* The illustration shows the Roboraider USV that is developed by the Naval Facilities Engineering Service Center. Altough Roboraider is mainly intended for reconnaissance, the image is used here as an illustration of using a USVs for mannedunmanned teaming in anti-submarine warfare.

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Studies of Manned-Unmanned Teaming using Cognitive Systems Engineering: An Interim Report

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Report title

Studies of Manned-Unmanned Teaming using Cognitive Systems Engineering: An Interim Report

Abstract

There is currently an increased interest in using unmanned robotic systems for tactical applications where manned and unmanned systems operate together as a team. Unmanned robotic systems may for example provide critical information while the manned systems remain in cover or outside of lethal range. Since it can be difficult to elicit user requirements for unmanned robotic systems, especially for tactical applications, a strategic research project was established at FOI to explore how a Cognitive Systems Engineering (CSE) methodology can be applied to manned-unmanned teaming. CSE focuses on the joint performance of manned and unmanned systems based on an analysis of application, decision, information, and coordination requirements for control of partly autonomous systems.

The report summarises the results from the project's first year regarding principles of human-robot coordination, the role of critical thinking for control of UMVs, UGV for MOUT scenarios, UCAV for SEAD and general strike missions, and tactical UAVs, UUVs, and USVs. Applying a CSE methodology has even at this preliminary stage helped to identify complexities of manned-unmanned teaming both from the operator's perspective of human-robot coordination, as well as secondary effects on team-mates and leaders. The applications that currently are of most interest to the Swedish Armed Forces are UGV for MOUT scenarios and UCAV for strike missions. These applications will therefore be investigated in more detail using cognitive task analysis (CTA) and conventional experiments in simulator environments.

Keywords

manned-unmanned teaming, human-robot coordination, cognitive systems engineering, cognitive task analysis, UMV, UGV, UAV, UCAV, UUV, USV

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Studier av samverkan mellan bemannade och obemannade delsystem med Cognitive Systems Engineering:
En delrapport

Sammanfattning

Det är för närvarande ett ökat intresse för att använda obemannade robotar för taktiska tillämpningar där bemannade och obemannade delsystem samverkar i ett team. Obemannade robotar kan t.ex. förmedla kritisk information medan de bemannade plattformarna befinner sig i skydd eller utanför skjutavstånd. Eftersom det särskilt för taktiska tillämpningar kan vara svårt att specificera användarkrav på obemannade system så har en strategisk forskningskärna initierats vid FOI för att studera om ”Cognitive Systems Engineering” (CSE) metodik kan tillämpas på bemannad och obemannad samverkan. CSE fokuserar på hur det totala systemet presterar baserat på en analys av tillämpnings-, besluts-, informations- och koordinationskrav för styrning av delvis autonoma system.

Rapporten sammanfattar resultaten från projektets första år vad gäller principer för människa-robot koordination, hur kritiskt tänkande kan användas för styrning av UMV:er, UGV för strid i bebyggelse, UCAV för anfall av luftvärnssystem och attackuppdrag, samt taktiska UAV:er, UUV:er och USV:er. Redan på det här preliminära stadiet så har CSE metodiken hjälpt till att identifiera svårigheter för bemannad och obemannad samverkan både från operatörens perspektiv i form av människa-robot koordination och följdeffekter för gruppmedlemmar och chefer. De tillämpningar som för närvarande är av mest intresse för försvarsmakten är UGV för strid i bebyggelse och UCAV för attackuppdrag. De här tillämpningarna kommer därför att studeras mer i detalj med kognitiva uppgiftsanalyser och konventionella experiment i simulatormiljöer.

Nyckelord
bemannad obemannad samverkan, människa-robot koordination, cognitive systems engineering, kognitiv uppgiftsanalys, UMV, UGV, UAV, UCAV, UUV, USV

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Contents

1 Introduction

Many unmanned robotic systems are currently used and developed for military operations since they may reduce costs or risk for military personnel, or have enhanced operating characteristics. Typically, unmanned robotic systems are used for strategic intelligence, surveillance, and recognizance (ISR). There is, however, a recent interest in also using unmanned systems for tactical situations where manned and unmanned systems operate together as a team. Unmanned robotic systems may for example provide critical information while the manned systems remain in cover or outside of lethal range. One example of manned-unmanned teaming for a tactical application is the use of unmanned aerial vehicles (UAVs) together with attack helicopters to scout ahead for targets, which has resulted in an increase in effective weapons range from 5 to over 50 km ("Army Pushing," 2001).

One problem when developing unmanned robotic systems, especially for tactical applications, is that it can be difficult to elicit user requirements using traditional methods (c.f. Ames, 2004). Instead a prototype is often developed with many of the conceivable functions. The prototype is then evaluated in an appropriate mission context, and the most useful functions are selected for the final product. A more efficient method to obtain the user requirements on robot functions may be to use a Cognitive Systems Engineering (CSE) methodology. CSE focuses on the joint performance of manned and unmanned systems based on an analysis of application, decision, information, and coordination requirements for control of partly autonomous systems (see Hollnagel & Woods, 2005). A successful CSE project is typically directed towards the cognitive system's triad of domain demands, the practitioner's information-processing characteristics, and the external representations and automation that the practitioner uses to interact with the domain (Roth, Patterson, & Mumaw, 2002; Roth & Woods, 1998). Cognitive task analysis (CTA) methods can be used to analyze the three elements of the triad for an understanding of the cognitive demands of the domain, the knowledge and strategies used for managing the demands, and the reasons for poor performance. The emphasis on uncovering underlying task demands and complexities that hamper performance makes CSE especially useful for complex and dynamic domains which may not be well understood.

In order to explore the potential of CSE for eliciting user requirements on tactical unmanned systems, a strategic research project was established at FOI in January 2005. The project was free to investigate any tactical application of interest to the Swedish Armed Forces. The activities during 2005 have had two foci, (1) orientating studies from a CSE perspective of tactical unmanned systems that are currently investigated by the Swedish Armed Forces, and (2) theoretical studies of principles for human-robot interaction that are applicable to tactical unmanned systems. The orientating studies have mostly focused on Snoken, an unmanned ground vehicle (UGV) for military operations in urbanized terrain (MOUT). The studies of Snoken have been performed in cooperation with the FOI project Operator Site (Lif, Jander, & Borgvall, 2005b). Initial evaluations show that the UGV improves the reconnaissance information while reducing risks, although the time required to deploy and start the UGV may slow the pace of advance (Lif, Jander, & Borgvall, 2005a). The next section provides further details of the UGV study. Other areas that have been studies are unmanned combat aerial vehicles (UCAVs) for suppression of enemy air defence systems (SEAD), and to a lesser extent UCAVs for manned-unmanned teaming in strike missions, tactical UAVs for the Nordic Battle Group, submarine warfare using unmanned surface vehicles (USVs), and unmanned underwater vehicles (UUVs).

The theoretical studies were mainly focused on principles of human-robot coordination and how critical thinking can be applied to unmanned military vehicles (UMVs). Svenmarck (2005c, 2005d) discuss how the issue of human-robot coordination can be approached both top-down using a CSE methodology to assess the requirements for joint control and bottom-up based on the interaction between the operator and the robot. Overall, four control layers of control can be described: tracking, regulating, monitoring, and targeting (Hollnagel, 2005). Additionally, there are interdependencies between the control layers and between control of the robot and payload. An understanding of these interdependencies is important to avoid problems of automation surprises and out-of-the-loop performance. From a bottom-up perspective, the amount of interaction required to achieve coordination often determines where the robot can be applied since there is a limit to how much attention the operator can devote to the robot in tactical situations. Generally, coordination problems can result from supervisory control of partly autonomous devices, and management of mode transitions that may be partly automatic. Supervisory control requires a sophisticated coordination based on prediction of system behaviour using knowledge about automation state, principles of operation, and performance boundaries. Mode transitions, on the other hand, are often problematic due to interface designs that lead to indeterminism, and long time delays between setting conditional values for automatic mode transitions and their application. Finally, the video streams that are used for manual control of the platform and payload may distort the natural field of view and disrupt the orientating perceptual functions for where to look next.

The theoretical study of critical thinking was a response to a NATO working group request. Svenmarck (2005a, 2005b) discuss how UMV operators often have to decide on a course of action even though available information may be uncertain or incomplete, or relevant information is simply missing. Since it can be difficult to judge whether a decision is correct or not in these situations, potential improvements can instead focus on the cognitive process for interpreting the information at hand. For example, how to consider the relevant factors, make plausible assumptions, and identify conflicts in the information. Marvin Cohen and associates show in a series of papers that critical thinking based on dialogue theory can be used to improve the cognitive processes for interpreting information (Cohen, Freeman, & Wolf, 1996; Cohen, Salas, & Riedel, 2002). The roles involved in a dialogue are: the proponent who defends a position, the opponent who critiques the position, and the facilitator who regulates the process. The type of dialogue and amount of questioning can be selected depending on the context and available time. Training in critical thinking increases the generation of new options and the number of reasons for positions. UMV operators may thus use critical thinking to assess the benefits of UMVs, such as less risk, relative the disadvantages of remote perception, tracking difficulty, slowness, and vulnerability, depending on the mission context.

The purpose of this report is to provide an overview of the project activities during 2005. The report begins with the studies of the UGV Snoken, followed by studies of UCAV for SEAD missions and manned-unmanned teaming for strike missions. Finally, there are some brief descriptions of tactical UAVs, USVs, and UUVs.

2 UGV for recognizance in MOUT scenarios

UGVs have been used operatively in MOUT scenarios for several years, such as in Iraq by the US Army. Since there are many advantages with UGVs, especially for reconnaissance and safety during MOUT missions, the use of UGVs will likely increase further in the future. MOUT scenarios are also important for the Swedish Armed Forces. The Swedish Army Combat School (MSS) has therefore evaluated a UGV system for a few years. Figure 1 illustrates the current concept of operations where the UGV is carried on the back until needed and then controlled from a tablet PC. There are many issues to investigate, ranging from sensor technology and human-machine interaction (HMI) to suitable concepts of operation. Often, a system that is introduced to increase a unit’s ability may also have other effects than intended. For example, tactics may have to be adjusted, the demands of personnel resources may change both in numbers and in competence, and the workload may be affected, not only for the operator and his/er unit but also at the higher organizational level. If issues such as these are not properly investigated there is a risk that the new system decreases the overall performance of the unit, even though specific tasks might be performed more safely and efficiently with the new system. Evaluations of UGVs at different levels have therefore started in cooperation between MSS and the department for Man-System Interaction (MSI) at the Swedish Defense Research Agency (FOI). The evaluations are mainly focused at the concept of operations, such as:

- How is the unit affected by using an UGV?

- Is it necessary to add resources to the unit for them to be able to conduct both ordinary assignments and handling a UGV system?
- Is it necessary to change the unit's working methods?
- Are organizational changes necessary?
- Does an UGV affect the ability to collect reconnaissance information at the group and platoon level?
- How are the group and the group members affected by the system?

Figure 1: Section leader sitting to the left, UGV operator with control panel in the middle, and carrier of the vehicle (when not in operation) to the right.

Currently, the HMI aspects are of secondary interest, and the technical issues are beyond the scope of the study, although both HMI aspects and concepts of operation are of course dependent on technical improvements and solutions.

2.1 Purpose and description of SNOKEN II

Figure 2 shows the latest version of the UGV, SNOKEN II which has been developed by Aerotech Telub. SNOKEN II is a research prototype that is intended for evaluations in different situations and not a commercial product. The main purpose of SNOKEN II is to serve as a platform for evaluations of using an UGV for military tasks, versus when soldiers perform the same or similar tasks without an UGV. Although SNOKEN II is designed for MOUT scenarios, however, it can also be used for non-military purposes within the police or fire department. The SNOKEN II system consists of three parts: the vehicle itself, a tablet PC for controlling the UGV, and a transceiver.

The weight of the vehicle itself is 9.5 kg, including 3 batteries, GPS, microphone, and one camera with pan, tilt and zoom. There are separate antennas for telemetry, GPS, and video. The vehicle has a maximum velocity of 70 km/h, but the velocity is currently limited to a slow and high speed mode. The slow speed mode is the main mode where the velocity is usually set to a walking pace of about 10 km/h. The high speed mode is set to about 25 km/h and is mainly intended for specific situations, such as open terrain with no obstacles and when going up a small hill. The high speed mode is seldom used since it is difficult to control the vehicle at this speed. SNOKEN II has no autonomous functionality, except slewing of the camera forward when the vehicle is moving.

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Figure 2: SNOKEN II.

Figure 3 shows the Field Tablet PC (FTPC) with a 800 MHz CPU, 1GB compact flash memory and 256 MB RAM memory. Battery lifetime at +20˚C is about 4 hours, and the weight with battery is 2.9 kg.

Figure 3: The Field Tablet PC with its functionality.

Figure 4 shows the transceiver that mediates information between the antennas (GPS/telemetry/video), vehicle, and the FTPC. The transceiver weighs about 2 kg. The SNOKEN II system was evaluated during a few MOUT exercises in Norrköping and Linköping during the spring of 2005. The exercises, evaluation methodology, and results are discussed next.

Figure 4: Computer, transceiver, antennas and joystick.

2.2 MOUT exercises in Norrköping and Linköping 2005

The MOUT exercises were a part of the training for conscripts in the Swedish Army. The conscripts that participated in the MOUT exercise in Linköping came from MSS Kvarn where they prior to the exercise had received training both as individuals and a unit regarding weapon systems, combat techniques, and leadership. SNOKEN II was controlled by officers during the Linköping exercise who had received almost two years of training as officers, including MOUT training, after one year of basic training. The soldiers that controlled SNOKEN II during the Norrköping exercise came from K3 in Karlsborg where they had received about one year of basic training. The military exercises in Norrköping and Linköping were organized by personnel from MSS Kvarn, but also include personnel from other army units in Sweden. The exercises covered both basic MOUT training for individuals, groups and platoons, such as advancing along a street and defending a crossing, and larger scale combat scenarios with blue and red teams using main battle tanks and other combat vehicles. During the exercises in Norrköping and Linköping, there were totally about 150 soldiers of the blue and red team in the same scenario. The UGV evaluation was performed over several days and included:

- Basic training with SNOKEN II.
- Separate evaluation of driving performance.
- A group of six soldiers advancing along a street while utilizing SNOKEN II.
- Platoons advancing through urbanized terrain, which included defending and securing a crossing with SNOKEN II as an extra resource.
- Real combat with SNOKEN II where the UGV system was used by a group of six soldiers, which were included in a platoon of about 30 soldiers.

Data collection was performed using surveys, interviews, and observations. The intention was to get an overall understanding of the UGV system as a whole, that is the effects for the group and platoon in addition to the operators' situation. The results show that both operators and group/platoon leaders identified positive as well as negative effects of the system. The positive effects were:

- The possibility to gather reconnaissance information while minimizing the casualties of own forces.
- Better possibility to conduct reconnaissance without being detected.

- The group/platoon leader could get direct information from an advanced position by looking at the screen instead of a verbal report of what the soldiers saw. Thus, the soldier's interpretation of the situation before reporting was avoided.
- The group/platoon leaders could receive information from the UGV display or operators and still perform ordinary duties.
- The SNOKEN II vehicle can be carried on the back without any substantially decrease in performance of ordinary duties, as illustrated in figure 5. However, the soldier carrying the system of course gets tired more quickly than the others and runs slower due to the extra weight. This is very important since an extra vehicle otherwise would have been required to transport SNOKEN II, which would have limited the use of the system and affected the concept of operations.

Figure 5: Soldiers that carry SNOKEN II on the back are still able to conduct their ordinary duties.

The negative effects of using SNOKEN II were:

- Increased time for the advance phase towards enemy positions due to the additional time required for the vehicle to scout the terrain for enemy activities, receive the information, evaluate it, decide how to proceed, and return the vehicle back to the operators.
- UGV operators cannot simultaneously perform ordinary soldier duties, such as scouting the surroundings for enemy activities since they have to focus on controlling the UGV. Figure 6 shows how another group member instead covers the surrounding area while the operator controls the UGV.

The MOUT exercise clearly shows that the tempo varies considerably from situation to situation. Soldiers sometimes run during the advance phase, but after securing a crossing the soldiers can stand still for 30 minutes or longer for tactical reasons. Although the UGV system was not useful in some situations, it had a substantial positive effect in many other situations. For example, the UGV system was useful for gathering reconnaissance information both before and after securing a crossing. Further, the UGV system was useful for scouting ahead of the next crossing while guarding to provide reconnaissance information about enemy activities and the surrounding area. The UGV system can also potentially be useful for identifying suitable targets for indirect fire and battle damage assessment, although these applications have to be investigated further. Finally, soldiers always have to prioritize the immediate situation during direct combat and cannot be UGV operators at the same time.

The evaluation also suggests that some functions may need to be automated. For example, the UGV could automatically follow the operator during some parts of the advance when the soldiers have to be in combat position with the weapons ready to fire. Another example is when soldiers have to withdraw from a situation and do not have time to operate the UGV system. It would be convenient to call the UGV back to a certain position in such situations with a voice or one button command.

In summary, the UGV system can be used successfully in a number of situations, although it is also important to understand the disadvantages so that the commander can decide in which situations s/he

Figure 6: The UGV operator controls the UGV while his/er group member scouts and provides cover over the surrounding area. The UGV operator needs cover since most of his/er attention is focused on controlling the UGV.

should use the UGV. For example, there is a tradeoff in accepting the limitations on pace of advance and the possibility of saving lives and gather reconnaissance information that otherwise would not be available.

The advantage of performing evaluations with field studies is that the area of interest can be studied in a real setting with good face validity. On the other hand, it is often difficult to control all the relevant factors. This was the case during the MOUT exercises in both Norrköping and Linköping. The next natural step in the research process is therefore to use the results from the field studies and investigate some aspects further in a more controlled laboratory setting.

2.3 Simulation of UGV and MOUT environment

A previous project at FOI has developed a simulated virtual reality (VR) environment of the same area in Norrköping that was used for the MOUT exercise (Kylesten et. al., 2004). The area is about 2.4 x 2.4 km with sparsely spaced houses without textures, and an area of 350 x 350 meters that is fully textured. The plan for 2006 is to introduce a simulated UGV in this environment by connecting the SNOKEN II's operator interface software to the VR environment and a simulated vehicle with performance characteristics that are similar to SNOKEN II. The intention is to create a simulated environment where various UGV issues can be investigated, such as the operator interface, automated functions, concepts of operations, and the use of multiple UGV systems. Relevant research questions will be identified based on the results from previous field studies. The measures of performance will cover several levels, from driving performance to attentional requirements during reconnaissance missions and the effects on enemy tactics.

Additionally, a cognitive task analysis (CTA) is also planned during 2006 for a better understanding of the UGV operator's decision making requirements. The CTA will be performed in conjunction with the other studies of simulated MOUT-scenarios. Several CTA methods are applicable, but the two of most interest here are the Critical Decision Method (CDM) (Hoffman, Crandall, & Shadbolt, 1998), and the simulation interview (Militello & Hutton, 1998). CDM is basically a semi-structured interviewing technique that consists of seven steps. The intention is to elicit expertise in decision-making by retrospection of own experienced events in a real domain case. The steps in CDM are:

1. *Preparation*: Train elicitors (interviewing skills, become familiar with the domain, define goals with the study). Make sure sufficient number of experts are available to interview.
2. *Incident selection*: Select an incident when the expert's decision altered the outcome. The incident must come from the person's own experience.
3. *Incident recall*: The participant is asked to recount the episode in its entirety and then retell or "walk through" the incident and to describe it from beginning to end.
4. *Incident retelling*: The elicitor then tells the story back. The participant is asked to attend to the details and sequence. The participant has the opportunity to add details, corrections, and clarifications. This allows the elicitor and the participant to have a common understanding of the incident.
5. *Time line verification and decision point identification*: The participant/expert goes back over the incident a second time and is asked for the time of key events. A time line is composed.
6. *Progressive deepening*: The elicitor leads the participant back over the incident a third time, employing probe questions that focus on each decision-making event within the incident. Probe questions could be for example: What information did you use in making this decision and how was it obtained?; What were you seeing, hearing?; What were your specific goals and objectives at the time?
7. *"What-If?" queries*: The fourth sweep through the incident is shifting the perspective from the participant actual experience of the event to a more analytical and hypothetical level.

Data Analysis is then carried out to put all the information from the interviewing protocol together and make sure it makes sense by trying to reason in a logical way. This step does not include involvement from the participants. See Jander (2005) for more information about how CDM has been applied to amphibious forces and treat warning systems in Mechanized Infantry Combat Vehicles (MICVs).

The second CTA method, the simulation interview, also provides a view of an expert's problem solving process in context, but with experiences from simulated events instead of real own experienced events as in CDM. The simulation of interest should be focused on difficult and challenging elements of the job, although the simulation does not have to be of high fidelity. The simulation interview starts with the participant interacting with the simulation. The participant is then asked to identify major events in the simulated incident. One event at time is then analyzed in terms of actions, situation assessment, critical cues, and potential errors.

Both CDM and the simulation interview can be used for many purposes, such as elicitation of decision making, problem solving, and team work. The methods are mainly suited for studies of Naturalistic Decision Making (NDM).

The CTA study during 2006 will use experienced participants from all levels within the system ranging from operators to platoon commanders, but also from the enemy's point of view. That will hopefully lead to a more holistic view of how the system operates today and potential future improvements.

3 Tactical application of UCAVs

No UCAV is currently operational but several prototypes are in development. The two programs that are particularly interesting are the US J-UCAV program which is mainly intended for strike missions, such as Suppression of Enemy Air Defenses (SEAD) (Warwick, 2004), and the European Neuron which is more focused on more general strike missions (Kenyon, 2005). Generally, the benefit of these platforms is that they combine the advantages of long range stand-off cruise missiles with tactical adaptation to changing mission requirements and threat situation (NRC, 2005). Since the Swedish Air Force is currently performing two separate studies of both SEAD and how UCAVs can be used for strike missions, preliminary investigations of manned-unmanned teaming has been performed for these applications within the project. The main focus has been to try and investigate which operational requirements this generates in order to support successful coordination between the platforms from a human factors perspective. The investigation of manned-unmanned teaming for SEAD was based on a literature review and a number of discussions with personnel from the Swedish Air Force. The concept of manned-unmanned teaming for SEAD is discussed next, followed by manned-unmanned teaming for general strike missions.

3.1 UCAV for SEAD missions

SEAD is an activity that neutralizes, destroys, or temporarily degrades surface-based enemy air-defenses by destructive and/or disruptive means. It requires detailed mission planning, extensive coordination, and rapid tactical responses to successfully attack an enemy's Integrated Air Defense System (IADS) in support of friendly forces. (Joint Pub. 3-01.4, 1995). The overall goal of SEAD is to allow friendly aircrafts to operate in airspace defended by enemy air defense systems. Hence, SEAD is mainly a tactical operation that admits other air operations, such as strike missions, reconnaissance missions, and sweeps/escorts to be performed under less threat during a certain amount of time. The SEAD course of action can either be destructive by using air-to-surface weapons, such as anti-radiation missiles, or disruptive by using an electronic attack. SEAD is therefore normally performed with attack jets, such as Tornado, Prowler, and F-16. Further, varying procedures are used for preplanned SEAD based on intelligence information and reactive SEAD of "pop-up" surface-to-air threats. The SEAD can also be sequential by preceding other missions in order to introduce a window of opportunity or it can be concurrent referring to when SEAD is performed simultaneously with other missions. A comprehensive description of SEAD can be found in MCWP 3-22.2 (2001). Ternblad (2004) also provides a description of SEAD and presents some examples of when and how SEAD has been used.

There is an international trend that SEAD operations are arranged in separate layers based on the distance from the enemy's IADS. The actual airspace above the IADS will be operated by UCAVs performing SEAD attacks when necessary. Immediately behind the first layer, manned platforms will control the airspace and perform any additional tactical objectives, such as reconnaissance. Another important responsibility for the manned platforms is also to identify and react to any air-to-air threats that might show up in any of the other layers since the UCAVs that are planned for SEAD missions are not sufficient for air-to-air combat and therefore need protection when such threats appear. Finally, any additional forces, such as a strike package, will wait in the third layer for clearance to cross the enemy's IADS airspace escorted by other manned platforms while the UCAVs suppress the IADS. The objective of the strike package might for example be a strike mission, close air support (CAS), or reconnaissance.

One of the advantages of using UCAVs for a SEAD mission is that personnel and manned platforms may be available for other tactical operations while the UCAV perform SEAD. For example, an increased number of manned platforms may be used for escorting a strike package through the enemy's IADS airspace while UCAVs are performing SEAD. Further, higher risks may be acceptable since the UCAV is unmanned. One possible effect of accepting a higher risk is an increased use of electronic attacks while reducing the use of weapons. This, in turn, could result in fewer fatalities, less environmental pollution, and lower costs. Foremost, however, UCAVs can provide access to enemy airspace for manned platforms to perform other tactical missions, such as surveillance and reconnaissance, which results in an improved overall effect.

There are, however, a number of issues that needs to be identified, addressed and resolved before UCAVs can fulfill the SEAD role. The collaboration and coordination between the UCAV and the manned platforms is one of the most important issues since a UCAV that is used for SEAD is a distributed collaborative control system that involves multiple agents (Flach, Eggleston, Kuperman, & Dominguez, 1999). How to achieve effective collaboration and coordination between agents with different levels of automation, capabilities and locations is a major challenge, however. Some of the issues that need to be addressed are:

- *Authority* – Who is in charge in a certain situation?
- *Responsibility* – Who does what, when and how?
- *Intentionality* – Is the intention of the UCAV observable and understandable?
- *Trust* – Do the other members of the team trust that the UCAV will take the right action in a certain situation, and does it perform the right action?

All of these issues need to be addressed for successful collaboration and coordination between manned and unmanned platforms. Common for all of them is that they are strongly connected to the level of automation (LOA) (Sheridan, 1992; Billings, 1997) of the unmanned platform and the level of control (LOC) by operators (e.g., Hollnagel, 2005). An old viewpoint, especially from a technological perspective, is that an increased level of automation will decrease the necessary level of control by human operators. In this case, however, an increased level of automation instead implies an increased need of control for a highly coordinated team of manned and unmanned platforms. One way to approach the control problem is to consider the team of manned and unmanned platforms as a joint cognitive system consisting of human operators and automated systems. This is the basis of Cognitive System Engineering (CSE) (e.g., Hollnagel & Woods, 2005) which is the main approach for the project. A cognitive task analyses can be performed within CSE to establish the human decision making requirements for controlling UCAVs in SEAD missions, such as:

Number and competence of operators: Recent practical experiences indicate that controlling a UCAV from an environment separated from the battle, solely relying on displays and indicators is a highly demanding task in terms of workload and competence (e.g., diverse competences such as knowledge of sensor and weapon systems, and piloting skills, etc. might be needed for a certain mission).

Remoteness: The remoteness of the operator in relation to the UCAV and the battle is a challenge for effective collaboration (e.g., where should the operator be located – on the ground or in a manned flying platform?).

Interface and control: Supporting the operator's situation awareness and performance is of greatest importance as well as limiting the workload to a sufficient level (e.g., how should the interfaces be designed?; what information should be displayed to whom?; when and how should the operator manually control the UCAV?).

Coordination: Ensuring the coordination between the operator, the unmanned platform and manned platforms is probably the most crucial aspect for successful performance (e.g., how is the information distributed between the different platforms?; how should the level of automation and the level of control be designed for optimal performance).

These factors are closely related to each other. With the established objective in mind (i.e., what is the purpose and goal of using the UCAV for SEAD), different settings could be designed and studied in a controlled manner in a simulated environment, such as the Swedish Air Combat Simulation Centre (FLSC).

3.2 UCAV for strike missions

The project is currently supporting a Swedish Armed Forces study regarding potential applications for UAV/UCAV and manned-unmanned teaming for strike missions. The study of manned-unmanned teaming is intended as an explorative evaluation of how different operator roles and UCAV sophistication affects mission effectiveness and coordination requirements. The evaluation will be performed at the Swedish Air Force Combat Simulation Centre (FLSC) using a fictive Peace Support Operation (PSO) scenario in the Kosovo region. Figure 7 illustrates the scenario where an allied flight takes off from southern Italy to attack a stationary target in Kosovo. The flight is supported by airborne aerial surveillance and electronic warfare. Several other allied flights also operate in the area. Potential threats may be Integrated Air Defence Systems (IADS), especially near the target area, as well as hostile fighters.

The composition of the flight is not completely finalized, but will generally consist of two manned fighters and two UCAVs that will be controlled from the fighter(s). The manned fighter(s) that control the UCAVs will be two single-seater JAS39C or a flight with one JAS39C and one two-seater JAS39D, although other combinations are also possible. The backseat operator in JAS39D will be responsible for controlling the UCAV and can devote more attention to the UCAV than the single pilot in JAS39C. The UCAV have capabilities that similar to the Neuron demonstrator, that is a large UCAV with stealth capability and onboard sensors for threat detection. The UCAV can autonomously follow a flight plan and terrain, avoid obstacles and threats, fly in formation, and return to base. Mission replanning, as well as configuring and overriding the autonomous behaviour is, however, the operator's responsibility. The UCAV is equipped with GPS-guided small diameter bombs that can find the target autonomously once released within a certain range and aspect angle. UCAVs with other capabilities may be considered for later evaluations.

Figure 7: Strike mission in support of a fictive PSO in the Kosovo region.

The project's main contribution to the UCAV study in FLSC will be to develop measures of coordination between the operators' expectancies and the actual behavior of the UCAV. The measures will cover configuration of autonomy modes, efficiency of supervisor control, and management of mode transitions. A cognitive task analysis will also be performed for a better understanding of the actual control, decision, and information requirements.

4 Tactical UAVs

Many types of UAVs can and are used for tactical applications, such as reconnaissance and target acquisition in support of advancing ground forces. The recent developments of small and inexpensive UAVs that are hand-launched by forward troops have, however, made this capability more readily available. Some examples of these UAVs are the Raven for the US Army, Dragon Eye for the US Marine Core, and Skylark which is developed by Elbit Systems. Skylark is currently evaluated by the Swedish Armed Forces as a potential resource for the Nordic EU-Battle Group that will be operational in 2008. Hand-launched UAVs typically weigh a few kilograms, have a 1-2 meter wingspan, and fly at an altitude of 100-300 meter for 30 minutes to 2 hours. The tactical UAVs are usually equipped with an electro-optical sensor for video stream, navigation system, and autopilot for autonomous navigation between waypoints. Tactical UAVs allow ground forces to observe potential adversaries that are not within line of sight due to surrounding terrain or structures in urban terrain.

The risk of major ambushes can thus be considerably reduced. Once a target has been identified, indirect fire or close air support can be used to neutralize the threat. The need for tactical UAVs is illustrated by reports of how the Raven quickly has flown around 5.000 hours in Iraq (Schloesser, 2005).

The rapid development of tactical UAVs often results in operator interfaces that are not optimal. Many improvements can probably be made using the principles for human-robot coordination that are discussed in the introduction (see Svenmarck, 2005d). More significant improvements may, however, be obtained if the control and interpretation of the sensor suite can be performed at a higher level of abstraction. Currently, all sensor control and target identification is performed manually by the operator who uses a simplified control station and may have other additional tasks when operating from a forward position. One possible solution for control at a higher level of abstraction is to use intelligent image processing techniques to identify events that require the operator’s attention. Such a system would thus free the operator from the most mundane aspects of sensor management. The possibility of sensor management at a higher level of abstraction is currently investigated in a project for intelligent surveillance systems (Murray, 2005). Their intention is to develop an event template hierarchy for event-based reasoning using an event-discovery protocol to uncover event categories and the temporal structure of events. The event template hierarchy can then be used to direct and focus the operator’s attention in order to detect anomalies. A similar methodology may also be applicable to sensor management for Tactical UAVs or even coordination of multiple unmanned systems to cover more complex events.

5 Tactical UUVs and USVs

Unmanned underwater vehicles (UUVs) have been used for a long time in maritime applications, such as inspection, oceanography, and mine countermeasures (e.g. Sheridan & Verplank, 1978). UUVs have traditionally been tethered and under full manual control. One example is the Double Eagle Mk II from Saab Underwater Systems that is used by the Swedish Navy for mine countermeasures. The Double Eagle operates a few hundred meters ahead of the surface vessel where mines are localized with the onboard sonar and then detonated using an explosive charge. Developments in sensor and control capabilities have, however, enabled more autonomous operation and expanded the potential range of missions. Potential missions for UUVs now include ISR, anti-submarine warfare, communication node, payload delivery, information operations, and time critical strike (DoN, 2004). Unfortunately, UUVs are not used tactically for any of these missions due to the limited communication bandwidth from audio data links and limited energy sources. Although anti-submarine warfare may seem like a tactical application, the UUVs primary role is to monitor and track submarine traffic through an adversary egress or choke point and then hand-off the submarine to other forces. Neither does there appear to be any tactical considerations for time critical strike where the UUV waits for a launch command at a predetermined launch point. A similar application is also investigated in the Swedish project Torpedo Mine Sensor for integrating sensor capabilities, autonomous operation, and agile remote detonations.

Unmanned surface vehicles (USVs), on the other hand, can both use radio technology for broadband data links and organic fuel which enables longer endurance. One of the most sophisticated USVs is the Spartan Scout Advanced Concept Technology Demonstrator (Maguer, Gourmeln, Adatte, 2005; Hewish, 2004). The Spartan Scout is 7 m long and intended as a modular and multi-mission USV for ISR, force protection, target acquisition, precision strike, and littoral mine and anti-submarine warfare. Many of these missions are of a tactical nature where continuous coordination is required between the USV and other surface vessels. For example, cooperative tactics may be used to detect and track submarines that can be neutralized by the USV or other surface vessels. Currently, however, studies of USV in Sweden have mostly focused on ISR (e.g. Byström, 2004).

6 Conclusions

The report shows that manned-unmanned teaming is useful for many tactical applications. The applications that currently are of most interest to the Swedish Armed Forces are reconnaissance during MOUT scenarios using UGVs and tactical UAVs, and strike missions using UCAVs. These applications will therefore be investigated in more detail during 2006 using more controlled laboratory and simulator environments. Other tactical applications, such as SEAD using UCAVs, submarine warfare using USVs, and using UAVs to scout ahead for attack helicopters, will probably not be investigated further due to the limited interest for the Swedish Armed Forces.

Further, even at this preliminary stage, applying a CSE methodology has helped to identify complexities of manned-unmanned teaming both from the operator's perspective of human-robot coordination, as well as secondary effects on team-mates and leaders. The cognitive task analysis during 2006 of manned-unmanned teaming for MOUT scenarios and strike missions will expand on these results and provide further suggestions for where and how autonomous functions may be useful. The progress therefore continues as planned towards the project's goals of developing at least one demonstrator of functional cooperation between manned and unmanned systems, and documented experiences of applying a CSE methodology.

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