Swarm View: Situation Awareness of Swarms in Battle Management Systems

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ABSTRACT

The use of multiple Unmanned Aerial Vehicles (UAV) gains in significance. Therefore, the interaction between human and robot and their interaction design become more and more important, especially in military reconnaissance on a battlefield. However, an increasing size of UAV swarm results in many challenges that need to be addressed, e.g. a complex situation with high dynamics increases the demand on a user. In this work, application-oriented options for an ergonomic display of human-swarm interaction were investigated, which focused on swarms in battle management systems. Within a literature survey, potential applications and challenges that may arise when a single operator monitors a large swarm as a highly automated system were identified. Moreover, design guidelines that already exist were determined. Based on these results, four different layouts for the visualization of swarms were prototyped with the objective of obtaining comprehensive situational awareness.

1.0 INTRODUCTION

The position papers on the use of AI (Artificial Intelligence) in the land forces of the German Army [1] outline scenarios for TaUAS (Tactical Unmanned Aerial System) battalions. The planned companies may contain up to four platoons of 5000 TaUAS. These will form different types of swarms depending on the respective payload. For example, the swarm of several hundred sensor UAS can reach a diameter of over two kilometers. In current battle management systems, all units and additional relevant information are displayed in a common situation picture almost in real time. The data is collected from various sensors and sub-systems to present it to the command level in a clear presentation. This allows the tactical leader on the ground or in the vehicle as well as the command level in the headquarters to see the same information on a map. With an additional consideration of swarms of the mentioned size, the situation picture can quickly become complex and overloaded. This currently affects the lower levels, where devices with small display sizes, such as smartphones and tablets, are used. In the future, the challenge will also become relevant for the higher command levels. Due to the high dynamics on the battlefield as well as the area-wide reconnaissance, classical, stationary command posts will no longer be useful. Command posts constitute high-value targets that should move permanently on the battlefield and should be planned redundantly. Therefore, the display size must be considered there as well. A role-based visualization and information fusion can provide initial support in minimizing information overload. Another approach could be a type of swarm visualization that allows to display parameters such as position and behavior of the swarm without unnecessarily crowding the situation image. Both current and future swarm states should be recognizable to achieve an optimal situation awareness [2]. Furthermore, the representation should be suitable for use in a battle management system.

1.1 Literature Survey

A literature survey on possible swarm applications, challenges of swarm interaction, and already existing design guidelines for the visualization was conducted. Reconnaissance was selected as the main application to be investigated. Swarms can cover large areas and are more robust than single reconnaissance drones [3]. In addition, a heterogeneous swarm can provide very different sensor systems. The information obtained can be used directly for marking or tracking targets and to attack enemy sensors or drones. Another possible use case is the formation of flexible communication networks (MANETs) to ensure communication between different tactical units.

A challenge with highly automated systems is that a loss of situational awareness can occur when controlled by a single operator in a supervisory role. Normally the cognitive workload of the operator is rather low, because the unmanned vehicles can handle their mission alone, but in critical situations the cognitive workload increases dramatically and the operator has to intervene suddenly. The human operator often lacks knowledge about automated processes, which can lead to serious operator errors. The large amount of information to display may degrade the human's operator attentional process [4]. In a complex, heterogeneous swarm, the individual systems can behave differently. Furthermore, their sensors, the payload, the main goal of the mission and the geographical situation may differ from one vehicle to another [5]. This may result in confusion of operators and inadequate responses during stressing events. The visualization of swarms is proposed in one or more of the following variants in [6], [7], [8], [9] and [10].

1. *Display of all individual agents (Robot Level)*

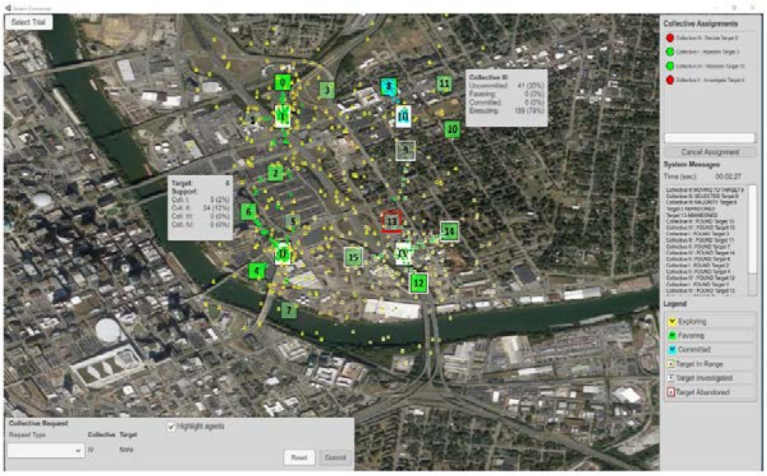

Figure 1-1: Robot level display [7].

2. *Split of the swarm into individual teams (Sub-swarm level)*

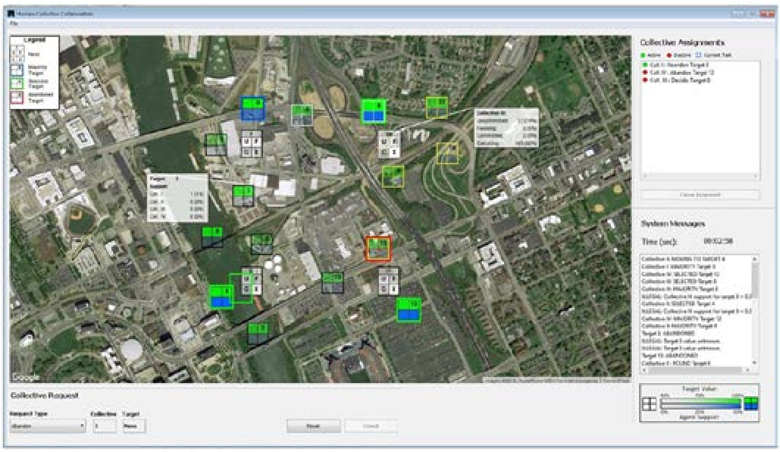

Figure 1-2: Sub-swarm level display [7].

3. *Single representation of the swarm (Swarm Level)*

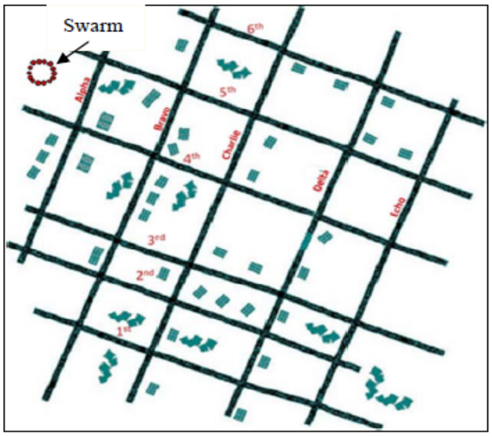

Figure 1-3: Swarm level display [9].

4. *Area based representation (Environment oriented)*

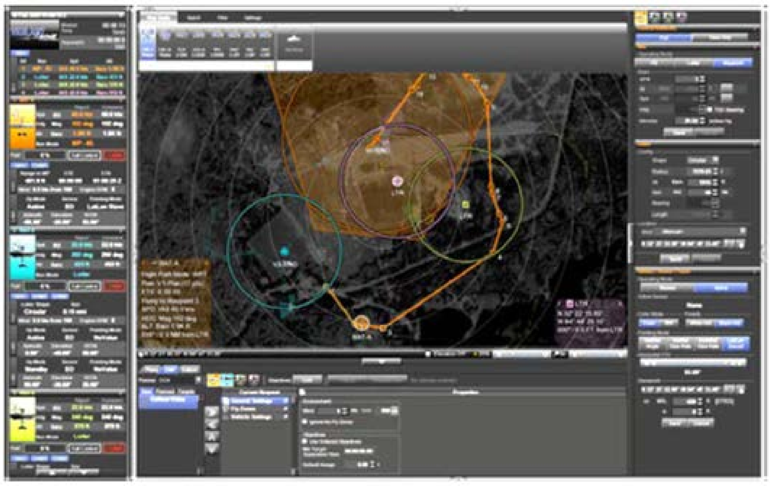

Figure 1-4: Environment oriented display [10].

In addition, it is important to provide the operator with various details about the swarm in order to create a comprehensible automation. The following additional information was identified:

- Map information: Map types, topography, minimap, scale, areas
- Blue/Red Force information: type, size, affiliation, behaviour, direction, goals, POIs
- Task management: Task, sub-task, interaction, planning
- Dialog: Messages, warnings, alarms
- Status of unmanned systems: Range, expansion, position, payload, communication
- Past and expected performance of unmanned systems

2.0 VISUALIZATION CONCEPTS

Based on the collected literature, four layouts for the visualization of swarms were defined. These were implemented in prototypical HMIs. The visualization focused on swarms in battle management systems. The human-machine interaction is implemented via traditional monitor and mouse/keyboard or touch control. First, the four layouts are presented and afterwards different components are explained.

Leader-based representation

A swarm can be divided into different teams. These can be formed e.g. due to specific system capabilities or spatial conditions (see figure 2-1). The visualization is only implemented for the leader robot of a team, but the expansion of a team can be added. Other parameters such as team size, payload or predicted status are displayed as well.

Figure 2-1: Leader-based representation.

Swarm-based representation

A swarm-based display shows the entire swarm as one unit instead of each agent individually (see figure 2-2). The user controls the entire swarm via high-level commands and the swarm organizes itself. It is still be possible to detach individual agents from the swarm or to send individual commands; these can be displayed or enabled separately.

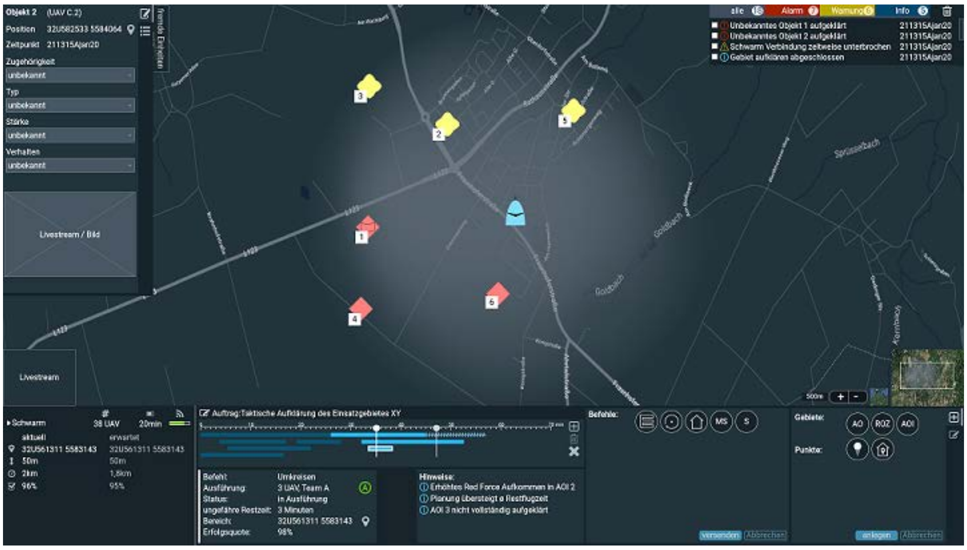

Figure 2-2: Swarm-based representation.

Area-based representation

In the area-based display, the user does not interact directly with the swarm or individual agents, but interacts with the environment (see figure 2-3). For example, the command can be given to reconnoitre a certain area. Based on this, the swarm interprets its new tasks without the user assigning them directly. It is not necessary to know where the swarm is currently located and which tasks it has. Nevertheless, it is still possible to display the position and expansion of the swarm. The system helps to identify missing areas or to comprehend what the swarm is currently doing.

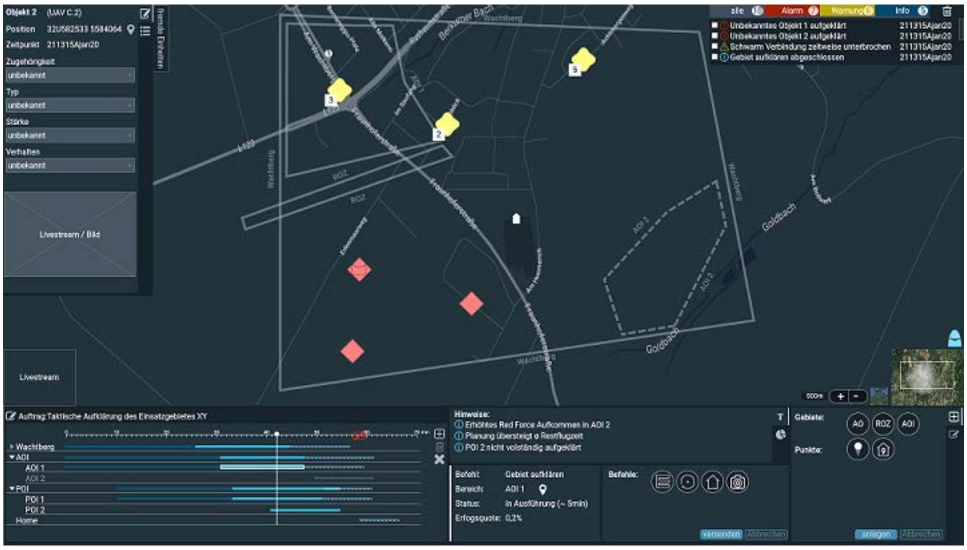

Figure 2-3: Area-based representation.

Zoom-based representation

A zoom-based display shows the amount of units (swarm, sub-swarm, single units) depending on the zoom level (see figure 2-4). The closer the user zooms into the situation image, the more individual units are displayed. If the user zooms out, first the sub-swarm and finally the swarm is displayed as one unit. The user can decide up to which level information should be displayed.

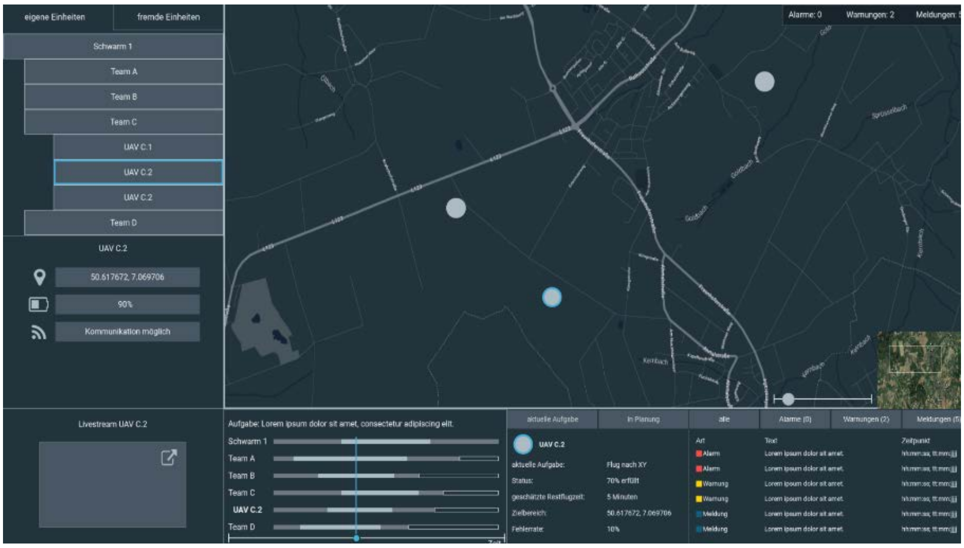

Figure 2-4: Zoom-based representation.

For each of the visualization layouts an assignment of the detailed information took place. Thereby the visualization layouts consist of the following six main components, which are intended to contribute to comprehensive situational awareness (see figure 2-5). Every component was adapted to the respective layout and its purpose.

1. Map (based on Google Maps, 2021): The map is the main part of all visualizations. It is placed in the center and include a zoom in / zoom out function, a mini-map and the possibility to switch between two different map types. Furthermore, Blue and Red Forces with additional information are displayed as well as reconnoitered unknown objects. Areas and POIs are shown optionally.
2. Territory Management: The user can create different areas, e.g. areas of operation (AO) or restricted operation zones (ROZ), or points, e.g. points of interest (POI) or base, and define them as active or planned for mission planning. It is also possible to edit them afterwards.
3. Task Management: The task management is divided into different parts. A timeline with all scheduled, current and completed tasks is displayed, optionally with some more details about a task. Moreover, depending on the layout, the user can plan new tasks for the entire swarm, a sub-team, a single UAV or the environment.
4. Status information + Livestream: Depending on the layout, the status of the swarm or a single UAV is presented. This contains information mentioned above. The display of the current and predicted status was designed to be layout-dependent as well. In addition, the display size of a livestream showing the recording of a selected UAV or a selected area is variably adjustable.
5. Red Force information: All reconnoitered unknown or known objects are not only displayed on the map, but also in a separate list. In that list, it is also possible to classify the unknown objects. An assistance system helps to prioritize all incoming reconnoitered objects in order to make a faster and better decision.
6. Dialog: Within the dialog frame, all incoming alerts, warnings and messages are displayed. The user can choose, whether all or only one category should be shown. The dialog design (alerts/warnings/messages) in the leader-based representation takes place at team level in contrast to the other layouts.

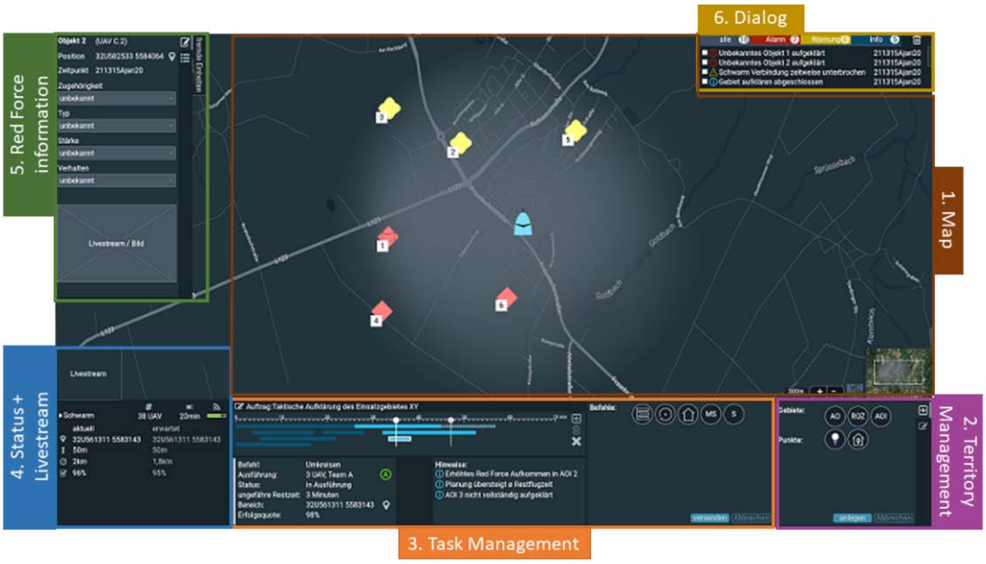

Figure 2-5: Visualization components.

3.0 EVALUATION

An evaluation will be conducted in the form of a focus group to gain qualitative insights into the visualization and interaction concepts. For this purpose, a guided discussion based on a predefined guideline is planned. The focus group will consist of heterogeneous participants from the German Army Reconnaissance Force. This will enable practical and specific feedback from military roles and different hierarchical levels. The primary objective is to identify strengths and weaknesses of the four layouts, to assess their operational suitability and to collect suggestions for improvement. The different contexts of use such as dismounted, in vehicles and in command posts and the resulting framework conditions for different input/output devices will also be included (e.g. augmented reality or speech input). The statements of the participants will be recorded during the discussion and then systematically assigned to topic clusters. With the insights gained in this way, conclusions will be drawn about the quality of the user interfaces and possibilities for improvement will be identified. An expansion of the group of participants from NATO states is conceivable in the next step in order to gain a more diverse picture. Based on the feedback gained, the concepts will be iteratively adapted and incorporated into future developments and experiments, in which situation awareness, user experience and intuitiveness can be determined. These will be conducted in laboratory and field tests. From the results, recommendations for the design of both cross-domain and specific user interfaces for swarm interaction can be derived.

REFERENCES

[1] Army Concepts and Capabilities Development Centre, "Artificial Intelligence in Land Forces," *Army Concepts and Capabilities Development Centre*, Köln, Germany, 2019

[2] P. Walker, S. Nunnally, M. Lewis, A. Kolling, N. Chakraborty and K. Sycara, "Neglect benevolence in human control of swarms in the presence of latency," *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, pp. 3009-3014, 2012.

[3] J. C Barca, "Swarm robotics reviewed," In *Robotica*, 31(3), pp. 345-359, 2013.

[4] T. Aubert, J. Corjon, F. Gautreault, M. Laurent, M. Causse and F. Dehais, “Improving situation awareness of a single human operator interacting with multiple unmanned vehicles,” *HOMOUS’10 conference – Humans Operating Unmanned Systems*, 2010.

[5] A. Finn, K. Kabacinski and S. Picton, “Design Challenges for an Autonomous Cooperative of UAVs,” *Information, Decision and Control*, Adelaide, SA, Australia, pp. 160-169, 007, 2007, 10.1109/IDC.2007.37454.

[6] A. Naghsh, J. Gancet, A. Tanoto and C. Roast, “Analysis and design of human-robot swarm interaction in firefighting,” *Proceedings of the 17th IEEE International Symposium on Robot and Human Interactive Communication*, pp. 255-260, 2008.

[7] K. Roundtree, M. Manning and J. Adams, “Analysis of Human-Swarm Visualizations,” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 62, pp. 287-5291, 2018.

[8] J. U. Patel and C. Pinciroli, “Improving Human Performance Using Mixed Granularity of Control in Multi-Human Multi-Robot Interaction,” *29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, 2020.

[9] E.C. Haas, M. Fields, C. Stachowiak, S. Hill and K. Pillalamarri, “Extreme Scalability: Designing Interfaces and Algorithms for Soldier-Robotic Swarm Interaction, Year 2,” *Army Research Laboratory*, 2010.

[10] Y. Lim, A. Gardi, R. Sabatini, S. Ramasamy, T. Kistan, N. Ezer, J. Vince and R. Bolia, “Avionics Human-Machine Interfaces and Interactions for Manned and Unmanned Aircraft,” *Progress in Aerospace Science*, 102, 1-46, 2018.