Meaningful guidance of unmanned aerial vehicles in dynamic environments

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INTRODUCTION

Human pilots and unmanned aerial vehicles work together to achieve common military objectives in manned-unmanned teaming (MUM-T). It is still an open question how exactly the interaction between pilot and unmanned systems will look like in an aircraft cockpit. In most approaches, the unmanned platforms are delegated by the pilot who is responsible for monitoring the derived actions (Miller et al., 2005; Uhrmann and Schulte, 2012; Doherty, Heintz and Kvarnström, 2013). In modern air combat, the tactical situation can change within minutes or even seconds requiring pilots to adjust their plan. When pilots are responsible for guiding multiple unmanned aircraft in addition to their own aircraft, time pressure for plan corrections will be vast. This pressure will further intensify when technological advances enhance decision-making times (e.g. by decision support systems and automated task execution).

To accelerate decision-making, more authority may be given towards automation or capable data-driven methods may be used. However, it is not clear if the pilot remains in meaningful control, when authority is transferred to automation and when decision-making is moved into uninterpretable algorithms (Lepri, Staiano, Sangokoya, Letouzé, & Oliver, 2017; Parasuraman, Sheridan, & Wickens, 2000)

Therefore, in this article, we want to discuss requirements to enable meaningful control of unmanned aerial vehicles in a highly dynamic military environment. We will discuss the formulation of tasks as a means of common understanding between human and automation and requirements for task delegation, UAV processing methods and UAV feedback.

TASK-BASED GUIDANCE

The distribution of roles and interaction between pilot and UAVs in manned-unmanned teaming can be described with the design patterns proposed by (Schulte, Donath, & Lange, 2016). To delegate UAVs, we need a common understanding of what should be done by the automation (Miller & Parasuraman, 2007). For this, we use a design pattern called task-based guidance, in which the pilot assigns high-level tasks to UAV agents aboard the unmanned systems, which, in turn, are responsible for task comprehension, decomposition and execution. An exemplary work system for task-based guidance of a single UAVs is shown in Fig. 1.

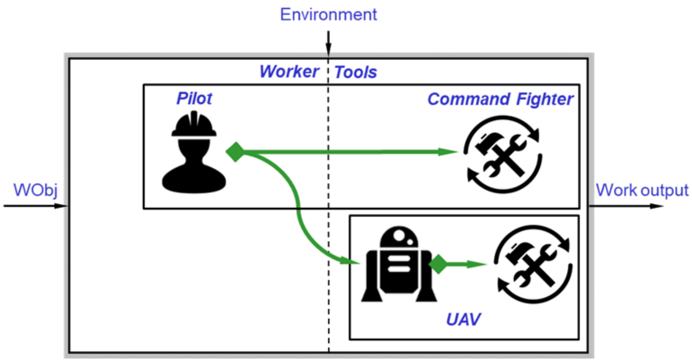

Fig. 1 Work System for task-based guidance of a single UAV

The interaction between human pilot and UAV agent in the above work system can also be represented as an information flow (Fig. 2).

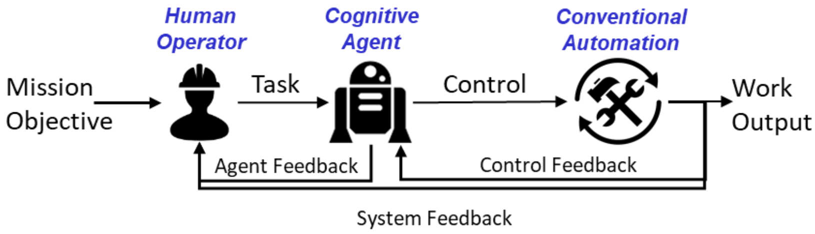

Fig. 2 Information flow in task-based guidance

The human pilot receives the mission objectives and assigns tasks to the UAV agents. These agents process the assigned tasks by controlling the conventional automation aboard the aircraft (e.g. Flight Management System) and providing feedback to the human operator. In this contribution, we focus on the interactions between pilot and UAV agents, i.e. task definition, task delegation, behavior generation and agent feedback.

Task definition

As a first step, we define military UAV tasks by a taxonomy adapted from (Lindner, Schwerd, & Schulte, 2019). In this taxonomy, tasks consist of the following components:

- *Action*: Actions represent military subgoals, such as the reconnaissance of a building.
- *Target*: The target to perform actions on. The variability of different object types can be abstracted to few spatial regions according to (Saget, Legras, & Coppin, 2009). We represent each object with a so-called *Feature* in one of the four geometric types *Point*, *Moving Point*, *Line* or *Area*.
- *Success criteria*: Criteria that define whether the task failed or succeeded. Possible success criteria depend on action and target.
- *Constraints*: Conditions or limiting factors such as resources or time requirements. The type and number of possible constraints depends on the respective task action (e.g., depression angle during reconnaissance).

Task delegation

A delegation consists of *Task Specification* and *Task Assignment.* Task Specification means the creation of a task with the components described before, whereas Task Assignment means the distribution process of this task to an eligible platform. Considerations for this distribution process may be the spatial distribution of platforms as well as previously assigned tasks and resource availability for each platform. The requirements that these two elements entail on the delegation interaction are described below.

With regard to Task Specification, the interaction must at least cover the specification of action and target. The definition of a success criteria may be obligatory for some tasks, while others have criteria that can be concluded by the action. The definition of constraints is optional, because constraints only limit the possibilities on how the tasks can be executed (e.g. time constraints) or because they specify values that could otherwise also be chosen by the system (e.g. depression angle).

The interaction also has to support a platform selection process during Task Assignment. This is because after the assignment, the generated task must be executed by a specific platform at a specific time. Different options exist on how this platform selection process is designed such as platform-based approaches (Heilemann & Schulte, 2020) or capability-based approaches (Besada et al., 2019), all of which could be assisted by automation or not. Regardless of the specific implementation, these delegation options place additional demands on the user interaction. In a platform-based approach, for example, the pilot has to name the platform whereas in a capability-based approach the pilot has to specify a timing for execution.

In summary, the delegation interaction must contain all elements to answer the question (Fig. 3):

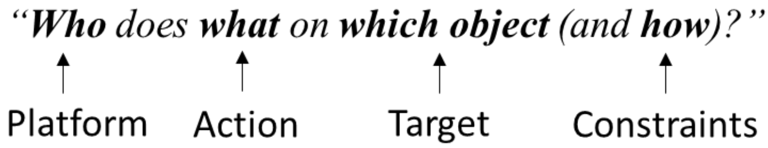

Fig. 3 Elements of a delegation interaction

There are different interaction design approaches to answer this question for guidance of UAVs from inside a fighter cockpit. Some are based on touchscreen interaction, others use voice interaction or cursor control devices. The individual benefits of these different interactions are still under research (Calhoun, Ruff, Behymer, & Rothwell, 2017; Dudek & Schulte, 2022; Levulis, DeLucia, & Kim, 2018).

Behavior Generation

The cognitive agents aboard of UAVs are responsible for decomposing and executing the assigned tasks. For this, cognitive agents have to consider the tactical situation and select the most appropriate action among a set of possible actions. To do so, various processing methods exist in UAV control domain that depend on knowledge representation, machine learning or optimization (Emel'yanov, Makarov, Panov, & Yakovlev, 2016). While each of these approaches has individual advantages when used for UAV behavior generation, one capability is particularly necessary for meaningful guidance of unmanned aerial vehicles: decision making transparency. To be able to provide reasonable feedback to the human pilot, the algorithm used at high-level decision making must allow embedding an explanation component, that creates action, goal and/or status feedback throughout the behavior generation. Model-based approaches are well suited for this requirement, because feedback can easily be integrated in the control flow.

Feedback

One of the most important characteristics of a cognitive agent is that it provides appropriate feedback to the pilot. (Chen, Barnes, Selkowitz, & Stowers, 2016) showed that agent decision-making transparency can benefit operator performance and support appropriate levels of trust. However, UAV agent feedback is not defined by transparency alone. Instead, agent feedback can be categorized into three modes:

1. Transparency: Measures that attempt to disclose agent decisions to the human pilot fall into this category. Feedback in this category can be classified by the Situation Awareness-based Agent Transparency (SAT) levels.
2. Assistance: Assistance offers troubleshooting steps based on a faulty condition, whether caused by a change in the environment or by incorrect pilot inputs.
3. Interaction: Pilot interventions on a lower-level than the definition of tasks.

We analysed the delegation process of task-based guidance to identify potential feedback measures in these categories (Table 1).

Timing	Description	Mode
Task specification	The task created by the pilot is checked for plausibility, offering alternatives for unfeasible task parameterization.	Assistance

Task assignment	Feedback can be given for tasks that are not in accordance with the mission objectives or for tasks that do not meet constraints with other tasks.	Assistance
Before task execution	A description of the desired action chain is appropriate at this point to externalize the UAV behavior model and convey a common understanding of the assigned task (SAT level 1/2).	Transparency
During task execution	Displaying the current action of each UAV can increase situation awareness during task execution (SAT level 1). For higher SAT levels, reasons for action selection can be displayed and projections on action changes can be made.	Transparency
During task execution	For tasks covering a wide scope of actions, involving the user in the choice of action could be beneficial to situation awareness and performance because the human pilot is not only involved with passive monitoring but also with contributing to the task, which could increase vigilance (Parasuraman, 1987).	Interaction
During task execution	The pilot can be informed, when the prediction changes whether goals can be achieved (SAT level 3).	Transparency
After task execution	After a task, the most important feedback is whether a task was completed successfully or whether it failed. Furthermore, providing an overview of resource usage can be beneficial.	Transparency

Table 1 Potential feedback measures in task-based guidance

GUIDANCE APPROACHES

After defining the requirements for meaningful guidance of UAVs, we want to present our research to fulfilling these requirements. We implemented tasking interactions using voice and touch input modalities and investigated the effects of these modalities on mission performance and modality preferences. We plan to further investigate the observed effects and implement multimodal tasking interactions. For the behavior generation, we used Behavior Trees, in which we also integrated a feedback creation component, that we use for action feedback and assistance generation. Regarding feedback, we plan to define a taxonomy for the different types of feedback and to map feedback on different modalities as a succeeding step. We also want to investigate the effects of different types of feedback on mission performance and situation awareness.

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