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European University–Industry Collaboration for Civil Counter-Drone Protection: A Human-Centered, AI-Game-Based Socio-Technical Systems Approach

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ABSTRACT

This paper presents a comprehensive framework for civilian counter-drone (C-UAS) systems, combining AI-based detection, data fusion, and decision-support tools with human-in-the-loop operational concepts. The research emphasizes early-warning and socially acceptable mitigation strategies to protect critical infrastructure and public spaces while adhering to European legal and data protection standards. The project further incorporates gamified, simulation-based training and evaluation approaches to support iterative testing, decision-making under uncertainty, and competence development. In addition, it integrates stakeholder engagement, interdisciplinary student involvement, and European cooperation to ensure both practical applicability and long-term workforce development in the field of civil drone defense.

Keywords: Civil drone defense, Critical Infrastructure Protection (CIP), AI-based drone detection, Student-driven applied research

INTRODUCTION

The rapid proliferation of civilian unmanned aerial vehicles (UAVs) necessitates advanced counter-drone (C-UAS) strategies to protect critical infrastructure, public facilities, and urban areas. Existing counter-UAS approaches often lack the necessary agility, proportionality, and social acceptance required for complex civilian operational environments. This research, therefore, focuses on developing civilian defense architectures that combine AI-based detection, data fusion, and decision support to optimize overall system performance while complying with European legal and data protection standards (Folds et al., 2008).

A central innovation of the project lies in the integration of gamified, simulation-based human-computer interaction concepts with AI-assisted decision support. Gamification is utilized as both a training and an operational tool: structured, game-inspired challenges enable operators to make decisions under time pressure, handle incomplete information, and evaluate alternative mitigation strategies. These gamified environments not only support precise

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threat neutralization using specialized interceptor drones but also facilitate iterative testing, performance feedback, and competence development within representative civilian security contexts.

This human-in-the-loop approach explicitly considers the characteristics of the civilian user group and the operational context while simultaneously aiming to reduce life-cycle costs and system complexity (Booher and Minninger, 2003). Furthermore, the project integrates interdisciplinary student participation, stakeholder engagement, and European cooperation to ensure practical applicability, knowledge exchange, and long-term professional development in the field of civilian drone defense. By embedding technological innovations within a legally compliant, socially accepted, and gamification-supported education and training framework, this research contributes to the sustainable advancement of civilian counter-drone systems.

Figure 1: 2CIDERS project logo.

STATE OF ART AND RESEARCH LANDSCAPE

Most counter-UAS solutions were designed for military or law-enforcement use, combining radar, RF, acoustic, and electro-optical sensing with disruption or interception measures (Kang et al., 2020; Poppinga, Anderson and Amendola, 2025).

Civil deployment is harder: in cluttered urban airspace, small and increasingly autonomous drones are difficult to detect and identify reliably, so multi-sensor fusion and AI-based classification remain central research challenges (Semenyuk et al., 2025; Poppinga, Anderson and Amendola, 2025).

Beyond technology, civilian operations face fragmented responsibilities and tight legal constraints on spectrum interference, data processing, and intervention rights (European Commission, 2019; European Commission, 2023).

This leaves clear civilian research gaps: proportionate and publicly acceptable protection concepts for public spaces and critical infrastructure, including context-aware risk assessment, decision support, and training/simulation that explicitly integrates human and organisational factors (Clothier et al., 2015; European Commission, 2023).

The proposed work places emphasis on civilian protection and the role of civilian actors as "defenders" by integrating early warning, accountable decision support, and forms of active, proportionate defence.

LEGAL, ETHICAL AND SOCIAL FRAMEWORK CONDITIONS

The Civil Defense project follows European regulations on unmanned aircraft systems and data protection (European Commission, 2021). Ethical guidelines emphasize human oversight, proportionality, and the separation of civil and military applications (Floridi et al., 2018). Social acceptance is promoted through transparency and stakeholder inclusion (Stilgoe et al., 2013). This ensures responsible innovation in the field of civil protection.

PROJECT OBJECTIVE AND STRATEGIC VISION

Short- and Long-Term Project Goals

The project aims to establish a European university–industry network for civilian drone defence and to prepare funding applications within programmes such as COST or Erasmus+. In the long term, it seeks to develop an AI-based civilian drone protection system for early threat detection, complemented by simulation and training formats to strengthen civil defence skills (Bundestag, 2024; BMBF, 2024).

Contribution to Public Safety

By addressing drone-related risks to public spaces, critical infrastructure and emergency operations, the project enhances civilian safety through a strictly non-military approach, focusing on preventive measures and practical response capabilities (European Commission, 2023).

Promotion of European Innovation

The project strengthens Europe's innovation capacity in civilian security through close university–industry cooperation, interdisciplinary knowledge transfer and active student involvement in international development processes (European Research Executive Agency, 2025).

Sustainability and Scaling Approach

Designed for long-term sustainability and European scalability, the project relies on modular and transferable structures while integrating ethics, data protection and transparency, clearly distinguishing civilian from military applications (Federal Ministry of Education and Research (BMBF), 2025).

PROJECT STRUCTURE, PHASING MODEL AND ORGANIZATION

The Civil Defense project follows a structured, multi-phase approach to ensure the systematic and transparent preparation of a civil research and funding proposal in the field of population protection. The focus lies on the conceptual, organizational, and content-related development of an application framework rather than on technical system implementation.

The project is organized into consecutive phases, beginning with an initialization and planning phase in which objectives, roles, timelines, and

the basic structure of the application document are defined. This is followed by a research and preparatory phase that combines literature analysis with targeted stakeholder engagement involving political actors, industry partners, and academic institutions across Europe, supported by a concise project pitch.

Subsequently, the application development phase consolidates research results and stakeholder feedback into a coherent proposal document, ensuring consistency and compliance through continuous internal coordination and supervision. The project concludes with a finalization and quality assurance phase, including formal review, revisions, and documentation of outcomes. Overall project management is ensured through clear leadership, defined milestones, and continuous review processes to maintain transparency and quality throughout the project lifecycle.

EUROPEAN COOPERATION AND PARTNER NETWORK

Stakeholders From Academia, Industry and Politics

The development of a civil drone defence system requires close European cooperation between academia, industry and politics. Research institutions provide scientific expertise and experience in the European Research area, while industry partners take care of technical implementation and application transfer (Council of the European Union, 2023; European Commission, 2023a). Political actors create the legal framework and promote networking through European programmes (European Parliament, 2024).

Distribution of Roles and Cooperation Models

The distribution of roles is based on established European cooperation models. Scientific partners are responsible for research and evaluation, while industrial partners are responsible for development and integration. Public institutions support coordination and funding, particularly within the framework of e.g. Horizon Europe (European Commission, 2023b).

International Coordination and Harmonisation

International coordination serves to pool expertise and develop common standards. The EU supports transnational cooperation through targeted funding and coordination measures, including via CORDIS and the Joint Research Centre (CORDIS, 2022; European Commission, 2023c).

Long-Term Network Building

The aim is to establish a sustainable European network. Long-term cooperation promotes knowledge exchange, follow-up projects and professional development. Clear governance structures ensure effectiveness beyond the project period (Council of the European Union, 2023).

Integrated Framework for Civilian Drone Defense: AI, VR, and Gamification

"The escalating complexity of civilian drone threats necessitates a multidimensional response that bridges the gap between automated detection and human intervention (Chen und Wang, 2021). To address these challenges, our research proposes a framework that utilizes Artificial Intelligence (AI) for operational efficiency, Virtual Reality (VR) for immersive visualization (Müller und Schmidt, 2023), and Gamification for cognitive load management and performance optimization (Al-Sabbagh et al., 2022; Kaufman und Sauvé, 2020)."

AI-Driven Detection and Autonomous Mitigation

In modern civilian drone defense, AI serves as the backbone of the "system-of-systems". High-fidelity sensor fusion—combining radar, radio frequency (RF), and electro-optical (EO) data—is processed via neural networks to ensure reliable classification (Kaur and Singh, 2022). Beyond detection, AI is increasingly used for autonomous navigation and swarm coordination in interceptor drones, enabling the system to adapt to evasive maneuvers or frequency-hopping tactics in real-time (Tardioli and Villani, 2023).

VR-Enhanced Visualization and Remote Operation

For the actual defense phase, Virtual Reality (VR) provides an essential interface for the operator. By projecting real-time sensor data into a 3D "Digital Twin" of the urban environment, VR allows personnel to visualize the airspace more intuitively than traditional 2D monitors (Liu, Yan and Zhao, 2024).

Operational Value: Operators can pilot interceptor drones or deploy electronic countermeasures within a virtual overlay of the physical world, enhancing spatial awareness and identification precision at night or over long distances (Bende, 2023).

Tactical Advantage: VR environments allow for "risk-free" real-time engagement, where complex data streams are rendered as manageable 3D objects, reducing the cognitive burden during high-stress neutralization tasks (Endsley, 2023).

Gamification in Training and Decision Support

The project integrates gamification not merely as a learning tool, but as a core component of the operational architecture. In the field of Human Factors and Ergonomics (HFE), this approach leverages:

Simulation-Based Training: VR-based simulations reproduce realistic threat scenarios, such as drone swarms in crowded urban areas, allowing operators to develop competencies without risk to physical infrastructure (Pasinato, 2022).

Gamified Decision Support: During active defense, structured, game-inspired challenges and immediate performance feedback help operators make rapid, proportional decisions under time pressure (Gleasure and Morgan, 2020).

Competence Development: Iterative testing in gamified environments provides measurable data on operator reaction times and decision accuracy, ensuring long-term skill retention and professional development (Humphreys and Gerson, 2021).

By embedding these technological innovations into a legally compliant and socially accepted framework, this research contributes to a sustainable advancement in civilian counter-UAS strategies, prioritizing human-in-the-loop efficiency within complex urban environments.

Student Involvement and Qualification Aspects

The structured involvement of students is a core element of the 2CIDERS project. Students are systematically integrated into the research and innovation process and contribute to qualification, applied research, and sustainable workforce development in the field of civil drone defense (Civil Defense) (European Commission, 2020). Training activities are primarily implemented through gamified, simulation-based challenge formats addressing representative civilian security contexts.

Interdisciplinary Student Teams

The project operates with interdisciplinary student teams from engineering, computer science, media, and economics (OECD, 2018). Within simulation environments, students assume defined functional roles and collaborate on structured challenge tasks. Gamified competitive and cooperative formats are used to organize problem-solving processes and to compare alternative solution approaches under predefined constraints.

Practice-Oriented Education and Competence Development

Qualification is achieved through serious game–based approaches incorporating iterative decision-making, time pressure, and incomplete information (Kolb, 1984). Students develop and test solution strategies across successive scenarios and receive structured performance feedback. Gamification is applied as a didactic structuring method to support experiential learning and comparability of outcomes, not as entertainment. Legal compliance, data protection, and societal acceptance form mandatory evaluation criteria.

Integration of Education, Research, and European Networks

The 2CIDERS project links academic education with applied research within a European cooperation framework. Students contribute to the refinement of simulation and challenge mechanisms and participate in COST networking activities, supporting the exchange of established practices in simulation- and game-based learning for civilian security contexts (COST Association, 2023).

Contribution to Workforce Development

By combining technical training, interdisciplinary collaboration, and methodologically grounded gamified simulation formats, the project supports the development of competencies relevant to civil security authorities, industry, and research institutions (European Commission, 2020).

FINANCING, SUSTAINABILITY AND OUTLOOK

Funding Strategy

The project strategically aligns with Horizon Europe (Cluster 3), specifically the "Fighting Crime and Terrorism" destination. As stipulated in the Project Charter, the current phase was strictly limited to administrative preparation, necessitating a clear delineation from technical implementation tasks. A consortium is currently finalizing the "Research and Innovation Actions" (RIA) application to secure funding for the subsequent development phase.

Sustainability and Competence Building

To ensure long-term impact, a "Civil Drone Competence Hub" will be established. This measure directly addresses the Drone Strategy 2.0 requirement for a network of civil defense testing centers to facilitate cross-sectoral knowledge exchange. Integrating this hub into the university curriculum ensures essential skills building and the continuous validation of theoretical concepts by future student cohorts.

European Added Value

The project bridges a critical regulatory gap regarding non-cooperative civilian drones, as identified by the European Commission. By prioritizing a "Safety by Design" methodology over kinetic military solutions, the project supports EU technological sovereignty. The resulting framework for protecting critical infrastructure (KRITIS) adheres to European ethical standards, reducing dependency on non-European technologies.

Outlook

Upon finalization of the application documents in January 2026 (Milestone M5), the project will transition into the acquisition phase. The roadmap prioritizes the establishment of a "Living Lab" for real-world validation. This marks the strategic shift to technical prototyping, aiming to deploy a scalable, AI-supported counter-measure system as a standard for civilian defense.

CONCLUSION

The Civil Defense initiative provides a structured, civilian-centered approach to drone defense, demonstrating how AI, human systems integration, and stakeholder collaboration can enhance safety, operational effectiveness, and societal acceptance. By prioritizing proportionality, transparency, and legal compliance, the project establishes a scalable model for protecting critical

infrastructure and public areas, while fostering sustainable knowledge transfer, European cooperation, and the development of future professionals in civil security technologies.

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