Future Combat Training System – improved live fire training by digitalization

Sebastian Hess	Frank Jaspers	Thierry Fredrich
Fraunhofer Institute for High-Speed Dynamics, EMI	Technical Test Center for Weapons and Ammunition	Fraunhofer Institute for High-Speed Dynamics, EMI
Freiburg, Germany	Meppen, Germany	Freiburg, Germany
Sebastian.Hess@emi.fraunhofer.de	FrankJaspers@bundeswehr.org	Thierry.Fredrich@emi.fraunhofer.de

ABSTRACT

Live fire exercises should prepare soldiers for their missions as realistically as possible. "Train as you fight" represents the ideal conception for military exercises. Consequently, the correct tactical behavior in the field requires complementation by live fire as an essential element. On the other hand, there are restrictions for live firing resulting from the efforts to ensure safety of trainees, trainers and third parties as well as the protection and preservation of equipment. In particular, the realistic representation of intelligent enemy forces is a major gap that can be closed by the increasing availability of robotic systems that can be used to represent people in dangerous areas.
The integration of robotic systems (and other modern techniques such as XR) into established range systems and use them together with other widely used technologies like pop-up targets, poses major challenges since the existing structures often lack the relevant prerequisites.
This paper provides a requirement analysis for a digitally networked training environment comprising modern training resources and established techniques. Further, we outline how a training system might look like and how various possible use cases fit into the connected environment. We show how digitalization assists during training execution including evaluation and after-action review going beyond the pure "train as you fight".
This paper highlights technical requirements for a future combat training system and presents a resulting system architecture. We outline the realization of the Future Combat Training System theoretically and present already implemented functionalities with practical examples.

ABOUT THE AUTHORS

Sebastian Hess studied mechatronics at Ulm University of Applied Sciences and graduated in 2010. In his diploma thesis, he dealt with the analysis and characterization of a novel high-g acceleration sensor design at Fraunhofer EMI. In his subsequent career steps at Fraunhofer EMI he managed various projects in the field of fuze technology and the development of customized testing facilities for investigations under high, dynamic mechanical loads. Since 2007, he is head of the Ballistronics working group, which focuses on fuze technology, the development of test and measurement systems for high-dynamic investigations, and digitization in the military training environment.

Frank Jaspers learned the profession of communications electronics engineer at the Technical Test Center for Weapon and Ammunitions in Meppen / Germany. After working in the areas of telecommunications technology and ergonomics as well as software ergonomics, he built up the AR, VR and MR department and is now head of that department. With the establishment of the department, he can pursue his passion. The department carries out practical R&D studies to create new XR applications. The result is, among other things, an action trainer for the team training of special forces of the German Army or an XR application for visualize virtual units in real terrain for the training of the Joint Fire Support Team. In addition to his role as XR department head, he is project manager for the first digital shooting range for live shootings and also responsible for R&D related to live fire systems.

Dr. Thierry Fredrich trained theoretical physicist providing an integral knowledge of physical principles related to mechanics and electromagnetics. He adds programming skills on multiple abstraction levels (from software to hardware) with relevant experience on High Performance Computing (HPC) on linux clusters. He joined the “Ballistronics”- group at Fraunhofer EMI starting with 2020. His research track features numerous peer-reviewed articles in international scientific journals, contributions to national and international conferences and an educational book-chapter.

Future Combat Training System – improved live fire training by digitalization

Sebastian Hess
Fraunhofer Institute for High-Speed Dynamics, EMI
Freiburg, Germany
Sebastian.Hess@emi.fraunhofer.de

Frank Jaspers
Technical Test Center for Weapons and Ammunition
Meppen, Germany
FrankJaspers@bundeswehr.org

Thierry Fredrich
Fraunhofer Institute for High-Speed Dynamics, EMI
Freiburg, Germany
Thierry.Fredrich@emi.fraunhofer.de

BACKGROUND

"Train as you fight" is the maxim that, in a nutshell, represents the ideal for military exercise. Exercise is existential for the survival and success of our soldiers in the field. In Live Fire Exercises (LFX) it includes tactical behavior and, as an essential element, live firing.
For safety reasons, the requirement to do live firing results in specific requirements for the organization, structure and equipment of shooting ranges and military training areas. These boundary conditions sometimes set narrow limits to the other ideal - the best possible training of tactical behavior. The annual report of the German Parliamentary Commissioner for the Armed Forces states, "The increase in safety and the improvement of LFX have a prominent function, especially in the context of the regained importance of national and alliance defense." (Defense Commissioners, Germany. 2021).

INTRODUCTION

In combat training, soldiers should be prepared for missions as realistically as possible. For this purpose, they practice live firing exercises at military training ranges. The presentation of targets, often implemented using pop-up targets, has so far been mostly static and is often still analog controlled. On one hand this leads to fairly inflexible, little interactive exercises and on the other hand reduces the flexibility in adapting new scenarios. A dynamic target presentation and intelligent target soldier interaction, which is fully integrated into a digitalized combat training system, promises more complex scenarios for more intensive training to approached the overarching objective "train as you fight".

To achieve this, an analysis by the German Bundeswehr outlines the following requirements for a modern combat exercise system which were incorporated into the work presented below:

- "Flexible, mobile target presentation independent of fixed connections, as well as
- close integration of simulation technology, situational awareness,
- shooting safety systems, and live-fire training."

USE OF COMPONENTS OF THE SHELF

Unlike the conditions on the battlefield, the constraints on the training ranges are far less restrictive. This is mainly due to the fact that the interaction between trainees and opponent in Live Fire Exercises (LFX) is unidirectional – the trainees engage the representation of the enemy with the weapons and weapon systems available to them. Unlike the situation on a real battlefield, this representation poses no direct threat to the trainees. In combat, however, every interaction with the enemy can elicit a reaction that poses a direct threat to oneself and one's forces.

This results in drastically different requirements for the systems, especially regarding aspects such as low signature and robustness. While even minimal signatures can be life-threatening in combat, they play a minor role during training exercises. Conversely, the availability of satellite navigation behaves differently. In operational conditions, one must expect a GNSS-denied environment, while on the training ranges, satellite navigation is generally available.

These differences result in various freedoms. For instance, market-available technologies and components of the shelf ("COTS") can be utilized, even if they have not (yet) experienced military hardening. Since innovation cycles in the industrial sector are significantly shorter than in the military domain, technologies from these areas can be used early on and independently of military development cycles.

A good example of the possibilities that arise from this are autonomous infantry robot targets, such as those used by the Bundeswehr Technical Test Center for Weapons and Ammunition (WTD 91), shown in Figure 1. These robots combine various COTS components into a system that generates significant added value during combat training. Even though the integrated COTS LIDAR used for navigation and spatial orientation operates at a wavelength that is invisible to the human eye but is visible with thermal imaging devices. That's why it would not be suitable and realistic for battlefield, especially at night.

Figure 1: Autonomous Infantry Robot Target at WTD 91

SYSTEM CONCEPT

To operate different systems, even from different manufacturers, in a common combat training system and integrate them into a unified control environment, their structure must first be defined. Based on the investigation of the status quo, interviews with operators and users of training ranges, project managers, as well as the insights gained from various workshops and market research, a concept for a future-proof combat training system was developed.

This concept envisions the modular construction of a scalable combat training system in which all components and participants are digitally interconnected. The system offers open interfaces, relies on commercially available communication infrastructure and components, and is open to future manufacturer independent expansions. By that the system can be maintained at the state of the art with moderate effort and is open for integration into a larger, overarching network structure. It comprises the following described components that collectively fulfill the requirements, thereby enabling realistic enemy representation to enhance mission-oriented combat training ("train as you fight"), program-based exercise planning with fixed as well as freely programmable scenarios, and subsequent discussion and evaluation of the training, e.g., within an "after action review."

The five proposed core components of the concept are:

1. **IP-based communication** between all participants / all different LFX components.
2. **Central data management system** (DMS) with open interfaces for heterogeneous target representation and integration of all training participants.

3. **Customized software applications** with access to the data management system.
4. **Networked target representation device** with sensors for trainees, weapons, etc.
5. **Qualified operating and maintenance personnel**.

IP-Based Communication

The established IP protocol family is used for the digital communication of components and/or participants in the combat training system. This allows for a wide variety of compatible, industry-proven solutions. For a broadly and flexible usable solution, a combination of wired and wireless interconnections is proposed allowing incorporation of existing communication infrastructure such as fiber optic networks. Wired networking is used between all components or participants where it does not restrict functionality or mobility, or where existing infrastructure can be utilized. The communication is complemented by wireless networking. The use of commercially available radio networks such as Wi-Fi or 5G is suggested here.

Due to the wide distribution of standard components and their compatibility, the long-term replacement of defective or outdated components is ensured. Likewise, the unified, IP-based communication simplifies the integration of systems. This allows to consolidate communication channels and reduce the number of different communication devices.

Central Data Management System

The IT core of the digital combat training system is a central data management system (DMS). This system enables computer-aided collection, processing, and storage of data relevant to the operation and the use of the training system. The DMS provides all necessary databases, as well as open interfaces for integrating heterogeneous data sources, participants, and systems. The data management system accepts information from various sources, processes them, and makes them available for further use. Applications, software, and integrated systems can access the DMS e.g., to visualize information on the leader of an exercise or to trigger events.

Customized Software Applications

The user interacts with the combat training system and its integrated components and participants through various software applications (e.g. front ends). These are connected to the data management system and exchange information with it. This includes retrieving, processing, evaluating, and displaying information, as well as transmitting data and (control) commands to the combat training system and the integrated devices.

Networked Target Representation Devices

A major motivation for modernizing training facilities on military training ranges is the use of modern target representation devices that enable more intensive training with greater realism. These devices can only fully realize their potential if they are an integral part of the digital combat training system and not a proprietary standalone solution. Therefore, the selected target representation devices must be networked with the data management system and be integrated into the combat training system through appropriate interfaces. Along with the use of networked targets, the capability to collect and utilize information through sensors like GNSS trackers or hit location sensors provides significant added value to a digitized combat training system. This information enables meaningful real-time situation representation and documentation, intelligent, automated, or interactive responses to training scenarios (e.g., by triggering an appropriate enemy reaction), and individual evaluation of trainees.

Qualified Operating and Maintenance Personnel

The drastic increase in the possibilities for designing interactive training scenarios also requires qualified operating personnel capable of utilizing these possibilities. This results in the need to train operating personnel early and qualify them for creating and controlling complex training sequences. Additionally, with the increasing number and complexity of integrated devices, the demand on maintenance personnel also rises.

SYSTEM STRUCTURE

Based on the previously described concept, a potential system structure for a future-proof combat training system was developed. This was then realized as a test system to demonstrate what is technologically feasible and which functions can principally be implemented. It is a form not yet ready for market but is intended to be used very early for gaining insights and making decisions about functionalities. In the following, the system is referred to as the "Future Combat Training System," or "FCTS" for short.

Figure 2 provides a rough overview of the system and communication structure of the FCTS. At the center are the servers on which the DMS is hosted. This, in turn, provides a multitude of services. These include various databases, a geographic information system (GIS), user and rights management as well as various communication servers.

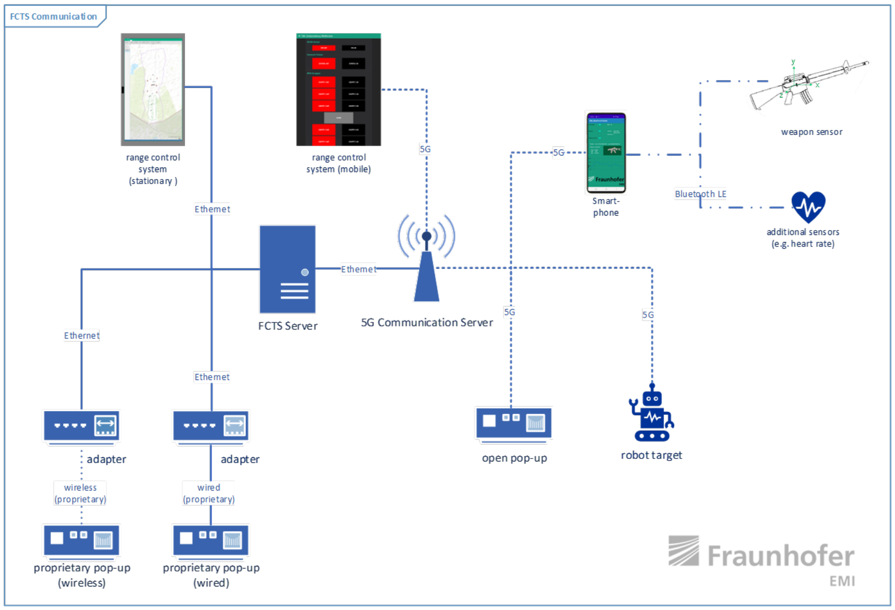

Figure 2: System and communication structure of the FCTS.

This structure roughly divides into the integration of target representation device, integration of the trainees, control devices for exercise and shooting range management, and communication as explained in more detail below.

Integration of the Target Representation Device

The DMS communicates wired and/or wirelessly with the integrated systems to exchange data and commands via unified interfaces. Since there is currently no internationally established standard standardization for such an interface that also takes different device types into account, very few manufactures offer open interfaces. Therefore, we decided to use an adapter solution in our investigations. In this setup, device- or manufacturer-specific adapters sit between the device, particularly target representation devices, and the server, translating the data and commands incoming over the IP connection from the FCTS to the proprietary device interface and vice versa (see Figure 3).

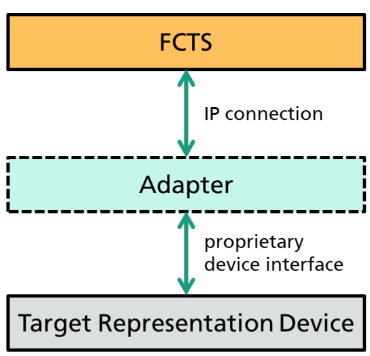

Figure 3: The adapter communicates within the FCTS via an IP connection, translates commands and uses them to address the device connected to it.

Integration of the Trainees

For a comprehensive analysis of the training activity, not only the targets but ideally all persons and devices involved in an exercise should be able to exchange information with the DMS. To integrate the trainees, we also use COTS components, in this case, commercial smartphones running an app that is developed for this purpose. An image of the user interface of this smartphone app is shown in Figure 4. Each trainee is equipped with such a smartphone.

The smartphone fulfills two tasks. Firstly, it works as a blue force tracker providing live individual position information for each participant using its integrated GNSS receiver. Secondly, it acts as a mobile communication node with the capability for short- and long-distance communication.

The smartphone can receive, pre-process, bundle, and forward sensor data from the trainee's immediate environment via short-range communication – such as Bluetooth-LE – and forward them to the DMS via long-distance communication. This allows the collection of individual data from each trainee (e.g., heart rate) and their associated equipment (e.g., orientation of their weapon measured by external sensors).
The use of energy-efficient short-range communication facilitates the development of compact additional sensors with long battery life while the smartphone provides the long-distance communication capability.

Compared to military equipment, commercial smartphones are inexpensive and still highly capable. Their standardized operating system ensures long software lifecycles usually continued on newer devices (with minor adjustments if necessary) allowing a hardware replacement or adaption without impairing the performance of the software. In addition, several smartphone vendors established robust versions of their products. In the current implementation of the FCTS, smartphones operate exclusively as sensor and communication nodes. The use of the smartphones as communication tools between participants is omitted, as the use of communication media available in the field is also part of combat training.

Smartphones can also be used for simple tracking of vehicles and also the soldiers on the shooting range in real-time. A direct integration of vehicles and other equipment with their own device specific interfaces has been initially omitted due to the variety of systems and interfaces but is conceivable in the future.

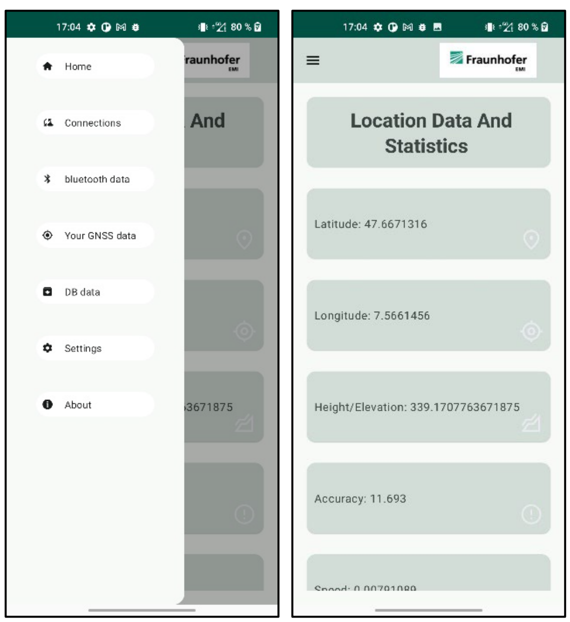

Figure 4: User interface of a smartphone app used for blue force tracking and as sensor node.

Control Devices for Exercise and Shooting Range Management

The FCTS provides two fundamental methods for controlling and operating the integrated target representation devices. Firstly, the automated control of the devices by the FCTS servers based on the behavior of the trainees, predefined timelines, etc. Secondly, manual operation by an operator. The user interfaces have been designed as web applications communicating with the FCTS server via an IP connection. This allows the operator to use a wide variety of devices such as PCs, laptops, or tablets without the need to implement specific solutions for each device class and operating system. Additionally, such a solution does not require the installation of special software on the devices, reducing the effort for software maintenance and upkeep during operation. The performance requirements for the end device are also minimal, as it only needs to display and operate a website.

Communication

The communication of all devices integrated into the FCTS happens IP-based. Ethernet is used for wired communication, while the 5G mobile communication standard is utilized for wireless communication. The mobile network is provided as a stand-alone campus network, allowing the full advantages of the 5G standard (increased data rates, reduced and guaranteed latencies, etc.) to be fully exploited. The use of military communication for communication within the combat training system has been deliberately avoided. From our perspective, the freedoms and possibilities arising from the use of COTS components significantly outweigh the associated limitations. Moreover, the collected data are currently not considered security-critical information – at least in Germany.

UNIFICATION OF THE CONTROL OF TARGET PRESENTATION DEVICES

When considering the functionalities of different types and manufacturers of target presentation devices, it becomes apparent that they differ significantly in some areas but are very similar in others. To design the interfaces for the various systems as generically as possible, we decided to cluster them based on their usage into different device classes. The following clusters were identified as the most important classes for target presentation in infantry training:

- Stationary Targets: Fixed target presentation devices such as pop-up target systems, usually wired and installed in stationary, fortified positions.
- Relocatable Targets: Target presentation devices that can be positioned freely in the field but then are fixed in place, such as radio-controlled pop-up targets.
- Stationary Movable Targets: Target presentation devices that can move along predetermined tracks.
- Self-Moving Targets: Targets that can move independently on the shooting range, e.g., robotic targets.

To address devices within a device class across manufacturers, it must first be determined which functions of the devices should be addressable at all. The focus was on the functions and information necessary for basic control and evaluation, without attempting to capture the peculiarities of individual systems. Instead, as shown in Figure 5, the properties and functionalities of different systems within a device class were compared to identify their intersection.

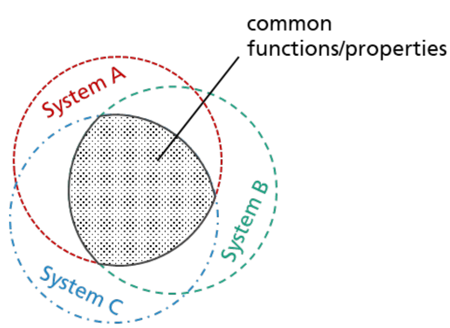

Figure 5: By comparing the properties and functionalities of different devices within a class, their common functions and properties could be identified.

From this intersection, the functions and properties that each device (either physically or via software) must provide were derived. Functionalities common to multiple devices but not necessary for the usability of the device class, as well as individual functionalities of single devices, were excluded. This approach is based on the idea of initially focusing on the basic functionalities in the common control and continuing to rely on the manufacturer's own tools for special functions and very specific settings.

Based on these considerations, appropriate interfaces for selected device classes were implemented and integrated into the FCTS to further investigate them in a practical context.

FIELD TEST

As part of a combat exercise, the integrability of existing shooting range equipment into the implemented FCTS design was evaluated, and the practicality of individual system components was examined in an environment relevant for usage. The aim was, on the one hand, to assess the practicality of the system and, on the other hand, to create a data basis for further investigations.

This field test was conducted on a shooting range at the Wildflecken Training Area (Germany). The exercise focused on infantry training. Therefore, primarily wired pop-up targets were used as stationary targets. In selected areas, these were supplemented by relocatable, battery powered, wirelessly connected pop-up targets (a total of around 120 pop-ups). The control of these targets was managed by the FCTS. To accurately record hit positions, selected targets were supplemented with acoustic hit detection systems ("LOMAH"). The stationary targets were supplemented in the exercise by several autonomous infantry robotic targets. Furthermore, the positions of the members of an infantry squad were tracked via smartphone and recorded in the FCTS. Figure 6 shows the user interface for controlling the pop-up targets on the left and the visualization of the hit detection for a pop-up target on the right.

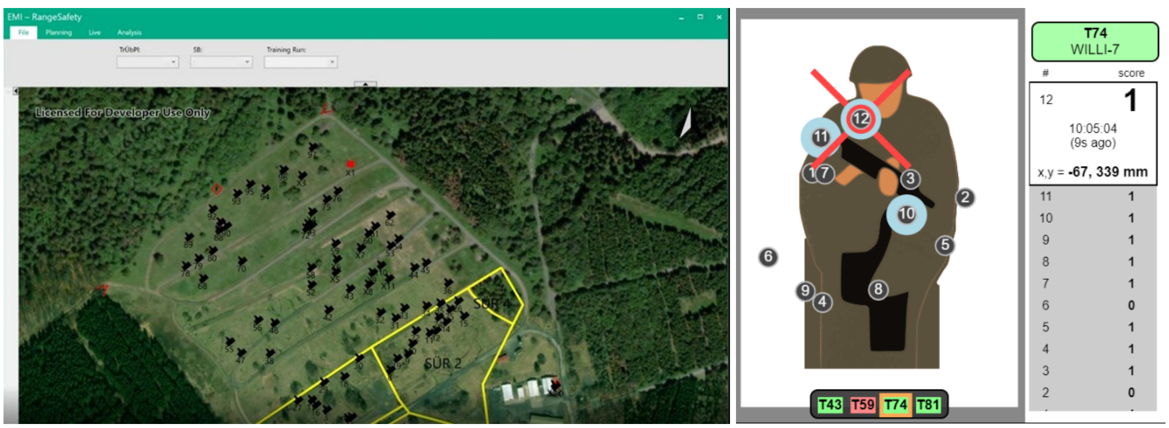

Figure 6: left: user interface for controlling the pop-up targets (exemplary illustration); right: visualization of the hit detection for a pop-up target.

The integration of the target presentation device into the FCTS enables the central collection of a vast amount of information regarding target presentation and engagement. Additionally, it makes accessible and analyzable information that, in many other systems, was partially processed internally but could not be used, or only in a rudimentary way, for a subsequent analysis. Particularly, a uniform, manufacturer-independent evaluation of exercise data is hardly possible in current systems. In the FCTS, these are data are recorded in a time-resolved manner for each exercise run and can thus be analyzed, for example, in the context of an after-action review.

In the following excerpt, the number of hits registered by the integrated stationary and relocatable pop-up target systems was evaluated as an example. These evaluations serve to illustratively demonstrate the new possibilities. The exemplary selected representations do not have any underlying tactical evaluation criteria.

The bar graph in Figure 7 shows the number of hits per target in one exercise run. Targets with fewer than two registered hits are not displayed for the sake of clarity. However, the abstract representation of the hit count chosen here makes the intuitive interpretation of the results and their comparison with the intended exercise goals more difficult.

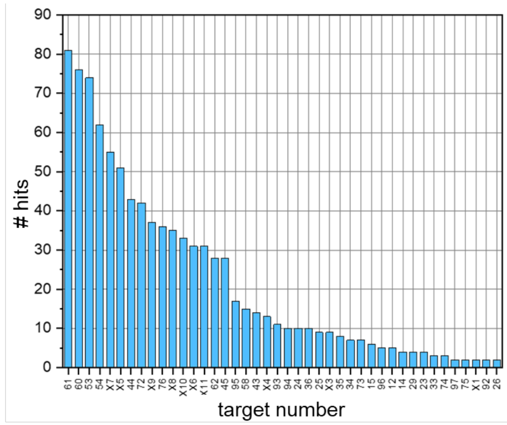

Figure 7: Number of hits per target in one exercise run.

To facilitate the interpretability of the results, the information of the bar chart was enriched with the known information about the geographical position of the individual targets stored in the FCTS database. Figure 8 shows the position of the individual engaged targets overlaid with the individual hit counts, visualized through a heatmap. The number of hits is represented by the color of the areas, ranging from blue (few hits) to red to yellow (many hits). The overlay of the "frequency areas" makes it difficult to distinguish individual targets, but it provides a very good overview of the regional hit distribution.

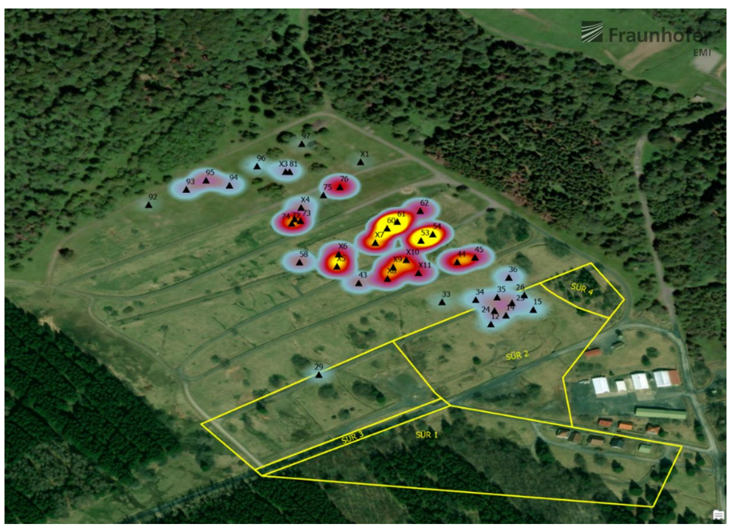

Figure 8: Number of hits per target shown as a heat map. The individual hit count is represented by the color of the areas, ranging from blue (few hits) to red to yellow (many hits)

The integration of a central control and data management system into exercise control allows the collection and evaluation of previously inaccessible information. When all essential information about the individual exercise runs, the shooting range, and the utilized target presentation device is maintained there, individual evaluations, like the ones shown previously, can be automatically generated. These can be used both to compare with the exercise objectives and in the planning of new combat exercises to answer questions such as: "In which area should the existing stationary targets be supplemented with mobile targets to increase the target density?" or "Was the density increased in the correct area?"

In discussions with experienced Bundeswehr trainers, they emphasized the high value of (quantitative) evaluations for qualified training, as it allows for an objective assessment of the exercise's success.

CONCLUSION

This paper explains the concept of a modern combat exercise system and discussed its five core components. From this abstract concept, the system structure of a possible implementation was derived, which was then transferred into a test system for further practical investigations. Using this test environment, referred to as the "Future Combat Training System" (FCTS), initial approaches to integrating different classes of target presentation devices were gathered in a field test.

A significant added value of a digitized combat exercise system results from the collection and use of sensor information during and after an exercise currently not available in Germany. This sensor information enables, for example, a meaningful real-time representation of the situation, its documentation, and an (intelligent) reaction of the target representations to exercise situations (e.g., triggering a context-appropriate enemy reaction). This, combined with the potential arising from the combination of the capabilities and strengths of systems from different manufacturers, promises to further increase the realism of battlefield exercises.

Furthermore, a digital combat exercise system like the FCTS forms the basis for integrating virtual training content via technologies from the fields of LVC (Live, Virtual, Constructive) and AR/MR/VR (Augmented Reality/Mixed Reality/Virtual Reality).

REFERENCES

Defense Commissioners, Germany. (2021) Annual Report 2021 of the Defense Commissioners. Printed Matter 20/900 p. 88.