ROLE OF VIRTUAL REALITY IN THE LIFE OF AGEING POPULATION

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Abstract: Virtual reality (VR) has been on the scene for several decades already. Its first applications were in gaming. However, hardware and software were expensive and thus not for everybody. Since that time, the development of technology proceeded fast and enabled to open new application areas for VR. Currently many commercial systems are available for gaming, training and education, simulations, design, and also for medical purposes. In the article we focus on VR applications in healthcare. First we present existing commercial solutions, and research studies showing the potential of VR in healthcare. In recent years there have appeared many interesting projects and applications aimed at ageing population as target users. We present examples of such projects. Based on our previous experience and after analysis of available solutions, we propose a conceptual architecture od software environment for development of such applications and discuss their potential use. Finally, the implementation of the proposed architecture for interactive application of experience sets is described.

Key words: *virtual reality, ageing, cognitive training, sensory activation*

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1. Introduction

Virtual reality (VR) was invented in 1950s. First VR system with head-mounted display was invented in 1968. Then it took more than a decade before it was made more popular. And only in 1990s VR was used for training and simulation in the USA (military and NASA). Last decade brought fast technological development that influenced positively development of hardware and software and successively new applications of VR systems. Gaming industry was among the first successful areas. Then many training and education applications appeared, followed by simulations and design for the industry, and last but not least healthcare. Since the devices have become more comfortable and user-friendly and more affordable, the number of various application areas has been growing recently.

In the article we describe examples of research and applications of VR in healthcare and as a tool having great potential for rehabilitation, cognitive training and

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sensory activation of elderly people. Then we discuss a proposed conceptual design of a system architecture that would support implementation of these applications. The application being developed in our project may have two main functions, namely activation and entertainment of the elderly and collection of data for clinical purposes. The results of data analysis may serve for evaluation of indicated therapy, proposal for changes in therapy, evaluation of stability of the health state.

2. Virtual reality in healthcare

Medicine and healthcare are areas, in which new technologies have a great potential in almost all types of activities. This is illustrated by a growing number of companies successfully introducing applications of VR/AR (augmented reality) in medical industry, see for example [1] (web – hitconsultant.net). One of the most popular areas is surgery, in which surgical planning, surgeon training and assessment, and surgical simulations dominate. New combinations of technologies appear, as for example VR with a surgical robot. Another large area is medical education and training. There appeared many applications for training in anatomy, [2, 3]. It is very important that VR allows using individualization. One example are 3D VR models utilizing patient's individualized medical imaging data that enable the doctor to see all details from different views in 3D [1]. Before the imaging systems offered to display 3D reconstructions on standard 2D computer monitors. Other applications focus on treatment of chronic pain or relief from the symptoms of mental disorders and fears. There have appeared first applications of augmented reality, such as holographic visualization of a patient's anatomy or AR guidance system for surgery [1].

2.1 Education and training in medicine

As mentioned above, education and training are fast growing and important VR application areas. They can be advantageously used in distant learning, which was a necessity in recent Covid-19 period. The decreasing price of the head-sets contributes to wider use. The potential for training medical students is obvious in particular in clinical courses. VR helps in training special skills, simulating situations and states that might occur in real life but training cannot be performed on real patients because they are not available at the given moment (having the required diagnosis, injury, health state, rare disease, etc.). Although there exist very realistic simulators (artificial patient) they are expensive and some functions cannot be simulated on them easily or at all. VR can simulate almost everything. And moreover, more students can work on the same task at the same time. Last but not least it allows recording all performed actions that can be successively replayed, analyzed and evaluated. That is a very important feature because it enables to explain students whether everything they did was relevant and corresponding to the patient state or what was done incorrectly and why. The students can be virtually present at an operation without the necessity to peek over the shoulder of the surgeon during the operation. In real situation, only very few students can be physically present and really see what the surgeon is doing. Using a virtual reality camera, the surgeon can stream operation and many students can watch it at the same time.

2.2 Virtual reality in treatment

Recent development shows that VR can be effectively used in many healthcare areas, in particular for therapeutical purposes. It already found its place even in psychological therapy where it can replace teletherapy through video calls. VR immersiveness proved to be a great advantage because it can increase the effectiveness of the therapy due to the fact that the patient is more relaxed and not disturbed by surrounding environment. These properties contribute to increased effectiveness of physical therapy and pain relief as well.

A great issue in medicine has been pain for many years. It is not measurable and the doctors have to rely on subjective complaints of the patients. Standard approach how to lower the pain is to prescribe medication, in most severe cases opioids that are addictive are prescribed. There have been performed numerous research studies that have proven that VR can alleviate pain. They focused on different patient groups. In [4] a pilot study performed in the St George's Hospital in London is described. They offered patients undergoing surgery to use VR headset prior to and during their operation to view calming landscapes. The results are convincing. All patients using VR considered the overall hospital experience as improved, more than 90 % felt more relaxed, 80 % felt less pain and more than 70 % felt less anxious. Another pilot study [5] focused on pregnant women to help them get through labor pain in case they like to give birth naturally. In [6], the authors report about a study, which included 120 patients who were experiencing moderate to severe pain due to medical or surgical conditions, showed a 52 % reduction in pain in the group watching VR compared to the group that watched the same type of content on the TV screen. The results of this and other research studies [7, 8] suggest that immersive VR could potentially be used to reduce the need for pain medications, notably opioids. All studies prove that the immersivenes of VR has positive impact on the patients because it helps patients relax and divert attention from the real world. As one patient described in [5], she forgot about time when watching calming scenes in VR.

Rehabilitation is another broad area for VR applications. Many of the developed applications use gamification principle and tailoring to the patients' therapeutic needs, see for example [9]. The reason for gamification is to make physical therapy more enjoyable and to increase patient motivation and engagement. Moreover, gamification can be used for group exercise and thus make it even more enjoyable. The observed positive effects are increased physical activity, reduced pain levels and willingness to attend next physical therapy sessions.

Recently we have started two connected projects. One proposes a solution for the personalized rehabilitation of full body with real-time feedback, recording, and evaluation. The system could be calibrated for each person individually. It is based on physical disposition (height, age, etc.) and movement ability. The whole system consists of affordable parts available on the standard market (see Fig. 1). The data from trackers are used both for evaluation of the user's movements and for generating the avatar's movements that copy the user's movements (see Fig. 2).

We can add an avatar representing a physiotherapist who performs movements correctly. Then the user sees immediately whether he/she is exercising well or how far is from the correct movement.

Fig. 1 *HTC Vive trackers used for body tracking.*

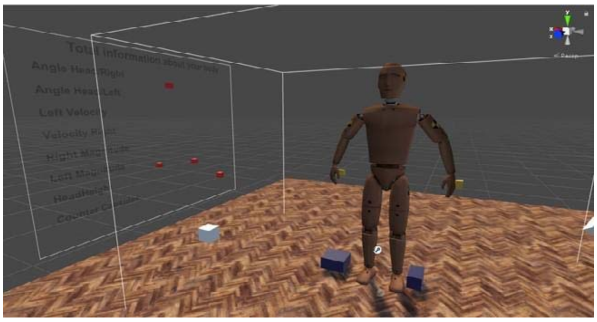

Fig. 2 *Visualization of the body model in VR.*

The other project is focused on coordination and motion learning. However, when designing adequate exercises, it can be also used for rehabilitation purposes. In the project we investigated the impact of VR motion learning to motion performance, motivation for motion learning and willingness to continue motion learning. The motion skills we focused on in the first study was juggling as an activity that requires coordination of both arms and hands [10]. It proved that VR might help, however for such exercises it would need good haptic interface for enabling the user haptic response as close as possible to the response in real world situation.

2.3 Virtual reality for ageing population

All applications presented above can be used by users of any age. However, in last years, we are witnessing fast development of many different VR applications targeted directly at ageing population. There are several reasons for that. The ratio of ageing population in developed countries is growing. There is a need for better and more efficient care of any kind. Technology seems to be good instrument for that. Current and near future elderly people are used to live and work with technology more than previous generations therefore the opportunities for VR applications become much broader. In addition to immersiveness, interactivity is another feature that keeps the user active and forces him/her to respond to new scenes or decide about next steps. All these features are used in cognitive training, memory training, space orientation, balance training, physical exercise, etc.

Several studies were focused on the appropriateness of using VR by elderly people. They considered the questions of safety, physical stability, subjective feeling. A pilot study of the University of Nice team Sophia Antipolis [11] demonstrated the appropriateness of using the VR to work with people over the age of sixty. Respondents in this study considered the virtual environment safe and did not show excessive fatigue. A study by Jeng, Pai and Yeh [12] highlighted the possibility of using virtual reality in seniors over 76 using the Wii game console developed by the American division of Japanese company Nintendo. Research results have shown that playing somatosensory games can improve the physical stability of seniors and also enhance their self-esteem. A very interesting study was performed by Park and Yim [13] who developed an enjoyable therapy for elderly that combined several activities and aimed at improving cognitive function, muscle strength and balance at the same time. The program was 3D VR kayaking and the results after six weeks of training (twice a week for 20 minutes) showed significant improvement in all measured parameters.

The VR use with the aim of improving the environment of seniors is the content of a number of several projects. For example, Rendever [14], Bettvr with Age [15], MyndVR, virtual reality pain reduction [17], aged care virtual reality [18], Lumeum [16] or Adventures with VR [19]. Here, the VR is a tool to help seniors reduce the sense of isolation from the outside world, avoid depressive states or stimulate their activity through new technologies.

Researchers at the National Institute of Mental Health, Czech Republic currently develop a project "Virtual City – a Game System for Cognitive Training in Virtual Environment" [20] that is aimed at training of cognitive and decisive abilities of elderly people. Virtual reality does not serve only for entertainment, but mainly for complex training of cognitive and physical abilities. A set of virtual games for cognitive training and training of everyday activities can be used for healthy ageing persons as a form of prevention and at the same time as positive stimulation of persons with mild cognitive disorder. The tasks train memory, space orientation, conscious decision making, planning or attention.

3. Conceptual design of system architecture

In 2019, the virtual reality keeping seniors active (VIREAS) project (financed by the Technology Agency of the Czech Republic; partners South Bohemian University; Czech Institute of Informatics, Robotics and Cybernetics of the Czech Technical University in Prague, and Association of Virtual and Augmented Reality) started. The idea behind is generating cognitive visual and auditory stimuli that need response. The stimuli are from the real world, as for example virtual tour through a city, virtual walk through a forest. There are always places where a decision must be made: where to go next, enter/not enter a building, etc. The first target group are residents. However, the application can be used by patients in hospitals (aftercare) and home care. The project aims to create a new form of activation, usable in other individual and group programs of the facility. Software called "Virtual Reality Experience Set" is being developed based on the needs, wishes and preferences of a selected sample of seniors [26, 27]. Design of the scenarios in the project was inspired by the work [21], in which the concept of sensory activation was described. Sensory activation is understood as "initiating the motion" in which all senses participate. Positive result of sensory activation is creation of motoric, cognitive, verbal, really complex activity and energy. In [21] a long list of goals of sensory activation is presented. Most of them can be reached only in interaction with other persons (caregivers, family members, friends, neighbors). However, these persons are usually not available all the time or cannot perform all the activities with the elderly so intensively.

While experimenting with new technologies we realized that the technology can advantageously support some of the activities. We came to this idea also thanks to our previous experience in the OLDES [22] and SPES [23] projects in which the eScrapbook was developed and successfully tested. In comparison to it VR offers more functionalities, in particular the 3D images that are closer to realistic perception and immersiveness. On the other hand, VR is more demanding on implementation.

Since our aim is to develop a software environment for flexible and efficient implementation of various scenarios for various groups of users, we focused first on conceptual design of the system architecture that would support such implementations and would not be just a single purpose software application. The analysis of functions and properties was based on the ideas published in [24]. The conceptual architecture is shown in Fig. 3.

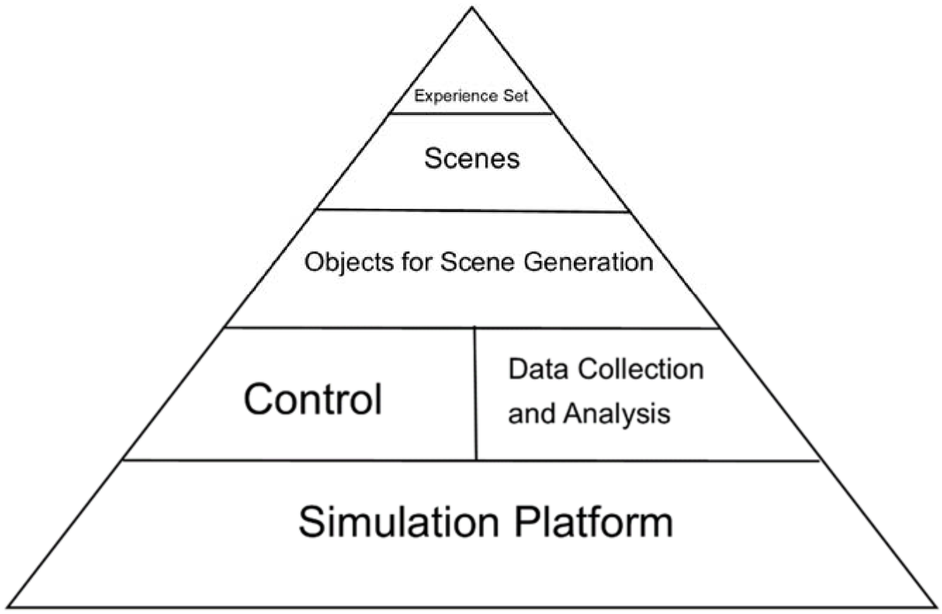

Fig. 3 *Conceptual system architecture.*

The fundamental part is represented by a simulation platform that is the core of the whole system. It controls all the execution, generation of scenes, interaction with the user, allows using different trackers and other additional peripheries. Next level has two modules: control and data collection and analysis. Control module serves for external control of the application by a trainer (caregiver, etc.). It enables direct interaction or changes of the scenes if required. Data collection and analysis module serves for collecting defined data from the user and providing detailed analysis of the acquired data. Since some of the VR headsets are equipped with eye-tracker it is possible to evaluate at which part of the scene the user is looking at. That can help several purposes. On one side the developers can evaluate the attractiveness of designed scenes or easiness of user control. On the other side the doctors (or other experts) can analyze the attention, orientation in the scene, fatigue and other parameters of the user. After the session the carer leads a dialogue with the VR user on the content of the tour/walk which activates the memory, emotions and verbal communication.

Next layer represents a general module for creation of diverse objects that can be used as building blocks in various applications. These objects are, for example, buildings and streets in a city, rooms in a house, trees, forests, lakes, roads, rivers, mountains, etc. The objects can be created using computer graphics tools or reconstructed from photos. Fourth layer from the bottom is a module for developing scenes from the pre-defined objects in the third layer. Another option is to include videos that must have decision points that can be controlled by the user. The top layer serves for generating final application by combining scenes into designed scenarios.

4. System implementation

4.1 Hardware requirements

Accurate imaging places higher demands on computing technology, which must be equipped with a high-quality graphics card to avoid unwanted and unnatural slowdowns in display and the subsequent disappointment of users due to poor functioning of the application. It is therefore always necessary to consider the technical parameters: memory size and image resolution, disk speed and capacity, size of operating memory, presence of connectors (e.g., HDMI 1.4).

We do not recommend using virtual reality kits with a standard office desktop or laptop computer, which are usually not equipped with a powerful processor and a high-quality graphics card. In this respect, desktops and laptops labeled as gaming or "VR-ready" meet the basic requirements. The minimum is a quad-core processor (Intel Core i5, i7), operating memory of at least 8 GB, and NVIDIA GeForce RTX or GTX graphics card (minimum 6 GB).

In this configuration, a wired connection of the VR headset to the computer is expected because of the fast transfer of data from the computer to the glasses. This arrangement is necessary if photos, videos, or computer graphics are to be of high-resolution quality. If it is for some reason necessary to use a wireless connection between the VR headset and the computer, the resolution of the image information must be reduced to a reasonable degree to maintain a sufficient transfer rate from the computer to the glasses. Slowing down the transmission results in interrupting the smoothness of the motion in the image, which negatively affects the perception of the experience, and also negatively affects the actual control of the application.

4.2 Spatial and technical requirements for the equipment

When we proposed the technical solution we had in mind that the described application will be used by seniors or people with special needs. It was also expected that in many cases help or assistance of another person would be required. As mentioned above, computational power, graphical card, memory and transfer rate are very important parameters. In addition to computer performance, it is important to check the compatibility of the computer and the selected VR headset.

It is also necessary to select the appropriate space where virtual reality will be used. Virtual experience can be implemented in a room that is also designed for other activities or – in the case of immobile residents – in their own room. The location should always be protected from direct sunlight to avoid disturbances when using the glasses. It should not be surrounded by windows and mirrors, as the localization of the glasses in the surrounding physical environment may not work properly. Last but not least, safety must be taken into account. The user of the glasses is focused on the virtual reality and does not perceive the physical environment around him/her, leading to the possibility of self-injury or to someone nearby, or potentially breaking something. Therefore, it is necessary to choose a place where the risk is minimized (no sharp edges nearby, no obstacles on the ground, no objects that could be dropped). The user (resident of a senior home) can also sit in a wheelchair or semi-sit in bed, enabling partial turning of the head at least.

A desktop computer with a monitor or a laptop can be used in a room that will be consistently dedicated to this type of activity. It is always essential that the activity worker has a clear view of the monitor and can watch the viewing experience or assist in operating the application using his/her own controller. A headset with a portable laptop is suitable for the option of using virtual reality by clients at the bedside.

4.3 Implemented experience sets

Several types of experiences can be used in work with older adults, which differ in their way and difficulty of creation, the degree of interactivity, or the way reality is portrayed. It is always necessary to be clear about the purpose that the use of virtual reality is to serve, but also about other factors such as the profile of the users, the available financial resources, etc. The first experience sets we created were selected based on suggestions of potential users. Their topics were: walk in a forest (a typical Central European forest), walk through a city center (selected cities in the country and neighboring countries) and travel (nature, mountains, spas, historical monuments, castles, etc.). Since a virtual experience can be created in computer graphics or photos or videos can be used, we decided to develop one experience set – the walk in the forest – using computer graphics and to use 360° photos for the remaining two experience sets.

4.3.1 Computer graphics

Experiences created by computer graphics allow creators to create virtually any scene with any number of interactive elements. However, creating them is very challenging and requires knowledge of programming, scene design, and sequencing. In principle, images can be created in 2D and 3D graphics. There are two basic approaches to 2D graphics: vector and raster graphics. Vector graphics stores precise geometric data, such as coordinates of points, connections between points (line segments and curves), and the filling of shapes. Most vector graphics systems allow the use of standard shapes such as circles, squares, etc. The basis of raster graphics is a regular grid of pixels, organized as a two-dimensional matrix of points. Each pixel carries specific information, such as brightness, color, transparency of a point, or a combination of these values. An image in a raster graphic has a limited resolution, which is given by the number of rows and columns.

3D graphics are related to 2D vector graphics. It also works with point coordinates and information about lines, curves, and surfaces, but the data is stored in a three-dimensional coordinate system. A 2D image is then generated from this three-dimensional data representing solids. In 3D graphics, various techniques can be used to create very realistic-looking images by faithfully simulating light and optical phenomena such as shadows, reflections, and light refraction. Advanced development tools also allow for realistic animations, including movements of clothing, hair, water levels, and simulations of physical phenomena such as gravity and reflections.

The advantage of computer graphics is the possibility of creating any environment (real or dream-like) with many possible user interactions within individual scenes. The disadvantage is the need for professional knowledge of scene creation and programming, and, depending on the complexity of the graphics and interactions, the creation is also highly time-consuming. For illustration, we present in the Fig. 4 a screenshot from The walk in the forest experience set.

4.3.2 360° photos and videos

The least technically demanding, yet very effective solution is to create a virtual experience as a 360° photo gallery. Such an experience has several advantages. Its creation is undeniably easier than computer graphics. The photographs reflect the reality that the older adults know or may know, and, moreover, they can be arranged in a set that makes viewing it feel like a walk through a given location, allowing the user to look around in all directions. However, one cannot move around in the environment: it can only ever be viewed from the one place from which the picture was taken. The image gallery can be combined with the environment created by PC graphics to add interactivity. This option was used in the Travel experience set, in which the user starts a trip from a railway station, created in computer graphics. Instead of train time tables, names of various places and/or themes (mountains, lakes, castles, etc.) are displayed. After the user selects a location or topic, the scene changes to the first photo in the set.

Another option for creating experiences is the shooting of video sequences (both real and fiction). The execution of such an experience requires a good technical and personnel base as well as the preparation of scenarios with multiple options to

Fig. 4 *Screenshot of a forest scene implemented in computer graphics.*

allow at least partial user interaction. Due to these reasons, we did not implement videos in this particular project.

Principles of 360° photography It seems on the first glance that to take 360° photos is easy because they can be taken with an amateur camera or even a mobile phone. However, we have to have in mind that the quality of the resulting photo depends on the technical equipment and the experience of the photographer. Therefore, we decided to describe here briefly basic guidelines to follow when taking 360° photos for (not only) older adults.

It is advisable to use at least the manual settings for aperture, time, ISO (sensitivity), and focus. It is recommended to place the camera on a tripod to keep it at the same height for all shots. The rotation of the camera around the non-parallax point (the point around which the camera has to rotate to produce a true 360° photo from a single point) and its correct adjustment are provided by the additional panoramic head. 360° photos capture the entire space around the photographer on all sides, thus occupying a field of view of 360° horizontally and 180° vertically. It is best to use a wide-angle lens, as a wider field is covered in one shot. An even wider field of view can be taken with a "fisheye" lens.

For the use of photography primarily and by less mobile older adults, it is important to adjust the height of the tripod. Since older adults often complete the virtual reality experience seated, the height from which shots are taken should match the view of a seated person. A height mismatch creates an uncomfortable

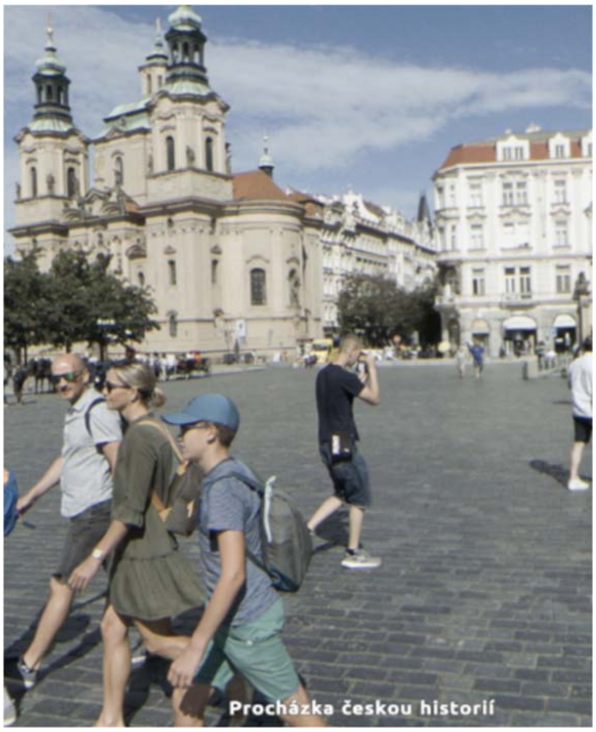

Fig. 5 *Screenshot of a city walk (taken from the series of 360°photos – Prague, Old Town Square).*

feeling of "floating" or hovering above the terrain for a seated person. The lack of a natural change of perspective can be similarly uncomfortable. Because the user cannot move in space, there is no change in perspective for nearby objects due to head movement. When taking photographs, it is necessary to test at what distance a change of perspective occurs for closer objects. Nausea and dizziness can also be caused by an inappropriate shot type. Shots taken, for example, from a lookout tower without a sufficiently high railing or protective netting being visible in the frame are completely inappropriate. The quality of the experience can be significantly impaired by poorly focused glasses or a sound system that is too loud (or too quiet). It is also recommended to have people in the photos of the scenes where we expect people in real life, as for example in city walks, in travel to castles or spas.

4.4 Virtual reality solutions for users with specific difficulties

When assessing the appropriateness of using virtual reality for older adults with sensory or motor difficulties, it is always necessary to take into account the subjective feeling of the individual. Each individual perceives his/her impairment differently and will undoubtedly also perceive how that impairment affects their experience of virtual reality differently.

Fine motor skills and motor coordination difficulties One of the basic prerequisites for an intense virtual reality experience is interactivity, i.e., the ability to influence the storyline of the experience. In practice, this means that the user can press the buttons of the controllers in their hands to determine the direction of movement or select the virtual environment they want to move to.

The standard controllers used to control the virtual experience are not practical for clients with severely limited hand mobility – they require users to hold the controller firmly in their hands while using the buttons in a controlled manner. In the case of older adults in general, it is advisable to use controllers that hold themselves in the palms of the hands using a fastening (see Fig. 6).

Fig. 6 *Example of a special controller using a clamp strap to simplify control for users with impaired hand mobility.*

A suitable solution is the aforementioned parallel assisted control provided by an additional controller in the hands of the accompanying activity worker. In the case of difficulties, the activity worker can help the older person "invisibly" (similar to a driving school instructor), without repeated manipulation of the older person's hands, which could make the older person feel incapable. The ease of use, together with a suitably interactive scenario and proper communication during the experience, allows the older VR user to be in full control of the situation and storyline, thereby enhancing self-confidence and dignity.

Another solution is to have agreement between the activity worker and the user, where the activity worker completely takes over control of the user's movement in the scene. However, this is not an ideal solution given the potential of virtual reality.

Eye and hearing impairments Eye impairments. If a user wears glasses to correct an eye defect, then it is possible to use them in virtual reality. The standard frame sizes fit into the VR headsets used without any problems. As for age-related visual impairments (macular degeneration, cataracts, etc.), it is always necessary to test whether and how the images projected in virtual reality can be seen by the user beforehand. It is not possible to generalize completely that a particular defect makes the use of virtual reality impossible or "problem-free". It always depends on the subjective feeling of the user.

Hearing impairments. The most common defect in older age is hearing loss, which is usually compensated to some extent by hearing aids. Two basic problems can occur here:

– If the virtual experience is accompanied by sound, then the user may not hear the sound well. Similarly, the user may not hear the activity worker's instructions properly.

– If the amplification of the hearing aid is set to a higher value, unwanted feedback may occur, causing amplification of environmental sounds (speech, music) or whistling.

Here again, the setting of the hearing aid must be done sensitively so that the user can hear well and at the same time no unwanted whistling occurs. At older ages, higher frequencies are usually particularly unpleasant.

5. Conclusion

In the article we presented main areas of healthcare and medicine where virtual reality applications are already used to certain extent. In some areas the applications are close to routine use. The basic features of VR – immersiveness and 3D visualization – enhance its operational properties. Another feature – recording all performed actions together with the whole displayed sequence – enables detailed analysis and evaluation of the session. Last but not least important feature is the personalization.

The area of applications of virtual reality in healthcare and care for elderly seems to be very promising. We have to consider that people currently in their 60ies or 70ies are used to handle smart phones, frequently computers and other technologies including wearables. That means the technology is mostly acceptable for them. The challenge is to develop useful and attractive applications they will be willing to use. One of the possibilities might be using VR for simulation experiments for elderly drivers. Such experiments are till now performed in car simulators [25]. VR can enhance the experiments through immersiveness and 3D visualization that make the experience more realistic.

The application we developed and already tested on a smaller group of seniors gave us a positive feedback that even seniors who did not have any previous experience with virtual reality and similar technologies are willing to try the experience sets. Some of them came with suggestions for development of thematically new experience sets. The study confirmed the findings presented in other international studies, in particular active involvement of the users both in the development and use of such applications.

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