instance, for a right handed patient with a right temporal glioblastoma, the resection step of a surgical procedure (partial temporal lobectomy) acts upon both tumor and surrounding cerebral tissue.

Currently, the model does not allow to differentiate the image entities that are crucial for the step realization from the image entities that are optional. To allow this distinction, the surgeons suggested to add an importance level attribute to the image entities.

The surgeons also underlined the need for a glossary, in order to maintain a common consistent terminology. We are currently working on this glossary, using existing terminology systems such as UMLS [8].

3.3 Planning software

The planning software is a prototype and has been used upon several clinical cases. Once in the operating room, the software is used to display the surgical procedure as it has been planned preoperatively (list of planned steps). The software allows the surgeon to display the 3D scenes. From this information, the realized surgical procedure is built and saved (list of realized steps) reflecting what has really happened inside the operating room. The modifications concerning the scenes (e.g. removal of entities finally useless, modification of display parameters) are also saved.

4. Discussion and conclusion

This article presents a model for describing the surgical procedures in a context of multimodal image-guided surgery. We have centered our study on a more clever organization and management of the information in order to improve and simplify the multimodal image-guided craniotomies, particularly for the neuronavigation systems based on surgical microscope with graphical superimposition into the oculars [9]. We did not aim at describing the surgical procedure in every details as it could be done for robotic purposes. We believe that management and organization of multimodal information can be improved by a priori knowledge of surgical procedures. This improvement carries two aspects : a data organization aspect, outlining when and why the information are essential for the realization of the surgical act, and a data representation and interaction aspect, focused on selecting appropriate display and interaction parameters for the image entities, according to their role and place inside the surgical script.

The model presented in this paper represents the information involved in the performance of neurosurgical procedures. Therefore, the model contributes to the definition of an ontology of this knowledge field. Thanks to the model, the semantic and the role given to the data images, in the prior defined context of image-guided craniotomies, can be explicited. Making this meaning explicit is a key aspect for successful information sharing between the different composants (software and systems) used to prepare and realized the surgical procedure. In that respect, our work could be compared to works dedicated to the design of medical terminology systems, specially the works of surgical procedures codification [10].

The first study of model consolidation, on 29 clinical cases, has shown the model relevance and has confirmed our principal hypothesis, by providing several leads to improve the model (e.g. modifying some cardinalities, refining the attribute values, adding new features to certain classes). Surgeon who filled the forms but did not participate in the model design confirmed that all image entities were not necessary at every step. They also confirmed that the model does improve the image entities organization and management.

The study of different clinical cases did outline the few variations between two object diagrams based on clinical cases requiring the same kind of surgical procedure. The same main steps are associated to the same actions and similar relevant image entities. Therefore, it may be worth defining models of these specific procedures, which would a priori include the expected steps and the associated image entities. In order to define these models of families of surgical procedures, we started the construction of a database where we stock the surgical procedures, under the forms of planned gesture and realized gesture.

This paper presents a work in progress. A deeper validation stage is required, involving others surgical departments, in order to confront the model with other surgical schools. The first benefits of this approach are already identifiable : the model will confer real added value to the different levels of the image guided surgery, from the planning stage to the surgery itself. Models of surgical procedures help to better organize and manage the information according to the surgical script, which leads to better anticipation of the surgery. Moreover, models of surgical procedures may greatly improve the ergonomy of microscope based neuronavigation systems, by optimizing both visualization and interaction parameters of multimodal preoperative images.

5. References

[1] Clarke L., Bucholtz R.D., Fuchs H. et al. White Paper: Challenges and Opportunities in Computer-Assisted Interventions. *Computer Asissted Radiology and Surgery,* H.U. Lemke, M.W. Vannier, K. Inumura, A.G. Farman and K. Doi Editors, 2001 : 198-203.

[2] Satava R.M., Carrico C.J. Advanced Simulation Techologies for Surgical Education. *Bulletin of the American College of Surgeon*, 1996, 81(7) : 71-77.

[3] Munchenberg J., Worn H., Brief J. et al. A pattern catalogue for surgical interventions for computer supported operation planning. *Medecine Meets Virtual Reality*, JD. Westwood, HM. Hoffman, GT. Morel and D. Stredney Editors, 2000 : 227-229.

[4] Jannin P., Raimbault M., Morandi X. et al. Modelling surgical procedures for multimodal image-guided neurosurgery. *Lecture Notes in Computer Science* (MICCAI), 2001, 2208 : 565-572.

[5] Muller P.A. Modélisation Objet avec UML. *Editions Eyrolles*, 1999.

[6] Rassmussen J. Skills, rules and knowledge ; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics*, 1993, 13(3) : 257-266.

[7] Rosse C., Mejino J.L., Modayur B.R. et al. Motivation and Organizational Principles for Anatomical Knowledge Representation. *Journal of the American Medical Informatics Association*, 1998 5(1) 17-40.

[8] Lindberg D., Humphreys B.L., McCay A.T. The Unified Medical Language System. *Methods of Information in Medicine*, 1993 : 32 : 281-291.

[9] Jannin P, Fleig O, Seigneuret E et al. A Data Fusion Environment for Multimodal and Multi-Informational Neuro-Navigation. *Computer Aided Surgery.*, 2000, 1(5) :1-10.

[10] Trombert-Paviot B., Rodrigues J.M., Rogers J.E. et al. Galen: a third generation terminology tool to support a multipurpose national coding system for surgical procedures. *International Journal of Medical Informatics*, 2000 : 59 : 71-85.

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