Optoelectronic tracking system for shooting simulator - tests in a virtual reality application

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Abstract—We present the test results of an authorial tracking device developed in the SteamVR system, optimized for use in a missile launcher shooting simulator. The data for analysis were collected using the virtual reality training application, with the launcher set on a stable tripod and held by a trainee who executed two scenarios with static and movable targets. The analysis of experimental data confirms that the SteamVR system together with the developed tracker can be successfully implemented in a virtual shooting simulator.

Shooting simulators [1] are one of the key applications in virtual reality (VR) systems. They can reduce extremely high training costs of portable missile systems and improve learning performance in various scenarios. Relying on the commercially available SteamVR environment [2], we developed the VR training application for a man-portable air-defense system (MANPADS) Piorun (Fig. 1). The SteamVR system [3] uses two base stations to establish objects position and orientation. The base stations emit a given sequence of optical signals. The heart of the system is the authorial tracker [4] attached to the launcher. Detectors located in the tracker acquire optical signals. Based on the time differences between optical signals, the position and orientation of the tracker and the launcher are calculated. Next, they feed the VR training system, which "knows" where the launcher is in the real coordinates. Simultaneously, the trainee observes the VR word using HTV VIVE head mounted display (HMD) goggles.

The goal of the present research was to determine if the developed tracker can provide accurate and stable localization of the launcher, which assures proper operation of the whole system.

Figure 1a shows the developed tracker with 24 detectors. The design and configuration of this device was optimized to ensure low random and systematic errors without interruptions during the tracking of the Piorun launcher. The prototype was built with 3D printed elements and electronic components from the SteamVR Tracking HDK set.

The tests were carried out in a 4.6 × 3.5 m laboratory with a height of 2.5 m. The working area was empty and screened with curtains to minimize spurious background reflections. The base stations were placed in the opposite corners of the working area at a distance of 5.4 m at a height of 2.1 m. During the measurements, the launcher and the tracker were placed in the center of the working area. We used the training launcher that had the dimensions and weight similar to a real combat launcher.

At the beginning of the experiments, calibration of the SteamVR system was performed. The boundaries of the working area were determined along the curtains. The designated center of the SteamVR coordinate system was near the center of the working area. Then the initial values of the launcher's model translations and rotations were corrected so that its virtual representation coincided with the real model.

We performed two types of tests. Firstly, the tests with the launcher installed stationary on a tripod (Fig. 1c). Secondly, we completed two scenarios for the launcher on the trainee's arm (Fig. 1b). The comparison of the tests results provided information about the performance of the tracker itself and impact of the trainee on system stability.

During stationary tests, the launcher was directed in four directions, and the system recorded measurement data for 30 s. The selection of two altitudes (350 m and 450 m) and two distances to the target (1 km and 2 km) provided four combinations of parameters, which corresponded to real shooting conditions.

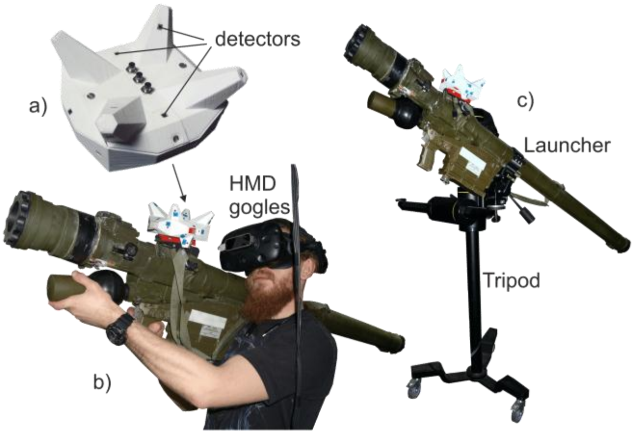

Fig. 1. Photo of the tracker (a), trainee with the launcher (b) and launcher on the tripod (c).

For tests with trainees, we prepared dedicated shooting simulator software with a given position or trajectory of two targets: stationary (Mi-9 helicopter) and moving (Su-

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27 fighter aircraft). The targets were observed through atelescopic sight in the VR environment (Fig. 2).

Fig. 2. Aiming at a fighter through a telescopic sight in the VR environment.

The tests with trainees embraced two scenarios. In the first scenario, the trainee aimed at a stationary target (Mi-9 helicopter) for 30 s. The set time was based on actual activities of Piorun operators, during which the shooter should fire or retreat. Four combinations of altitude-distance used in stationary tests were applied.

In the second scenario, the target (Su-27 fighter aircraft) traveled with a constant speed at an altitude of 150-600 m between the points P1-P5 (Fig. 3). The flight time through each section was 30 seconds.

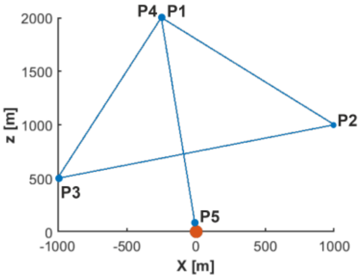

Fig. 3. Path of the fighter during the second scenario (top view). The orange point indicates the trainee's position.

At the beginning, the trainee finds a stationary target. Next, the supervisor initiates the tests. The scenario aims at keeping the moving target in the telescopic sight by the trainee in due time. The data acquisition rate from the tracker was synchronized with an image frame refresh rate of the HMD goggles equal to 45 fps. For each frame, the acquisition module saved the position (x, y, z) and orientation (α, β, γ) of the tracker and HMD as well as the target position and aiming angle. The aiming angle describes the angle between the line connecting the launcher muzzle with the target and the line extending the longitudinal axis of the launcher barrel.

Figure 4 shows the measured positions of the tracker collected for two types of stationary targets for four combinations of altitude-distance. When aiming at the stationary targets, the recorded deviations are more important than the absolute position of the launcher. Thus, to compare the results, the average values were removed from the presented data.

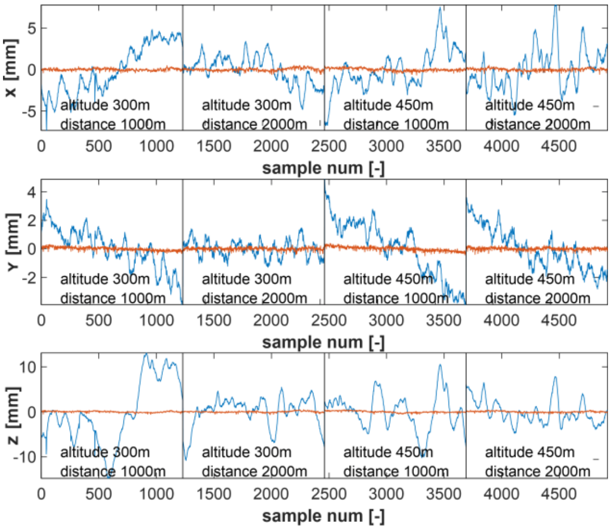

Fig. 4. Position of the launcher for stationary targets for x, y, and z coordinates. The measurements on the tripod are marked in orange; the measurements with the trainee are marked in blue.

The fluctuations of stationary launcher position on the tripod were associated with the random error of tracker measurements. This error expressed as standard deviation (*SD*) for all axes is below 0.17 mm and is negligible when compared to the fluctuations recorded for the trainee, where *SD* ranges from 1.4 mm for the *Y* axis to 4.7 mm for the *Z* axis. For the *Z* axis, the biggest values of *SD* are justified by movement of the fighter towards and away from the observer. This fact has an insignificant impact on target tracking in the sight.

The second, probably even more important value describing the performance of the launcher is the orientation (Fig. 5).

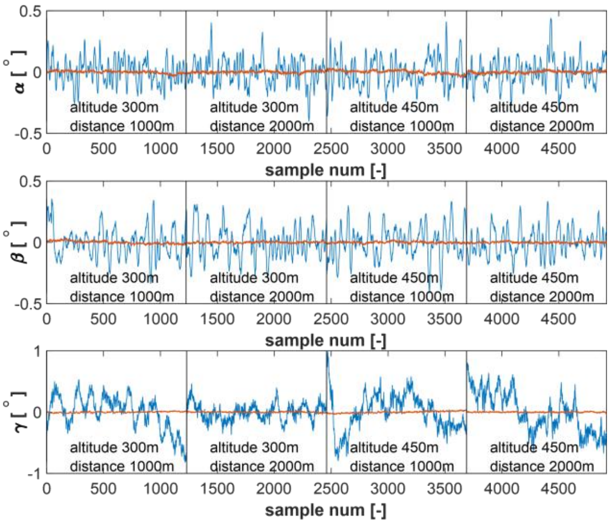

Fig. 5. Orientation of the launcher for stationary targets for α, β, and γ coordinates. The measurements on the tripod are marked in orange; the measurements with the trainee are marked in blue.

The random orientation error of the stationary launcher on the tripod expressed by *SD* is below 0.012°, which is much lower than the error made by the trainee. For the trainee, for angles α and β, related to rotation around the yaw and pitch axes, *SD* is 0.11° and 0.12°, respectively. For the third of the rotational axes, corresponding to the roll, a larger *SD* equal to 0.27° was observed. This value, however, has a negligible effect on the aiming angle, because it describes the rotation around axis along the barrel of the launcher. This fact is confirmed by low fluctuations of the aiming angle for stationary targets (Fig. 6).

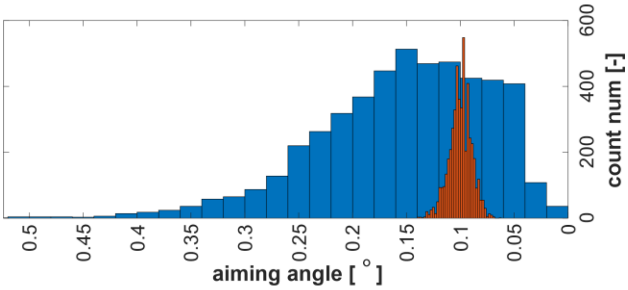

Fig. 6. Histogram of the aiming angle for stationary targets. The measurements on the tripod are marked in orange; the measurements with the trainee are marked in blue.

During the measurements, the trainee had to track the target in the 1° field of view using the telescopic sight to perform the tests. It means that the correct aiming angle should not exceed 0.5° for the point target. Moreover, targets closer to the tracker are bigger in the sights and are easier for tracking. Figure 6 shows that during the stationary measurements the aiming angle did not exceed 0.5°. When measuring with the tripod, the aiming angle was set to 0.1°. Thus, the obtained results oscillated around this value with *SD* = 0.01°.

Figure 7 presents the aiming angle for the second scenario. The maximum angle (the dashed blue line) represents the threshold above which the target was outside the field of view of the launcher considering the distance from the target and its height of 5.5 m (Su-27).

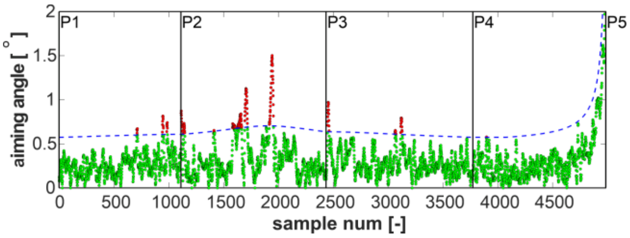

Fig. 7. Aiming angle for the second scenario. The blue line marks the maximum aiming angle.

The maximum angle is proportional to the arc tangent from the size of the target divided by the distance. This angle is higher in the middle of the segment P2-P3 and reaches the maximum around the point P5 because then the distance to the target is the smallest. 96% of the aiming angles are below the threshold (green points), which proves correct system operation. Most of the remaining points fall in the middle of section P2-P3 (red points) because this part of the flight requires the largest changes of launcher orientation to track the target.

This scenario was much more difficult than the stationary one and we think that the errors were caused only by the lack of experience of the trainee and not by the tracker inaccuracy or instability. The constant tracking of a moving target in the field of vision of the launcher proved that the trainee's movement caused small deterioration of the parameters of the launcher tracking system in comparison to the first scenario.

Table 1 summarizes the most important parameters of the tracking system, which are position and orientation stability expressed by standard deviations. All values are small in comparison to the movement of the launcher caused by the trainee while aiming.

Tab.1 Standard deviation of selected parameters.

	standard deviation							
	x	y	z	α	β	γ	Aiming angle	
							stationary target	moving target
	[mm]			[°]				
tripod	0.16	0.11	0.17	0.01	0.01	0.01	0.01	NA
trainee	2.44	1.45	4.7	0.11	0.12	0.27	0.08	0.24

What is also very important, the launcher was continuously tracked during all tests. We also did not observe any sudden changes in position or orientation values which could indicate a malfunctioning of the tracking system. This meant that the trainee could undergo all planned exercises and perform them correctly without any disruption, which proves the proper functioning of the VR system. To assess the performance of the system in detail, it is planned to conduct such tests for a larger number of trainees, also for those who have experience in using MANPADS Piorun. However, this requires time to obtain consent from competent military entities.

To sum up, our experimental results proved that the developed tracker can be successfully used in the shooting simulator for MANPADS Piorun.

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