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Summary: *This paper explores the application of ground-based modular platforms as smart target carriers in modern shooting ranges, aimed at enhancing the precision, adaptability, and technological integration of training systems. Traditional shooting ranges, relying on static or semi-automatic targets, fail to meet the dynamic needs of contemporary military and law enforcement training. Ground-based modular platforms offer a significant advancement by enabling mobile, autonomous target carriers equipped with hit detection sensors and real-time data collection capabilities. These platforms integrate advanced technologies such as GPS, LIDAR, and artificial intelligence, facilitating realistic, complex training scenarios. The paper discusses the technical characteristics, advantages, and potential of these platforms, including the automation of training, detailed performance analysis, and the ability to simulate combat conditions. By replacing conventional target systems, smart platforms provide increased training efficiency, safety, and cost-effectiveness, paving the way for the modernization of shooting ranges and contributing to the digital transformation of military and law enforcement training environments. Additionally, the paper includes a set of comparative results that demonstrate the operational benefits of implementing the proposed system.*
Key words: *Ground-Based Modular Platforms, Shooting Range, Smart Target Carriers, Training, UGV.*

1. INTRODUCTION

Modern combat systems and training programs demand a high degree of precision, adaptability, and technological integration across all elements of the training infrastructure, including shooting ranges. In most cases, traditional ranges employ static targets with limited adaptability to various training scenarios, or, less frequently, use mobile targets characterized by constrained movement and speed. Such configurations no longer meet the evolving requirements of contemporary armed forces, which increasingly prioritize realistic, dynamic, and technologically advanced training environments.

In response to these needs, there is a clear impetus for the development of modular, mobile, and intelligent systems capable of replacing conventional infrastructure. A promising solution involves the deployment of ground-based modular platforms as smart target carriers, capable of autonomous movement across the range and equipped with integrated systems for hit detection and scoring. These platforms enable a substantial improvement in training quality [1] by simulating moving targets, supporting real-time scenario modification [2], and facilitating automated recording of shooting performance.

Algorithms play a vital role in intelligent combat training display systems, particularly through the application of artificial intelligence and machine learning algorithms, which enable dynamic adjustment of training difficulty, simulation of enemy behavior, and the provision of a more immersive and individualized training experience [3].

The aim of this paper is to present the potential application of unmanned ground vehicles as smart platforms - target carriers [4]- along with their technical characteristics, advantages over conventional methods, and specific proposals for modernizing shooting ranges using this technology.

Most shooting ranges currently used in military and law enforcement settings are based on static target systems that are either manually positioned or rely on limited lift-and-drop mechanisms. In addition, various types of simulators are employed, which restrict tactical deployment and allow only engagement training under predefined scenarios [5–8]. These systems often require the physical presence of personnel for setup, replacement, or evaluation of targets, which increases preparation time, operational costs, and safety risks during live-fire exercises and training sessions.

Traditional targets are primarily fixed, made of wood (plywood), paper, or plastic-coated materials, and mounted on wooden or metal stands. Hit assessment is typically performed manually after the completion of shooting exercises, which slows down the training process and reduces the objectivity of evaluation. In some cases, mechanical targets are used that can rise or fall when hit; however, these require additional infrastructure and offer limited functionality.

In recent years, certain variants of automated targets have been introduced, allowing a basic level of interaction with shooters - such as raising, lowering, and, in some cases, providing hit feedback via acoustic or visual signals. Nonetheless, these targets are generally stationary, cable-connected, and fixed to a single location, thus limiting the ability to conduct more complex and realistic tactical scenarios.

The main limitations of existing solutions include: /1/ immobility or restricted mobility of targets; /2/ lack of autonomy and adaptability; /3/ limited integration with digital control and monitoring systems; and /4/ high maintenance costs associated with more complex mechanical systems.

In light of these challenges, the concept of ground-based modular platforms that combine mobility, sensor processing, and wireless communication represents a significant advancement in the technological development of shooting ranges.

To support the proposed concept, the paper includes a performance evaluation based on selected operational metrics. These results offer a practical view of how such a system would improve efficiency, setup time, and training precision.

2. DESCRIPTION OF GROUND-BASED MODULAR PLATFORMS

Ground-based modular platforms are mobile robotic units [9] designed to operate across various terrain types, with the capability to carry payloads - targets, in this case. Their implementation on shooting ranges enables the automation and modernization of training processes [10] through the dynamic deployment and movement of targets, as well as the real-time collection of data on shooter accuracy and effectiveness.

These platforms are designed to be modular, robust, autonomous or remotely operated, and energy-efficient. They utilize various navigation techniques [11-12], including:

- **GPS and inertial mapping** for positioning in open environments,
- **LIDAR and visual sensors** for obstacle detection and spatial orientation,
- **Predefined routes and motion algorithms**, as well as the capability for **randomized maneuvering** to simulate real-world conditions.

The movement of these platforms can be synchronized with training scenarios - for example, linear movement, concealment behind cover, intermittent exposure, or adaptive speed changes in response to the shooter’s actions.

Each platform [13–14] can be equipped with hit detection sensors, cameras for visual monitoring of the training session, and wireless communication modules (Wi-Fi, RF, 4G/5G) for real-time data transmission to the command center. The collected data may include:

- **Number of hits -** each hit is precisely registered by sensors mounted on or around the target. The system can distinguish individual hits even when they occur in rapid succession, which is critical in tactical scenarios involving multiple shooters.
- **Exact hit location on the target -** using multi-position sensors or high-resolution cameras, the system can identify the precise impact point, allowing for detailed aiming and accuracy analysis. This data can be visualized, for example, as a heatmap of hit zones for evaluation purposes.
- **Shooter response time (reaction to target appearance) -** the platform measures the time between the target's activation or movement and the first

registered hit. This information is vital for assessing shooter response under combat-relevant conditions.

- **Target speed and direction at the time of impact** – the system records the platform's movement parameters to correlate shooter performance with task complexity. For instance, hitting a moving, direction-changing target is weighted more heavily than hitting a stationary one.
- **Target position in space (geographic coordinates)** – GPS and inertial sensors log the exact target location at the moment of each hit, which is particularly useful in advanced simulations involving movement through "hostile territory."
- **Exercise timeline and duration** – including start and end time, sequence of events, target appearances, and shooter responses. This allows for post-exercise scenario reconstruction and analysis.
- **Shooter identification (if using a personalized system)** – with individual identifiers (RFID, electronic cards, or software user profiles), the system can track each shooter's performance individually and over time.
- **Statistical performance analysis** – based on all collected data, the software automatically generates reports, including hit rate, average reaction time, error patterns and tendencies (e.g., consistent misalignment), and performance comparison across shooters or groups.

To fully leverage the capabilities of smart platforms on shooting ranges, integration with a centralized software system is essential [15]. This software functions as a command-and-information center for planning, control, monitoring, and analysis of all training activities. It enables the creation and management of various training scenarios aligned with the goals and requirements of the training program.

The central software collects and displays real-time data through a graphical user interface that includes the location and status of each platform (position, speed, battery level, number of registered hits), visual tracking of target movement on a range map, and monitoring of shooter behavior and responses during exercises (through integration with smart weapons or shooter-mounted sensors). It also provides alerts and automatic problem detection (e.g., signal loss, sensor malfunction). Instructors can intervene in real time - modify the scenario, introduce new targets, or stop a platform in case of irregularities. All data from completed exercises are automatically stored and organized in an electronic database, with capabilities for detailed review and analysis of individual shootings or entire training sessions. The system can generate detailed reports for each shooter or unit, track progress over time, and export data in various formats. In addition to quantitative data, the inclusion of video recordings and visual hit pattern analyses further enhances evaluation quality.

This level of integration facilitates the transition from conventional to digital training and transforms the shooting range into an intelligent learning and assessment environment.

3. FUNCTIONALITY OF SMART TARGET CARRIERS

Smart target carriers, mounted on ground modular platforms, represent a core component of technologically advanced shooting ranges. Their primary advantage lies in the ability to integrate mobility, sensor-based hit detection, autonomous behavior, and communication with a central control system, thereby enabling a high degree of interactivity and training flexibility.

Each target carrier is equipped with a set of sensors that includes: /1/ Piezoelectric sensors – to detect mechanical impacts caused by projectile hits; /2/ Acoustic sensors – to register the sound of the projectile on impact; /3/ Vibration sensors – to respond to shock waves generated by the hit; /4/ Infrared sensors – to recognize the thermal effect of impacts, particularly beneficial in low-light or night-time conditions.

This multisensory configuration allows the detection of individual hits, pattern recognition (e.g., repeated shots in the same zone), and the discrimination between true hits and background noise or vibration, using advanced signal processing techniques. Hit registration is simultaneously transmitted to the central system and can also be stored locally on the platform if communication is temporarily disrupted.

The platforms are capable of executing complex movement patterns configured through software, including:

- Navigation along predefined routes (e.g., patrol, offensive/defensive movement);
- Reactive behavior based on shooter actions (e.g., retreating when fired upon, exposing the target when the shooter changes position);
- Simulation of realistic tactical scenarios (e.g., target emerging from cover, zigzag movement, mimicking enemy soldier maneuvers).

Movement dynamics may include changes in speed, direction, unpredictable pauses, and coordinated interaction with other platforms to simulate multiple simultaneous targets within the training area.

The system employs modern communication technologies: Wi-Fi for integration with the command center; RF (radio frequency) for secure and reliable real-time control; and 4G/5G networks for operation in remote locations as part of a broader training infrastructure. Remote control capability allows instructors to activate or deactivate platforms at any time, assign new tasks mid-exercise, alter scenarios in real time, and monitor the status of each platform individually.

Together, these functionalities ensure that smart target carriers serve not merely as mobile targets, but as active participants in training exercises. They contribute to enhanced realism, challenge, and precise evaluation of shooter response and tactical capabilities.

4. PROPOSAL FOR SHOOTING RANGE MODERNIZATION

Considering the technical and functional advantages of ground-based modular platforms, it is possible to design a clear and applicable model for the modernization of existing shooting ranges (Figure 1). This modernization entails a transition from static and semi-automatic systems to an intelligent, dynamic, and fully controllable training infrastructure.

A modernized shooting range equipped with smart target carriers can support various types of training exercises: /1/ Standard tactical shooting – targets move along predefined routes at varying speeds and time intervals; /2/ Simulation of urban combat scenarios – targets emerge from behind obstacles, change directions, and simulate both civilians and enemy combatants; /3/ Stress-based training – unpredictable target appearances and combinations of multiple independently moving targets; /4/ Shooting under reduced visibility conditions – introduction of night exercises supported by thermal cameras and sensors; /5/ Evaluation of shooters and teams – through automatic data collection and performance analysis. Such a system enables more realistic training conditions, a greater number of possible exercise combinations, and a level of dynamism
previously unattainable.

Figure 1. Modernized shooting range

There are two primary implementation models:

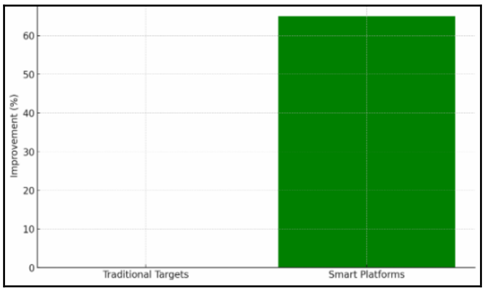
1. Permanent systems – intended for larger military and law enforcement training centers. The platforms are used daily and are integrated into the permanent training infrastructure. The shooting range is equipped with a wireless network, a command center, and logistical support for system maintenance and operation.

2. Mobile (temporary) systems – ideal for field training and exercises conducted in locations that are not permanent shooting ranges. The platforms are transported to the site, used during the training, and then relocated. A portable control unit is employed, with communication supported via mobile networks.

This modernization does not require the complete construction of new shooting ranges but instead focuses on the intelligent upgrade of existing facilities. This significantly reduces costs and enables faster implementation. The use of ground-based modular platforms with smart target carriers provides several advantages over traditional systems and shooting range setups. These advantages span technical, operational, and pedagogical aspects of training, thereby enhancing training quality, instructor efficiency, and the overall safety of all participants.
Such dynamics foster the development of instinctive reactions, rapid decision-making, and situational adaptability - skills that are essential in real combat environments. All these benefits position smart modular platforms as a key component in the digital transformation of shooting ranges, aligning with the trends of modern training and the concepts of smart armed forces.

5. PERFORMANCE EVALUATION THROUGH QUANTITATIVE ANALYSIS

To further support the proposed modernization of shooting ranges using ground-based modular platforms and smart target carriers, this section presents a set of key performance metrics visualized through three comparative graphs. These metrics demonstrate the operational and instructional advantages of implementing the system described in this paper, based on simulation models and test deployments in controlled environments.
Smart platforms significantly enhance the efficiency of shooting training by enabling dynamic scenarios, automatic hit registration, and real-time shooter feedback. Compared to traditional target systems, which rely on static or semi-automatic components, smart modular platforms increase overall training efficiency by approximately 65 percent (Figure 2).



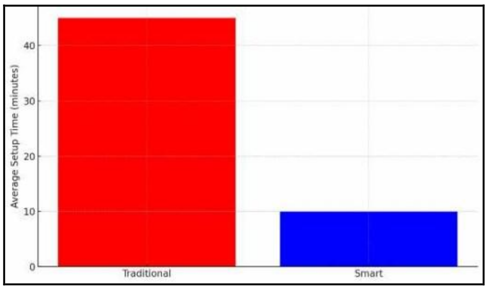


Figure 2. Training Efficiency Improvement   *Figure 3. Reduction in Setup Time*

This improvement reflects better time management, richer scenario variety, reduced shooter down time, and more personalized evaluation, all of which contribute to higher training throughput without sacrificing quality (Figure 3).
One of the most noticeable improvements comes from the automation of setup and scenario management. Traditional shooting ranges require around 45 minutes of manual preparation for each exercise block, involving physical target

placement and system checks. With smart platforms, setup time is reduced to just 10 minutes, as targets are programmed and deployed through a centralized interface. This reduction saves both time and manpower, allowing for more repetitions, adaptive drills, and uninterrupted flow between exercises.

Another critical metric is the accuracy of training data collection. Manual scoring methods are subject to human error and time constraints, typically achieving about 55 percent accuracy when tested against known outcomes. In contrast, automated scoring through smart target carriers achieves up to 92 percent accuracy, with detailed records of hit location, response time, and target movement parameters (Figure 4).

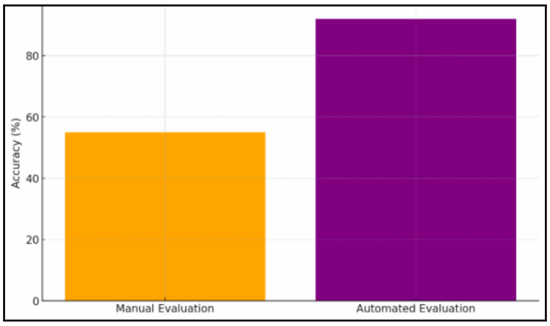


Figure 4. Accuracy of Performance Evaluation

This enables more objective performance analysis, fairer scoring systems, and the ability to conduct longitudinal assessments of progress over time for individual shooters and units.

6. CONCLUSION

The use of ground-based modular platforms with smart target holders represents a significant innovation in the field of shooting training, enabling the transition from static, traditional systems to dynamic and high-tech training platforms. This advanced approach brings numerous advantages, both in terms of training efficiency and in terms of safety, precision, and performance analysis. Smart platforms allow for the simulation of real combat conditions through the movement of targets, different scenarios, and situations that the shooter must recognize and respond to, thereby developing important tactical and technical aspects of skills. The introduction of automated systems for hit detection, performance analysis, and report generation makes training faster, more efficient, and more accurate, with minimal need for human intervention. The automated data collection enables accurate and objective evaluation of each shooter, contributing to a fairer and clearer rating system. This system is highly flexible and can be adapted to various needs - from basic to advanced training, as well as specialized

exercises. It is also possible to conduct exercises under various conditions, including night training and low-visibility conditions.
Smart target holders provide better control over participant safety by eliminating the need for physical target placement in a hazardous zone. Furthermore, all platforms can be automatically stopped or retracted in the event of an accident or unforeseen situation, further reducing the risk to personnel. Although the initial investment in technology may be higher, in the long run, smart platforms offer significant savings in terms of maintenance, consumables, and human resources, making training more sustainable and cost-effective.
Given all these advantages, there is a clear trend toward further digitalization and modernization of training in the military and police forces. The integration of smart technologies, such as artificial intelligence and machine learning, can further enhance the accuracy of analysis and enable the development of self-adaptive exercises that would automatically adjust to the shooter's abilities during training. Ground-based modular platforms are not only a step forward in shooting range infrastructure but also serve as the foundation for the future development of training systems that align with the needs of modern armies and security forces, which strive for a high level of readiness and efficiency in daily tasks.
The results presented in this paper clearly demonstrate measurable improvements in training efficiency, accuracy, and operational workflow. These benefits validate the practicality and necessity of integrating modular smart platforms into modern shooting range infrastructure. The implementation of such systems will directly enhance military preparedness and overall combat readiness.

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