TECHNICAL UNIVERSITY
OF CLUJ-NAPOCA

Faculty of Automation and Computer Science

PHD THESIS

3D Graphical Annotation Techniques in e-Learning Applications

- summary -

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The extensive spread of the computers in the educational domain, together with the technological evolution from the last few years, has enabled the inclusion of complex multimedia elements in the educational resources. Similarity between the 3D models and the real world recommends these types of elements in the exemplification of some complex notions and concepts, helping the trainees to better understand them. However, at the same time, the complexity of the 3D space generates many interactivity problems with the users that have limited understanding of 3D geometry and no technical background.

This thesis proposes new user interaction techniques based on 3D graphical annotations placed directly on the surface of 3D objects. Inspired from the real life, this approach ensures a powerful, natural and efficient way of interaction, even for the users with minimum technical background. For implementation purposes in this paper will be described one of the first conceptual models and XML coding formats that will allow different applications or different users of the same application to communicate and exchange data represented through 3D annotations. The validity of the proposed solutions has been verified in the e-Learning context through the development of two dedicated applications, named eTrace and eGLE. In these solutions, the user interaction through graphical annotations has been introduced in all the phases of the pedagogical process. The instructors can benefit from the advantages on these techniques in the development of teaching materials, for the presentation and analysis of didactic elements, and also in the automatic knowledge evaluation sessions.

The knowledge evaluation through graphical annotation allows each trainee to describe the solution for an exercise in a more creative and original approach. At the same time, the instructor is provided with the required functionality to perform a complex evaluation by analyzing of the final result (the graphical annotation) and of the basic concepts applied by the trainee in order to create that response. Nevertheless, this flexibility in concepts description generates very complex problems regarding the automation of the evaluation process. In order to enable the integration of this type of knowledge evaluation in a real e-Learning application, with thousands of trainees, we have described in this paper an approach based on the definition of specific evaluation structures based on 3D graphical annotations. The description of these models can be achieved in a simple and efficient manner, using the 3D annotation based user interaction.

The usability evaluation of the user interaction techniques based on 3D graphical annotations placed on the surface of the 3D objects has been performed through a custom developed methodology and three specialized experiments, which are described in detail in the thesis. The results obtained with the help of 48 users have confirmed a high usability of these techniques by emphasizing their ease to be learned, their efficiency in task fulfillment and their natural approach to 3D interaction. Implicitly, through these tests we have also performed a preliminary validation process for the algorithms presented in this paper as a solution for efficient annotation tracing through input devices like mouse and pen.

The creation of high quality 3D models is a very expensive process that can be carried out only by IT specialists through dedicated third party software that is independent of e-Learning applications. Addressing this lack of specialized tools for teaching materials development, eGLE application introduces a new concept of resources development based on creating new learning materials by reusing and adapting previously created ones. This process, called *repurposing*, can be achieved through 3D annotation based interaction directly into the e-Learning applications, and can be performed even by instructors without technical background.

Furthermore, the distributed architecture of the eGLE platform and the flexibility of the visual structure for data representation allows the teachers to access educational resources from distributed geogra-

phical areas and databases, through different communication protocols, without requesting specialized technical skills from the users. The scenarios implemented proved the capabilities of eGLE application in displaying into the same material, in a unitary fashion, the results of Grid processing, 3D traces from graphics clusters and information retrieved through OGC web services.

The research activity presented in this thesis has been financed through the following research projects: i-Trace, SEE-GRID-SCI, GiSHEO, mEducator and enviroGRIDS.

Objectives

This thesis aims to present new approaches in the context of e-Learning applications, that will enable users to:

- express a wide range of concepts and knowledge through interactive graphics;
- communicate and collaborate in live working session through new and more efficient techniques;
- automatically evaluate the knowledge described through graphical interaction techniques;

The main research direction followed for achieving the above mentioned objectives can be shortly described as:

> *the development of new user interaction techniques with 3D scenes of objects through 3D graphical annotations placed on the surface of the 3D objects included into the scene*

The research activity has been organized in the following main phases:
- definition of a new conceptual model for the description of 3D graphical annotations placed on 3D surfaces;
- development of a flexible XML format for annotation representation;
- validation of the proposed model through implementation in a real context of use: e-Learning applications;
- adaptation and extension of existing algorithms, specialized in 3D surfaces analysis, in order to enable the computation of the graphical representation of 3D annotations;
- creation of new algorithms and tracing methods for defining 3D graphical annotations;
- development of specialized mechanisms for the evaluation of the proposed user interaction techniques;
- implementation of pilot e-Learning applications in which to integrate and test this type of interactions;
- definition and implementation of the required models for automatic knowledge evaluation through 3D graphical annotations;
- study the repurposing procedures of 3D models through user interaction techniques based on 3D graphical annotations.

Thesis structure

The contributions presented in this paper have been published in two book chapters, 5 ISI and ACM journal articles and 19 papers presented at ISI, ACM and IEE national and international conferences.

The bibliography list has 141 references. The content of this thesis has been organized in 9 chapters, as follows:

Chapter 1 presents the context and motivation of the research activity and emphasizes the objectives of this thesis.

Chapter 2 includes a survey of the user interaction techniques that are currently used in e-Learning applications. A special analysis has been performed on the influence of these interaction approaches in the different phases of the pedagogical process: teaching resources development, concepts presentation by the teacher, materials analysis activities in individual or collaborative working sessions and knowledge evaluation. Different communication tools are analyzed in order to identify their advantages and disadvantages in the information exchange between trainees, or trainer and trainees. Some of the most important usability aspects of the current e-Learning applications are also discussed in this chapter.

Chapter 3 presents the application types and domains that are currently using the graphical annotations as user interaction technique. The available formats and standards for graphical annotation description are analyzed in order to identify their capabilities in encoding the information related to 3D annotations. A classification of the graphical annotations in the context of e-Learning applications, based on the representation space and the context and purpose of the annotation definition, is also presented together with an analysis of the usual input devices that are available in this domain.

Chapter 4 describes the conceptual model of the 3D annotation placed on the surface of 3D polygonal objects. A survey of the most common solutions in 3D surfaces representation is included in order to identify their main components. Based on these observations, the annotation model has been organized in the following elements: *geometric model*, *graphical attributes*, *contextual specifications* and *list of parameters*. The information is transmitted between applications in 3D graphical annotations encoding through the dedicated XML format proposed in this chapter, inspired from the InkML standard. Finally, the main difficulties that are encountered in 3D annotations tracing have been identified and thoroughly analyzed, practical solutions being proposed for each situation.

Chapter 5 analyses the specific requirements of the e-Learning applications concerning the information that must be encoded into the 3D annotation and extends the basic conceptual model described in Chapter 4 to meet these new constraints. The user interaction based on 3D graphical annotation is studied in all the phases of the pedagogical process. For the automatic knowledge evaluation are defined four basic conceptual evaluation models that allow the teachers to perform complex answers evaluation described through 3D annotations. The XML description format is also extended to enable the encoding of the new evaluation specifications. New types of exercises specific to the evaluation through graphical 3D annotation are presented and the new structure of the teaching resources that enable user interaction through annotations is explained.

Chapter 6 presents algorithms that provide the computational support for 3D annotation geometrical model definition. As most of the e-Learning users are interacting with the computer through mouse and graphical pen, new user interaction techniques are described for a more efficient and natural 3D annotation description. The users will describe the concept in 2D while the application through these specialized algorithms will represent the graphical form in 3D. A similar approach is proposed for the definition of the annotation parameters, mainly for the ones that are related with specific attributes of the 3D annotated surface (ex. distance intervals). Specific algorithms for the evaluation of graphical annotations through the conceptual models presented in Chapter 5 are also defined: *key point*, *key points set*, *pattern annotation* and *contour annotation*.

Chapter 7 describes in detail the methodology and the experiments developed for the usability evaluation of user interaction techniques based on 3D graphical annotation. Two distinct approaches have been used: *heuristic evaluation* and *experimental evaluation*. The analysis based on the 10 heuristics proposed by Jacob Nielsen allowed the identification of some very important aspects of the user interfaces that implement interaction through graphical annotations. The experimental evaluation has been divided into two phases: 1. comparative evaluation of the two most common input devices in e-Learning: *mouse* and *graphical pen* through 2D graphical annotations; 2. 3D graphical annotations evaluation through three custom developed experiments and one user questionnaire that allowed the measurement of the ease in learning, the level of efficiency and efficacy, and how natural these interaction techniques really are. The results obtained confirm that the user interaction techniques through graphical annotations have a high level of usability.

Chapter 8 presents shortly the experiments carried through the two e-Learning applications developed: eTrace and eGLE. In eTrace most of the interaction techniques available for teaching materials analysis are based on 2D and 3D graphical interaction. The experiments made through this application have revealed many of the advantages and limitations of this approach in user interaction. eGLE application provides specialized tools for creating complex pedagogical materials in a visual and non-technical way by presenting in a unitary fashion resources gathered from distributed sources. Furthermore, eGLE allows the trainers to decide what types of user interaction they desire for a specific resource, by combining multiple different techniques in the same material. In this manner, for each data type (image, video, 3D model) the teacher can select the most appropriate user interaction approach. As the creation of high quality teaching resources is a challenge that has a great impact on the distribution of 3D models in e-Learning materials, we are discussing in this chapter a new approach in reusing and adapting existing scenes of objects through 3D annotations placed on the surface of 3D objects.

Chapter 9 presents the final conclusions of the research activity, highlights the main contributions of the thesis and shortly presents the future development possibilities.

Thesis contributions

The main contributions of this PhD thesis are as follows:
- describes a conceptual model for the representation of 3D annotations placed on the surface of 3D polygonal objects;
- proposes a new XML based format, inspired from InkML standard, for a flexible description and easier communication through 3D annotations;
- identifies the main challenges in tracing 3D annotations over 3D polygonal surfaces and presents practical solutions to these problems; *[publications no: 8]*
- describes new user interaction techniques, based on 3D graphical annotations, in the context of e-Learning applications; *[publications no: 21, 23]*
- extends the conceptual model and the XML description format of 3D annotations to meet the specific requirements of the e-Learning applications;
- formally describes new mechanisms and models for automatic knowledge evaluation through 3D graphical annotations, and presents specialized algorithms for the implementation of the described concepts; *[publications no: 18]*
- identifies new types of exercises for knowledge evaluation in e-Learning applications; *[publications no: 17]*

- defines new interaction techniques for the tracing of 3D graphical annotations placed on the surface of any 3D polygonal object; *[publications no: 8]*
- implements and extends specific 3D surface analysis algorithms to allow the computation of the geometrical model of 3D annotations, following the bi-dimensional instructions provided by the user;
- develops a new testing methodology and dedicated experiments to evaluate the usability of the user interaction techniques based on 2D and 3D graphical annotations; *[publications no: 22, 24]*
- formulates recommendations for the successful implementation of these new user interaction techniques in user interfaces, based on heuristic evaluation and on the results obtained through experimental evaluation;
- the first implemented e-Learning application where the main user interaction techniques with the teaching materials are implemented based on 2D and 3D graphical annotations; *[publications no: 20, 23]*
- eGLE application, that allows the teachers to create complex pedagogical resources with components from distributed sources; the user interaction can be tailored on each type of element (image, video, 3D model), independent of the other elements, as the instructor desires; *[publications no: 4, 6, 12]*
- describes new methods for creating new 3D teaching materials based on the existing ones, through 3D graphical annotation interactions; *[publications no: 1, 3]*

Publications

Book chapters

1. **T. Ştefănuţ**, D. Gorgan, E. Kaldoudi, N. Dovrolis and S. Dietze. Creating Educational Resources for Medical Education in the Web2.0/Web3.0 Era. *Information Systems and Technology for Organizations in a Networked Society.* [Online]. IGI Global, 2013. pp. 275–294. doi:10.4018/978-1-4666-4062-7.ch015

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3. **T. Ştefănuţ**, D. Gorgan, N. Dovrolis and E. Kaldoudi. Modelarea reutilizării resurselor în domeniul medical prin intermediul reţelelor sociale şi a internetului semantic. *Revista Română de Interacţiune Om – Calculator*, Volume 5 (1), ISSN 1843-4460, pp. 1–18, 2012

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9. **T. Ştefănuţ**, D. Gorgan, N. Dovrolis, E. Kaldoudi and S. Dietze. Creating Medical Related Learning Resources Using Repurposing Procedures and Semantic Web Functionalities. *Proceedings of Iadis e-Society International Conference 2012*. March 10-13, Berlin, Germany. ISBN: 978-972-8939-67-0, pp. 52–59, 2012

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11. **T. Ştefănuţ**, G. Popescu and D. Gorgan. Elearning platform for educational resources repurposing in Earth Observation. *12th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing – SYNASC 2010*. September 23-26, Timişoara, Romania. ISBN: 978-076954324-6, pp. 308–314, 2010

12. M. Mărginean and **T. Ştefănuţ**. Unelte Interactive pentru Dezvoltarea Lecţiilor în Sisteme Colaborative de eLearning. *RoCHI2010 – Conferinţa Naţională de Interacţiune Om-Calculator*. September 3-5, Bucharest, Romania. ISSN 1843-4460, pp. 65–70, 2010

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2. Earth Observation oriented teaching materials development based on OGC Web services and Bashyt generated reports, *EGU 2012 - European Geosciences Union General Assembly*, Vienna, Austria, April 22-27, 2012

3. eGLE – Grid Oriented Scenarios, *5th Grid and e-collaboration Workshop: from Digital Repositories to Digital Earth Communities*, ESA/ESRIN Frascati, Italy, May 12, 2010

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