The Tasks of Designing and Developing Virtual Test Stands

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Abstract— **Virtual test stands are used for research when live experiment is either difficult or impossible. The possibility of multiple launches is necessary for the program simulating processes with various parameters, along with computer simulation experiments for complex technical objects with VR visualization of the results. Such systems are used, for instance, in the automobile industry. However, there is no mainstreaming yet, probably, because the existing issues have not been properly worked through. The paper discusses a number of problems connected with designing and developing virtual test stands. Determination of overall and interim goals of computer simulation for these systems is required. The use of specialized computer simulation means and/or simulation packages is possible. Computer simulation requires parallel computations. It is necessary to choose VR means suitable for the aims and objectives of the specific system. The necessity arises to use VR in online visualization mode, which presupposes graphic output in the course of program execution and the opportunity to interact with the program. This interaction can change the execution progress and the output graphic information. A major problem is organizing interaction with a virtual test stand. Interfaces for VR environment control and interfaces for simulation control are being considered. Device and natural interfaces are used in VR systems. Natural interfaces can be used to control the VR environment. Problems arise with natural interfaces in setting simulation parameters. Motion capture interfaces can also be used. When working with the stand, a user may experience undesired conditions, which should be studied and prevented.**

Keywords— virtual reality, virtual test stand, interfaces for virtual reality, cyberpsychology

I. Introduction

In the late 1980s – early 1990s, NASA implemented a project of a virtual wind-tunnel. The system was used in design and testing of the Space Shuttle. As it is impossible to conduct tests for such a device in a usual wind-tunnel, full-fledged models of the whole spaceship and its elements were reconstructed and displayed in a virtual environment. Researchers could change the parameters of the models and observe the simulation results in the virtual reality environment [7]. Arguably, the idea of a virtual test stand is a generalization of the idea of a virtual wind-tunnel.

A virtual test stand is considered as an environment for conducting a computing experiment. A modern computing experiment is based on super productive parallel computations and powerful visualization means, including virtual reality means. The idea of a virtual test stand is connected with conducting computing experiments and with the possibility of multiple launches of the program simulating certain processes with various simulation parameters. Such models emerge in a whole range of studies connected, in particular, with aerodynamics, explosion physics and other tasks where multiple live experiments are either difficult or simply impossible to organize. Simulation results should be visualized by means of powerful CGI, including virtual reality environments. At the same time, the necessity arises to use virtual reality in an online visualization mode, which presupposes graphic output in the course of program execution and the opportunity to interact with the program. This interaction can change the course of the program execution and the output graphic data [15],[17].

Currently, virtual test stands have been used in a range of spheres; for example, in automotive industry for checking the dynamic behavior of the car under development [4] Analyzing the possibilities and designing virtual test stands are carried out by Russian researchers [13], [14]. For CAD-designers and engineers of complex mechanics, it will be useful to combine CAD tools, mathematical simulation packages using the resources of modern supercomputers (for example, Logos [16]), and visualization means based on virtual reality within one interactive system. Prototypes of such systems are already being developed [12], although creating full-fledged design environments with the use of virtual reality is for now a long-term goal.

Extensive elaboration of the issues occurring in the course of design and development of virtual reality stands is necessary. Such elaboration should provide real implementation and effective use of virtual reality stands. In the next section, we shall examine some of the issues and briefly describe part of them. Those issues for which we have made certain developments will be discussed further in more detail.

II. Certain issues of design and development of virtual test stands

First, one needs to choose a specific virtual reality environment to implement virtual test stands. Those environments may include VR glasses or headsets, systems like CAVE or mini-CAVE. The choice depends on numerous factors; in particular, on the set simulation tasks, the cost etc.

It appears that the CAVE-type systems fit best for the implementation of virtual test stands. They allow quick implementation of cooperation between researchers. CAVE-type systems also allow the use of device interfaces, which can be relatively convenient for stand users. At the same time, CAVE-type systems are quite demanding, both financially and in terms of computational capacity and energy consumption. They require significant operation areas. With any virtual reality equipment one needs to consider the problems of choosing the corresponding views and types of interfaces used in the visual component of virtual test stands. And, of course, one needs to consider the issues of implementing the visual component of the stands. Specialized visualization systems are required, aimed at specific tasks. Implementation problems in online visualization will be discussed in one of the following sections.

Implementing the visual component is closely connected with the issues of computer simulation. It is necessary to determine the general and interim goals of computer simulation used in virtual test stands. What is more, one needs to analyze both the models of the whole device or mechanism and the models of separate blocks and details. In terms of implementing the model one needs to decide on the means of simulation to be used – specialized ones, developed for the specific task, or mathematical simulation packages (or both). Let us note that it is better to use standard packages in systems

The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0006

developed for designers and engineers. It is crucial to coordinate the implementation of models and the visual component of the stands.

Another important issue is choosing the methods of interaction when working with virtual test stands. One can distinguish two types of actions of a virtual test stand's 'operator': actions to control the virtual reality environment and actions to control the course of the simulation. Hence, two types of interfaces: interfaces to control the virtual reality environment and interfaces for direct control of the simulation process.

When working in virtual reality environments one can use device interfaces (those implemented by means of operations with various devices) and natural interfaces (those based on fixing and detecting any combinations of human movements or organ activity). Natural interfaces can be used to control the virtual reality environment itself, both in the case of glasses (headsets) and in CAVE-type system; for instance, when cameras tracking the operator's movements are connected or eye tracking is used. However, when setting the parameters of the simulation it is difficult to use natural interfaces as a necessity arises to put in a large amount of numerical data, and such input is hard to implement with gestures and suchlike movements. At the same time, it is interesting to organize interaction directly with the simulation objects; for example, to change the shape of a wing by means of certain operations with visual images, thus changing the parameters of the simulation. It is, however, unclear whether it is convenient for the designers and whether it can provide simulation accuracy. A question also arises if we can continually enter data being inside a virtual environment. What if we have to exit virtual reality to set the simulation parameters? Maybe it is easier to use CAVE and mini-CAVE environments for prolonged time periods.

It is necessary to consider the opportunities of modern device interfaces in terms of their use in virtual test stands. Further we discuss the opportunities of natural interfaces, device interfaces and their combinations.

One should study the states of the users of virtual test stands, as well as possible problems arising due to cybersickness (distressing symptoms occurring in virtual reality users similar to seasickness). It is necessary to set research tasks to study the states of virtual test stand users in order to prevent the unwanted symptoms that may occur in the process of work. This will be further discussed in more depth.

A. Online visualization

Online visualization is a methodology in which computation and visualization of this computation are performed simultaneously. It is worth reminding that online visualization presupposes graphic output in the process of program execution as well as an opportunity to interact with the program. Sometimes it is also referred to as computational steering and in situ visualization.

It is relatively simple to visualize computation running in one process, especially if a graphic user interface environment is available. However, it becomes problematic to visualize computation running in a supercomputer environment due to myriads of processes employed in the computation, huge amounts of data, and other factors [4]. At the same time, computation visualization is a demanding feature. The main modern approach to solving the stated problems is, whatever it looks like, to provide fast access to computation data for visualization algorithms. It is accompanied with an approach of putting all or parts of visualization algorithms into the supercomputer, and even straight into computation processes [5]. An approach of steering over visualization algorithms deployed in supercomputer is used, which allows a user to interactively control the way data should be visualized.

B. A note on late binding

It is interesting that most modern online visualization frameworks (The Sensei, ADIOS-2, Ascent, Damaris, etc.) do not include visualization algorithms. Instead, they provide computation data description API mentioned above and the opportunity to describe the following:

- which algorithms should be applied to data directly in the computational processes;
- compression that should be applied to data before sending it away from the computational processes;
- external components that should be launched together with primary computation;
- which data should be sent to which components.

Online visualization frameworks offer such description in a special text file, often in the XML format. This file is independent and is external to the codes of computation algorithms. This brings a great level of flexibility: a developer can configure and execute simulation+visualization process without accessing and recompiling computation codes, he or she can have numerous versions of such configurations, etc. Actually, when a developer codes such a description, he or she codes a bigger software component, which contains both computation and visualization.

This is about late binding: for instance, establishing connections between system components at a later time, somewhere in runtime, which is performed by an online visualization framework.

For example, a developer might state that, together with computation, a visualization subsystem like Visit should be launched, and data description should be sent to this visualization. In turn, visualization subsystem might have pre-configured mapping from these data to visual entities, and thus a computation+visualization is ready to perform for the benefit of a user.

C. A note on a model

Online visualization libraries imply a certain model of the way computation is going on. All of them in general suppose that:

- computation is going on by iterations;

- computation data consists of meshes, grids, point clouds, and multidimensional arrays;
- these data types are divided spatially per processes of computation;
- data changes during iterations;
- data list is more or less constant over time.

The libraries offer an API for describing computational data and its evolution according to this model. For example, a user has to notify the library that a new iteration has occurred by a special call to the library's API, and so on.

The knowledge of the computation process reflected in the described model simplifies an API and directs further system design, such as data compression, saving to storage, streaming methods.

As will be seen in the following section, this specific knowledge is not always the case.

D. *Analogy to online visualization in industry*

Online visualization in scientific computations has an analogy in industry – the monitoring of equipment and processes. We may observe such monitoring in digital components of industrial plants. It might also be observed in digital businesses like web services.

All these systems require monitoring and even automatic reaction, for example, an emergency stop action on gas plants when monitored parameters go beyond the valid ranges.

From an online visualization perspective, these systems imply their own models of operation, different from scientific computations. For example, web services might be imagined as continuous computation, involving calculation of answers to externally generated questions, e.g. accommodating requests. Apart from that, web services have their own internal algorithms executed in the course of time; for example, billing steps, state changes, backups, and so on.

For particular classes of systems and their aspects, the corresponding 'online visualization' and analysis tools emerged. For web services, these are systems of class 'application performance monitoring', 'log analyzer', 'network monitoring'; for bank systems – 'transaction monitoring', so on.

Despite all these classes being different, they share a common requirement – inspection of particular aspects of a state of the running process and steering over it – by human or by automata.

E. *Natural interfaces*

There are several definitions of natural interfaces. In some cases, user operations are described as being intuitive and based on natural everyday behavior. Other definitions point out a basically invisible (or becoming invisible in the course of mastering by the user) interface based on natural elements. This paper treats natural interfaces as those based on recording and detecting a certain combination of a person's movements or their organ activity.

Natural interfaces provide interaction 'from head to toe'. In particular, one can distinguish the following interfaces:

- brain-computer interfaces (brain-machine interfaces);
- interfaces based on direct use of neural impulses;
- interfaces based on speech recognition;
- interfaces based on lip-reading;
- interfaces based on facial expression recognition;
- interfaces based on eye tracking (or eye gaze);
- tactile interfaces and interfaces providing tactile feedback (providing the feeling of touch);
- interfaces based on motion capture of the whole human body or its separate parts (head, arms, hands, fingers, legs);
- interfaces based on the tools of motion capture, in particular, foot-operated computer interfaces;
- gesture interfaces, sign languages.

At the same time, one needs to take into account the possibility of combining several natural human activities within one recording implementation.

Different types of natural interfaces have been used for virtual reality environments. Headsets used in aviation simulators were the blueprint for virtual reality systems; there an image was adjusted depending on the pilot's line of vision. Tactile interfaces are of interest to us in terms of creating gesture interfaces and providing feedback when working in virtual reality environments and with 'big' screens. When organizing movement in a virtual space natural interfaces based on recording and detecting a person's whole body or parts of the body moving are widely used. In the early days of virtual reality environments development, special costumes were used recording foot movements. Now, special panels and platforms are widely used, steps and movements on which are connected with movements in virtual space [1]-[2][3], [11]. The paper [3] considers walking in reality as the best way of organizing movements in the virtual environment, in comparison with virtual walking or flight. On the other hand, moving in abstract virtual spaces is technically easier to organize by means of virtual flight. It is worth noting that movements that are not controlled by the user may cause unpleasant sensations described by the term of cybersickness.

The task of building a set of recognizable movements in sign languages is an interesting one. As a rule, in this respect, sign languages (meaning hand gestures) presuppose one of the options: either a set of trajectories (two-dimensional or three-dimensional) of a point of interest corresponding to the operator's hand position in space, or a set of static hand positions of the operator. One can consider the approach representing a generalization of these options and allowing combined use with the benefits of both options.

This can be achieved by using a system of modifiers, trigger functions, receiving one of the two values depending on the system's state. This approach analyzes the trajectory of a point of interest with consideration for the modifiers' values.

Modifiers can be of various nature: they can be device ones, based on spatial criteria (for example, manipulative areas and virtual buttons), or they can rely on additional schemes and structures (for example, hand position detection or the use of the given syntactic constructions of a sign language).

The use of a modifier system makes it possible to extend the expressive abilities of the created language of human-computer interaction. In particular, modifiers simplify the implementation of the following aspects:

- the metaphor of virtual tools;
- contactless interfaces for working with 'classic' input devices, such as a touchless screen or a virtual keyboard;
- the 'drag & drop' metaphor of interacting with virtual objects;
- joystick-type metaphors of interacting and navigation in virtual space.

An approach towards creating sign languages based on a system of modifiers makes it possible to increase the expressive ability of a language almost indefinitely, by changing the interpretation of the trajectory of a point of interest depending on the modifier's value. The system of modifiers also allows easy creation of new dictionaries for a sign language, including the construction of new elements from the basic and already existing ones. This, primarily, provides the opportunity to build individual dictionaries for various users of the same language. This way, an opportunity arises to develop a sign language of interaction, allowing interaction directly with a virtual object in a natural way, i.e. with implicit account of the interaction context.

By way of example one can indicate virtual planning of an operation, in the course of which an expert can use precise digital input along with direct interaction and virtual tools, depending on the situation and the necessity. Another example is designing in computer-aided engineering systems (CAE systems), in the course of which a user can interact directly with the studied object visualization, thus changing the parameters of the simulation and of the object itself, while keeping the opportunity to put in precise values.

F. Device interfaces

Device interfaces can include the existing VR controllers used for video games and various extensions to them. Additions to them may include mockups with controller holders imitating a real object (tool) or additional equipment for fine hand movement capture (with microelectromechanical sensors – MEMS).

Firms producing controllers, one way or another, develop their own systems of tracking fine movements. Valve Index [10] HMD has 87 sensors on each controller and pressure sensors to track hand and finer positions. Oculus Rift does not have this function yet, but it is being tested by Oculus Quest in the form of hand recognition in video stream. The same approach has been chosen by HTC VIVE. Among less popular devices [9] are Etee and PS VR , which test tracking all five fingers.

The following devices can be noted as additional equipment: Manus Prime One [6], Senso Glove [8], Forte Data and Noitom Hi5 Glove. All of them relate to the MEMS motion capture.

Fine movement tracking capabilities:

- more precise control of the existing 3D simulation packages;
- application both in VR sets and in CAVE;
- more variety in control commands;
- application in simulations requiring fine movements. For example, an operation simulation for medical training;
- absence of necessity to hold the controller in one's hand (except the case with video capture of fine movements).

Problems:

- time of continuous operation is limited by the accumulator capacity;
- with video capture of fine movements there can be data loss due to hand crossing or poor lighting;
- for precise capture of the absolute hand movement a large number of external positioning stations must be used;
- if there is a system tracking movements with absolute positioning and fine movements, the latter can be redundant for the specific task.

III. Psychological Issues of the Development

A large number of papers have been devoted to a user's state in virtual reality; however, they mostly discuss interaction with either entertainment systems or systems specially developed for experimental purposes. The field of human interaction with systems developed for practical activities remains under-investigated.

A person's state during such work is determined by the essence of the work, the degree of his or her motivation and understanding, and by the influence of the virtual environment. Among such states cybersickness can be distinguished, which is a state similar to seasickness, occurring due to conflicting signals from different sensor systems (primarily, vision and the vestibular apparatus). Another state is the sense of presence, a feeling of being directly in the virtual reality environment, which is accompanied by perception of virtual objects as being real, as enabling a person to physically interact with them.

Another crucial state is social presence, the feeling of another person being present nearby, both in the physical room and in the same virtual environment. Working with a virtual test stand presupposes, among other things, cooperation, so phenomena connected with being together in virtual reality should be studied in depth primarily in the context of production intellectual activity.

Let us examine certain aspects of experiencing social and spatial presence occurring in the process of working in HMD and CAVE.

When using virtual reality like HMD, this means a computer-generated scene, in which each person who puts on the HMD has their own coordinates. Participants can be presented as avatars or as hands or tools, with which they interact with the model and with the environment. They determine each other's location both visually, based on the avatar's location, and aurally, based on the sounds that each person makes, even if he or she stays in one place (steps, sounds of shifting weight from one foot to the other, breath, puffing, clothes rustling, button clicking sounds, mobile devices signals). This way, a person in virtual reality, along with the mental model of the object under study, has a mental model of the space in which he or she is, including the people in there, whether they are present in the virtual environment or not. However, in this case, we are interested in not only in the notion of spatial characteristics of the people with whom the researcher shares virtual reality, but also in the possibility of cooperative work. Facilitating cooperative work starts with providing joint understanding, which means that one participant's notion of his or her location in space, the location of the object under study and the location of another participant should coincide with the way the other participant sees the object.

Another crucial question relates to the possibilities of control for the participants. One participant's intervention into the scene, leading to major changes in its visual view, can cause unpleasant sensations in other participants, as it will not correspond with a person's perception of plausibility. One needs to decide whether all the participants should have the opportunity to introduce major changes or only one of them, with the others being able to make small changes. Access to making any changes, even insignificant ones, should probably be granted to only one participant. However, it is important to decide whether anything should precede major changes, in order to make the transition more natural for those participants who are observing them. A metaphor of magic transformations should probably be used in this case.

There is also an issue of coordinated use of the menu and/or other controlling objects of the scene and their location in relation to the participants of the virtual environment.

When using a CAVE-type system, the majority of the raised questions do not occur, because the image is generated not onto individual HMD screens but on the screen located around the participants of the virtual environment, and in the space between screens. This way, people working together in CAVE can see each other, precisely determine their respective location, and understand what angle of visibility other participants have of the object under study. However, the issue of mutual control in CAVE-type systems remains open. Besides, CAVE-type systems allow physically easy transition from virtual reality to the real world and back – one simply has to exit the area surrounding by screens and enter it again. The issue of a person's experiences during such transitions in the process of complex intellectual activity is currently not investigated. When designing a virtual environment using a CAVE-type system, one should also take into consideration the dimensions of the area limited by screens and the number of participants in the group, who will simultaneously be working with the stand.

Thus, when designing virtual scenes for virtual test stands, the following aspects should be considered:

- control possibilities for one or several participants of the environment;
- the size of the scene and the number of people involved;
- representing the avatars and objects as truthfully as possible, with respect to mutual location and angles of vision;
- representing control elements (menu and others) as reasonably as possible (perhaps, defying the principle of truthfulness).

Conclusion

Let us note that some of the virtual test stand design and development tasks discussed above do not cover all the issues that designers have to face. In particular, one needs to study the role of the customer when choosing the necessary means of virtual reality environments for the stand. Of utmost importance is also the role of future users when choosing and designing views and interfaces used in the stand (both for controlling the virtual reality environment and for the simulation parameters). It is worth noting an important role of the customer when describing the models underlying the stand. Due to the pivotal role of the customer / future user, there occurs the necessity to study the aspects of their activity in virtual reality environments when working with the stand, conducting both a theoretical study and experimental research. Virtual test stands require the development of not only specialized but personalized visualization systems, taking into account not only the goals and tasks of the simulation, but also the aspects of perception of virtual reality and interaction with it and within it.

The preliminary notion was that natural interfaces can be applied only to organize control of the virtual environment, while device interfaces can also be used to set simulation parameters. However, analysis has shown the possibility of using natural interfaces for this task. For example, in order to interact with the model a user can change its parameters by changing visual parameters of the object, for instance, changing the shape of its wing in the case of virtual aircraft tests. Apart from that, simulation parameters can be changed by putting in digital data. At the same time, we should take into account the fact that complex cases require the use of traditional input devices (keyboard, mouse etc.) to set the parameters. This poses the abovementioned question of users exiting and entering virtual reality. What is more, such exiting and entering differ in creating virtual test stands based on HMD and CAVE.

Let us note once again that the issues of studying a person solving serious tasks in virtual reality remain neglected. In this respect, the corresponding research tasks should be set and this area should be examined.

ACKNOWLEDGMENT

The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0006.

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