Operator Assistance and Semi-autonomous Functions as Key Elements of Future Systems for Multiple Uav Guidance

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Abstract. This paper will discuss technologies for use in a work system comprising a single operator working in a control station being supposed to supervise several UAVs. The overall setup of a typical manned-unmanned teaming scenario will be described and analyzed using the approach of the work system as a human factors engineering framework. This approach facilitates to identify the research areas of cognitive operator assistance and semi-autonomous guidance of co-operating UAVs. Furthermore, this paper will refer to recent research activities and experimental facilities for the evaluation of the solutions.

Keywords: Cognitive automation, UAV guidance, operator assistance.

1 Introduction

Future military aerial missions in asymmetric warfare or peacekeeping will be characterized by growing information demand onboard the operating units. This information demand asks for high timeliness, which can be encountered by using deposable sensor platforms for real-time and locally close reconnaissance. These platforms can be Uninhabited Aerial Vehicles (UAVs), equipped with appropriate sensors, operating in proximity of the manned mission asset, collecting information based on reconnaissance assignments. A possible scenario could comprise a manned helicopter with several UAVs being guided from a human operator onboard that helicopter. Regarding the UAV guidance there is need for the consideration and investigation of a vehicle to operator ratio larger than one. This typically leads to the demand for extensive automation. Generally spoken, traditional automation approaches provide systems, which can be regarded as tools or equipment supporting the operator to fulfill certain well defined sub-tasks. This leaves the operator in the role of the high capacity decision component determining and supervising the work process. Suchlike *conventional automation* does not assist the operator in performing tasks like decision-making with the aim to achieve the top-level mission goals because it lacks a comprehensive understanding of the situation and the overall work objective as well as decision-making and problem solving on the basis of knowledge processing.

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In order to cope with these deficiencies, *cognitive automation* [1] shall be used as the underlying paradigm. This enables the automation to offer semi-autonomous and co-operative capabilities. Here, UAVs are enabled to accomplish missions semi-autonomously with respect to a given mission objective and to co-operate with both, other UAVs and the human operator. As part of the control station, cognitive operator assistant systems shall be enabled to assist the human in achieving the mission specified by the given mission objective and according to the situation. These operator assistant systems shall also be able to change the level of automation in order to adapt to the current workload, i.e. the availability of mental resources of the human operator.

This paper describes the overall set-up of a typical manned-unmanned teaming (MUM-T) scenario and analyses it with a top-down approach using a human factors minded systems engineering framework. It will identify and describe two relevant research areas, firstly *cognitive assistant systems* including automation capable of adapting to situational changes, and secondly *semi-autonomous* and *co-operative behavior* of UAVs facilitating multiple vehicle guidance by a single operator. Finally, relevant research project, results and experimental facilities will be described.

2 Relevant Issues Concerning Multiple Uav Guidance

By use of *conventional automation* UAVs can perform predefined tasks automatically, thereby unburdening the human operator from various sometimes tedious or even dangerous routine works. Thus uninhabited vehicles will in most cases not require a human for manual control. Although being prerequisite for safety critical performance, today there are only few and very conservative approaches on the market, concerning automatic on-board decision-making capabilities handling contingencies such as the loss of data link connection. Despite all these technological endeavors human operators will still be involved in higher level tasks such as planning, problem solving or pursuit of the overall mission goal. So, in any case we are considering a human-machine system with spatially dislocated components, as being discussed later. In fact, it is very undesirable to design fully automated systems without the possibility for a human operator to (re-)define the mission goals as well as to interact and engage during the mission process.

When regarding operation and flight guidance concepts of actual UAVs in service it can be stated that various concepts are applied. Some vehicles have to be started and landed manually by pilots standing at the runway possessing line-of-sight (e.g. *Hunter, Pioneer*) and beyond these flight phases control is transferred to a remote pilot in a ground control station (GCS). Other vehicles like the *Predator* will be controlled manually during takeoff and landings by use of a nose camera from the GCS, whilst during the mission phase the vehicle is controlled by an autopilot. Other vehicles (e.g. *Global Hawk, Shadow*) are fully automated during all flight phases (including takeoff and landing). All these flight guidance concepts require an operator to vehicle ratio of one or even larger. This is one of the factors leading to inter-crew related problems as well as fundamental flight guidance problems based on human factors implications. Studies on accidents and incidents of UAVs show that a notable percentage of mishaps are human factors related [2]. These range from display and HMI (Human-Machine Interface) problems over premature software versions to procedural errors including wrong decision making on the part of the operator crew [3]. As stated above, conventionally designed automation fulfills strictly specified sub-tasks leaving the operator in the role of the supervisor coordinating the numerous automated functions in order to comply with the mission objectives. Within the design phase of automation systems it is difficult to anticipate all possible states and contingencies that might occur during operation. And even if the automation works as designed, unintended consequences can occur due to events that were not anticipated. Some examples are illustrated in [4]. When trying to reduce the operator to vehicle ratio to one and below (i.e. single operator guiding a single/multiple UAVs) the inter-crew related problems may be solved although the expected work load level will exceed the available human resources. Therefore assistant systems, human – machine and machine – machine collaboration are an appropriate remedy to lower the workload of the human operator. All these systems will be based on *cognitive automation* as the underlying paradigm. Further details on this approach will be portrayed in the following chapters.

3 Work System Analysis of a MUM-T Scenario

In order to be able to detail approaches for coping with problems anticipated for the guidance of multiple UAVs, this section will analyze a typical MUM-T set-up using the work system as engineering framework. Afterwards, different possibilities to introduce automation into the work system will be presented and the *Cognitive Process* as approach to the realization of artificial cognition will be explained.

3.1 The Work System as a Human Factors Engineering Framework

The work system (see figure 1) as a general ergonomics concept [5] has been utilized in a modified definition and adapted to the application domain of flight guidance by Onken [1] and UAV guidance by Schulte & Meitinger [6]. It is defined by the *work objective*, being the main input to the process of work. Usually, the work objective comes as an instruction, order or command from a supervising agency. Further constraining factors for the work process are *environmental conditions* including useful information and *supplies*. On its output the work system provides the current *state of the work* and finally a *work product* representing what has been accomplished by the work process. [7]

The work system itself consists of two major elements, i.e. the *operating force* (OF) and the *operation-supporting means* (OSMs). The *operating force* is the high-end decision component of the work system with the highest authority level. It is the only component which pursues the overall work objective. Therefore, it determines what will happen in the course of the work process and which OSMs will be deployed at what time. One major characteristic of especially a human as OF is the capability to define the work objective himself. Apart from operating on the basis of full authority competence this is the decisive criterion for what we call an *autonomous system*. The concept of the *operation-supporting means* can be seen as a container for whatever machinery or technology at the work place is available. Common to the nature of various operation-supporting means is the fact that they only perform certain well-defined sub-tasks assigned to them by the operating force. [7]

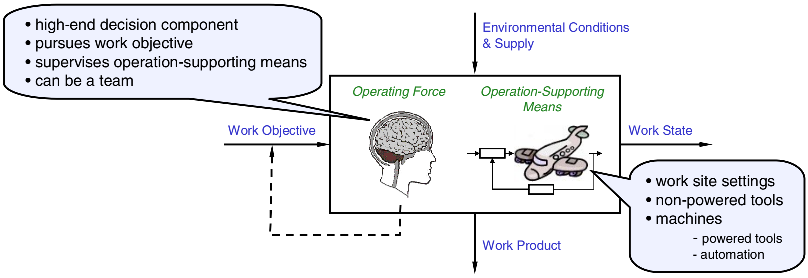

Fig. 1. The work system

In the following, the work system will be used to analyze a typical MUM-T scenario, which will serve as an example for the deduction of design criteria for introduction of advanced automation into the work system. The set-up consists of a manned helicopter being guided by a human pilot and several UAVs being guided by a human UAV operator onboard the helicopter.

Figure 2 shows one possible work system configuration consisting of two work systems – the *helicopter work system* being composed of the helicopter pilot and the helicopter itself and the *UAV guidance work system* being made up of the UAV operator and several UAVs. Here, both work systems receive the same mission objective from a superior command and control authority, while reconnaissance demands of the helicopter work system pose constraints for the UAV guidance work system. In contrast to an also imaginable configuration, in which the UAV guidance work system is subordinate to the helicopter work system, here the UAV operator can take the initiative with respect to the overall mission objective.

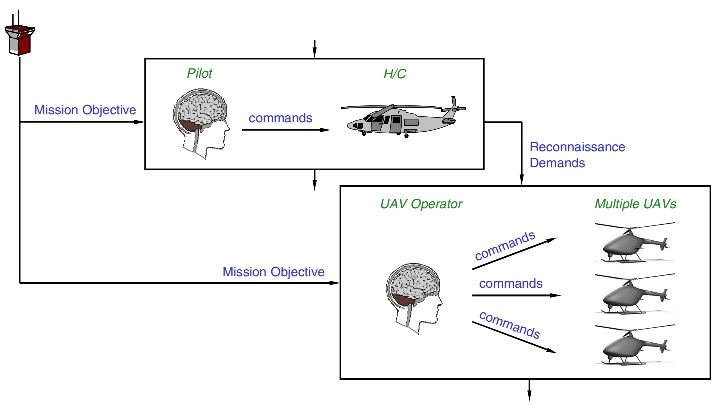

Fig. 2. System of work systems for guidance of multiple UAVs from an airborne control station

Given this arrangement, problems are likely to occur such that both humans, but especially the UAV operator, will be overloaded with their tasks, i.e. the guidance of the helicopter or the UAVs respectively. In order to keep the humans' workload on an acceptable level, automation can be introduced into the work system in different ways, one of which will be discussed in the next section using the UAV guidance work system as an example.

3.2 Introduction of Cognitive Automation into the UAV Guidance Work System

In order to increase the productivity and efficiency of work systems, we propose to introduce cognitive automation which promises to avoid the problems of conventional automation as sketched in section 1. Common to all cognitive automation is that it "*works on the basis of comprehensive knowledge about the work process objectives and goals […], pertinent task options and necessary data describing the current situation in the work process*" [1]. There are two ways to introduce such cognitive automation into the work system, namely as *semi-autonomous systems* or *assistant systems* (cf. [1][6][8]). *Semi-autonomous Systems* can be understood as former work systems, in which advancing automation has become capable of pursuing the given work objective and has taken over the role of the human operator as part of the operating force, but is **not** allowed to define or alter the work objective. They are always part of the operation-supporting means of a newly created work system. Thus, they are tasked by the respective operating force and capable of accomplishing these tasks in a goal-directed manner, taking the current situation into account.

The primary task of *assistant systems*, them being part of the operating force, is to support a human operator in pursuing the given work objective. Thus, the main difference to semi-autonomous systems is the requirement to know about, understand and pursue the work objective in contrast to assigned tasks. In order to be able to support the human adapted to his or her current needs, an assistant system moreover has to understand human resources and be capable of human-machine co-operation.

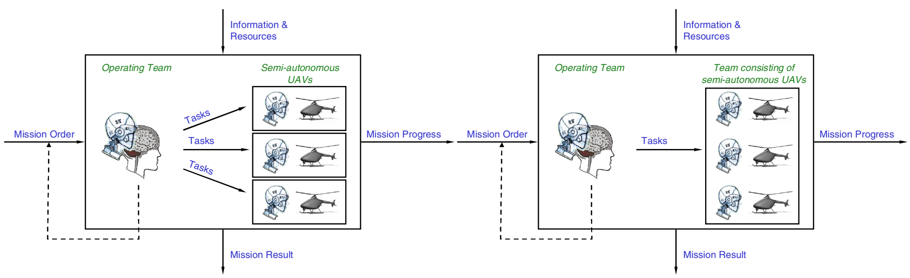

Fig. 3. Introduction of ACUs into the UAV guidance work system

Figure 3 (left) shows an obvious approach to introduce semi-autonomous and assistant systems into the UAV guidance work system as introduced in the previous section. In a first step, each UAV is equipped with an *Artificial Cognitive Unit (ACU)* (depicted by a robot head) being capable to accomplish tasks as opposed to the execution of detailed instructions, thus, each forming a semi-autonomous system. In order to be able to cope with his or her primary task, i.e. to supervise several semi-autonomous systems and allocate tasks to them in order to achieve the work objective, the human operator will be assisted by an ACU. A further improvement of the operator-to-UAV ratio may be achieved by enabling the semi-autonomous UAVs to

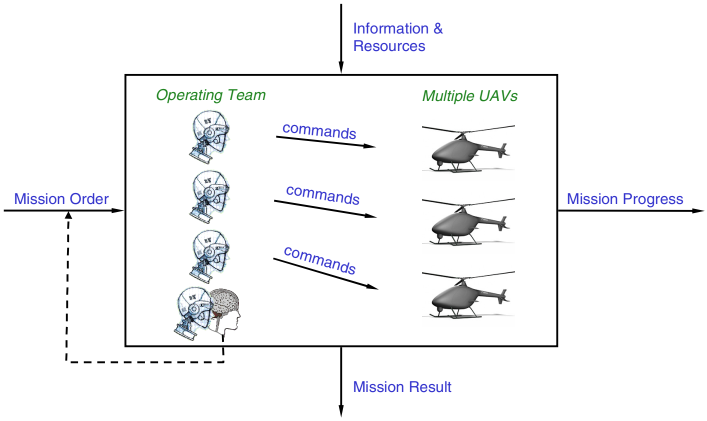

Fig. 4. Alternative Introduction of ACUs into the UAV guidance work system

co-operate (see Figure 3, right). Here, the UAVs can be tasked as a team, thus taking over the co-ordination task from the operating force.

Figure 4 shows an alternative configuration acting on the maxim to put as much automation as possible into the OF (cf. [7]). This recommendation is based on the assumption that the more automation knows about the work objective to achieve, the better decisions can be made. Here, the ACUs being responsible for the guidance of the UAVs become part of the OF, thus pursuing the given work objective and acting in co-operation with the human. Such teamwork also increases the involvement of the human operator as opposed to a mere supervisory participation in the work process.

3.3 The Cognitive Process

As indicated above, both semi-autonomous and assistant systems can come in the shape of *Artificial Cognitive Units (ACUs)* being capable of goal-directed and rational behavior. As underlying theory for the realization of such systems, the *Cognitive Process* is suggested, which is an adequate model of human information processing [9].

It follows a knowledge-based approach, i.e. separates knowledge from knowledge processing. The behavior of systems developed according to the theory of the Cognitive Process is mainly driven by the *a-priori knowledge*, which is modeled by the system developer. There are four kinds of a-priori knowledge. *Environment models* represent objects, relations, and abstract concepts, which are expected to occur in the environment or be relevant for the mission in some way. They are used to gather a belief about the situation of the environment. *Desires* model potential goals, at which the central question is, which goals should be pursued. The set of active goals represents a situation, which shall be achieved. *Action alternatives* are used to put together a plan, which is suited to transfer the current situation into the desired one. Finally, *instruction models* are used to determine the instructions which can execute the elements of the plan and finally effects and change the environment.

The paradigm of the Cognitive Process can be used to develop different application capabilities separately, the knowledge belonging to each capability being encapsulated in so-called *packages*. These packages are linked by dedicated joints in the a-priori knowledge and together form the complete system.

4 Cognitive UAV Co-operation

Having introduced a team of semi-autonomous UAVs into the UAV guidance work system and presented the *Cognitive Process* as underlying theory for realization of artificial cognition, this section details an approach to implement co-operative capabilities of semi-autonomous systems, which provides a basis for human-machine co-operation as discussed in the following section.

In general, *co-operation* is characterized by a common objective, which is pursued by all members of a team being committed to its achievement. In the context of the work system, the common objective is usually the work objective for a team in the operating force and an assigned task for a team being part of the operation-supporting means. In order to achieve the common objective, team members have to *coordinate*, i.e. manage dependencies among their activities [10]. This includes task allocation within the team as well as the assignment of shared resources or the temporal arrangement of tasks, the execution of which e.g. depends on the successful completion of another task. Coordination among team members in turn requires *communication*. In this context we distinguish between explicit and implicit communication. Explicit communication includes the exchange of messages as well as non-verbal actions, which are executed in order to provide some information to somebody else. Implicit communication in contrast deduces information by observation of actions, the primary purpose of which is not to communicate, but to e.g. perform a mission-related task.

In order to facilitate co-operative behavior of ACUs, the appropriate models of the a-priori knowledge within the Cognitive Process have to be developed. According to the *Cognitive Process Method* [11], at first, desires have to be modeled, as they finally drive the behavior. Top-level desires being relevant in the context of co-operative behavior are based on requirements for human-machine co-operation by [12] and training of human teams [13] and cover teamwork per se as well as the achievement of the common objective and coordination and communication aspects [14]. Action alternatives which are suited to achieve co-operation goals are modeled next and either refer to information exchange or the assignment of tasks or resources to team members.

A more detailed description of the a-priori knowledge necessary for the realization of co-operative ACU behavior is given by [14]. This paper also describes the results obtained with an implementation of such capabilities taking a simplified Sead-/Attack mission performed by five UAVs with heterogeneous capabilities as an example.

Finally, it shall be emphasized, that successful co-operation of several semi-autonomous systems always depends on the capabilities of individual team members to actually comply with the responsibilities which have been assigned to them.

5 Cognitive and Co-operative Operator Assistance

Another research area to be addressed here is the development of cognitively co-operating UAV operator assistant systems. For such operator assistant systems the basic requirements for pilot assistant systems stated by Onken [15] can also be applied. They state that the attention of the operator has to be directed to the most important task in the current situation and, if this has been achieved, and there is still a situation with human overload, this situation has to be transferred into a normal one by the use of technical means.

In order to be able to realize such functionalities the *Cognitive Process* (see section 3.3) shall be used as the underlying paradigm for the implementation. Concerning a UAV operator assistant system, mainly two packages will be required. The first one shall address the domain of UAV guidance and could thus be called "*domain expert*". Environment models of this package incorporate knowledge about the work objectives (usually a mission order), environmental elements and conditions, and the UAVs including their states and capabilities. The desires include models such as to accomplish the mission and consider the tactical situation. Possible action alternatives cover the deployment of available operation-supporting means i.e. the UAVs and their on-board automation functions, depending on their resources and capabilities.

The second package shall address the human operator and could thus be called "*operator assistance*". Environment models for this package include models to evaluate resources and behaviors of the human operator as well as his or her intents and possible errors. The desires incorporate models to form a team with the human operator and to jointly achieve the common work objective (cf. section 4). Action alternatives cover models regarding interaction and dialog management with the human operator. Forthcoming works in the context of our MUM-T project (see next section) are aiming for the realization and evaluation of such a system.

6 Projects and Experimental Facilities

Two already completed projects, namely CAMA (Crew Assistance Military Aircraft) and CASSY (Cockpit ASsitant SYstem) have been accomplished and tested under real world conditions in flight campaigns [16][17][18]. Main focus of research in these projects were the development of a fully automatic on-board *flight planner* and a *pilot model* used to anticipate expected pilots' actions depending on the mission phase. On the basis of this, pilot errors are distinguished from intended but deviating pilot actions. In any case, the assistant system will adapt its interventions accordingly. Ongoing projects include PILAS (Pilot Assistant System) where an assistant system is designed to track the actual mission phase and to support the operator depending on the current situation if appropriate [19]. Another ongoing project is MiRA (Military Rotorcraft Associate) where the focal point is set on adaptive function allocation for operator workload adjustment. The research on machine-machine co-operation is the main subject to the project COSY^{team}, where several UAVs are accomplishing a given mission in co-operation under loose, so far unassisted human supervision [14].

The last project to be mentioned here is MUM-T (manned- unmanned teaming). It combines all aforementioned research areas, i.e. multiple UAV guidance from an airborne platform. Therefore, a surrogate scenario is set up by keeping the same work system relationships as explained earlier in this paper. This experimental system is called Co²SiMA (Cognitive & Co-operative System for intelligent Mission Accomplishment). Co²SiMA facilitates a mobile control station on the basis of a Mercedes Sprinter truck. This component will be the surrogate for the manned helicopter with full functionality of the UAV-operator station. The second main component of Co²SiMA is comprised of a fleet of flying model based type-different UAVs (rotorcraft and fixed-wing aerial vehicles) equipped with adequate technology (e.g. autopilot, flight management system, hardware infrastructure to host the cognitive functionalities, sensors e.g. AHRS, DGPS, CCTV and data links). Figure 5 depicts the main components of Co²SiMA.

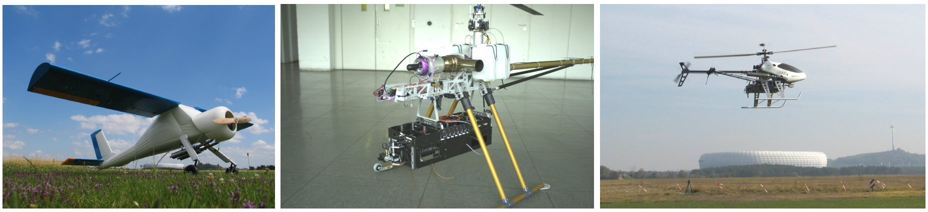

Fig. 5. Main components of Co²SiMA

The surrogate scenario envisions the mobile control station being guided by the reconnaissance information (e.g. real-time TV stream) provided by the UAVs through the UAV operator. This setup allows the testing and evaluation of developed technologies under simulated and real world conditions. Experimental focus will be set on validating the performance of the UAV-UAV co-operation, the investigation of a operator to vehicle ratio smaller than one, the validation and possible application of operator models as well as the appliance of human factors related assessments and measurement techniques (e.g. eye movements, workload). Future developments of co-operative assistant systems will benefit from these experimental resources and results. Concerning real-world trials the focal point will be set on the possible viability of critical functionalities and capabilities.

7 Conclusion

Manned-unmanned teaming, as it is understood within our research group, poses new and heavily demanding task load on operators. On the one hand there should be mentioned the adverse work environment of an airborne platform maneuvering in a threatened military theatre. On the other hand there is the demand for interaction with necessarily highly automated systems, i.e. multiple UAVs designated to accomplish a complex mission in a coordinated manner. This entails both, high mental workload as well as extreme load on attention allocation and situation awareness processes. The proposed solution, as recommended by our research group and presented in this paper, is the approach of cognitive and co-operative automation. Various recent and current research activities in the fields of knowledge-based operator assistant systems and co-operative semi-autonomous UAV flight guidance systems, which led to very promising results, point out the way ahead. Within a German MoD funded research project these findings shall be transferred to the domain of manned-unmanned military helicopter missions. This includes the development of a UAV-operator assistant system and semi-autonomous co-operating UAVs as remote sensor platforms.

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