A Multi-modal Interface for an Interactive Simulated Vascular Reconstruction System

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Abstract

This paper is devoted to multi-modal interface design and implementation of a simulated vascular reconstruction system. It provides multi-modal interaction methods such as speech recognition, hand gestures, direct manipulation of virtual 3D objects and measurement tools. The main challenge is that no general interface scenario in existence today can satisfy all the users of the system (radiologists, vascular surgeons, medical students, etc.). The potential users of the system can vary by their skills, expertise level, habits and psycho-motional characteristics. To make a multi-modal interface user-friendly is a crucial issue. In this paper we introduce an approach to develop such an efficient, user-friendly multi-modal interaction system. We focus on adaptive interaction as a possible solution to address the variety of end-users. Based on a user model, the adaptive user interface identifies each individual by means of a set of criteria and generates a customized exploration environment.

Keywords: vascular reconstruction, virtual environment, speech recognition, adaptive interaction, user modeling

1. Introduction

The simulated vascular reconstruction system is a real-time interactive simulation-visualization complex that helps surgeons in pre-surgical treatment and vascular reconstruction. Its purpose is to assist in pre-operative planning of abdominal vascular bypasses [2, 3].

Vascular disorders in general fall into two categories: stenosis and aneurisms. A stenosis is characterized by the narrowing of an artery caused by the buildup over time of fat, cholesterol and other substances onto the vascular wall. An aneurysm is a ballooning out of the wall of an artery or vein due to weakening of that wall. Aneurysms are often caused by high blood pressure or wall shear stress.

The purpose of vascular reconstruction is to redirect and increase blood flow or repair a weakened or aneurysmal artery if necessary.

The best treatment is not always obvious because of the complicated vascular disease of the patient and/or different other diseases that he may have. The interactive environment being developed provides a surgeon with the possibility to verify whether the treatment that he has planned is appropriate under the circumstances. Verification of the operation is a complicated task even for experienced surgeons. The simulation-visualization complex may help in this process. This complex can also help in training novice specialists in vascular surgery.

Different treatments for vascular diseases exist today. These include adding shunts and bypasses in the case of aneurysms and applying thrombolysis techniques, balloon angioplasty, bypasses, stent placement, etc. for a stenosis. At the moment, the procedure of adding bypasses is of most interest to us as it can be used both for treatment of aneurysms and stenosis.

The simulated vascular reconstruction system puts a surgeon into an experimental cycle, controlled by a computer and allows him to apply his expertise to find the most viable solution among different alternatives. A simulation component of the complex simulates the parameters of a patient's blood flow, i.e. velocity, pressure and shear stress on a parallel computer system. A visualization component of the complex presents the graphical interpretation of the simulation results together with data about the patient obtained from MRI or CT scanners.

Both the simulation and visualization modules of the vascular reconstruction system are closely interrelated and connected with the interaction module that provides a generic multi-modal interface to the complex. [17]

The current system is provided with a multi-modal interface that combines natural input modes of context sensitive interaction by voice, hand gestures and direct manipulation of virtual 3D objects.

The next two sections focus on the interaction in the virtual operating theatre for vascular reconstruction [3]. Section 2 is devoted to interaction and multimedia system output. Section 3 provides information on the speech recognition part of a multi-modal interface. The paper also contains information about possible future improvements of human-computer interaction provided by such a system. Section 4 is devoted to the design of adaptive interface based on user model to be applied to the existing multi-modal interface.

2. A Virtual Environment for Simulated Vascular Reconstruction

The simulated vascular reconstruction system provides visualization and interaction methods for the simulation of a vascular reconstruction procedure and visualization of the results of a proposed treatment on a patient's blood circulation in real time [2, 3, 17].

The system can be used in stereoscopic 3D immersive virtual environments such as a CAVE or the PC based *Distributed Real-time Interactive Virtual Environment* (DRIVE) system [21], as well as on workstations providing 2D interaction and a projected representation of 3D objects. Within this paper interaction in an immersive virtual environment is addressed.

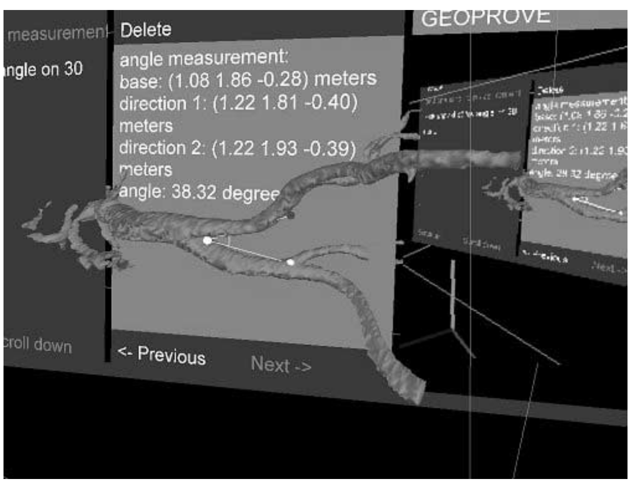

Fig. 1: GEOPROVE; a system to perform measurements in virtual environments, here used with the vascular reconstruction environment [2]

By its very nature the virtual environment demands interaction. It is not a passive medium, the user is free to explore and interact with objects wherever he wants (within certain geometric or scripted constraints). In our case the virtual environment should allow a surgeon to explore a patient's data and plan a surgical procedure.

The visualization component of the vascular reconstruction environment presents 3D data obtained from medical scanners. It also provides the visualized results of blood flow simulations (pressure, velocity and shear stress of blood flowing through the artery) while its exploration part allows inspections and probing of the simulation results.

As the data is presented in 3D, the environment should also allow users to interact with this data in 3D.

An immersive environment always requires several interaction techniques. In our case one of them is ray-casting that is used for selecting an object from a set of visible objects [1]. A wand in the user's hand specifies the direction of a virtual ray used for selection. The actual intersection test of the ray with the object is performed to all visible objects. After that, the distance between two points is calculated such that the closest object can be identified.

Once an object is selected twelve rotational handles are attached to the edges of the object's bounding box. The manipulations on the selected object can be performed via the movement and rotation of the wand, scaling by moving a joystick up and down.

The interaction can also be conducted by means of a virtual menu [15]. The vascular reconstruction system contains one navigation menu and several submenus designed in accordance with the following principles.

1. The menu must be clearly visible.
2. The structure of the menu should be optimal.
3. It should support simple interaction techniques (ray-casting or voice control in our case).
4. The menu has to provide consistency at all levels.

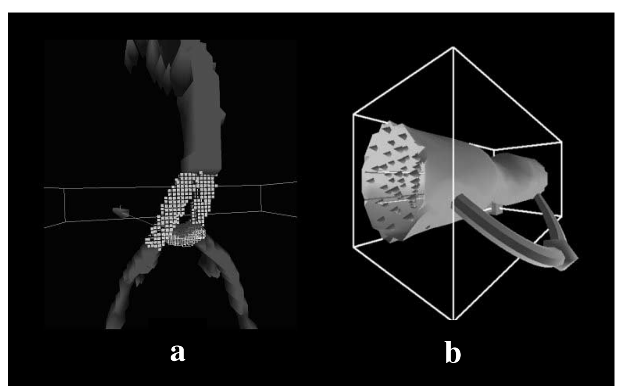

Fig. 2: Simulated interactive vascular surgery using (a) grid editing and (b) splines [6]

A screenshot of a quantitative measurement submenu is represented on Fig.1. It can be used to conduct measurements in the virtual environment (i.e., angles, sizes, distances between objects, etc.). These measurements help to diagnose the disease and the definition of a location at which to add a bypass.

The virtual environment for simulated vascular reconstruction provides two different ways of adding a bypass to the artery. A bypass can be added either by grid editing (Fig.2a), where a user directly modifies individual elements of the structured grid visualized as voxels, or by creating a spline primitive (Fig.2b). If a bypass is added as a spline the user should first define its position on the artery either by using ray-casting techniques or via a virtual submenu.

For the implementation of the vascular reconstruction system several libraries have been used [3]. *SGI's Volumizer* is used for volume rendering while the *Visualization Toolkit* (Vtk) and *OpenGL* libraries are used for surface rendering of simulation data and for the rendering of user interface widgets (such as the menus). CAVELib provides graphical output to the CAVE and the DRIVE system. As for the direct object manipulation techniques, a multi-modal *Speech CAVE and Vtk Interaction* (SCAVI) toolkit has been developed for deploying this functionality [6]. SCAVI also helps to provide audio input/output to the virtual environment as it makes use of a *Context Sensitive Speech Recognition* library that has been specially developed for this purpose.

3. Context Sensitive Speech Recognition

Language is a communication and interface medium. Speech recognition technology is essentially a global input device but can be made directional when it is combined with other input devices.

In the virtual environment for simulated vascular reconstruction, most interaction commands are also available via voice commands. For example, a user can make a choice from a virtual menu via ray-casting or by a voice selection command. But there are some commands that are available only by direct manipulation (grid editing, probing, etc.).

The speech recognition part of the simulated vascular reconstruction system classifies each recognized word based on the context of the system at that moment. Based on this context, voice commands are either directed to objects that belong to this context (which then receive a message to this fact), or otherwise a global callback handles the speech message.

In accordance with their context the voice commands of the vascular reconstruction system can be divided into three main groups [2, 3]:

- visualization commands;
- simulation commands;
- interaction commands.

Visualization commands permit to load patient data from CT/MRI scanners in stereoscopic 3D format, show the results of flow simulations, change the representation of objects in the virtual environment.

Examples of visualization commands:

1. *"Load data"*
2. *"Set color to blue"*
3. *"Increase sample rate"*

Simulation commands provide control over the process of blood flow simulation, based on the Lattice Boltzmann method [7]. As a result, a flow field is represented in the virtual environment. The pressure, velocity or shear stress are calculated from particle densities and represented by streamlines in the virtual environment.

Examples of simulation commands:

1. *"Start simulation"*
2. *"Pause simulation*"
3. *"Calculate shear stress"*

Interaction commands provide the possibility to select objects and volumes and conduct manipulations on them. They also permit to make a selection from virtual submenus and to launch the help component of the simulated vascular reconstruction system.

Examples of interaction commands:

1. *"Select volume"*
2. *"Create bypass"*
3. *"Show/hide menu"*

For the implementation of the voice recognition parts of the interface, a speech library has been developed [6].

The core of the speech system uses IBM's ViaVoice. ViaVoice is a speaker independent, automatic speech recognition system that supports both dynamic command vocabularies and structured grammars. Communication between server (the speech recognition system) and client (the application) is done via TCP sockets.

4. User-centered Approach to Improving the Interface Usability

At the moment the working prototype of the vascular reconstruction system is almost ready. That means that the system provides a sufficient set of functionality, enabling us to take a much closer look at usability. The available forms of interaction supported by the system are far from perfect, which is why we concentrate our current activities on the user interface of the system. The final goal of our research is to decrease the discomfort of a user while using the system by providing a environment with an adaptive user interface that will permit him to customize the working environment in accordance with his professional and psychological features.

The usability satisfaction of real users is a benchmark of success for most computer systems [11].

When we talk about a virtual environment, ideally it should provide an environment where users can interact freely with a 3D space and the entities within it. The main problem here is that our mental representations come with other expectations as to how the environment may behave; expectations that are not necessarily met by a virtual environment.

The potential users of the vascular reconstruction system (radiologists, surgeons and medical students) vary by their professional knowledge, experience of working in a virtual environment and some psychological and psycho-motional features. As a result, their expectations about interaction in a virtual environment may also vary. The user interface supported by the vascular reconstruction system today is too complicated. Thus only an experienced, specially pre-trained user can currently work efficiently with the environment.

Making the virtual environment user-friendly is a complicated task that can be addressed only by applying the approach of adaptive interface design based on a user model.

The aim of an adaptive user interface in general is to help the individual's interaction with a computer system by providing a personalized dialog scenario of interaction for each concrete user [12].

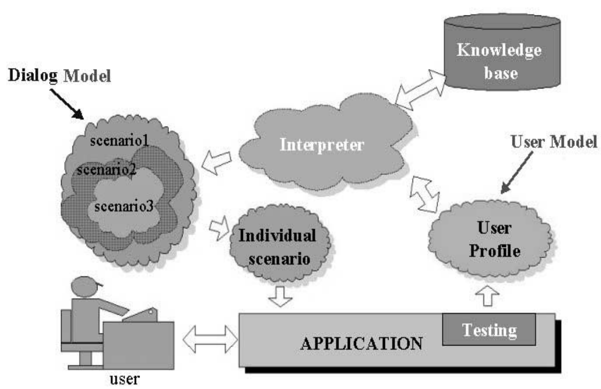

Fig. 3: A scheme of interface adaptation

The interface adaptation is controlled by several criterions that form the user model of a system. A user model is a set of personal user characteristics that have an influence on the interaction with a computer. These characteristics are also called human factors [16]. A special testing [19] subsystem of an adaptive environment that generates a user profile (a set of measured characteristics from the user model [10]) is responsible for the identification of users.

The knowledge base of the interface adaptation contains rules where each available dialog scenario [9] is connected to the appropriate user profile or profiles (Fig. 3). The value of each human factor has to be taken into account there.

By applying the approach of interface adaptation to a virtual environment for vascular reconstruction the user interacts with a system that will become more comfortable over time. It will be possible:

- to select the type of interaction that fits each concrete user best (e.g., direct manipulation or voice command);
- to dynamically change the content of virtual submenus;
- to provide user-centered speech vocabularies [4];
- to generate clear help instructions and feedback in proper time;
- to save the customized layout (sizes and location of objects, volumes and virtual submenus, color palettes, light effects, etc.) of the virtual environment by tracing the user's behavior;
- to choose a comfortable form of navigation from a set of available forms, i.e. walking, jumping, panning, flying or applying a "wayfinding" technique.

Rather than trying to improve the user's performance by creating a highly realistic virtual environment, we are going to present the user with such interaction elements that have relevance to his skills and preferences. This can be achieved by providing individual user accounts to a system in accordance with the user profiles generated by the testing environment [13].

In earlier publications [5, 18, 20] we have discussed what kind of user characteristics should be included into the user model in different cases. It has also been investigated what the influence is of seven groups of user characteristics (demographic, psychological, psycho-motional, cognitive, motivation, working and interaction) on the interface adaptation.

To find out the priorities of different human factors in the sense of interface adaptation a series of experiments has been conducted. [5, 8]

During these experiments, 21 human factors from the Wagner's Ergonomics Model [16] have been selected for analyses (Table 1). The estimated values of these factors formed user profiles of participants. Most of the factors were estimated via Q&A tests ("USK" test, Kettle's test, etc.) or play graphics tests (test "White & Black Table", Rowen's test, etc.) [19]. Such form of testing as tracing users' behavior also was used for the estimation of motivation and interaction characteristics.

Three groups of participants (18, 25 and 21 people in each group) took part in the experiments. All participants were undergraduate students of the MS Course in Artificial Intelligence. They were asked to work as testers with the Knowledge Engineer's Workbench [5] and to customize its environment manually so that it would fit them better.

Twelve manipulated interface parameters were available for update (i.e. menu layout, dialog type, I/O format, available forms of data representation, level of help instructions, color palette, etc.). The number of accomplished interface updates conducted by every participant was calculated and the value of each human factor corresponding to this concrete person was analyzed.

DEMOGRAPHIC CHARACTERISTICS	• Age • Gender
PSYCHOLOGICAL COMMUNICATIVE FEATURES	• Ability to Study • Subjective Control Level (interest in the help) • Attitude to Innovations
PSYCHOMOTIONAL QUALITIES	• Concentration • Self Control Cultivation Degree (mistake inflicting) • Stress Factors.
COGNITIVE FEATURES	• Cognitive Style • Perception Style • Verbal/Nonverbal Intelligence
MOTIVATION	• Expectations • Needs • Tasks
WORKING QUALITIES	• Education • Professional Qualification • Computer Skills • Expertise Level
INTERACTION CHARACTERISTICS	• Preferences • Customs • Specific Situations

Table 1: Human factors [5]

The detailed information on the statistic analyses of the information gathered during the experiments can be found in [8]. For checking a hypothesis about dependence-independence of a pair <human factor, interface parameter> the Monte Carlo method of the interval estimation with the confidence interval of 50% was used.

As a result it has been found that working skills, psycho-motional characteristics and the user's motivation are the most important for the organization of interface adaptation and they can be included in the user model of an interactive system from any domain.

That is why we also consider these characteristics as the most important to be included into the user model of the vascular reconstruction system discussed here.

Working skills define the user's experience and understanding of the problems he is going to solve [14]. These characteristics are closely connected to all the human-computer interaction aspects. Moreover, the majority of working skills can evaluate during the exploitation process. It will permit to adapt the exploration environment even in real time. It is also necessary to take into account the user's experience of working in virtual reality. If the user is a novice he should start from some primitive interaction modes and accumulate experience step by step. Also, the assistance provided for this user must be more extensive than for an experienced one. Moreover, if the reliability of a system is crucial a user will not be able to deal with some working processes while he does not have enough experience.

Psycho-motional characteristics permit to organize such a kind of interaction when user's discomfort is minimized [11]. They help to define whether the user needs additional help and control during the interaction and provide them if necessary. For instance, a human factor such as concentration permits one to predict how comfortable a user will feel while interacting with several objects or processes at the same time and whether he can switch easily between them or not.

Appreciation of *motivation* makes it possible to simplify the work of a user and to increase the speed of human-computer interaction through the organization of a motivated working environment. The human-computer interaction becomes highly efficient and productive by mapping the tasks to user goals. This is the most common form of adaptation when during the exploitation process a user manually customizes the working environment in accordance with his needs and tasks and all interface updates that he made are traced and saved by a system. [15]

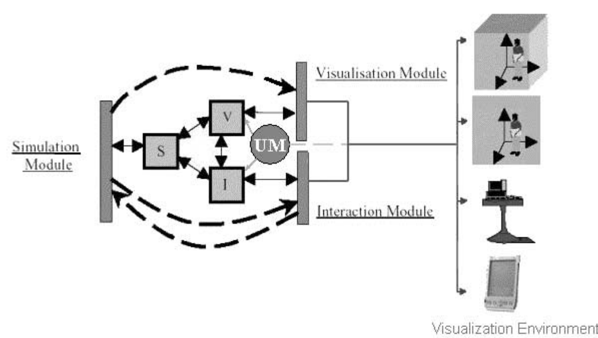

Fig. 4: The scheme of interaction within adaptive simulation-visualisation environment (UM - user model).

Development of an adaptive exploration environment is a complicated task requiring long-term collaboration with potential users of such a system.

It is planned to compose a set of available dialog scenarios together with surgeons. These scenarios will be analyzed and the interaction elements of the highest importance are going to be selected. The possibility to adapt each of these interaction elements will be investigated. Characteristics as professional experience of users, their expertise level, concentration, every-day tasks and habits will be taken into account.

The selection of the most appropriate projection system (Fig.4) will be also addressed [20]. It is planned to investigate the various projection modalities that better fits the user's tasks and psycho-motional features, where stress factors (e.g., motion sickness) are of importance.

5. Discussion and Future work

In this paper the multi-modal interface to an interactive simulated vascular reconstruction system has been introduced. The work on this system is still in progress and one of the crucial issues that we are focusing on now is its interface. As the potential users of the system are surgeons who are usually not familiar with computer applications, it is very important to make the process of human-computer interaction as comfortable as possible.

The main idea is to provide a virtual environment for the simulated vascular reconstruction with an adaptive user interface that will permit users to interact both with its simulation and visualization components with a minimal effort and in accordance with their experience and preferences. This task can be solved only in collaboration with potential users of the system. For these case studies we collaborate with the Leiden University Medical Center and the Technical University of Twente.

6: Acknowledgements

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