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LEOPARD 2A4 TANK DRIVING TRAINING SIMULATOR. PART 2. DISPLAY SYSTEM

Abstract. The article presents a display system developed at OBRUM for the LEOPARD 2A4 tank driving simulator (codenamed SJCL-6P). The solutions adopted in the design compliant with client's technical requirements are discussed. The analyzes presented take into account the current state of the art. The choice of solutions used in the most important structural units, including the vision system and auxiliary tools, is explained. The summary highlights the distinguishing features of SJCL-6P among the training equipment used.

Keywords: simulator, training device, tank driver training, display system, image projection.

1. INTRODUCTION

Currently, the main goal of the majority of the leading armies in the world is to provide comprehensive and multi-level use of simulation and training systems in the process of training various types of troops. Such systems, in addition to raising the skills of soldiers in the use of increasingly complex equipment and weapons, should also provide the possibility of using instruction and training devices in the process of developing new fighting procedures, simulating the use of new equipment and arms, and the ability to interact with individual vehicle crews and making decisions at various positions and levels of command [1].

The LEOPARD 2A4 tank driving simulator (SJCL-6P) developed by OBRUM is designed to train future tank drivers. The scope of the training includes learning how to drive: in urban area, on public roads, off paved roads, such as in a forest, wooded area or an open area. The designed and fabricated simulator supplements the existing training base [2] in Świętoszów for LEOPARD tank crews.

The modular design of the simulator, with particular emphasis on the cab with the driver's seat, was described in [3]. Another important module of the simulator, which will be discussed in the article, is the display system, which allows an appropriate representation of the view from the tank driver's cab, created by a virtual simulation environment.

2. TECHNICAL REQUIREMENTS

OBRUM constructed three driving simulators for Leopard 2A4 tank drivers under a contract with the Ministry of National Defence.

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Fig. 1. SJCL-6P simulator with a display system on a motion platform

The initial tactical and technical requirements (WZTT) [4], being an attachment to the main contract, set out a number of requirements and guidelines as well as recommendations regarding the imaging performance of the virtual simulation environment implemented in the simulators. One of the key aspects associated with obtaining high quality mapping of tank driving conditions is a properly configured vision system. As indicated in the works [5], [6], as well as by the experience drawn from the computer simulation systems used, the basic element responsible for human perception when driving a vehicle is the sense of sight. Therefore, the requirements for the vision system had to be subjected to detailed analysis, and the parameters defined in the WZTT document were supplemented with additional requirements allowing to achieve the optimal imaging effect in the simulator. When preparing the design operations, the requirements defined by the client were divided into two basic groups.

The first one defined the requirements for the display system - non-functional requirements (the list keeps the original terminology used in WZTT - e.g. image generation system or visualization system):

- the simulator should be equipped with a computerized system for generating a "three-dimensional" colour image of the virtual space seen from the driver's cab;
- the minimum resolution of each graphic channel shall be of the FULL HD standard;
- angular resolution, at most 4 arc minutes per pixel;
- horizontal refresh rate, at least 30 kHz;
- vertical refresh rate, at least 60 kHz;
- image contrast min. 1000:1;
- the visualization range should be at least 30° in the vertical plane and 160° in the horizontal plane.

The second group of requirements included functional requirements:

- tank driving simulation should reflect real tank driving, including driving with the hatch closed or open;

- the training carried out in the simulator must include exercises allowing for faithful rendering of the characteristics of land objects (maintaining their dynamic properties) and airborne objects;
- it should also be possible to simulate driving using visualization in infrared spectrum and using night vision;
- the driver's field of view must be identical with that in a real tank with the hatch open and closed;
- image projection should be generated on all simulator observation devices intended for observation during the day and at night;
- the designed visualization system should be modernizable and modifiable by the contractor.

Based on the analysis of other requirements and guidelines specified in WZTT [4] and related to the place of installation of the simulators, as well as in order to optimize the effectiveness of training, some additional functional requirements for the display system were defined.

The system should have the following features:

- high resistance to changes in lighting conditions at the place of simulator installation;
- the ability of mounting on motion platforms or the ability of "working out" deformations and changes in the viewing of the displayed image due to changes in the position and orientation of the motion system;
- high serviceability;
- wide image calibration range;
- the ability to work with the projection system at relatively low brightness values of the displayed image - the need for long-term training;
- generating maximum low latencies in image transmission, processing and display circuits (input lag, monitor response time, colour change time, e.g. "grey to grey time").

Upon defining all project technical requirements for the display system for the SJCL-6P simulator, a series of analyzes was carried out to find the right solution. Among the available solutions, three potentially applicable technologies were analyzed in detail:

- LCD/LED/OLED displays (TV sets/monitors);
- LED arrays;
- DLP/LCD projectors.

3. SELECTED IMAGE DISPLAY TECHNOLOGIES

Due to the plurality of available technologies, the basic features and characteristics of selected solutions are presented below, highlighting their advantages and disadvantages. The list presented has been limited to solutions that meet the specifications/requirements of the SJCL-6P project.

3.1. LCD/LED/OLED displays (TV sets/monitors);

One of the most important requirements for imaging in the SJCL-6P simulator was the field of view defined in angular values: 30° in the vertical plane and 160° in the horizontal plane. For the comfort of the system user, it was assumed that the minimum distance of the trainee from the screen should be above 80 cm. Installing the screen at the set distance from the user translated into a display surface area of the following dimensions: 2.2 x 0.5 metres. Using commercially available LCD displays, the system had to be based on 3 devices with a minimum diagonal of 50 inches and arrays with a widescreen image format (16:9 aspect ratio). Compliance with the above-mentioned requirements regarding the display space meant that the angle between the planes of adjacent arrays would be (depending on the arrays used) between 120° and 135° (Fig. 2). Despite the significant progress in the technology of large-sized LCD displays, most of the monitors currently manufactured have a frame around the screen. Such displays, when aligned side by side, create "dead zones" between the adjacent screens. An important issue was also the thickness of the display housing frame, which could affect the comfort of use. In addition, in the case of an even number of displays arranged symmetrically in relation to the user, the contacting frames of the two central screens would be directly in the centre of the display system. For this reason the concept of using 4 screens inside the simulator cabin was rejected.

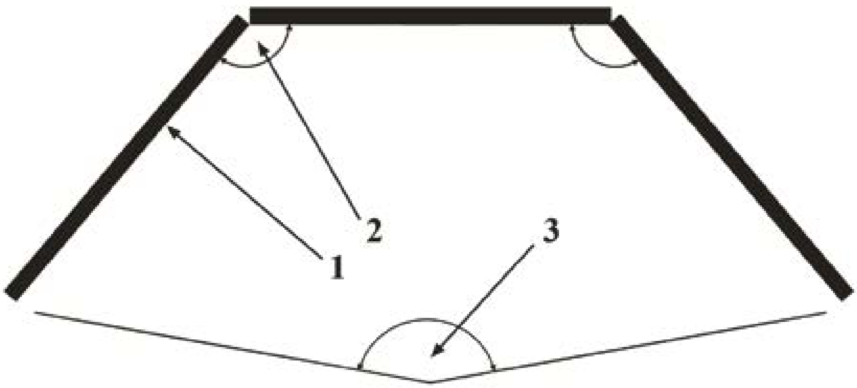

Fig. 2. Display system composed of monitors/TV sets

1 – monitor/array
2 – angle between screens (120° to 135°)
3 - specified maximum viewing angle (160°)

Frameless displays available on the market are still a relatively new solution, which is reflected in their high prices [7]. In addition, most of them have relatively small screen sizes. The same applies to displays with curved screens. The first models entered the market around 2014. The curved shape of the screen better fills the field of view, which results in the impression of a greater depth and width of the screen compared to flat displays. In addition, the colour contrast is clearly improved compared to standard monitors, and the effect of image quality loss when viewing at an angle is significantly reduced.

The above advantages spoke in favour of monitors/TV sets. Despite the high costs of purchasing large format monitors, the main reason eliminating the choice of a display system based on monitors, was the insufficient mechanical resistance (declared by the manufacturer) to possible overloads caused by the movements of the platform. Despite the impressive key performance specifications, such as the input lag (about 1 ms) [8], which translated into high refresh rates of the graphical input, further studies showed that it would not be possible to set up a structure based on three graphic channels. Another important contraindication for the use of this type of devices is their relatively large weight in relation to the size of the image attained. Assuming the use of 3 monitors for setting up a single vision system, it was necessary to take into account a weight even in excess of 150 kg, including only the weight of the devices themselves plus basic mounting components.

3.2. LED arrays

The methods of image projection which use LED arrays are employed in products of other simulation system manufacturers (in particular in the civilian sector) [9]. LED arrays (jumbotrones) generate saturated colours which appeal better to the viewer. These displays also provide high brightness (1000 cd/m^2) and high contrast (3000:1). LED screens are made up of individual modules (panels) having minimum dimensions of 25 cm x 25 cm. This means that by assembling them in a suitable way, a display with a relatively smooth curved shape can be constructed (Fig. 3).

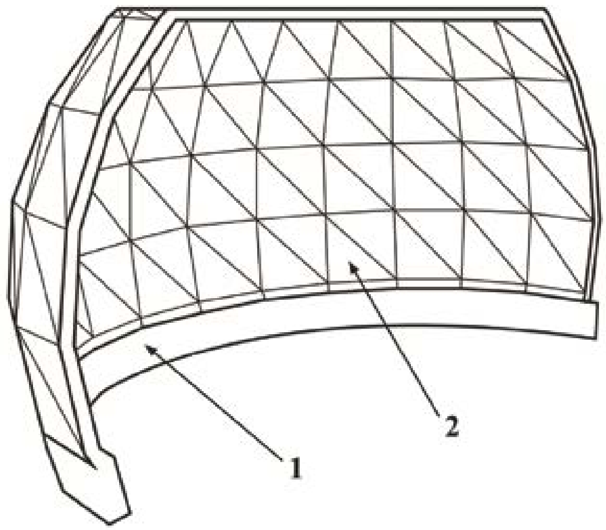

Fig. 3. Concept of a display system based on LED arrays

1 – base
2 – LED module

These features were not insignificant in the context of ensuring adequate viewing angles for the simulator driver. The most important parameter of LED arrays is the so-called pixel pitch which determines the density of LED spacing and has an effect on the quality of the displayed image. In the latest available LED displays for indoor use in permanent installations, the distance between LEDs goes down to 2 mm to 2.6 mm. However, the quality of the presented image depends on the distance between the screen and the viewer [10]. In the case of the SJCL-6P simulator, the distance between the screen and the viewer is not large enough to ensure sufficient image-viewing quality. Also the refresh rate of each LED at close distances (user-screen) can cause irritation and affect the user's concentration [11]. The above disadvantages were crucial to the rejection of the use of LED arrays inside the simulator cabin.

Another concept considered was setting a display made up of LED arrays outside the simulator and displaying on it an image large enough to meet all the requirements regarding the field of view and angular resolution at extreme platform displacements/inclinations [9].

However, the resulting structure proved to be far too large. The required surface area of the screen was estimated at close to 30 m^2. After initial calculation of the costs of the screens, of fabricating a structure for installing the screens, and of purchasing the necessary equipment for image processing and scaling, this concept was rejected.

3.3. Image projectors

Another solution considered for displaying the image in the display system in the SJCL-6P design was the use of projection devices. Projectors can display images of high resolution, while ensuring an adequate contrast and necessary refresh rate. The DLP [12] technology provides high contrast and minimizes pixel spacing, contributing to improved brightness and sharpness of the image. DLP projectors faithfully reproduce colours and display images of surprising quality. Effective use of projectors, however, requires that the room where the image is projected be "darkened". This feature must have been taken into account at the design stage of the simulator cabin structure and installation of the vision system.

There are two basic modes of image projection: front and rear. In the rear projection system [13] the projector is installed behind the screen. The projector casts the image towards the viewer on the back side of a special screen, foil or smart glass. It is therefore necessary to have sufficient free space behind the screen for the projector, which translates into increased dimensions of the structure. Additionally, if a curved screen (cylindrical layout) is used and the projectors are installed on the outer side of the screen, the image to be cast would have to be subjected to great distortion. With this solution, the combination of several image sources (video projection) into a single panoramic view generates additional technical problems.

The concepts considered at OBRUM's Simulator Department were focused on the use of front projection. As was the case of LED arrays, two options were taken into account: installing the projectors (and projection surface) on the simulator cabin, or outside the cabin. The second option (projectors outside the cabin) would require a complex system for computing the inclination angles of the platform in relation to the displayed image, performed in real time. There have therefore been concerns about possible additional undesirable latency in providing a suitably synchronized video signal during the simulator operation.

4. DISPLAY SYSTEM

After the analyzes, a design of the projection system was adopted, in which the image sources, i.e. projectors, together with installations ensuring "darkening", will be mounted on the simulator cabin. The block diagram (Fig. 4) shows all the simulator video channels used.

SJCL-6P, in addition to presenting the view as seen through the driver's periscopes or when driving with open hatch, allows observation of the view from the rearview camera and the use of a "free" observer camera - real-time view of the simulation environment from any position of the camera. In addition, all views observed by the trainee are also available at the instructor station.

In order to meet all the requirements regarding the range of viewing angles, assuming the minimum distance between the screen and the user, calculations were made, which showed that the projection surface (optimum version) should be cylindrical in shape with approximate dimensions of 420 cm x 120 cm, and curvature radius r = 140 cm.

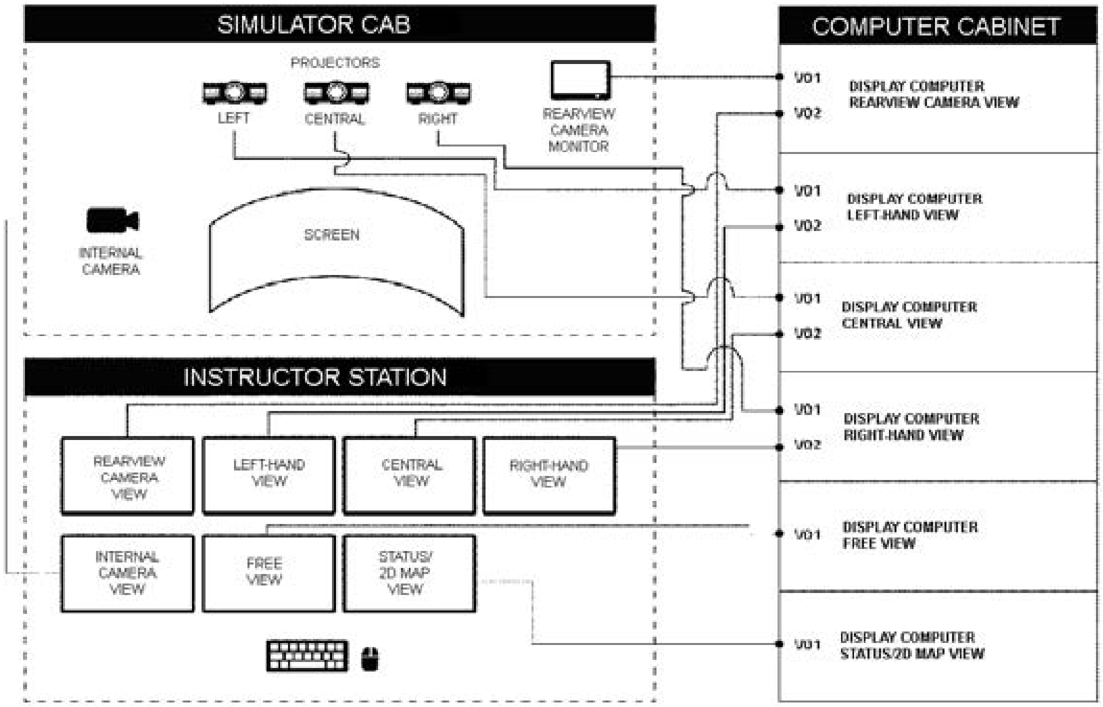

Fig. 4. Diagram of display system

To cover the screen surface with an image, it was necessary to use three projectors fitted with wide-angle lenses. Decision was made to install a vision system in which the projectors were suspended from the ceiling of the projection system housing (Fig. 5).

Fig. 5. Projector mounting - bottom view

1 – projector
2 - screen

To create the optimum operating conditions for the display system, three projectors were mounted as close as possible to the axis of rotation of the cabin and its centre of gravity. The projectors were placed above the driver's hatch, which eliminated the undesirable obstructing of the image by moving parts of the simulator or by the trainee when driving the vehicle with the hatch open. In addition, mounting the projectors directly under the ceiling, allows optimal removal of heat generated by the display system. The use of a cylindrical screen allowed to reduce the span/width of the projection screen while maintaining the field of view of 160° in the horizontal plane.

The adopted solution has many advantages. When a wide-angle, seamless screen is used there is no need to duplicate the image on special screens installed in periscope imitators, as is the case in other, competitive solutions. This greatly simplifies the design of imitators and increases the realism of training by preserving optical parameters identical with those of real periscopes (e.g. the possibility of "leaning out" or viewing angles). Moreover, the image being reflected from the screen (projection surface), which in itself is not a source of light, causes the observed image to be more natural to the human eye [14]**.** Another advantage of the adopted solution is the high quality of mapping of the actual view from the vehicle cab, which increases the driver's feeling of immersion during the training.

The solution based on several wide-angle projectors requires synchronization of video signals and edge-blending. This allows two or more projectors to be used to create a large, panoramic, high-resolution projection area. Before installing, the projectors were categorized into groups with the most similar optical parameters (even optical channel elements manufactured on a larger scale have variable values of parameters such as brightness, display angles, image centre offset, etc.). This solution allowed for the optimization of the calibration process and simplification of the elements for fastening the projectors to the display system housing.

In the SJCL-6P simulator the projectors were installed in a row (in contrast to other systems where the projectors are mounted one above the other). They were arranged so that the images they displayed (while maintaining the requirements of a total viewing angle of 160° horizontally and 30° vertically) overlapped each other within at least 25° (adjacent projectors).

After the devices were mounted in the simulator, calibration of the displayed images was required, made by aligning and adjusting the projection axis, using the following tools:

- special test images (grids of fixed line spacing);
- dedicated software developed by the Simulator Department;
- integrated lens adjustment functions (focusing, etc.);
- special apertures for "blurring" the edges of images (mounted in front of the projector lens).

In the SJCL-6P simulator it was necessary to mount the above mentioned aperture, because of the use of ultra short throw projectors (installed on the same side as the projection screen) that do not have edge-blending functions in their dedicated software.

The next stage of image calibration was precise image adjustment (warping), which would allow proper projection for all three display sources across the entire curved plane of the screen inside the cab. To achieve the appropriate image geometry, the software developed for the simulator was finally used. The Shader developed at OBRUM provides appropriate quality of the displayed image, while maintaining low load on the graphics cards.

In order to minimize the impact of the motion platform (vibrations, shocks) on the projection system (image desynchronization), the projection system was fitted with a housing of relatively high stiffness. The whole projector bracket module was mounted to the cab structure with the use of vibration isolators, significantly reducing thereby the number of harmful vibrations transferred to the projectors. The design applied minimizes the effects of projector axes movement relative to each other, and the displayed image remains stable enough even during fast movements of the cab. The view of the projection system built into the simulator is shown in Fig. 6.

Fig. 6. View of the mounting elements of the projectors

1 - screen
2 – projector

To achieve appropriate, consistent lighting conditions inside the cab, the space above the screen and on its sides has been enclosed. In order to minimize the amount of stray light falling on the screen of the vision system, all air inlets (required for cooling the projectors) in the housing of the vision system were blanked with ventilation grids set in a "herringbone" mode, where the blinds were arranged in two vertical rows, with adjacent elements joined at right angles.

The last item that had an effect on the correct operation of the display system was the need to duplicate at the instructor station the image generated on the driver's devices. The projectors used in the construction of the simulator had no factory-provided blending and warping capabilities, therefore achieving the desired effect inside the cab required development of a shader software. The image displayed on the instructor's monitors without proper processing remained heavily distorted, which made the objective evaluation of trainee driving performance difficult. In view of the above, the problem was resolved by devising a piece of software allowing to capture the image frame, processing it and finally generating the image on the screen at the instructor station.

5. CONCLUSIONS

The above-presented display system design solutions applied in the SJCL-6P simulator, developed and implemented for small lot manufacture, were compliant with the tactical and technical requirements (WZTT). Spatial limitations, including the use of short focal length projectors to display the image on a cylindrical surface, resulted in relatively high levels of image distortion.

Attaining the desirable image quality required high accuracy in fabricating the mounting and connecting fixtures of the projectors.

The major distinguishing features of the discussed solutions in the SJCL simulator include:

- uniform, seamless image on the screen;
- proper contrast and brightness of the images, without the need to emit high-intensity light;
- virtual image of space as close to natural as possible, no effect of dazzling of the trainee;
- ability to achieve very large image display angles (exceeding by far the specified requirements).

The vision system developed as part of the SJCL-6P project meets all the requirements of the contract, as well as additional adopted parameters, allowing to achieve a sufficiently high level of graphical representation of the battlefield environment. The solutions implemented in the simulator place the SJCL-6P in the forefront of simulators used in the training of the Polish Armed Forces, especially in terms of the quality of the display system used and the fidelity of mapping of real driving conditions in the field.

Extensive analyzes and conclusions contained in the text regarding the practical aspects of the system under design may be useful to other teams that design devices of similar purpose.

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