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PROCEDURAL AND DIAGNOSTIC SIMULATOR OF THE VIRTUAL REALITY ANTI-AIRCRAFT MISSILE SET WITH ELEMENTS OF AUGMENTED REALITY*

Key words: virtual reality, augmented reality, training systems, procedural and diagnostic simulator, simulation.

Abstract: This paper introduces the issue of supporting operation and diagnostic processes of technical facilities, as well as the possibility of using modern technologies that facilitate and increase the operational safety, on the basis of the procedural and diagnostic simulator of the anti-aircraft missile set. The paper presents the system's construction, a training concept, and the most important technical issues in the simulator's design using virtual and augmented reality. The simulator in the virtual technology creates new quality in the process of acquiring knowledge and experience by its users, reduces the training costs, and at the same time, it is a device that provides multilateral development opportunities in technological terms.
The paper demonstrates a new approach to the use of modern graphics and simulation technologies, which focused on operational applications in the aviation training so far. An innovative approach through the preparation of training for technical personnel was offered. This new approach results in a very important aspect, which is a life cycle of such prepared training, because, thanks to the use of virtual technology, it is possible to very quickly adapt the simulator, and thus the training, for the real equipment after its modernisation. For this purpose, software (graphics and interactions) is modified in the simulator, and the training can be continued without the need of building a new simulator.
The vulnerability of modern technologies for implementation in all areas of life, especially in the broadly understood education, was also emphasised.

Symulator proceduralno-diagnostyczny przeciwlotniczego zestawu rakietowego w technologii wirtualnej z elementami poszerzonej rzeczywistości

Słowa kluczowe: rzeczywistość wirtualna, poszerzona rzeczywistość, systemy szkoleniowe, symulator proceduralno-diagnostyczny, symulacje.

Streszczenie: Artykuł przybliża problematykę wspomagania procesu obsługi i diagnostyki obiektów technicznych, jak również możliwości zastosowania nowoczesnych technologii ułatwiających i zwiększających bezpieczeństwo obsługi na przykładzie symulatora proceduralno-diagnostycznego przeciwlotniczego zestawu rakietowego. W artykule przedstawiono budowę systemu, koncepcję szkolenia oraz najważniejsze zagadnienia techniczne w projektowaniu symulatora wykorzystującego wirtualną i poszerzoną rzeczywistość. Symulator w technologii wirtualnej tworzy nową jakość w procesie nabywania wiedzy i doświadczenia przez jego użytkowników, redukuje koszty szkolenia, jednocześnie jest to urządzenie dające wielostronne możliwości rozwoju pod kątem technologicznym.
W artykule zaprezentowano nowe podejście do wykorzystania nowoczesnych technologii graficznych i symulacji, które do tej pory w szkoleniu lotniczym skupiało się na zastosowaniach operacyjnych. Zaproponowano nowatorskie podejście poprzez przygotowanie szkolenia dla personelu technicznego. To nowe podejście przekłada się na bardzo ważny aspekt, czyli cykl życia tak przygotowanego szkolenia, ponieważ dzięki zastosowaniu technologii wirtualnej jest możliwe bardzo szybkie dostosowanie symulatora, a tym samym szkolenia, do sprzętu realnego po jego modernizacji. W tym celu w symulatorze modyfikowane jest oprogramowanie (grafika i interakcje) i szkolenie może być kontynuowane bez potrzeby budowania nowego symulatora.
Podkreślono również podatność nowoczesnych technologii do implementacji w każdej dziedzinie życia, a szczególnie w szeroko rozumianej edukacji.

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Introduction

The primary objective of the procedural and diagnostic simulator development was to provide the operational safety of anti-aircraft sets.

One of the important factors affecting the proper operation includes the technical efficiency of components and systems installed in the missile set. Despite a constant increase in reliability as well as the development of supporting tools based on computer technology, a human – a mechanic or an electrician with qualifications, knowledge and experience [6], who are generally the personnel dealing with technical services, is still a key element in the control and diagnostic processes of systems.

The technical services cover a very wide range of works and activities, which could include current, periodic, technical, and training services. They can constitute both the works carried out directly on the technical equipment, in laboratories, after removal of aggregates, and on associated equipment, which co-create a broadly understood operation system. The organisation of performing technical services is a complex issue that is very important from the perspective of the operational safety on military equipment; therefore, the maintenance procedures should be implemented with the utmost care. Unfortunately, due to their high complexity, there is the possibility of their erroneous and incorrect performance by a person implementing the check.

The obvious solution, which allows improving and increasing the safety of performed technical services, seems to be using a diagnostic and procedural simulator involving the augmented reality technology, in the training process. This technology allows providing the operator with data on the environment in association with data received from the computer system. Examples of using the augmented reality technology are in [4, 5, 13, 15, 16, 17, 23].

The procedural and diagnostic simulator enables one to carry out maintenance procedures, including function checks, and allows one to carry out basic training of combat operations of the NEWA-SC system. It allows, among others, to perform standard checks, inspections and operation processes associated with the service, but it can also be used to simulate emergency states and errors, and to archive the service operation on the simulator. The application of augmented reality with the use of goggles, a tablet, or another multimedia device allows, among others, to start the launcher or the antenna column drive, and to control the anti-aircraft system's external elements. The simulator also has the ability to involve other devices in the virtual simulation system during mixed exercises. While creating the simulator, the authors took on the tasks of attempting to improve their performed technical services and the training efficiency of the technical personnel. It was assumed that the addition of new contents, in the form of a text, 2D tracked objects (arrows, circles, and regular polygons), 3D semi-transparent models, and animated sequences, as well as multimedia contents, in the form of images and videos of actual scenes, may significantly reduce operating time while increasing the worker's mental comfort.

In the first chapter, the issue of supporting the operation and diagnostic process of technical objects was introduced, and also the possibility of using modern technologies, which facilitate and increase the safety of their operation, as well as the construction and potential possibilities of the application using the augmented reality technology was presented. In the second chapter, a concept of the procedural and diagnostic simulator, which virtually images the anti-aircraft missile set, as well as its basic technical elements, occurring damage and their symptoms, and allows carrying out selected elements of the combat operation by the personnel under the air situation conditions was demonstrated. The third chapter presents the main aspects of creating a three-dimensional virtual environment on the example of the presented simulator.

1. Support of the operation and diagnostic process of technical objects

The anti-aircraft missile set is characterised by a great number of technical gaps, and operation cabinets located at various heights, with variable and limited operating space. The works are carried out both outside and inside the system and are subjected to standard limitations associated with changing weather conditions. The operator moves with the use of traps, and the operating space most often consists of metal platforms in the form of trusses, limited by metal railings and ladders, and metal fronts of cabinets from three sides. Inside the cabinets and gaps, there are units, devices, and inspection and control panels used for the verification and regulation of operating parameters of individual systems during all current and periodic services.

The surfaces on which the operator stays are usually small and allow the operator to observe the equipment installed in cabinets and technical gaps from a distance of 0.5 m to 1.0 m. In special cases, when the technical gap is accessible from the ground, this distance is greater. The available usable area, after opening the doors, manholes, and covers ranges from 0.16 m^2 to 0.75 m^2. The depth of technical gaps is different and ranges from 0.2 m do 0.5 m. However, it should be noted that most of the elements, which are subject to basic technical services, require the involvement of hands inside the cabinet or the technical gap not deeper than 0.15 m. In cases related to the exchange of aggregates, the gap penetration depth may reach even 0.5 m, and the natural lighting level may radically change, forcing the need of using auxiliary lighting. In the missile set's enclosed areas, the operator most often performs its work in a sitting position only with the use of artificial lighting, and the operated devices are within reach.

The main assumption during its development was the possibility of using a tablet or a tablet with a head mounted display for supporting the use of the anti-aircraft missile set while performing simple operation and repair activities and self-education. The device is to provide the operator with additional information that are imposed on the actual image, which is observed by him, in the form of a text, active arrows, any figures and convex solids, 3D models, animated sequences, and multimedia, during operation, in order to facilitate the performed maintenance procedures on the equipment. The used hardware architecture is shown below (Fig. 1):

Fig. 1. Hardware configuration that allows using a tablet or a tablet with head mounted displays of an "Opticalsee-through HMD" type

The application that uses augmented reality elements was written in Python script. The procedures for controlling the location of 3D objects in scenes related to augmented reality were written with the use of ARToolKit libraries [25] cooperating with Vizard game engine [24]. It consists of execution and calculation blocks, and cooperating peripheral devices.

Optionally, the set can be supplied in a gyroscope with three degrees of freedom, the so-called "headtracker," which allows controlling the angular position of a head and the viewing direction in the cooperation with a compass.

On the device's monitor, in addition to graphic standard elements, the actual objects seen by the camera are visualised. Some actual elements may be associated with 3D and 3D virtual objects (Fig. 2). They are automatically visualised, as prompts, in accordance with the created scenario of events. The implemented software provides the operator of the device with many tracks operating in parallel in the form of the following:

– Sound instructions that determine the current task together with remarks and warnings;
– Text instructions supporting the currently performed activity;
– Supplementary information in the form of tracked arrows, circles, 2D regular polygons or their 3D solids following the assigned actual objects visible on the screen;
– The observation of semi-transparent, animated 3D models associated with the currently observed scene and 3D tools such as wrenches, screwdrivers, etc. which are to assist the operator while performing repair or maintenance procedures;
– Viewing in various variants and scales of semi-transparent 3D models; and,
– Viewing in multimedia contents in the form of images and videos.

A key element of the application was to create a software module responsible for the provision of virtual contents. This module, the so-called "scenario of events," allows the user to independently create all the scenarios, individual stages of works, and maintenance procedures, and to remove the perceived shortcomings straight away and modify the existing ones without interfering in the programme code.

The "decision block," which was additionally implemented, allows one to create contingent events changing the path of action depending on a decision taken by the operator. 2D and 3D virtual elements (on-the-fly) associated with actual objects are visible at the time when the operator's eyesight is directed to the actual object and a marker is visible in his surroundings. In more complex tasks performed by the operator, virtual objects, such as 3D tools, are to additionally indicate the potential location of their application and perform moves in the planned planes, imitating the actual tool necessary to perform the operation (Fig. 3).

Fig. 2. Screenshot during the scenario performance

Fig. 3. The example method for presenting virtual tools in the real world

In the set using the head mounted display of "Opticalsee-through HMD" type to perform simple operation and repair activities and to support the training of operators of military equipment, augmented reality technology was applied, which made it possible to introduce 2D objects in the form of arrows, any figures, 3D interactive models, animated sequences, and multimedia to the real world. The works carried out in the laboratory [22, 23] and partially on the field equipment confirm the right direction of conducted works and also the technical personnel's great interest in modern methods of supporting the training and operation processes.

2. Training concept for technical personnel with the use of virtual reality technology

The procedural and diagnostic simulator in the presented concept is a kind of CPT simulator (Cockpit Procedures Trainer) – representing the operators' console of the missile set in the virtual reality technology. The objective includes the Simulator, which will allow a trained person to get familiarised with the console and distribution of indicators and to train the selected procedures [8]. The simulator operation was provided for two modes, such as work without damage and work with simulated damage. The work in the mode without damage is intended for getting familiarised with and training the performance of subsequent verification activities, in the order predicted by the missile set operation procedures, by a trained person. The second mode, the work with damage, is designed for acquiring skills to cope with frequently occurring damage on the selected missile set. A student should determine the type of damage, which is shown as a malfunction of a given indicator (or indicators), and offer the possibility of removing the failure. The entire education process is monitored by the instructor, so he can observe whether further diagnostic activities were implemented correctly and in the right order.

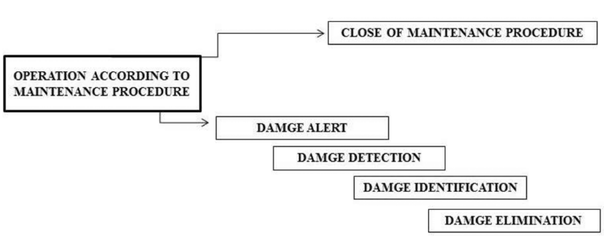

Fig. 4. Adopted diagram of procedure in the procedural and diagnostic simulator

The selected maintenance procedures implemented on the actual hardware (see Fig. 4) will be implemented in the simulator and used during the training. On their basis, a database containing the scenarios with damage and without it will be constructed.

The student performs various scenarios given straight away by the instructor. The basic workplace of the trained operator includes a virtual console (Fig. 5) of the missile set. The implemented activities of the missile set's operating procedure require, especially in the work mode with damage (Fig. 4), the use of different indicators for identification and repair than those available on the fundamental stand. In this case, the student performs selected activities of the maintenance procedure on the stand (Fig. 5) defined as large-format graphic presentation. The proper performance of the operation procedure is visible on the console's indicators in the missile set cabin. The indicators, visualised on the large-format graphic presentation stand, are synchronised with indicators on the console in the missile set cabin regardless of the work mode of the procedural and diagnostic simulator. Both stands use 3D visualisation of indicators of the missile set.

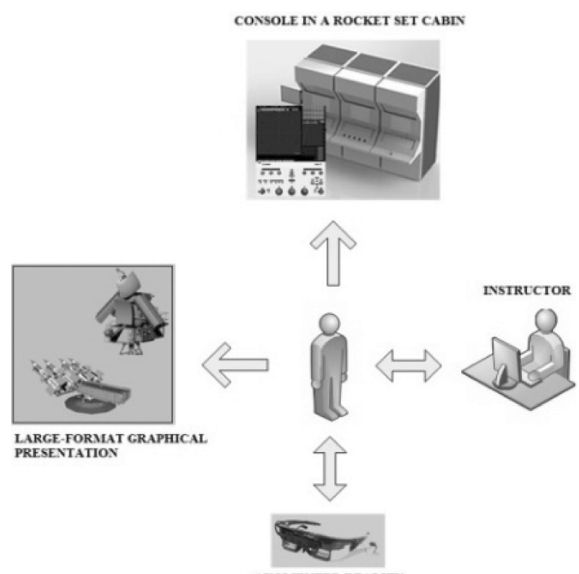

Fig. 5. Structure of the procedural-diagnostic simulator for the missile set

The student in the procedural and diagnostic simulator can also learn the scenarios given by the instructor with the use of Augmented Reality technology, which was discussed in the first chapter of the paper.

The simulator is developed on the basis of commercial computer hardware in Windows 7 system environment in ETHERNET local network. The simulator switching on and switching off as well as on-line diagnostics of the functioning of its individual nodes will be implemented from the Instructor's Stand (Fig. 6).

The adopted concept of the procedural and diagnostic simulator is based on the experience of the team dealing with this issue for several years. The rapid growth of new technologies using increasingly fast processor units

Fig. 6. Instruments of the Command and Homing Cabin and Large-format Graphic Presentation System

allows the development and implementation of solutions in an immediate manner, which in turn, results in the increase of operational safety, and in this particular case, it is combat equipment.

3. Technology of virtual environment development for the procedural and diagnostic simulator

One of the virtual reality definitions formulated by Jaron Lanier and Steve Bryson, which according to the authors' beliefs truly reflects its essence, provides that „Rzeczywistość wirtualna jest sposobem użycia technologii komputerowej w tworzeniu efektu interaktywnego, trójwymiarowego świata, w którym obiekty dają wrażenie przestrzennej obecności". ("Virtual Reality is the use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence").

$$I^3 = \text{Interaction} + \text{Immersion} + \text{Imagination}$$

A person perceives the reality with four basic senses, namely:
- The sense of sight,
- The sense of hearing,
- The sense of taste, and
- The sense of smell.

3D object modelling is implemented in several stages. The first of them involves the preparation of detailed descriptions taking into account its design and operating principle. While developing the simulator, which assists the training in the scope of the implementation of the technical device's diagnostic procedures, it is important to thoroughly learn and describe the relationships of all its components. Then, it is crucial to develop a detailed graphic documentation of a modelled object including images, two-dimensional drawings, and precise dimensions of all its components.

After thorough identification and description of the modelled object, it is important to determine and complete the necessary software and technical tools that will ensure the success of the project implementation. In case of the processing of two-dimensional objects, the software that allows supporting vector and raster graphics is used. Three-dimensional objects are developed with the use of advanced software packages for 3D graphics creation. The animations and interactions are developed in the special software environment that enables the creation of the virtual reality and interactions with it. While selecting the software, it is important to pay attention to its compatibility, understood as the possibility of changing (import and export) created graphic objects between individual software environments. Nowadays, the modelling of three-dimensional objects can be implemented on the basis of powerful PC computers equipped with powerful graphics cards. In order to present the virtual reality, high-resolution monitors or multi-format visualisation systems are used. The interaction is usually performed with the use of touch pads that support "multi-touch." The high-quality sets for generating sound effects are also applied.

This paper describes a procedure for the development of virtual control panels of the work of the Shooting Officer Stand (SOS) in the Command and Homing Cabin of the anti-aircraft missile set. The actual stand is presented in Figure 7.

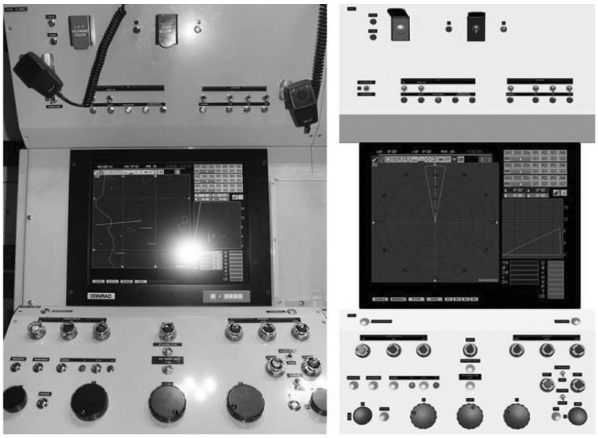

Fig. 7. Shooting Officer Stand in the Command and Homing Cabin of the anti-aircraft missile set – actual (left) and virtual (right)

The shooting officer stand consists of lower and upper control panels and a monitor for visualisation of the air situation and the set condition. The actuators used in the course of operation at this stand include the following:

– Toggle switches,
– Momentary switches,
– Push button-lamp switches,
– Knobs,
– Protecting flaps, and
– Signalling diodes.

The first virtualisation stage involves the creation, based on technical and photographic documentation, of actual actuators of graphic models, whose size, design, and distribution on individual panels faithfully reflect reality.

In the second stage of creating the virtual shooting officer stand, the graphics with marked locations of the distribution of individual actuators (i.e. auxiliary bases) were developed. In order to choose import, positioning, scaling, and alignment of 3D objects on the monitors' screens, a special application, the so-called editor, was developed. After configuration of each panel, the editor programme generates a text file in which a complete description of this panel's configuration is included. On this basis, the procedural and diagnostic simulator's application software implements the visualisation of individual panels of stands of the Command and Homing Cabin of the anti-aircraft missile set.

The ultimate effect of designing includes fully functional virtual panels visualised on the screens with touch pads. In Fig. 7, the actual stand of the Shooting Officer (on the left side) and its virtual replica (on the right side) were presented.

Conclusions

The dynamic growth of hardware and IT technologies provides new possibilities in terms of design and development of simulation systems for the broadly understood training. The modern tools allow one to create virtual reality that accurately reflects the objects and phenomena existing and occurring in the real world. By using such possibilities in the Air Force Institute of Technology, a procedural and diagnostic simulator of the anti-aircraft missile set, which is dedicated for training of services in the field of implementation of diagnostic procedures and selected elements of the combat operation, was developed. Importantly, the simulator, in such an application, will enable the reduction of training costs and the deterioration of the combat equipment occurring in case of traditional training methods of the technical personnel.

Despite the dynamic increase of AR technology in many areas including training systems, there is still place for development as digital image processing and interpretation. In the authors' opinion, these problems will be solved in the next few years and the next challenges will appear. Using of AR in training systems is already popular, and such systems are developed for every type of personnel. The future challenges for the use of air forces can be the integration of many training systems and sharing information in the real time as a support tool for the staff at the service.

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– Military University of Technology (Warsaw),
– Digitalia (Kraków).

The simulator was first presented at the 23d International Defence Industry Exhibition in Kielce. It achieved a special award of the Minister of National Defence. After the completion of the design, the simulator will be implemented in Air Force Training Centre in Koszalin.

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