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Innovative Concept of Augmented Reality Training for Countering UAVs

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Abstract:

Contemporary armed conflicts are characterized by the increasing use of unmanned aerial vehicles (UAVs). One key approach is firearm-based defense. This paper presents the concept of an innovative trainer based on augmented reality (AR) technology. The system integrates a virtual environment generated by the Unreal Engine in real-time (including realistic models of drones and firearms) with real-world maps displayed through HoloLens 2 glasses. The paper covers the technical design and implementation, enabling battlefield simulation. The prototype includes features such as dynamic training scenario generation, real-time user position synchronization, and realistic UAV behavior simulation. Findings highlight AR's potential in military training while addressing challenges like GPS integration and cross-environment synchronization. The system demonstrates selected capabilities for the future of military training.

Keywords:

AR, augmented reality, training, UAV, unmanned aerial vehicles, counter-drone

1 Introduction

The use of unmanned aerial vehicles (UAVs) in the military sector includes reconnaissance, transportation, targeting enemy personnel, and infrastructure destruction. UAVs play a significant role on the modern battlefield – as single units or as swarms of interconnected drones [1-5]. This statement is substantiated by the widespread deployment of UAVs by both parties in the Ukrainian – Russian conflict. Allied drones constitute a critical operational asset, whereas adversary UAVs necessitate effective countermeasures. UAV defense strategies comprise three fundamental phases: detection,

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identification, and neutralization [6, 7]. Counter-drone methods can be categorized into destructive (e.g., the use of ammunition, and non-kinetic, e.g., the application of electromagnetic waves) and non-destructive approaches (hard, e.g., interception by a hunter drone, and soft, e.g., cyber interference that disables the UAV without causing its physical destruction) [7-10]. A common approach involves the use of electromagnetic pulses (EMP), which can disrupt communication or damage the sensitive electronic components of UAVs. EMP devices are often large and cumbersome, limiting their practical deployment [8, 11, 12]. An alternative approach involves anti-drone systems that integrate multiple techniques [13] or the use of small-caliber firearms. However, the effectiveness of small arms is limited due to drones' mobility and small size [8, 14, 15].

In countering manned aerial vehicles, weapon systems employing missile and gun-based propulsion are commonly used, and these technologies can be adapted for UAV neutralization. Various types of projectiles are utilized in UAV defense, including nets that immobilize drone rotors, programmable explosive ammunition, and paint projectiles that obscure camera lenses, thereby disrupting remote control functionality [8, 13, 15, 16]. Established counter-UAV strategies also include the deployment of artillery systems for combating drone swarms, utilizing high-rate firepower to effectively disrupt and neutralize multiple UAVs simultaneously [17]. Additionally, specific combat strategies utilizing firearms and small-caliber ammunition have been proposed, such as the creation of barrage fire. In each of these methods, the precision of the shooter plays a critical role in ensuring effective UAV neutralization. One of the main concerns is the risk of collateral damage, as there remains a significant probability of inadvertently striking bystanders while engaging an enemy UAV [14, 15]. Another limitation of this approach is that drones, being small and highly maneuverable targets, present considerable challenges for effective neutralization, which consequently reduces the overall efficacy of this method [8]. Nevertheless, in combat situations, every soldier is equipped with a standard-issue firearm, whereas not all units have access to dedicated UAV countermeasure systems. In real-world scenarios, particularly during unexpected engagements, the most practical solution is the deployment of small-caliber ammunition to neutralize hostile drones.

Based on a comprehensive literature review, it has been established that the use of firearms and small-caliber ammunition remains one of the key methods for countering UAV threats. Despite the limitations – such as reduced effectiveness due to drones' small size and high agility – the method's universality could still be leveraged effectively. Training in this domain requires modern methodologies that precisely replicate real-world conditions, thereby improving overall training efficacy. Existing military training systems predominantly function within confined environments and are largely dependent on screen-based simulations [18, 19]. Training systems, such as the Polish system called "ŚNIEŻNIK", facilitate the assessment of trainees' performance in assigned tasks through the utilization of sensor networks, such as those detecting infrared radiation [20]. Systems (or their conceptual designs) employing virtual reality (VR) or augmented reality (AR) are being developed. An example is the Korean Tactical Assault-shooting Drill-simulator (TAD), which, using HoloLens 2, allows soldiers to train in tactical scenarios [21, 22]. However, the authors have not found any information about systems specifically designed for training in the field of UAV countermeasures. To bridge this gap, the authors have proposed a system utilizing AR technology.

The real-world environment is enhanced with statistical data and virtual, three-dimensional models of UAVs, along with a sample weapon model – an M4A4 carbine – downloaded from the internet. With data synchronization, a soldier using AR can locate themselves on a map, detect other trainees, and track generated enemy UAVs. To enhance battlefield realism, the system is designed to coordinate training so that each soldier equipped with a head-mounted display (HMD) can identify allied units and neutralize incoming UAVs without multiple trainees targeting the same threat simultaneously. The proposed solution, enhanced with realistic scenarios simulating modern battlefields, would allow soldiers to rapidly adapt to dynamically evolving operational conditions. At the same time, the system would facilitate learning how to avoid undesirable situations, such as accidentally striking bystanders during UAV neutralization. This could significantly improve both operational effectiveness and safety.

2 Materials and Methods

The goal of developing a virtual environment is to simulate simplified actions related to the elimination of UAV-type flying objects using small arms. To achieve this, a training simulator concept has been proposed, which could serve as a supportive tool in the soldier training process. A schematic diagram of the developed concept is presented in Fig. 1.

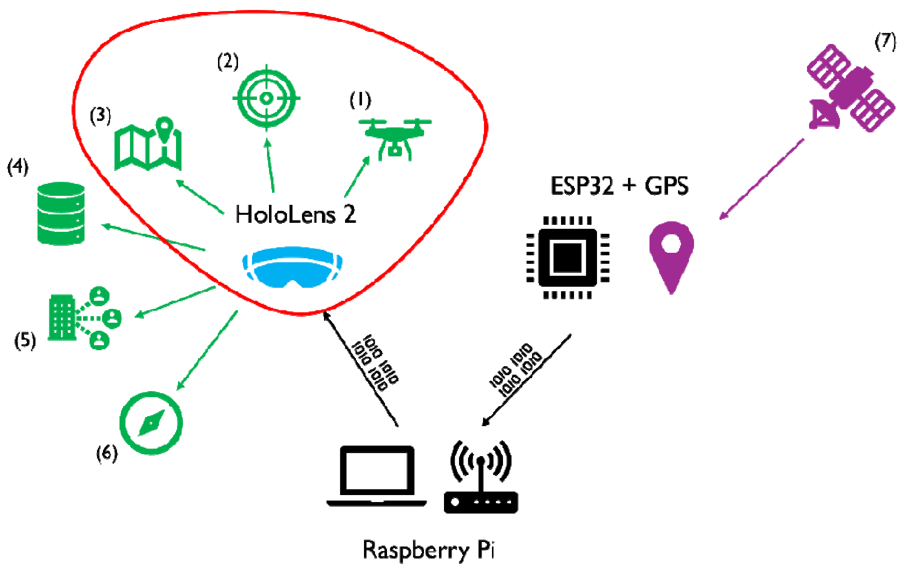

Fig. 1 Schematic diagram of the proposed concept

The operational concept of the training system involves transmitting key information about objects, including their relative position, distance, and velocity. It also incorporates data acquisition for objects identified as system users (5) from external sources via satellite navigation (7). On the other hand, data related to virtual objects (4) will be inherently integrated into the virtual environment. Firstly, during the initial stage of concept development (the area highlighted by a red line in Fig. 1, the methods for loading maps (3), drone movement (1) and simulation of gunfire (2) were developed. Since HoloLens 2 lacks the capability to measure GPS location, the authors propose using an external GPS module supported by an ESP32 chip, properly integrated with an internet-based application responsible for generating the real-world map in the later stages of concept development. The purpose is to overlay the trainee's exact location on the map and indicate the location of other trainees as well as enemy UAVs in relation to it. The map of the real world with markers overlayed on it, in concept, will be part of a larger display, the so-called Heads-Up Display (HUD), which will display information useful to the trainee, such as the amount of remaining ammunition, or a compass (6) for orientation in space. The HUD will be implemented using Widgets, which are Unreal Engine objects designed for user interface (UI) development. According to the proposed concept, the map (web application), glasses application, and ESP32 chip with GPS module will connect to the Raspberry Pi server as clients, enabling bidirectional data transmission essential for the system's proper operation.

The virtual environment was designed using Unreal Engine 5.0.3 in an application dedicated to AR glasses Microsoft HoloLens 2. In order to ensure the correct operation of the application, it was necessary to add developer tools to the engine for application development in the form of Microsoft OpenXR and Mixed Reality UX Tools plug-ins. An integrated development environment (IDE) Visual Studio 2019 was used to program the environment's elements in C++. The selected versions of the engine and IDE are the latest supporting tools for developing applications designed for HoloLens 2 glasses. The way the real-world maps are implemented in the trainer is shown in Fig. 2.

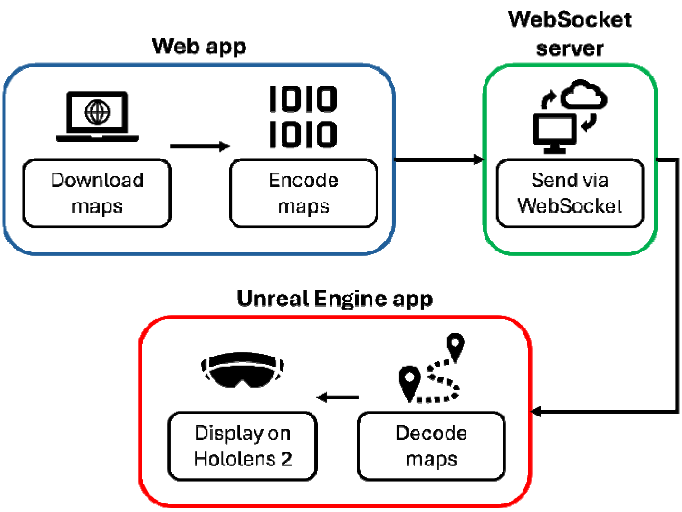

Fig. 2 The way real world maps are implemented in the trainer

In the designed virtual environment which simulates the battlefield, the user's orientation in space is crucial, which requires knowledge of both his own location and the coordinates of other users of the system. However, the integration of real-world maps with applications developed with the Unreal Engine for HoloLens 2 glasses enabling AR is a non-standard approach in the use of this type of device. Due to the lack of native tools for handling real-world maps in the engine, it was necessary to create the maps in the form of a separate web application to implement them. The web application was developed using Hyper-Text Markup Language (HTML), Cascading Style Sheets (CSS) and JavaScript programming language. The maps are generated using the Leaflet.js library, the use of which provides the ability to use Open Street Maps tiles under the Open Data Commons Open Database License. The complexity of the symbols displayed on the map and the need to manipulate them determines the implementation of a script outside the utilized library – L.CanvasOverlay.js – posted on GitHub under the MIT license. Maps and the virtual environment were implemented as two separate applications, so it is necessary to develop a way to communicate between them. Data transfer between the two applications is provided by a server using the full-duplex WebSocket protocol implemented as a separate application.

The next stage of concept development is the implementation of three-dimensional models into the designed virtual environment. Fig. 3a presents a three-dimensional model of the M4A4 carbine, sourced from the Sketchfab platform under Creative Commons Attribution license [23]. In Fig. 3b three-dimensional model of a drone sourced from the CGTrader database under Royalty Free No AI license is shown [24].

Fig. 3 Models used: a) M4A4 carbine; b) UAV

The optimization of models for operation in the Unreal Engine was achieved through their implementation as so-called Static Meshes, a type of object that allows for the precise rendering of geometric details while ensuring high performance in real-time rendering. This approach guarantees high system performance while preserving visual quality. The UAV model maneuvers along a path comprising randomly selected waypoints. The simulation of the virtual drone’s flight accurately replicates the behavior of the physical machine, for instance, by tilting the model in the direction of motion. The weapon model is directly integrated with the view provided by the glasses, so that it automatically follows the direction in which the user is currently looking, thereby simulating the handling of a rifle. The act of firing is simulated through the dynamic generation of a projectile, represented by a small collision-detection area (so-called hitbox), which facilitates hit detection and enables the assessment of shot effectiveness within the conceptual framework. The shot simulation is initiated by an appropriately executed left-hand gesture, triggering the creation of a projectile instance at the muzzle.

3 Results

Based on the assumptions of the concept illustrated in Fig. 1, the design process was undertaken for the components of the trainer system (1), (2), and (3). The outcome of this development consists of three applications that collectively constitute the trainer system. Fig. 4 provides a schematic representation of the practical implementation of the concept depicted in Fig. 2.

Fig. 4 Diagram of the implementation of the trainer system concept

The first component of the trainer system is a web application responsible for generating a real-world map. Fig. 5 shows the generated real-world map in the form of a mini map.

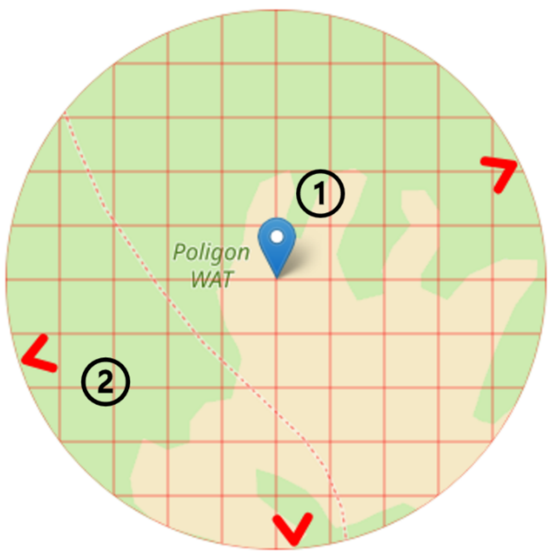

Fig. 5 Generated real-world map

The marker representing the glasses user (1) is positioned at the center, while the remaining markers are distributed around it. If an object's marker is positioned outside the area displayed by the mini map, an indicator (2) appears on the map – an arrow pointing in the direction of the object's location. The concept presupposes the use of colors to differentiate between allies and adversaries: blue for friendly forces and red for enemy forces. According to the concept, as the user moves, the map will shift relative to the permanently positioned glasses user marker in the center. The generated map is permanently oriented to the north. To enhance the user's spatial awareness, the HUD will include a dedicated compass widget that displays the current position relative to the Earth's topographic north pole. According to the concept, the map will utilize the GPS data of the system users and the coordinates of the virtual UAVs, which will be converted into GPS coordinates. Another component of the trainer system is an application created in the Unreal Engine and executed on HoloLens 2 glasses. This application is responsible for generating a virtual environment overlaid on the real-world using AR technology. The application enables the detection of a virtual UAV, the firing of a virtual weapon, and real-time visualization of the environmental map. To start the trainer, a WebSocket server must be activated at the start of the process. It allows the other two applications to communicate. Then, after launching the program on the HoloLens 2 glasses, the virtual environment is loaded and the HUD is generated. The HUD is always displayed in front of the system user's eyes and follows the user's head movements.

Finally, for the trainer to function properly, the web application must be launched. The trainer system becomes fully operational once the glasses application and the web application displaying the map successfully establish a connection with the WebSocket server. Fig. 6 shows the user-level view after launching the trainer application on the glasses.

Fig. 6 View of the trainer in HoloLens 2 glasses. 1 – real-world map, 2 – carbine model, 3 – UAV model

A mini map (1) displaying the environment has been positioned in the upper right-hand corner, allowing the user to maintain spatial awareness of their own location, hostile objects, and other system users at all times. A three-dimensional model of the weapon (2) was set up from the perspective of the equipped user so as to represent the trainee's holding of the weapon. This procedure was intended to replicate the natural shooting stance as closely as possible. A ray emerges from the muzzle to indicate the direction of shooting to the user. The three-dimensional model of the UAV (3) was appropriately programmed to realistically represent the dynamics and unpredictable behavior of the real machine.

4 Conclusions

A review of the literature on UAV countermeasures has revealed that soldiers' standard-issue firearms constitute a fundamental component of the arsenal employed against drones. Nevertheless, the limited experience of soldiers in addressing contemporary battlefield threats – particularly operations against drones – significantly reduces the effectiveness of this approach. Furthermore, insufficient training in responding to rapidly evolving threats can not only compromise combat effectiveness but also heighten the risk of accidents [14, 15]. Introducing soldiers to the challenges of countering UAVs with conventional weaponry would significantly enhance their proficiency in this domain. As a result, this would address one of the method's primary weaknesses – its limited effectiveness stemming from insufficient experience and knowledge in countering modern threats. In response to this problem, the authors of the paper have proposed a concept of AR-based trainer system. AR systems, which function similarly to VR, represent a potential pathway for the advancement of the defense sector. They facilitate the development of realistic training environments, including those specifically designed for particular types of armament [21]. The project discussed in the paper assumes the design of an integrated system that enables the simultaneous training of multiple individuals. According to its design principles, the trainer is intended to facilitate communication among multiple system users by displaying their coordinates on a shared real-world map, presented as a HUD on AR glasses. Furthermore, the system should accurately simulate the real-world conditions that trainees are likely to encounter when confronting the challenge of countering UAVs. This is achieved by utilizing a real-time three-dimensional rendering engine and appropriately designed training scenarios. The solution presented in this article marks the first step towards the practical implementation of this concept. Real-world maps have been integrated into the Unreal Engine, and consequently, into the simulation program running on HoloLens 2 AR glasses. Additionally, prototypes of systems have been developed – one for controlling the three-dimensional UAV model and another for simulating firearm discharge.

At this phase of development, the system prototype demonstrates considerable potential for the application of AR in the training process. Modeling interactions between the user and the device is essential for both training effectiveness and the attainment of educational objectives, facilitating the optimization of learning processes and the improvement of practical skills. The use of HMD not only facilitates the visualization of the shooting process but also enables the identification of errors in aiming, distance estimation, and coordination with other trainees. The authors' implementation of three-dimensional models is particularly important for simulating realistic scenarios. Additionally, the separation of the real-world map into a standalone web application and its integration with HoloLens 2 via the WebSocket protocol enables the incorporation of maps as part of the augmented environment. This approach represents a significant advancement in the development of immersive information systems that leverage user location data.

A limitation of this solution is that the HoloLens 2 AR headset does not have an integrated GPS module that would enable real-time user location tracking. As a result, the retrieval and processing of trainee coordinates will be handled by a separate GPS module operated by a microcontroller within the ESP32 system. Another challenge encountered by the authors during the project was the lack of real-world map support in the Unreal Engine. This required the development of a dedicated system to perform this function. The resulting system, which integrates real-world maps into the Unreal Engine, constitutes an innovative solution with potential applications across various AR environments. In this paper, the authors have identified several potential directions for further project advancements. The first approach involves integrating a GPS module to enable users to visualize their real-world location, as well as a server based on a Raspberry Pi single-board computer to facilitate communication between the mini map and the headset application. Subsequently, it would be necessary to connect two pairs of HoloLens 2 headsets, enabling multiple trainees to communicate by determining their relative positions. Another planned improvement is refining the UAV flight simulation so that the drone follows the headset user while performing evasive maneuvers, such as avoiding incoming fire when the user aims a weapon at it. Additionally, various training scenarios could be designed, incorporating a wider range of drone models. A UI should also be added to enable scenario selection, simulation initiation and termination, and performance evaluation. The trainer system is designed in response to the rapidly evolving modern battlefield and the emerging threats posed by continuous technological advancements that soldiers must address. The anticipated outcome is that the final system, built upon this prototype, could serve as a foundation for the development of advanced training solutions. These solutions would enhance the capabilities of future soldiers, equipping them to operate effectively in the face of both present and emerging threats.

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