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Interaction in an immersive virtual reality application

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***Abstract*—Immersive VR (virtual reality) applications usually require styles and devices of human-computer interaction other than the conventional ones like mouse and keyboard, as the user typically wears a head-mounted display and does not see his/her real environment. Moreover, such interaction is usually three-dimensional. This is where relatively new (or at least previously not dominant) paradigms come into the picture: natural user interface (NUI) and gestures. The paper overviews some definitions for these and discusses the communicative aspects of gestures. The abovementioned paradigms affect the process of interaction design, which has to be even more thorough, more conscious than before. If we use gestures for input, the actual requirements of the application have to be analyzed in detail and decision about gesture "vocabulary" has to be taken. In the paper, an actual implementation under development is discussed: the interaction – consisting of navigation in 3D space and manipulation of virtual objects – in an immersive VR application simulating the conventional control room of a nuclear power plant. The implementation is touchless, using a hand movement detector.**

Keywords—virtual reality; immersive virtual reality; interaction; gesture; natural user interface; NUI; Leap Motion

I. Introduction

The definitive book about cognitive infocommunications (CogInfoCom), which describes its theoretical foundations, states that "*one can find in it the influence of well-established research fields (e.g. augmented cognition, human-computer interaction, virtual reality and others)*"[1, p. ix]. Chapters 4.7 and 4.11 of the book are dedicated to human-computer interaction (HCI) and virtual and augmented reality, respectively, and it is noted that "*HCI is strongly relevant to CogInfoCom when it comes to the analysis and design of functionally motivated user-device interactions*" [1, p. 49].

Immersive VR (virtual reality) systems can be described as VR systems where "*Users wear displays that fully immerse a number of the senses in computer generated stimuli. The stereoscopic head-mounted displays (HMD) are a distinctive feature of such systems* [2, p. 59]*.*" Such applications usually require styles and devices of HCI other than the conventional ones like mouse and keyboard, as the user does not see his/her real environment (which includes input devices). Moreover, the spatial part of the interaction usually occurs in three dimensions. This is where relatively new (or at least previously not dominant) paradigms come into the picture: the so-called *natural user interface* (NUI) and *gestures* on which the interaction may be based. Some CogInfoCom-related papers mention or discuss gestures and/or NUI from a practical point of view [3]–[18], but the definition of these concepts has not been in the focus of the papers ([19] excepted).

II. NUIs

Baranyi and Csapo note, "*The inspiration to create engineering systems capable of communicating with users in natural ways is not new* [20, p. 141]." Nevertheless, technological advancement has recently created new possibilities for this paradigm.

Natural user interfaces are regarded as the third generation of human-computer interfaces, after command line interfaces (CLI) and graphical user interfaces (GUI). CLIs are based on text input typed by the user (and usually text output is provided by the computer), while GUIs are mostly based on the desktop metaphor and the WIMP (windows, icons, menus, pointers) style of interaction.

The definitions for the term NUI are numerous and somewhat diverse. According to Glonek and Pietruszka, "*Term NUI stands for the ways of interaction with a device based on methods other than a mouse and a keyboard that would at the same time be as natural and intuitive for a human being as possible* [21, p. 28]."

A book entirely dedicated to NUIs, written by two touchscreen specialists, gives a somewhat vague definition, linking NUI to the emergence of new input devices: "*Decades of cumulative experience in creating interfaces for new technology led us to two important realizations. First, that new input devices do not, in and of themselves, facilitate a better user experience—we argue that the iPhone and Microsoft Surface UIs are highly successful in spite of, rather than because of, the use of a touchscreen. The second realization is that these input devices, while not themselves creating a better user experience, could be enablers for the creation of a UI that is more natural to use, and could fundamentally change the* *way we interact with technology. We dub this the natural user interface* [22, p. ix]."

As far as this definition is concerned, it must be noted that touchscreens have been around for several decades. However, with the ever-increasing use of smartphones they have become popular, also affordable, they have gained new, more sophisticated features and the use of some already extant features has become widespread (e.g. multitouch – the ability to detect input from multiple contact points simultaneously –, better sensitivity etc.). Increased affordability and sophistication actually characterize most of the input devices NUI is based on, even though the devices are hardly completely new.

Another expert in the field, Joshua Blake, has defined NUI as "*A natural user interface is a user interface designed to reuse existing skills for interacting directly with content.*" [23, p. 2]

The three important features of the above definition are:

- NUIs are designed, i.e. they must be carefully planned, with the future use and users in mind.
- NUIs reuse existing skills, where 'skills' mean mostly non-computing skills: human-human communication – verbal and non-verbal –, and human-environmental interaction. An interface will feel "natural" when it builds upon these existing skills. According to Blake, "*Computing power and input technology has progressed to a point where we can take advantage of these existing non-computing skills. NUIs do this by letting users interact with computers using intuitive actions such as touching, gesturing, and talking, and presenting interfaces that users can understand primarily through metaphors that draw from real-world experiences* [23, p. 2]."
- NUIs have direct interaction with content. Blake explains it as "*(...) the focus of the interactions is on the content and directly interacting with it. This doesn't mean that the interface cannot have controls such as buttons or checkboxes when necessary. It only means that the controls should be secondary to the content, and direct manipulation of the content should be the primary interaction method* [23, p. 2]."

Wang et al. state that "*NUIs build on traditional human-to-human interaction models, intend not to be instrumented through artificial control devices (that is why they are named as 'natural') and aim at being or becoming "invisible" after a learning process (the system is naturally giving the user the feeling that he is continuously and instantly successful). Voice control, gaze tracking or gesture identification are taken as a basis to implement NUIs* [24, p. 535]."

Harpstead et al. view the matter this way: "*(...) we reviewed the HCI literature on natural interactions and identified four common characteristics of systems that support naturalness: they (1) support the goals of the user, (2) do what the user expects, (3) allow the user to work the way they want, and (4) leverage users' experience to minimize training* [25, p. 2]."

Wigdor and Wixon note that "*we see natural as referring to the way users interact with and feel about the product, or more precisely, what they do and how they feel while they are using it.*" "*Users focus on content and so should the interface. Provide the absolute minimal number of interface elements that are required for the interaction. For some interactions that is no interface beyond the content.*" They also warn that "*The greatest challenge in building a NUI system is making it learnable.*" Also, "*Never rely on an action being 'natural' (a.k.a. 'guessable'). It's not* [22, p. 9]."

Based on the above listed definitions and features and her own developer's experience and reasoning, the author of this paper proposes the following, somewhat colloquial definition: *A NUI is a human-computer interface which serves and is based on human nature more closely than the currently widespread traditional interfaces.* (Here "human nature" means common human characteristics and skills we are born with or develop in our early or more advanced years. It must be noted that cultural differences apply.) Obviously, this definition may become outdated after a while if and when NUIs start dominating the field. However, GUIs based on the desktop metaphor will surely stay with us for a while.

It should also be emphasized that the learning of the NUI should always be facilitated.

III. Gestures

Media philosopher Vilém Flusser has defined gesture in this manner:

"(...) one way of defining 'gesture' is as a movement of the body or of a tool attached with the body, for which there is no satisfactory causal explanation. To understand a gesture defined in this way, its 'meaning' must be discovered. That is exactly what we do all the time, and it constitutes an important aspect of our daily lives. But we have no theory of the interpretation of gestures and are restricted to an empirical, 'intuitive' reading of the world of gestures, the codified world that surrounds us. ... If someone punches me in the arm, I will move, and an observer is justified in saying that this reaction 'expresses' or 'articulates' the pain I have felt. There would be a causal link between the pain and the movement, and a physiological theory to explain this link, and the observer would be right to see this movement as a symptom of the pain I have suffered. Such a movement would not be a 'gesture' according to the suggested definition, for the observer would have explained it in a satisfactory manner [26, pp. 3–4]."

By emphasizing the lack of the causal explanation, Flusser actually says that gestures are intentional, deliberate.

Later in his book Flusser notes that "*the communicative aspect of a gesture overshadows all else*" [26, p. 161].[1]

Several similar definitions can be found in the literature:

"*A gesture is a motion of the body that contains information* [27, p. 310]."

1 For those wanting to see this field from the viewpoint of communication and sensory perception, Part III of [1] is recommended.

"*Gestures are the motion of the body which is used with an intention to communicate with others. And to make this communication effective and successful both sender and receiver must have the same set of information for a particular gesture* [28, p. 633]."

"*As a gesture, in the context of HCI, we define a coordinated and intended movement of body parts to achieve communication* [29, p. 1]."

"Gestures are not just movements and can never be fully explained in purely kinesic terms. They are not just arms waving in the air, but symbols that exhibit meanings in their own right [30, p. 105]."

Thus, based on the above definitions of Flusser and the others, we can say that *a gesture is a movement of the body* (or of a tool which can be regarded as the body's extension, but it is also operated by the body, and this includes the brain in a brain-computer interface), and *a gesture always has a "meaning", a message,* i.e. it is somehow *coded*. It must be noted that not only humans but also animals can make gestures.

The "coded" quality means that gestures should be interpreted according to a common "code book" shared by the gesturer (the one who gestures, the sender) and the receiver/interpreter(s) of the gesture. A well-known example illustrating the importance of this is the shaking (moving from side to side) of one's head: this gesture means "no" (denial or disagreement or rejection) in most countries and cultures. However, there are a few countries such as Bulgaria and Greece, where this particular gesture indicates affirmation, i. e. "yes" [31].

Some authors narrow down gestures to hand gestures, which may be true for a lot of HCI applications, but this approach is too restricted overall, as people can also communicate with their legs, head movements, facial expressions etc.

The question may arise whether a simple keystroke is a gesture or not. The author of this paper is of the opinion that this depends on the context, the coding. Let us take the pressing of the space bar on a keyboard as an example. If a text interface (CLI) writes, "Press the space bar to continue", then by pressing that key you convey the message that you want to continue, so this can be regarded as a gesture (even if the interface is not a NUI). If a bored child randomly hits the space bar on a keyboard (and perhaps the computer connected to the keyboard is not even switched on), we can say that this is not a gesture in itself. However, if the child wants to attract mom's attention by randomly pressing a key or keys, then the action already has a message, and thus may be regarded as a gesture (it is another thing whether mom notices the gesture and decodes it correctly).

It must be noted that gesture control of machines existed long before electronic computers came into existence. An example is a music instrument called the Theremin, invented in 1920 [32]. It is an early type of electronic music synthesizer, controlled by touchless gestures, the frequency and the volume of the generated sound can be modulated by hand.

As far as the use of gestures in HCI within NUIs is concerned, there are several potential pitfalls to be aware of.

A critical expert in the field of design and human-computer interaction, Donald A. Norman, has listed several problems with NUIs and especially gesture control in his article provocatively titled "Natural User Interfaces Are Not Natural" [33, pp. 6, 9, 10]:

He states that "*Most gestures are neither natural nor easy to learn or remember.*" He cites cultural differences (the same gesture may mean different things in different cultures).

He remarks that physical gestures may have side effects. In extreme cases they can even do damage. He illustrates this with a case of the Nintendo Wii game controller used in a virtual bowling game. "*(...) the 'natural' interface was to swing the arm as if holding a bowling ball, and then, when the player's arm reached the point where the ball was to be released, to release the pressure on the hand-held controller's switch. Releasing the pressure on the switch was analogous to releasing the ball from the hand and it was readily learned and employed. Alas, in the heat of the game, players would also release their hand pressure on the controller which would fly thorough the air, sometimes with enough force to hit and break the television screen on which the bowling lane was being displayed. (...) Here, the gestural convention was too natural.*"

He is of the view that it is "*unlikely that complex systems could be controlled solely by body gestures because the subtleties of action are too complex to be handled by actions – it is as if our spoken language consisted solely of verbs.*"

According to him, "*Because gestures are unconstrained, they are apt to be performed in an ambiguous or uninterruptable manner, in which case constructive feedback is required to allow the person to learn the appropriate manner of performance and to understand what was wrong with their action. As with all systems, some undo mechanism will be required in situations where unintended actions or interpretations of gestures create undesirable states. And because gesturing is a natural, automatic behavior, the system has to be tuned to avoid false responses to movements that were not intended to be system inputs.*"

He states, "*Gestural systems are indeed one of the important future paths for a more holistic, human interaction of people with technology. In many cases, they will enhance our control, our feeling of control and empowerment, our convenience, and even our delight. But like all technologies, gesture-based systems will come at a cost. Different systems will devise different conventions. There will be a learning curve. People with handicaps will have to be accommodated. And there will be an entirely new source of material for comedians. Imagine the problems when a system has a repertoire of dozens of gestures, all of which mean something, but not all of which may be known by person near the device. I am reminded of those old movie comedies of people in formal clothing at auctions doing silent bidding. One person sneezes and thereby purchases an unwanted painting. A couple argues, and as they wave their hands at one another, the hand waving gets interpreted as ever-escalating bids.*"

IV. DESIGNING GESTURE-BASED INTERACTION

Wigdor and Wixon provided this guideline, based on their long practice in the field:

"Understand that there is no such thing as a 'natural gesture' — you need to design the set of gestures in your system [22, p. 209]."

What does this mean in practice? The "set of gestures" means a gesture "vocabulary": these particular gestures will be recognized and interpreted by the system. As discussed above, gestures are always coded, each has a meaning. One of the first question the designer has to ask is whether all interaction in the system can be handled by gestures. If there are too many functions to be fulfilled, it would be impractical to go beyond a certain number of distinct gestures – some gestures would be too similar to each other and thus could be misinterpreted. Also, the user would have to keep a too large "vocabulary" in his/her mind. In such a situation you should either not design a gesture interface, or create a hybrid system integrating NUI gestures with more conventional methods of interaction, like a soft keyboard occasionally displayed in the application with keys to be pressed (as discussed above, these key presses may be considered gestures but they cannot really be considered part of a NUI).

The set of possible gestures is highly dependent on the *hardware* which has to detect these gestures. You should not choose hardware which is not accurate and reliable enough for the purpose. Do not rely on descriptions and hype, thoroughly test gesture recognition with the hardware before designing the interaction in detail. For the recognition of gestures, some hardware manufacturers provide a gesture recognition library, in other cases you have to develop your gesture recognition code yourself.

Another decision to be taken early on is the question of *modality*. A gesture may have different meanings in different contexts. Example: a sweeping gesture may mean the intention to move away in a navigational situation, to scroll a document when reading, to dismiss some object etc. If there are different modes in the interaction, then it should always be made clear to the user which mode is actually in effect, and how to go into another mode when desired. The number of modes should be heavily restricted, too many modes are impractical and confusing.

A lot of thought should also be given to how the user will *learn* the use of the system, the gesture vocabulary, the various modes. It is practically inevitable to educate the user in advance about the use of the application. This education should be short, effective, entertaining and quickly refreshable. It should also be decided what kind of *help* (visual or other, if any) should be given to the user during the use of the application.

Then there is the problem of *user fatigue* (bodily and mental fatigue as well) which can occur especially when the user has to repeat the same physical gestures over and over, perhaps in a body position which is not entirely comfortable.

All this points to the necessity of careful design and extensive and rigorous testing.

V. APPLICATION: INTERACTION IN A VIRTUAL CONTROL ROOM

The full-scope simulator of the Paks Nuclear Power Plant has been in service since the 80's. Even after several refurbishments to the simulator itself [34, 35, 36, 37], the replica control room, which is a conventional control room containing a lot of conventional displays, pushbuttons and switches, is still relatively unchanged. The personnel of the four units of the power plants all receive their training on this simulator, which exists only in one copy, and is much in use. It is also used for testing new control room equipment. With the advancement of technology, it has become possible to create a virtual reality application, the 3D model of the control room [38], which has been integrated with the software simulating the plant, thus it has become possible to use copies of the simulator with the virtual control room. This version of the virtual control room uses large monitors for output, keyboard and mouse, optionally a Nintendo Wii Nunchuk controller as input. The realism could be increased by using immersive virtual reality technology. For the immersive version, the virtual control room model, which uses the Blender Game Engine (BGE) (*www.blender.org*), has been integrated with the OpenHMD package (*www.openhmd.org*) which makes it possible to use HMDs like the Oculus Rift. The Blender version used is 2.76b, under the 64-bit Windows 10 operation system. The interaction has had to be completely rethought. After careful consideration of the technical possibilities and the costs, the relatively accurate and inexpensive, touchless Leap Motion hand movement detector (*www.leapmotion.com*) has been chosen as the input device, for gesture-based control and for interaction with the – virtually represented – physical input devices in the control room. (A good survey of the Leap Motion's use for 3D interaction and gesture control can be found in [39]. The device has been used in several CogInfoCom-related projects [13]–[15], [40]–[42].) For displaying the user's hand in the virtual space, a complex rigged hand model [43] has been developed for the BGE. (The virtual hand is necessary for giving feedback to the user about his/her hand movements and for handling the pushing of buttons and the turning of switches on the panels.) When using the application, the user is seated at a desk and has a HMD on his/her head. His/her hand is above the Leap Motion device. He/she can freely navigate in the control room by using hand gestures and will be able to handle all pushbuttons and switches. Only the user's virtual hands – and not his/her other body parts – are displayed in the VR application.

The navigation is realized by gesture-based control. The currently implemented version uses the following operation modes:

- Translational mode (implemented, in beta phase): the user is able to move along the 3 axes of the Cartesian coordinate system. This mode is in effect when only the left hand is within the detection range of the Leap Motion, the right hand is out of sight. The user moves his/her hand along 1, 2 or 3 coordinate axis/axes simultaneously, and the view – and the user's virtual body – moves with it. The most important direction is along the horizontal axis. As the user sometimes has to travel large distances in the huge control room, acceleration has been implemented. This mode ends when the user puts his/her right hand into and/or pulls his/her left hand out of Leap Motion's "sight". When the user's left hand is clenched into a fist, the movement of the hand does not result in the movement of the view – this sub-mode is necessary to make it possible for the user to return his/her hand into the field of detection ("sight") of the sensor and perform further movements. This solution is a bit analogous to a feature of 2D interaction with a mouse: when the mouse reaches the edge of the mouse pad (or of the area provided for the mouse), the user can lift it, return it to the center and continue the movement as if it continued from the edge of the mouse pad.

- Rotational mode (implemented, in beta phase): the user is able to rotate his/her body around the vertical axis, by rotating his/her right hand. This mode is in effect only when the right hand is within the detection range of the Leap Motion and the left hand is out of sight.
- Object manipulation mode – under development – is in effect when both hands are visible. They can interact with buttons and switches in the control room. In the case of pushbuttons, the collision-handling features of the BGE are used (collision sensors can be deployed among the so-called logic bricks, and when the hand object collides into a pushbutton object, the sensor activates a Python code). The turning of the switches requires self-developed gesture recognition code which has already been written and tested. It determines whether, after the hand-switch collision, there is a rotational movement of the hand and, if so, whether it is clockwise or counterclockwise. It is based on analyzing the change of rotational data (pitch, yaw, roll) obtained from the hand detector.

Additionally, head rotation input – provided by the gyroscope of the HMD – is possible all the time. Unlike the rotational mode described above, this may occur around all 3 axes. It rotates the user's view of the control room.

VI. Conclusion and Future Directions

Definitions and features of natural user interfaces and gesture control have been discussed. Guidelines for designing gesture-based control for applications have been provided. An actual immersive virtual reality application, which is under development and uses a set of gestures detected by the Leap Motion hand movement detector, has been outlined.

Further development of the application is aimed at performing tests and trying out alternative gesture solutions. Several questions are still open, e.g. how to signal when the user, represented by the hands, collides into a panel during navigation. The use of tactile feedback devices is not really an option, as the representation of the human body is only partial in the model, and tactile feedback devices – even for the hand – still do not give satisfactory services. Therefore, the use of different modalities (like an auditory display), as suggested by [1, p. 48] could be a solution, but these ideas should be experimentally validated for the actual application.

The application would probably be primarily used for instruction and education (though preliminary ergonomics tests of planned control room equipment would also be possible with it), so some thought should also be given to the preparation of the students/users for this style of interaction. As the already quoted [22] opines, it is usually a great challenge to make such an interface learnable. As it is rightly stated e.g. in [44], immersive VR/AR technologies have the potential to transform learning and create engaging experiences for students, when used in the right way and when not only students but also educators are prepared for them.

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