New effective aid for teaching technology subjects: 3D spherical panoramas joined with virtual reality

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Abstract. Rapid development of modern technology and its increasing complexity make high demands to the quality of training of its users. Among others, an important class is vehicles, both civil and military. In the teaching of associated subjects, the accepted hierarchy of teaching aids includes common visual aids (posters, videos, scale models etc.) on the first stage, followed by simulators ranging in complexity, and finished at real vehicles. It allows achieving some balance between cost and efficiency by partial replacement of more expensive and elaborated aids with the less expensive ones. However, the analysis of teaching experience in the Military Institute of Armored Forces of National Technical University "Kharkiv Polytechnic Institute" (Institute) reveals that the balance is still suboptimal, and the present teaching aids are still not enough to allow efficient teaching. This fact raises the problem of extending the range of available teaching aids for vehicle-related subjects, which is the aim of the work. Benefiting from the modern information and visualization technologies, we present a new teaching aid that constitutes a spherical (360° or 3D) photographic panorama and a Virtual Reality (VR) device. The nature of the aid, its potential applications, limitations and benefits in comparison to the common aids are discussed. The proposed aid is shown to be cost-effective and is proved to increase efficiency of training, according to the results of a teaching experiment that was carried out in the Institute. For the implementation, a tight collaboration between the Institute and an IT company "Innovative Distance Learning Systems Limited" was established. A series of panoramas, which are already available, and its planned expansions are presented. The authors conclude that the proposed aid may significantly improve the cost-efficiency balance of teaching a range of technology subjects.

Keywords: 360° panorama, VR glasses, simulator, vehicle cabin, academia-industry collaboration.

1 Introduction

Technology plays a vital role in modern world. At present, most occupations and activities imply utilization of some devices and equipment. Among the variety of classes, an important representative is vehicles. A wide assortment is designed and extensively used in civil (transport, building, service etc.), military, and paramilitary (emergency, police) fields. The following features are typical for modern vehicles and their exploitation process:

- Increasing complexity of the chassis itself and the installed equipment;
- Fast development, resulting in frequent appearance of upgraded and novel models;
- Often, hard use conditions (especially for military and paramilitary vehicles);
- High costs of repairing and replacement of broken samples.

Consequently, extensive knowledge about the proper exploitation of the vehicle and related skills must be delivered to trainees during education in order for them to become qualified users.

2 Related work

In the teaching of vehicle-related subjects, there is an established and accepted hierarchy of teaching methods and corresponding aids [3]. It is summarized in table 1.

Table 1. The accepted hierarchy of teaching aids in teaching vehicle-related subjects.

Stage	Teaching aids	Goals
1	Common visual aids (posters, animations, videos, scale models etc.)	Provide the knowledge about the constitution, functioning, appearance, and exploitation of the vehicle. No skill developing is assumed.
2	Simulators	The purpose is two-fold. Firstly, providing information about appearance and exploitation of the vehicle. Secondly, a more or less wide range of skills may be trained, depending on the class of simulator.
3	Real vehicles	Providing real-world driving experience and developing exploitation skills.

An extensive literature, both pedagogical and technical, is available about the problems of design and use of simulators [19; 22; 23]. The transition from the first-stage aids to the last-stage ones is characterized by two features. On one hand, the trainee's experience becomes more relevant to the real-world use experience. On the other hand, expenditure for material resources and time per one trainee increases, as well. The reasons are manifold:

- A vehicle and, to a lesser extent, a simulator are expensive to obtain and maintain;
- Exploiting vehicles is material-expensive;

- Each vehicle or simulator is able to accommodate a single trainee only and, thus, have very low throughput: each trainee has to enter and leave it one by one.

The above hierarchy is aimed to balance the quality and cost of training, which is to provide the best training for a given budget, by partial replacement of more expensive aids with the less expensive ones. The stated aim is actually achieved.

3 Statement of problem

Nevertheless, the analysis of teaching experience collected in the Military Institute of Armored Forces of National Technical University "Kharkiv Polytechnic Institute" (Institute) reveals that the reached balance is still suboptimal. The identified deficiency is extensive use of simulators just as advanced visual aids, when they act simply as 1:1 scale models. Their purpose here is familiarize trainees with the appearance of the vehicle cabin (show the location of controls, indicators etc.). This fact leads to the next problems:

- Trainees are able to occupy the simulator one by one only, extending the duration of the class (i.e. the throughput is very low);
- The time available for using the simulator at its full capacity for developing skills by other trainees is, thus, reduced;
- In education establishments, which do not possess a simulator, the trainees are actually unable to receive this kind of training.

Let us consider a simple example. In a group of 15 trainees and one teacher, during a 75 minutes class, each person will receive just 5 minutes of experiencing the simulator in the best case (i.e. no preliminary instruction is needed, entering and leaving the cabin occur rapidly etc.). Importantly, the teacher is focused on a single trainee sitting in the cabin and, thus, cannot perform teaching with the rest of the group. Simultaneous utilization of 3-4 simulators at the same time may improve the situation, but requires corresponding expenses. The reason of such unpractical use of simulators is the absence of other teaching aids, which may be employed instead. In other words, there is a pronounced gap between the first and second hierarchy positions, which is forcedly filled by simulators. It is illustrated in fig. 1, where the particular sensational features, provided by the discussed teaching aids, are listed.

In the described situation, only two basic sensational features of simulators are used out of four, that is evidently suboptimal. The situation may be illustrated by a case from the Institute experience.

Trainees, who learn subject "Basics of driving combat vehicles", have their module finishing with exam "Preparation to starting-up and starting-up of the engine". The education is organized as follows. Firstly, trainees are acknowledged with the appearance of controls in the driver's cabin by means of posters, slides, videos. Secondly, the order of engine starting-up is explained using text descriptions and posters. Then, trainees are allowed to enter a simulator in order to perform the operation practically. The drawback of this approach is that actually trainees require considerable time to familiarize with the driver's cabin. "To familiarize" here means to establish the connection between the remembered flat two-dimensional pictures of the cabin with its actual spatial three-dimensional appearance and to work out the head, arms, hands movements needed to activate the learned controls. Because, as was shown before, the total time available for each trainee in a simulator is short, there remains too little time to work out the exam operation. The only way to increase it is to devote more classes at simulators in the curriculum.

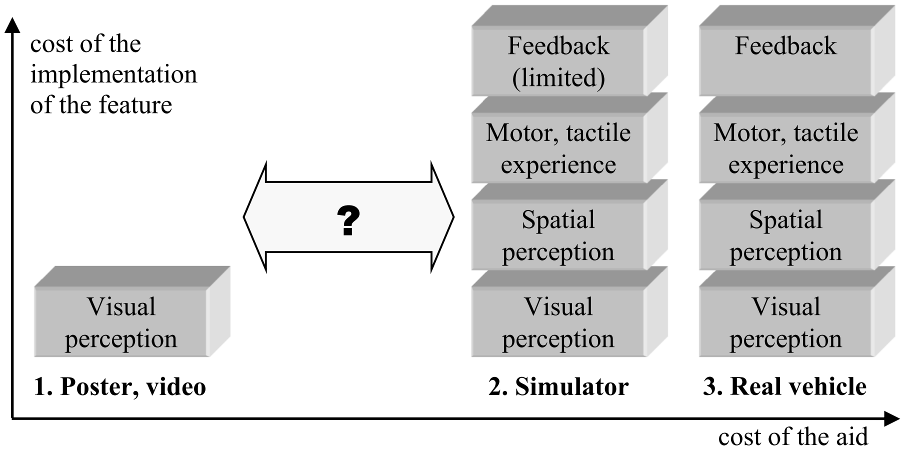

Fig. 1. Sensational features provided by the teaching aids in the accepted hierarchy, ordered by the cost of their implementation in the teaching aid. The question mark represents the gap.

Summarizing, the available range of teaching aids is markedly incomplete, which limits the quality of teaching vehicle-related subjects. The goal of our work is to introduce a new teaching aid in order to increase the stated quality.

4 Proposed solution

We propose a new teaching aid that constitutes a spherical (360°) photographic panorama and a Virtual Reality (VR) glasses. It is able to provide both visual and spatial perceptions plus limited motional experience, hence, it is located in between posters and simulators in the diagram (fig. 1) filling the described gap. Below we describe both components of this aid and their functioning.

4.1 Spherical panorama: Overview

Spherical panorama (also called 360° or 3D panorama) is an image that covers and contains the full horizontal and vertical field of view around a fixed point. It may be either artificial (i.e. drawn manually or computer-generated) or photographic. The photographic ones are created by processing a number of ordinary photographs (each having field of view less than 180°) shot from the same position to all the directions around; the principle is shown in fig. 2. Specialized software is used for this sake. Unlike ordinary images, 360° panoramas obviously cannot be viewed as a whole at a time (without slicing); therefore, during viewing on displays it is scrolled to the position of interest using computer mouse or other input device. At present, they are widely used for advertisement and entertaining purposes; some educational use is also present, e.g. panoramas of museum interiors [6; 30; 32].

Fig. 2. The principle of composing a spherical panorama. The camera is located in the center of the field of view. A single photograph shot is shown explicitly, while for the rest, only borders are shown.

Spherical photographic panoramas possess some features, which make them favorable for application in teaching:

- In contrast to ordinary photographs, the whole field of view is contained in a single panorama. This allows teacher to smoothly and continuously explore the field of view in order to find the needed area, creating in trainee's mind a solid and coherent image of the vehicle interior.
- In contrast to 3D models drawn in graphics and engineering software (like 3D Studio MAX, SolidWorks etc.), the image looks exactly as it is in reality, making the content (controls, indicators etc.) easily recognized when the trainee meets the real vehicle or device.
- Fabricating a photographic panorama is much less labor-intensive and time-consuming than drawing a high-quality poster or a 3D model because it does not involve manual reconstruction of the image from scratch. Making a series of photographs is a routine process, and composing the panorama is almost completely automated by software.

Nevertheless, the full potential of 360° panoramas may be utilized only if they occupy the whole field of view of a trainee instead of being viewed at a distant display.

4.2 Virtual reality: Overview

Virtual reality (VR) is the technology that allows achieving this effect. The goal of VR is to create the effect of the person's presence in some environment, either artificial or having a real counterpart, by specific affecting their sensors (eyes, hears, skin etc.) via VR equipment. It is usually called "immersion" in the literature. The central component of the equipment is a head-mounted display (called VR glasses), which form the person's field of view by displaying the picture, provided by VR software. The most important feature of the glasses is their interactivity: the movements of the person's head are monitored, transferred to the software and processed by it for the sake of updating the image in accordance with the new direction of the head [27]. Hence, it becomes advantageous to employ VR glasses for viewing 360° panoramas. The following benefits may be reached:

- The image of the spherical panorama completely surrounds the trainee, convincingly imitating staying in a vehicle cabin;
- The panorama becomes interactive, i.e. responding to the look-up movements of the trainee's head.

These features turn a passive spectator to an active viewer, who is able to look around. Also, the viewer is able to perform movements of arms and hands in order to imitate using controls seen in the field of view. Although the trainee's hands are not visible in VR glasses (without involving additional elaborate VR equipment), this is still useful and provides correct (through incomplete) motor experience because the location of controls in the field of view created by VR glasses is the same as in that inside the vehicle cabin. This feature even more distinguishes the proposed teaching aid from common visual aids (posters etc.), which are unable to provide reasonable motor experience.

In general, the possibilities of utilizing VR in teaching various subjects have been actively discussed for several decades, and different software and hardware solutions were proposed. Mostly, the fields where practical study involves large hazard or expenses were worked out, for example, medicine [5; 21; 25], technology and fire safety [16; 20; 24; 31; 33], driving [1; 9]. At present, it became accepted, particularly, in medicine and military training [2; 13], while at other fields, its usefulness is still discussed. For detailed reviews of the place of VR in education, the reader is referred to subject papers [7; 8; 10; 11; 12; 14; 15; 17; 18; 26; 28; 29; 31].

However, despite the opportunities VR may provide, its practical application is hindered by the following major obstacles:

- Creating content is in general case complicated and labor-intensive, demanding developed 3D design, art, and programming skills for creating the virtual environment;
- Costs of VR equipment are generally high.

Here we show that both these obstacles may be successfully overcome, having the introduced teaching aid as an example. Considering the first one, the problem is largely simplified by the fact that the content is created by photographing the existing vehicle, and the process of composing a 360° panorama is largely automated (see above). Some programming is still necessary but it is rather limited because no visual effects or virtual scenes is needed to implement. The second obstacle is solved by a proper choice of the equipment among the available, as will be shown below.

Next, wearing VR glasses by a trainee during teaching process introduces two important difficulties. Firstly, the teacher is unable to monitor the actions of the trainee because they is unable to see the image on the display. Therefore, in order to allow control over the trainee's actions, it is required to involve a secondary display, whose purpose is to demonstrate the image that is displayed at a moment by VR glasses.

The second difficulty is the very limited ability of the trainee wearing VR glasses to answer teacher's questions about the image seen (e.g. "indicate the button named X on the control panel"). It is caused by the fact that by default, the surrounding is interactive just to some extent: it responds to the rotations of the user's head, but the user is unable to affect it in any other way. To solve the problem, the trainee has to be provided with a separate device called controller. Its purpose is to receive user's input and affect the image seen in the VR glasses and, as a result, on the teacher's display.

Taking all the above into account, the proposed teaching aid consists of four components, which are depicted in fig. 3. It may be implemented using a range of hardware; the author's choice is stated in paragraph 4.5.

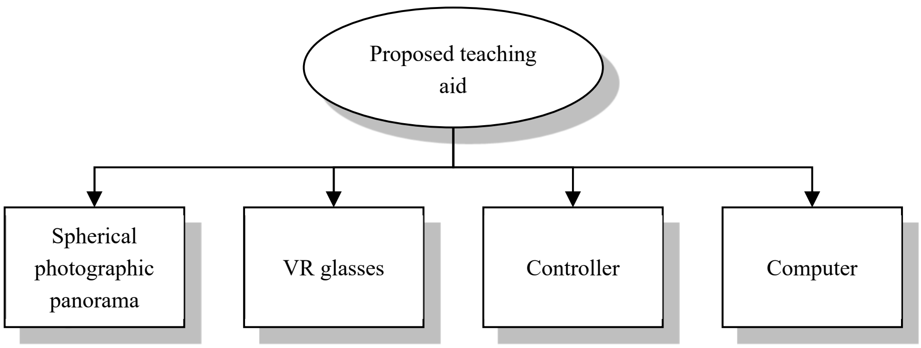

Fig. 3. Composition of the proposed teaching aid.

4.3 Application in teaching

The described features of spherical photographic panoramas suggest that the most precise and realistic result may be achieved for small, confined premises designed for one, at most two persons, where all the points of interest (labels, controls, indicators etc.) are located at about arm's length from the viewer. Actually, this is a case for most vehicle cabins. Another case is portable equipment, transported by truck (e.g. portable chemical laboratories). Therefore, the aid is most suitable for teaching subjects considering the above things. Particular examples in the military field are:

- Armored armament;
- Exploitation of combat vehicles;

- Renewal of armored armament;
- Technical support;
- Driving combat vehicles;
- Armament and firing;
- Electric equipment of armored armament.

Considering the financial side, the total price of the aid is very limited (hundred to thousand times less than a price of a single simulator), which makes feasible for educational establishments to obtain the aid. Moreover, the price makes readily possible equipping specialized classes for groups of 10-20 trainees. This option proportionally increases the time a trainee spends in the teaching aid and, thus, further improves teaching quality.

4.4 Test of effectiveness

In order to test the efficiency of the proposed aid, a teaching experiment was carried out at the Institute. The points #1 "Location and operation rules of controls and indicators" and #2 "Preparation of the vehicle to engine starting-up and movement» of the practice lesson "Training at simulators on preparatory exercise #1" belonging to the credit module "Driving basics" of the subject "Basics of driving combat vehicles" were chosen. The exercise #1 in this module is "Preparation to starting-up and starting-up of the engine" (further called "the exercise"), its procedure contains 19 steps.

The experimental class was held at an experimental multifunctional room. For comparison and estimation of efficiency, the reference class on the same lesson was held in a traditional way using common teaching aids (simulators).

Both classes started from learning the general structure of the BTR-4E transporter, its cabins, controls, and exploitation basics. The trainees were provided with the general information about the purpose of the control cabin and the driver operating procedure by means of distance course "Structure and exploitation basics of BTR-4E" (experimental group) [4] or posters and textbooks (reference group).

Then, the training was continued either with the help of simulator (in the reference group) or using the proposed teaching aid further called "a VR simulator of the driver cabin" (in the experimental group). In the latter case, the procedure was as follows. The teacher divided the group to pairs, and in each pair, trainees were assigned with #1 and #2. Then, the following tasks were specified to #1 and #2:

Actions of #1: Help #2 to wear a VR simulator and take a controller. Read the text of the exercise procedure step by step making pauses after each step to allow #2 find the needed control. Check the correctness of #2's actions by watching the laptop, do corresponding notes and write down the results of training into the control sheet.

Actions of #2: Wear a VR simulator and take a controller, repeat the steps read by #1, find the needed control and point it with the controller. Then, pronounce each step of the procedure by memory, find the needed control and point it with the controller.

When the actions were completed the trainees #1 and #2 exchanged their roles.

The success of teaching during the experimental and reference classes was assessed by the results of the next class, when both groups of trainees had to execute the exercise at a BTR-4E simulator. This class has been carried out identically with both groups. The main results are as follows.

The marks for completing the exercise are summarized in table 2. Here, the mark is determined by the consumed time: “excellent”, “good”, “satisfactory” corresponds to no longer than 1 min 30 sec, 2 min, 2 min 30 sec, respectively. It is seen that both groups have similar distribution of marks that indicates they received equivalent training before. This proves that the proposed teaching aid is able to successfully replace simulators in the task of familiarizing trainees with vehicle cabin.

Further, the occupation of the simulator by the experimental group was 4 times lower than by the reference one. Hence, application of the proposed aid allows free substantial amount of the simulator time, which then can be used for conducting other classes where full range of its capabilities is employed.

Table 2. The success rates of the two groups of trainees.

	Control group	Experimental group
Total trainees	25	25
“Excellent” marks	10 (40%)	11 (44%)
“Good” marks	8 (32%)	6 (24%)
“Satisfactory” marks	7 (28%)	8 (32%)
“Unsatisfactory” marks	–	–

4.5 Details of implementation

For the implementation of the software part, a tight collaboration between the Institute and IT company “Innovative Distance Learning Systems Limited” was established. The Company developed the viewing software, and the experts of the Company performed photographing the interiors of vehicles, fabrication of 360° panoramas, and loading them to the viewing software. The Institute took part in developing the content, carried out approbation, and developed methods for the most efficient application of the product in teaching.

The access to the program is provided after registration procedure: the user has to fill the registration form with their contact details, affiliation, and International Mobile Equipment Identity (IMEI) code of their device. This information is manually processed by the responsible staff at the Institute. This measure allows control the distribution of the program and limit it to trusted persons and organizations only. The association with IMEI code of a device prevents illegitimate copying the software to devices belonging to unregistered persons.

The hardware part was chosen in accordance with the following considerations.

The VR glasses are of two kinds. The first kind comprises a built-in display; such glasses must by connected to a source of video signal, which is usually a computer running VR software. The second kind of glasses is called “VR boxes”. There, the role of display is played by a smartphone, which has to be installed (reversibly) into the VR box. In this case, the source of video signal is the same smartphone, which runs VR software.

The teacher's display must be attached either to the computer that generates the image for VR glasses of the first kind, or to the computer that receives the image from the smartphone installed in VR glasses of the second kind.

The simplest kind of controllers is computer mouse: when attached, a pointer is shown on the image, and the trainee is able to move it and set to the needed position (e.g., to the position, at which some control is seen at the moment).

Taking this into account, we used the following hardware in our implementation:

1. A VR box because it does not require a computer to work, is much cheaper than VR glasses, and still provides the ability to view 360° panoramas;
2. A smartphone running Android operating system, where VR software is installed and 360° panoramas are uploaded;
3. A computer mouse as a controller because it is a common and inexpensive device requiring no adaptation for trainees;
4. A laptop running Windows 10 operating system because we concluded that it is the most convenient option: the needed configuration is relatively simple, and the image from VR glasses may be received wirelessly via Wi-Fi.

5 Conclusions

A deficiency in the available range of teaching aids for vehicle-related subjects is identified, which decreases the teaching quality of the subjects. For the sake of its increase, a new teaching aid is introduced that constitutes a spherical panorama of the vehicle cabin joined with Virtual Reality glasses. Its main feature is the possibility to provide visual, spatial, and motor experience that is approaching to the provided by simulators, by much lesser cost. The efficiency of the aid was proved by a teaching experiment that showed it can serve as an alternative of simulators on the stage of trainee's familiarizing with vehicle cabin appearance.

At present, we have completed the 360° panoramas of a series of armored vehicles (BM "Oplot", BMP-2, BTR-4E) and emergency vehicles (fire engine). Under development are the ones for trucks.

In general, the study provides new evidence that VR technologies may be effectively used in education and, hence, deserve attention from researchers in the field. The additional motivation is that at present they became available and affordable to obtain by educational establishments. Several practical difficulties appearing during use at classes are shown to be non-critical and solved by means of additional devices.

We think the proposed aid may significantly improve the cost-efficiency balance of teaching a range of technology subjects, where vehicles or mobile equipment are considered, and may receive wide application in civil and military education establishments, emergency and military units, enterprises using special equipment.

Because the aid is new and rather unusual, our further research in the field is focused on working up advices for teachers regarding the technical aspects of the aid use at classes, developing methods of application of the aid in teaching various subjects, optimizing the choice of hardware constituents.

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