Interactive 3D visualizations for studying combat experiences and life cycles

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Abstract

Studying the dynamics and outcomes of combat engagements is crucial for analyzing military tactics and developing practical recommendations. This article proposes using interactive 3D visualizations and an automated method for selecting rational combat scenarios to thoroughly analyze combat episodes. The approach allows reconstructing the life cycle of a battle in terms of space, time, and involved elements. Key criteria for the visualizations include information completeness and reliability, while indicators encompass the dynamics, effectiveness, and terrain of the engagement. The NATO-standard After Action Review methodology, coupled with mathematical modeling of combat using Lanchester's equations, enables pinpointing mistakes and successful tactics. The article describes visualization system design principles and outlines a phased process for gathering data, building 3D terrain models, and animating unit actions to create an accurate reconstruction. Two combat episodes from the war in Eastern Ukraine in 2015 serve as case studies. The proposed approach facilitates an in-depth analysis of actual battles and the investigation of prospective combat scenarios for diverse purposes, from education to military planning.

Keywords

After Action Review (AAR), 3D visualizations, combat experiences, battle reconstruction, military training and simulation

1. Introduction

Studying the experience of combat engagements is vital for analyzing the actions of opposing forces, identifying shortcomings and successes, and developing military art [1]. However, open information sources often present emotionally and politically charged accounts that lack sufficient detail for a thorough analysis [2, 3].

Seeking to reform its Armed Forces to NATO standards, Ukraine is adopting the After Action Review (AAR) methodology [4]. A key AAR tool is interactive 3D visualization, which accurately reconstructs the course of a battle in time and space [5]. For studying past engagements and forecasting potential scenarios, an automated method of selecting a rational combat scenario with homogeneous forces is proposed [6].

This article aims to substantiate and put forward interactive 3D visualizations for studying combat experiences in the Joint Forces Operation in Eastern Ukraine. It discusses visualization criteria and indicators, outlines the principles and process of creating reconstructions, and demonstrates the approach with two case studies.

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2. Literature review

The use of After Action Reviews and 3D visualizations for analyzing combat actions has garnered increased attention in military research and practice. Holsenbeck [7] described the mental health aspects of the AAR process during a joint aeromedical mission in response to Hurricane Andrew. Darling et al. [8] highlighted how the U.S. Army's Opposing Force (OPFOR) uses rigorous AARs to generate lessons that are fed back into the execution cycle, in contrast to the pro-forma reviews often conducted in corporate settings.

In the context of multinational operations, Conyers et al. [9] reported on Tactical Combat Casualty Care training provided to NATO forces at the Hamid Karzai International Airport, with AARs completed to categorize best practices. Truesdell et al. [10] discussed an expert opinion approach to managing cardiogenic shock, drawing parallels to elite military units' use of AAR to combine adaptability and cohesion.

Autonomous systems have also been a focus of research. Duan et al. [11] developed a hardware-in-loop simulation platform for unmanned aerial vehicle (UAV) autonomous aerial refueling, using an eagle-eye vision mechanism. Karthik et al. [12] proposed a GPS-less 3D inertial routing system for multi-floor indoor positioning during urban combat operations, facilitating after action review.

Regarding visualization system design, Murray [13] described an intelligent tutoring system for commercial games, the Virtual Combat Training Center, which lowers the cost of training while exposing trainees to the full complexities of combat. Rickard et al. [14] emphasized the need for interface standards in Live, Virtual, and Constructive (LVC) fighter aircraft training to ensure a common configuration and enable realistic mission debriefing.

In terms of case studies, Rosenbach and Tien [15] analyzed strategic leadership in the battle of Tal Afar, Iraq, demonstrating how Army officers combined classic and unique aspects of leadership to transform the war's trajectory. Stout et al. [16] reviewed the aeromedical evacuation response to the 1997 airplane crash in Guam, with the AAR resulting in multiple improvements to readiness and procedures.

These studies underscore the importance of detailed data collection, advanced modeling and visualization, and systematic analysis for extracting lessons from combat experiences.

3. Methodology

3.1. Visualization criteria and indicators

The key criterion for assessing 3D visualizations is the degree of their adequacy to the actual combat episode in terms of stages, timeline, and elements [1]. The visual information should aim to maximally approach reality.

Proposed criteria for the interactive 3D visualization of a battle's life cycle include:

1. *Information completeness and reliability*
   Sufficient, accurate data must be gathered from multiple sources to reconstruct the battle in detail. This includes tactical maps, unit positions, stage-by-stage descriptions, communications, and outcomes. Contradictory or missing information should be rectified through additional research and participant interviews.
2. *Battle dynamics*
   The visualization should capture the flow of the engagement, including unit movements, firing, maneuvering, and changes in control over time. Dynamic elements such as explosions, smoke, and vehicle damage enhance realism.
3. *Effectiveness of combat actions*
   Indicators of effectiveness include casualties inflicted and sustained, ground gained or lost, and objectives achieved by each side. These can be represented visually and quantitatively.

4. *Terrain characteristics*
   The 3D model should accurately depict the landscape, vegetation, structures, and fortifications where the battle occurred. Line of sight, cover and concealment, and mobility corridors influence tactics and outcomes. Geospatial anchoring aligns the virtual and real-world terrain.

Measures of information content range from sufficient, to partial yet adequate, partial and inadequate, and insufficient or missing data. Analysts must carefully assess available sources and work closely with military experts to construct a credible visualization.

3.2. After Action Review and Mathematical Modeling

NATO's AAR methodology focuses on evaluating the outcome of an event by answering three main questions [1]:

1. **What happened during the combat episode?** This involves establishing the facts, sequence of events, and overall outcome based on reports, interviews, and other records. An initial timeline and narrative are constructed.
2. **Why did the episode unfold in this manner?** Analysts probe the causes and contributing factors behind key decisions and actions by each side. This includes assessing the use of terrain, maneuver, fires, leadership, and adaptability. Participant perspectives are elicited to uncover rationale and mindset.
3. **How can the outcome be improved?** Insights from the preceding analysis are distilled into lessons and recommendations to address gaps in planning, execution, and capability. These may span doctrine, organization, training, materiel, leadership, personnel, and facilities. The emphasis is on actionable, specific measures.

Mathematical modeling of combat using Lanchester's equations complements the AAR by quantifying the dynamics and outcomes of engagements. Lanchester models represent attrition between two homogeneous forces as a system of ordinary differential equations [17]:

$$\begin{aligned} \frac{dm}{dt} &= -\alpha n(t) \\ \frac{dn}{dt} &= -\beta m(t) \end{aligned} \tag{1}$$

where $m(t)$ and $n(t)$ are the force levels of the two sides at time t, and α and β are attrition rate coefficients representing the effectiveness of each unit against the opposing side.

By considering different initial force ratios, attrition rates, and engagement termination conditions, analysts can explore the sensitivity of outcomes to various factors. This enables quantitative evaluation of alternate courses of action and highlights the leverage points for achieving desired results.

Lanchester models have been extended to incorporate heterogeneous forces, spatial effects, morale, and logistics [18]. However, their core insight remains valuable: the relationship between attrition rates and force ratios fundamentally shapes the dynamics of combat.

The AAR findings can inform the selection of appropriate Lanchester model parameters to represent a given battle. Conversely, modeling results can guide inquiry into the drivers of observed outcomes during the AAR process. This symbiotic relationship strengthens the analytic rigor of both methods.

4. Visualization system design

A combat visualization system typically consists of a graphics pipeline and a set of control programs (figure 1). The pipeline involves the formation, geometric processing, and rasterization of reliable data. Control programs handle pipeline initialization and interaction with the external environment.

Key requirements for landscape visualization algorithms include minimizing central processor load to free up resources for combat episode modeling. Techniques such as discarding invisible terrain

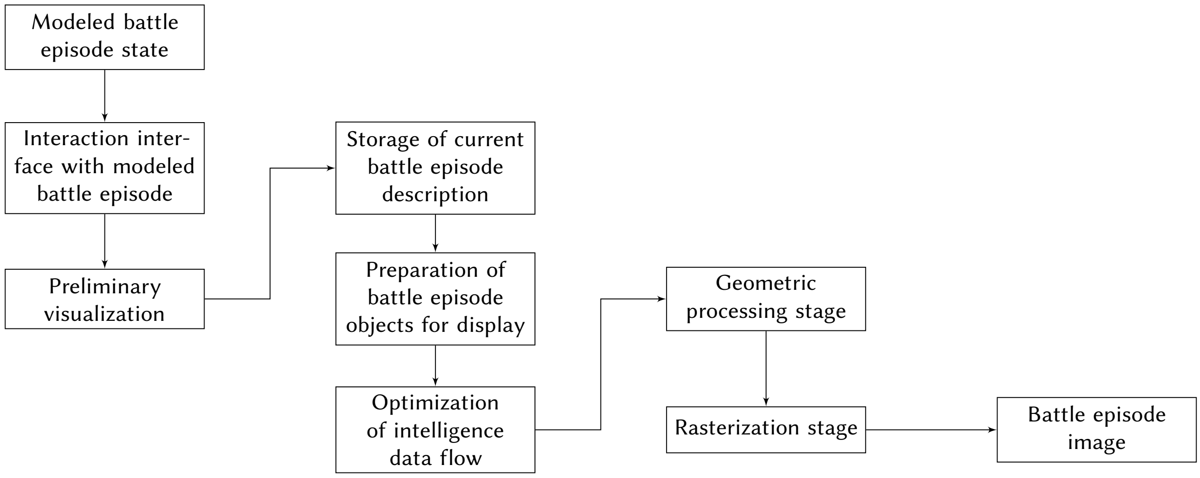

Figure 1: Battle episode visualization system.

sections and reducing detalization of distant areas help to optimize performance. The use of regular or irregular grid-based methods, like Fast Terrain Rendering Using Geometrical MipMapping [19] or Thatcher Ulrich's Chunked LOD [20], is common.

Several principles guide the design of an effective combat visualization system:

- Modularity: The system should consist of loosely coupled components with well-defined interfaces. This allows for iterative development, testing, and extension of individual modules without disrupting the overall architecture.
- Scalability: The visualization framework needs to accommodate scenarios of varying size and complexity, from small unit actions to large scale operations. Techniques such as level-of-detail rendering and adaptive scheduling can help maintain interactive performance.
- Interoperability: The system must interface with a range of data sources, combat simulations, and command and control systems. Adherence to standards such as Distributed Interactive Simulation (DIS) and High Level Architecture (HLA) promotes integration with existing and future military systems.
- User-centricity: The user interface should be intuitive and tailored to the needs of different stakeholders, such as commanders, analysts, and trainees. Customizable views, query tools, and playback controls enable users to effectively explore and manipulate the visualization.
- Extensibility: The design should allow for the integration of new types of data, entities, and behaviors as modeling and simulation capabilities advance. This may include support for higher-fidelity physics, artificial intelligence, and virtual/augmented reality technologies.

5. Visualization process

Creating an interactive 3D visualization of a combat episode involves several stages [1]:

1. **Gathering and analyzing information from various sources to reconstruct the battle in sufficient detail.** This includes tactical maps, operations orders, unit positions, communications logs, imagery, after action reports, and participant interviews. A systematic data collection plan helps ensure completeness and identifies gaps requiring further research.
2. **Building a 3D model of the terrain using a digital elevation model and overlaying relevant features such as vegetation, roads, rivers, bridges, buildings, and fortifications.** High-resolution remote sensing data, maps, and site surveys contribute to an accurate environmental representation. Terrain analysis tools can derive mobility corridors, intervisibility lines, and avenues of approach.

3. **Placing 3D models of personnel, vehicles, and equipment according to their initial positions on the tactical map.** Models may be based on standard military assets or specifically designed to match unique features observed in the battle. Attention to details such as unit markings, camouflage patterns, and weathering adds realism.
4. **Animating the actions of each entity over the course of the battle based on the collected data.** This includes movement along routes, changes in formation, deployment of forces, firing of weapons, detonation of ordnance, and incapacitation or destruction of assets. Timing of actions is synchronized with the battle narrative to reflect the dynamism of combat.
5. **Integrating additional elements to enhance the immersion and information content of the visualization.** These may include audio recordings of commands and radio traffic, video clips from cameras or unmanned systems, graphical overlays showing unit boundaries and phase lines, and data displays of ammunition expenditure, casualties, and system status.
6. **Rendering the complete visualization and packaging it for interactive display on various platforms.** Users can control the viewpoint, playback speed, and information layers to suit their analytic needs. The visualization becomes a key artifact supporting the AAR process, enabling participants to review the battle from multiple perspectives.

As a concrete example, the Interactive 3D Visualization Constructor software suite, developed at the National Technical University "Kharkiv Polytechnic Institute", was employed to reconstruct two combat episodes from the war in Eastern Ukraine [21].

For each case, data was first collected from open sources, tactical maps, and surveys of participants. 3D terrain was built from digital elevation models, and features such as trees, roads, and buildings were added based on overhead imagery. 3D models of Ukrainian and Russian equipment, such as tanks, infantry fighting vehicles, and anti-tank guided missile systems, were placed at their initial locations.

The movement of each vehicle and unit was animated over time based on the battle records. Engagements, artillery strikes, and destruction of assets were recreated, with special effects like explosions, smoke, and flying debris. Sounds of gunfire and radio communications were layered over the visual scene.

The resulting visualizations were rendered and packaged for viewing on desktop and mobile devices. Users could freely move the camera to observe the action from any angle, pause and resume the playback, and toggle information overlays showing unit positions, engagement ranges, and kill counts.

These interactive 3D visualizations supported detailed AAR sessions with the participants and military students. By virtually stepping through the battles, reviewers could identify decisive moments, discuss the rationale behind decisions, and assess the application of tactics, techniques and procedures. Alternative actions could be explored by manipulating the visualization, fostering counterfactual reasoning.

Beyond AAR, the visualizations served as case studies for professional military education, exposing students to the complexity and chaos of modern combat. By studying the battles from multiple viewpoints, learners developed an appreciation for the challenges faced by commanders and the importance of factors such as terrain, timing, and coordination.

The 3D visualizations were also used to brief senior leaders on the operational situation and outcomes. The realistic and immersive nature of the presentations facilitated understanding and communication of the battles' significance.

6. Case studies

The previously described methodology was applied to reconstruct two combat episodes from the war in Eastern Ukraine [21]:

- The defense of the "Seroga" strongpoint near Sanzharivka by Ukrainian mechanized and tank units on January 28, 2015.
- The assault on Logvinove by Ukrainian mechanized and tank units on February 12, 2015.

6.1. Defense of the "Seroga" strongpoint

The first case study examines the defense of the "Seroga" strongpoint by elements of a Ukrainian mechanized brigade against a Russian-backed separatist assault on January 28, 2015. The strongpoint, located near the village of Sanzharivka in Donetsk Oblast, consisted of a company-sized force equipped with T-64 tanks, BMP-2 infantry fighting vehicles (IFVs), and 82mm mortars.

At approximately 0400 hours, the separatists launched an attack on the strongpoint with a battalion-sized force, supported by artillery and multiple launch rocket systems (MLRS). The initial assault was repelled by direct fire from the Ukrainian tanks and IFVs, which inflicted heavy casualties on the advancing infantry and disabled several enemy vehicles.

However, the separatists regrouped and commenced a sustained bombardment of the Ukrainian positions with 122mm howitzers and 120mm mortars. This fire destroyed several Ukrainian vehicles and forced the defenders to seek cover in their trenches and bunkers. Under the cover of this fire, the separatists maneuvered a company of tanks and IFVs around the Ukrainian right flank, threatening to cut off their withdrawal.

Recognizing the danger, the Ukrainian commander ordered a fighting withdrawal to a secondary defensive position 2 km to the rear. The Ukrainian tanks provided covering fire while the IFVs and dismounted infantry conducted a bounding overwatch movement to the fallback position. Despite taking additional casualties from enemy fire, the Ukrainians successfully disengaged and occupied their new defenses by 0900 hours.

The visualization of this battle was created using the Interactive 3D Visualization Constructor software. Tactical maps and overhead imagery were used to build a detailed 3D terrain model of the strongpoint and surrounding area, including the village, fields, roads, and treelines. 3D models of the Ukrainian T-64 tanks, BMP-2 IFVs, trucks, and 82mm mortars were placed at their initial positions based on the commander's sketch and participant interviews. Separatist T-72 tanks, BMP-1 IFVs, and MLRS were similarly modeled and positioned.

The movement of each vehicle was animated based on the tactical map and narrative of the battle. Key events such as the initial assault, artillery strikes, flank attack, and withdrawal were visualized with appropriate effects and sounds. The user could view the battle from any angle, including from the perspective of individual vehicles or commanders, and pause the action to examine the situation in detail.

The AAR of this battle identified several key lessons:

- The importance of well-prepared defensive positions and interlocking fields of fire in repelling an attack by a numerically superior force. The Ukrainian tanks and IFVs were able to inflict heavy casualties on the separatists due to their dug-in positions and coordinated fire plan.
- The decisive role of artillery and MLRS in suppressing defensive positions and enabling maneuver. The separatists' concentrated and sustained bombardment forced the Ukrainians to seek cover and degraded their ability to repel the flank attack.
- The value of a timely and organized withdrawal in the face of an overwhelming attack. By displacing to a secondary position before becoming decisively engaged, the Ukrainian commander preserved his force and avoided encirclement.
- The criticality of situational awareness and rapid decision-making in a dynamic battle. The Ukrainian commander had to quickly assess the situation, anticipate enemy actions, and issue clear orders to his subordinates to maintain cohesion and effectiveness.

These lessons were incorporated into subsequent training and doctrine for Ukrainian mechanized units. The 3D visualization became a valuable tool for educating new commanders and soldiers on the realities of high-intensity combat against a sophisticated opponent.

6.2. Assault on Logvinove

The second case study focuses on the Ukrainian assault to retake the village of Logvinove from separatist forces on February 12, 2015. Logvinove, located along the strategic Debaltseve-Artemivsk highway in

Donetsk Oblast, had been captured by the separatists two days prior, cutting off the main supply route to Ukrainian forces defending the Debaltseve salient.

The Ukrainian command mobilized a tank company and a mechanized infantry company to assault Logvinove and reopen the highway. The tanks, a mix of T-64BVs and T-64BMs, were tasked with leading the attack and destroying enemy armor, while the mechanized infantry in BMP-2s would clear the village and secure the flanks.

At 1000 hours, the Ukrainian force departed its assembly area and began advancing towards Logvinove along the highway. Approximately 1 km from the village, the lead tanks came under fire from separatist T-72s and anti-tank guided missiles (ATGMs) positioned on the high ground to the north. Two Ukrainian tanks were quickly disabled, forcing the remainder to seek cover and engage the enemy armor at standoff range.

As the tank battle unfolded, the Ukrainian mechanized infantry dismounted and began clearing the outlying buildings of Logvinove. They immediately came under heavy small arms and RPG fire from separatist infantry occupying prepared positions in the village. The fighting devolved into a brutal close-quarters battle, with the Ukrainians using grenades and armored vehicle support to dislodge the defenders house by house.

By 1400 hours, the Ukrainians had cleared the southern half of Logvinove and advanced to the center of the village. However, they were unable to progress further due to well-coordinated separatist resistance and the threat of encirclement. Running low on ammunition and fuel, and with night falling, the Ukrainian commander ordered a withdrawal to avoid becoming decisively engaged. The assault had failed to completely clear Logvinove or reopen the highway.

To visualize this battle, the terrain team built a highly detailed 3D model of Logvinove and the surrounding area using tactical maps, UAV imagery, and photographs. Particular attention was paid to modeling the buildings, streets, and defensive positions in the village. 3D models of the Ukrainian T-64 tanks and BMP-2s, as well as the separatist T-72s, ATGMs, and infantry were created and placed at their starting locations.

The assault was animated in phases, showing the initial Ukrainian advance, separatist ambush, tank battle, village clearance, and withdrawal. Cameras were placed in the turrets of the tanks and BMP-2s to give the viewer a sense of the limited visibility and situational awareness of the vehicle crews. Sounds of tank and small arms fire, RPG launches, and radio communications were synced with the action to create an immersive experience.

The AAR of the Logvinove assault surfaced several important lessons:

- The difficulty of attacking a well-defended urban area without significant numerical superiority and combined arms support. The separatists' interlocking fields of fire, prepared positions, and coordinated resistance stymied the Ukrainian advance and inflicted heavy casualties.
- The vulnerability of armor to ATGMs in complex terrain. The separatist Konkurs and Fagot ATGMs, positioned on high ground flanking the approach to Logvinove, quickly knocked out several Ukrainian tanks and forced the remainder to seek cover, disrupting the momentum of the assault.
- The importance of reconnaissance and intelligence preparation of the battlefield (IPB) prior to an attack. The Ukrainians lacked detailed information on the separatist positions, strength, and dispositions in Logvinove, leading to an underestimation of the defense and a piecemeal commitment of forces.
- The challenge of sustaining an assault without robust logistics and force rotation. The Ukrainian attack faltered in part due to the exhaustion of ammunition and fuel, and the inability to replace personnel and vehicle losses, as the battle progressed.

These hard-won insights were applied to refine Ukrainian urban warfare tactics, adjust force compositions and task organizations, and improve the planning and execution of future offensive operations. The Logvinove visualization became a cautionary case study, illustrating the complex dynamics of combat in built-up areas against a determined and well-equipped enemy.

Both the Sanzharivka and Logvinove case studies demonstrate the power of interactive 3D visualization to reconstruct and analyze complex combat episodes. By creating an immersive and data-driven representation of the battle space, these visualizations enable military professionals to explore the multi-dimensional factors that shape the course of engagements, from the decisions of individual commanders to the effects of weapon systems and terrain.

Moreover, by subjecting the visualizations to structured AAR processes, practitioners can derive actionable lessons learned and identify best practices for future operations. The integration of 3D visualization with established analytic frameworks like AAR creates a potent tool for military learning and adaptation.

As the fidelity and sophistication of modeling and simulation technologies advance, the potential applications of interactive 3D visualization in the military domain will only expand. From mission planning and rehearsal to after-action review and training, immersive visualizations will play an increasingly central role in preparing armed forces for the challenges of 21st century warfare.

7. Conclusion

Interactive 3D visualization, coupled with AAR methodology and mathematical combat modeling, provides a powerful tool for analyzing past combat episodes and testing prospective scenarios. The proposed approach enables an accurate reconstruction of battles in space and time, helping to identify mistakes and successful tactics.

The case studies of the Sanzharivka strongpoint defense and Logvinove assault demonstrate the value of 3D visualization in understanding the complex dynamics of modern combat. By collecting and integrating data from multiple sources, modeling the terrain and units in detail, and animating the flow of the battle, these visualizations create an immersive and data-driven representation of the engagement.

Subjecting the visualizations to structured AAR processes enables military professionals to explore the key factors that shape the outcomes of battles, from decisions and maneuvers to the effects of weapon systems and terrain. By deriving lessons learned and best practices, practitioners can adapt tactics, techniques, and procedures for future operations.

The methodology presented in this article can benefit a wide range of military applications, from mission planning and rehearsal to education and training. Future research may further explore the integration of 3D visualization with other analytic methods and data sources, such as combat logs, equipment sensors, and participant interviews. The development of automated tools for data ingestion, entity behavior modeling, and scenario generation could streamline the visualization process and allow for more rapid and flexible analysis.

The use of virtual and augmented reality technologies may also enhance the immersion and interactivity of combat visualizations, enabling users to more naturally explore and manipulate the battle space. Collaborative visualization environments could allow geographically distributed teams to jointly analyze and discuss combat episodes, facilitating shared understanding and decision-making.

References

[1] I. V. Barkatov, V. P. Varakuta, V. S. Farafonov, V. O. Tiurin, S. S. Honcharuk, A. A. Lozko, Using Interactive Three-Dimensional Visualizations to Study Combat Experiences of Units in the Joint Forces Operation, in: Science and Technology of the Air Force of Ukraine, volume 3, 2021. doi:10.30748/zhups.2021.69.04.

[2] Y. Butusov, War and guilt, 2021. URL: https://gazeta.zn.ua/internal/voyna-i-vina-_.html.

[3] O. Yarchuk, Battle Analysis. Debaltseve Bulge 26.01–02.02.2015, 2015. URL: http://oyblogg.blogspot.de/p/blog-page_4.html.

[4] After-Action Review, 2024. URL: https://drive.google.com/file/d/1oM2fTGUtOwD46AHNKIVOg844bBKHfwhn/view.

[5] V. S. Farafonov, I. V. Barkatov, S. A. Babak, Application of Interactive 3D Tactical Field Model to Study Combat Experience in the Anti-Terrorist Operation Zone, in: Academic Support for Service and Combat Activities of the National Guard of Ukraine, 2017, p. 144.

[6] I. V. Barkatov, V. S. Farafonov, S. O. Holovach, Development of an Interactive 3D Tactical Field Model to Enhance the Effectiveness of Tactical and Tactical-Special Disciplines Classes in Reserve Officers Training, in: Prospects for the Development of Automated Command and Control Systems and Geoinformation Systems, 2015, p. 144.

[7] L. Holsenbeck, Joint Task Force Andrew: The 44th medical brigade Mental Health Staff Officer's after action review, Military Medicine 159 (1994) 186–191. doi:10.1093/milmed/159.3.186.

[8] M. Darling, C. Parry, J. Moore, Learning in the thick of it, Harvard Business Review 83 (2005) 84–92+192.

[9] K. Conyers, A. B. Gillies, C. Sibley, C. McMullen, M. A. Remley, S. Wence, J. M. Gurney, Where There's a War, There's a Way: A Brief Report on Tactical Combat Casualty Care Training in a Multinational Environment, Journal of special operations medicine : a peer reviewed journal for SOF medical professionals 23 (2023) 130–133. doi:10.55460/WKSE-6PVS.

[10] A. G. Truesdell, B. Tehrani, R. Singh, S. Desai, P. Saulino, S. Barnett, S. Lavanier, C. Murphy, Expert opinion: 'Combat' approach to cardiogenic shock, Interventional Cardiology: Reviews, Research, Resources 13 (2018) 81–86. doi:10.15420/icr.2017:35:3.

[11] H. Duan, Q. Zhang, Y. Deng, X. Zhang, Biologically eagle-eye-based autonomous aerial refueling for unmanned aerial vehicles, Yi Qi Yi Biao Xue Bao/Chinese Journal of Scientific Instrument 35 (2014) 1450–1457.

[12] B. Karthik, M. Usila, M. Sundararajan, GPS less 3d inertial routing system for multi-floor indoor positioning during urban combat operations, Journal of Chemical and Pharmaceutical Sciences 9 (2016) S283–S286.

[13] W. R. Murray, Intelligent tutoring systems for commercial games: The virtual combat training center tutor and simulation, in: Proceedings of the 2nd Artificial Intelligence and Interactive Digital Entertainment Conference, AIIDE 2006, 2006, pp. 66–71.

[14] R. N. Rickard, W. R. Bennett Jr., C. Colegrove, Development of fighter aircraft live, virtual and constructive (LVC) interface standards, in: Fall Simulation Interoperability Workshop, 2013 Fall SIW, 2013, pp. 250–260.

[15] E. B. Rosenbach, J. Tien, How the west was won: Strategic leadership in Tal Afar, in: Military Leadership: In Pursuit of Excellence, Taylor and Francis, 2018, pp. 223–232. doi:10.4324/9780429495007.

[16] L. R. Stout, J. R. Jezior, L. P. Melton, J. A. Walker, M. L. Brengman, S. T. Neumeier, R. L. Smith, C. A. Vanfosson, T. E. Knuth, J. B. Holcomb, L. C. Cancio, Wartime burn care in Iraq: 28th Combat Support Hospital, 2003, Military Medicine 172 (2007) 1148–1153. doi:10.7205/MILMED.172.11.1148.

[17] R. L. Helmbold, A. S. Rehm, "The influence of the numerical strength of engaged forces in their casualties," by M. Osipov, Naval Research Logistics (NRL) 42 (1995) 435–490. doi:10.1002/1520-6750(199504)42:3<435::AID-NAV3220420308>3.0.CO;2-2.

[18] J. T. Christian, An Examination of Force Ratios, Monograph, U.S. Army Command and General Staff College Fort Leavenworth United States, 2019. URL: https://apps.dtic.mil/sti/citations/AD1083211.

[19] W. H. de Boer, Fast Terrain Rendering Using Geometrical MipMapping, 2000. URL: https://www.flipcode.com/archives/article_geomipmaps.pdf.

[20] T. Ulrich, Rendering Massive Terrains using Chunked Level of Detail Control, in: Super-size It! Scaling Up to Massive Virtual Worlds, The Eurographics Association, 2002, pp. 211–224. URL: http://tulrich.com/geekstuff/sig-notes.pdf.

[21] I. V. Barkatov, V. S. Farafonov, S. S. Dychko, The War in Donbas 2014-2018, in: Proceedings of the IV All-Ukrainian Scientific Military-Historical Conference, National Military History Museum of Ukraine, 2019.