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Research Position Paper

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Executive Summary

INTUITION is an EU funded Network of Excellence operating under the 6th Framework of the Information Society Technologies programme, focusing on virtual reality (VR) and virtual environment (VE) applications for future workspaces.

Its major objectives include the integration of resources and VR equipment all around Europe, the structuring of the European Research Area on VR and the worldwide promotion of Europe as a leading force in this field.

To perform this, a number of activities are being carried out in order to establish a common view of the current status of VE technology, open issues and future trends, including the creation of research roadmaps.

Within this framework, a number of position papers or white papers, as we call them within INTUITION, have been created in order to highlight both short-term and long-term research needs in specific areas.

Virtual Reality and Medicine and Neuroscience: requirements for future Research Initiatives

INTUITION consists of 60 partners and its major objective is to bring together leading experts and key actors across all major areas of VE understanding, development, testing and application in Europe, including industrial representatives, SMEs, key research institutes and universities, and major international organisations in order to overcome fragmentation and promote VE establishment within product and process design. Other objectives include the integration of resources and VR equipment all around Europe, the structuring of the European Research Area on VR and the worldwide promotion of Europe as a leading force in this field.

One of the working groups within INTUITION specifically addresses issues related to the use of VR/VE in Medicine and Neuroscience. This group consists of 18 partners (including academics, industrial partners,) from 9 different countries. The participating organisations have a long history of research and expertise in using VR/VE in Medicine and Neuroscience.

The potential advantages of using VR/VE technologies in Medicine and Neuroscience have been discussed for many years, however, there is still research evidence missing to demonstrate that use of these technologies has an added value over traditional methods of diagnosing, therapy, rehabilitation and training. The overall goal is to use VR/VE in order to make lasting improvements in all health care fields.

The following passages give a brief overview about the research field "Medicine and Neuroscience". They have emerged from the discussions and fruitful work within the INTUITION Medicine and Neuroscience working group. The topics are outlined below and described afterwards. At the end of each paragraph future research needs are described:

1. **Neuroscientific oriented Brain Computer Interfaces:**

- Identification of brain signals, whether evoked potentials, spontaneous rhythms, or neural firing rates that users are best able to control independent of activity in conventional motor output pathways
- Development of efficient algorithms for translating these signals into device commands effective identification and elimination of artefacts coming from muscular activity

2. **Neuroscience and VR**

- Physiological parameters: level of stress, anxiety measured via EEG or ERP (event –related potentials)
- Simulator sickness, Lack of vestibular stimulation

3. **VR for Diagnostic and Rehabilitation**

- Phobias,
- Motor functionality/ Rehabilitation
- Biofeedback/ Neurofeedback (Relaxation)
- Immersion

4. **VR for medical training/ Interaction and Interfaces**

- VR for surgical training, Biomedical Human Models
- Haptic applications: user interaction within the virtual environment by means of the haptic sense (object selection/ manipulation)

5. **Distant and remote collaboration tools**

- Easy access to the electronic patient record sharing of different images (CT-scan, MRI)

Ad 1: Neuroscientific oriented Brain Computer Interfaces:

Virtual reality research continuously seeks for improved human-computer interfaces. It is true that the use of the traditional joystick or mouse, often used for interaction with virtual environments, appears to have a negative result on probably the most essential expectation from a VR environment, the feeling of being "present" in there. One of the main reasons has to do with the handling of conflicting information in our brain. Another could be related to the adoption of unnatural ways of exploration, i.e. different than those employed when acting in the real world.

Compared to traditional graphical 2D user interfaces with mouse and keyboard as input devices the interaction in three dimensions is related with big challenges. Besides handling objects, user navigation in space has to be performed. Additionally, in many virtual environments the keyboard cannot be used as the user is in a standing posture. Sets of objects arranged in space are not easy to select for manipulation. Thus alternative efficient input devices have always been a requirement that could not be satisfied perfectly up until now. In order to increase efficiency, usability and performance and the sense of presence of the users, the cognitive information processing when interacting with the VE should ideally be supported by the interface.

The ultimate interface between a human and VR would be to navigate and explore by thought, or better intention. Indeed, during the last few years scientists developed VR navigation systems using a brain-computer interface (BCI) based on the brain's electrical signature, the electroencephalogram (EEG). These systems perform real-time EEG signal analysis in order to generate control commands for VR. BCIs, although appear to be identically suited for control of VR environments, they encounter certain problems regarding accuracy, speed of information transfer, and relevance to the task to be performed, i.e. how close is the task that the user is obliged to do (in order to give rise to the BCI-required brain activity) to what the user really intends to do. Up to date, there are reports of BCI systems which do succeed to control a VR environment, demonstrating the potential of this application.

Future research needs in Brain Computer Interfaces:

BCIs attracted reasonable interest for their applicability in helping people with severe neuromuscular disorders to communicate and become more independent in every day life tasks. In this sense, ABI (Adaptive Brain Interface) funded by the ESPRIT 4 (1994-1998) programme of the European Commission allowed patients with neuromuscular deficits to select different items on a computer screen. There is a marked effort developing the last few years to exploit this relatively unexplored communication channel in new applications. Representative examples include the application of BCIs in Virtual Reality technology.

Future research activities should be centralized on mental strategies to operate a BCI. First steps towards possible solutions are motor imagery (training of central mu and beta rhythms in a similar way as observed during execution of a real movement), focused attention (modifing the P300 component) or operant conditioning (feedback to produce negative or positive slow cortical potential shifts).

Ad 2: Neuroscience and VR

Physiological parameters derived from the human autonomous nervous system provide information on the users' level of comfort, strain, stress, relaxation, anxiety, etc. - by and large without the possibility on the user side to influence these parameters voluntarily. By adding neurophysiological parameters to such a set of measurements (for example EEG), even concepts such as mental work load, cognition, etc. can be addressed.
Neuroscience advance, and specificially brain function and brain imaging studies can have a significant impact in VR. A direct impact is related to the better understanding of perception and cognitive processes which can be applied to the interfaces of the user to VR and the ways he can interact with the virtual environment. An indirect impact is related to the improvement of the above mentioned BCI research, in order to use EEG signals more effectively to drive the virtual environment.
Equivalently, neuroscience can greatly benefit from the use of VR. VR technology finally offers the possibility to perform neuroscience experiments with ecological validity (i.e. presenting real life situations to the user) and at the same time provides full control and monitoring of all the parameters presented to the user. VR constitutes a powerful tool for exploration in neuroscience research and a unique platform to study complex functions of the human brain.
Moreover, the study of the user's eye movements when he or she explores a VR environment can offer another source of information about how he/she uses visual information inside VR and how the user perceives depth and virtual distance. Vergence movements (eye movements in depth) are not the same inside VR than in the real world. It is possible that the lack of accommodation vergence inside VR is related with fatigue and general unpleasant feelings of the user after a relatively short use of VR.

Future research needs in Neuroscience and VR:
The Identification of brain signals, whether evoked potentials, spontaneous rhythms, or neural firing rates that users are best able to control independent of activity in conventional motor output pathways will be a major challenge in future research activities. Basic experiments are needed to develop efficient algorithms for translating these signals into device commands and the effective identification and elimination of artefacts coming from muscular activity.

One possibility for a BCI (Brain-Computer Interface) is based on the analysis of the electroencephalographic signals (EEG), recorded during certain mental activities for example to control an external device. Performance of BCI will depend, to a great extent, on the ability of the subject to control his or her own EEG patterns. To this end, it is necessary to provide suitable training, which can sometimes go on for a long time. It is also very important to provide some type of feedback allowing subjects to see their progress.

Ad 3: VR for Diagnostic and Rehabilitation

One of the uses of this kind of applications is the treatment of phobias. In them, both presence and navigation are the most important aspects to take into account. Regarding to presence, this one has major importance due to the fact that the sensation that the user has "of being there" is necessary for credibility and efficiency of the treatment based on the virtual experiences. Another aspect to emphasize is the navigation process, since in the majority of this kind of applications the user only navigates across the environments facing to the treated phobia for example overcome the fear of spiders. In this simulation, the patients cross a kitchen in which spiders appear and the user can interact with them. Other applications in this field are those whose aim is to abstract the patient of the real world, that is, to attract his attention and to achieve to reduce his psychological perception of the pain. For example there is a specifically designed simulator for treating burn patients where the idea is to help the patients take their mind off their pain.

Future research needs VR for Diagnostic and Rehabilitation:
Major focus in this field should lie on the technical improvement of the naturalness of the Virtual Environment. New tracking systems have to be developed to increase the feeling of presence. Beside technical aspects further future research effort should focus on the therapeutical effect, the user acceptance and the relapse rate of the VR treatment tools.

Ad 4: VR for medical Training/ Interaction and Interfaces:

The idea of using computer-based surgical simulators for training of prospective surgeons has been a topic of research for more than a decade. However, surgical simulation (for example Bone Drilling medical training system, Munich Knee Simulator) is still far from being included into the medical curriculum.
One of the major needs on these kinds of applications consists of stimulating properly the Virtual Reality user's senses. In this case, sight and touch senses are more important since they would provide the needed effect to the user. Haptic force feedback-rendering systems that enable users to touch and manipulate objects in virtual space have to be refined, since some of the medical simulators that incorporate haptic feedback systems are based on an elementary understanding of haptic perception, whereas there is a real need for guidance not only in the development and implementation of haptic models but also in the psychophysical methods needed to gain more knowledge about perceptual issues when touching real and virtual tissues.
In developing the underlying intelligent simulation and Virtual Reality capabilities, more research about the following issues still remains: provide tactile feedback both for the manipulation and representation of the virtual environment, incorporate a force feedback model of the haptic response of medical recognition and develop techniques for interactive composition and control of complex scenarios.
A field where it should be given major attention in the next years is the modelling of deformable objects. Nowadays, this field needs a high computational cost so this makes it difficult to perform tasks of interaction since they must be carried out in real time.
Another important need is to provide a deep study that will support the simulation technology and develop the metrics for performance evaluation and outcomes analysis.
Regarding to evaluation, the decision of whether an interaction technique is the most suitable technique for a medical virtual application depends on two factors from the human point of view: the sense of presence and the concept of task performance. The sense of presence, that is, the sense provided by the system to the user of being in the environment, is a subjective parameter. In fact, there is not a standard measurement system which allows the measurement of presence. Despite of this and the benefit of the sense of presence is unclear depending on virtual applications, nowadays there is a tendency of study about the relationship between presence and interaction. In addition, due to the fact that presence is a subjective parameter of evaluation, it is necessary to investigate new metrics that allow its correct evaluation taking into account the way of interacting of the used technique in each case.

Future research in VR for medical Training/ Interaction and Interfaces:
Virtual Reality technology is especially suited for the simulation of endoscopic operations, as the surgeon has neither visually nor manipulative direct contact with the operation site. This way, current man-machine interface technology provides an optimal basis for simulator development, even if units have to be adapted to the special needs of minimally invasive surgery especially on the field of force feedback manipulators. Still, the lack of reasonable level of realism seriously hinders the widespread use of this potentially very useful technology up to now. While more realistic simulation is in some respect theoretically possible, the computational complexity of these solutions is still too high to allow cost-effective implementations. Virtual Reality-based technology is even in a less advanced stage in open surgery training, an area of great socio-economic importance.

Ad 5: Distant and remote collaboration tools

The inherent three-dimensionality of anatomical data is currently not properly exploited due to the limitations of current display technology (lack of resolution, problems in multi-user data visualization, etc).

3D view is highly effective in several medical procedures and tasks such as:
- Image-guided surgical procedures (minimally invasive surgery) and radiation therapy of cancer patients;
- Analysis of complex medical images such as those derived from multi-slice computed tomography (CT) where hundreds of images can be more effectively analysed - all at once - through a 3D reconstruction of the specific part;
- Collaborative immersive experiences (tele-presence) such as tele-mentoring, remote surgery, remote training and education, remote consultancy, surgery planning, etc.

Future research in Distant and remote collaboration tools:

The lack of a suitable 3D display technology in minimally invasive surgery and telesurgery is particularly limiting for complex procedures and techniques for which the experience of watching a traditional 2D image is simply not sufficiently close to experiencing the actual procedure (open surgery); this because of the fixed point of view and lack of depth perception and spatial relations between the anatomical parts and between them and external objects such as surgical tools. New, more effective 3D visualization solution will be highly beneficial.
A 3D visualization solution for medical applications has to be developed by taking into account some specific requirements such as:
- Multi-viewer collaborative environment (clinical tasks are often performed by a team and all the members of the team need to have access to the displayed information / images);
- Movement freedom (the doctor needs to continue to perform his task while looking at the 3D display); this - together with the above mentioned multi-view approach - translates into the need of a wide 3D field of view;
- No image quality compromise due to the critical nature of the task and to the importance - from a clinical point of view - of even small details; this translates into a 3D display technology which avoids the loss of resolution, sharpness, brightness and avoids artefacts, etc;
- Ergonomic issues (3D displays in the clinical tasks are intensively used - hours and not minutes- so the 3D view has to be “natural” and comfortable);
- A “natural” and efficient approach asking for new user interfaces, “intuitive” and easy to experiment, able to deal with the added third dimension, often “hands free” (doctor with his hands busy to perform other tasks, sterile environments, etc).

Summary of Research Initiatives Needed

- Development of smart Brain Computer Interfaces (BCI): identification of relevant brain signals
- Measurement of presence, “vection” (illusory feeling of self-motion), and simulator sickness
- VR as a treatment tool to prevent PTSD (Post Traumatic Stress Disorder) at military service and to treat phobias, depression and personality disorders
- high end visualization Image-centric approach in diagnostics, therapy and in training for surgery with increasing interest for the 3D visualization;
- A multi-speciality approach in the clinical procedures with a distributed knowledge; Collaborative experiences
- Widening of the hospital boundaries through remote consultancy, telesurgery, teleradiology, distance training, telementoring, etc.