DECISION SUPPORT FOR THE GRIPEN AIRCRAFT AND BEYOND

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Abstract

This article is a report on ongoing projects at Saab Aerosystems on decision support functions for collaborating aircraft and ground control systems. We use the future Gripen aircraft and the Skeldar rotor UAV as example actors and a Close Air Support (CAS) scenario to outline a number of decision support elements and architecture. The most important elements include collaboration between unmanned rotor UAV:s & manned aircraft, advanced image geocoding and processing, and autonomous UAV functions.

1 Decision support functions for fighter aircraft

Many modern fighter aircraft systems have traditionally been designed for the traditional air-to-air and air-to-surface and reconnaissance tasks in military offensive and defensive scenarios. This division of labor is usually reflected in the decision support systems. However, experiences from recent conflicts - often called irregular or asymmetric warfare - show that missions may involve a complex mix of aggressive single-aircraft long-distance missions, home-land defense to purely peace-keeping operations involving several cooperating aircraft and ground based systems with a complex combination of civilian and military situations. The decision support system for fighter aircraft will have to focus on the following areas:

- Optimization of aircraft resource allocation (task and multi-sensor allocation)
- Semi-automatic image-based target recognition and moving target identification and Tracking
- Automation of evasive maneuvers from pop-up threats
- High-level control of sensors and external assets (UAV:s)
- Missile threat assessment
- Collaboration between manned and unmanned aircraft
- Image-based geocoded tracking
- Situation analysis (targets, threats and non-combatants)

Some programs at Saab are looking into more general threat analyses and situation awareness problems. In this article we will focus on the following decision support for a close air support scenario and collaboration between manned and unmanned aircraft.

1.1 Previous work on fighter aircraft decision support systems

There have been several programs for automation of tactical support functions for aircraft heavily influenced by work in artificial intelligence and agent modeling. The general theme here is to recommend or automate decisions using cognitive models of the pilot and models of the situation. Many approaches have been influenced by the seminal work of Endsley [1], who gives a general definition of situation awareness as a 3-level process: Perception, Comprehension and Projection of future status.

In the open literature, previous work in automation of decision support functions for fighter aircraft include the study of P.C. da Costa [1] who used a framework that combined Bayesian decision networks with influence diagrams ("Dynamic Decision Networks") in a divide-and-conquer approach to fuse track and sensor data to produce threat assessments.

A pilot assistant demonstrator using multi-agent technology was built at the Dutch Aerospace Laboratory NLR [3]. The Pilot's Associate was an ambitious American DARPA program [4] [5] that used expert system technology to produce real-time recommendations to the pilot (< 0.1 s). The approach was based on plan-goal graphs, and the system provided the pilot with automatic re-planning alternatives given a complex situation. The PA program was followed by the DERA program, focused on Rotor aircraft that often operate in more varying and dangerous conditions than fighter aircraft.

In the French program Pilote Electronique [6] the main focus was to make a cognitive model of the pilot to model activities (as opposed to goals) during an attack mission, balancing between short-term navigation and long term mission goals. The main focus here was to model activities and to provide suggestions of actions. A similar cognitive approach was taken in the Swedish program for pilot, using an expert system approach with a framework called COGNET [7]. Several diploma theses performed at Saab have treated situation assessment multisensory control and situation analysis [8] [9] [10]. The Threat Response Processor was developed at Georgia Tech Research [11] to automate electronic warfare (EW) systems.

A recent thesis [12] gives an overview of decision support approaches in various problem domains and compares different techniques such as AI techniques, mathematical programming (optimization), Bayesian networks, and meta-heuristics in the electronic warfare domain. Missile tactics has been considered by many authors, see e.g. [13]. The CASSY and CAMA programs [14] was initiated by the German department of defense and was focused in modeling pilot behavior and intent, mainly for large transport aircraft.

A main problem with multi-agent systems and cognitive agent models in the manned fighter aircraft pilot domain, is that pilot assistant models are mostly useful in complex but predictable domains. In the fog of war ontologies may switch within seconds, and automated decision or assistants must be extremely robust to deserve pilot trust. Therefore, it is probably more realistic to introduce decision support in well-defined context independent domains such as threat analysis and aid the pilot with more simple condition-action rules. Another important area of automation will also include sensor scheduling and control, and cross-platform task allocation.

1.2 UAV:s as external sensors and decision support aids

The use of unmanned aircraft systems has exploded over the past 10-15 years, and there is an emergent need for collaboration between manned and unmanned aircraft systems. While decision support has in general implied aiding the fighter pilot with automation of decision making, less emphasis has been put on providing the pilot with external sensor information to aid the situation awareness.

Here various AI and autonomous agent approaches will be of great use, and are being used today in some advanced technology applications. In planetary robotic missions like the Mars Rover Spirit and Opportunity a certain amount of autonomy is essential due to the communication time-delay [15]. In many civilian applications like fire fighting and search and rescue autonomous cooperating UAV:s can be very useful [16]. For tactical reconnaissance, automatic functions for scouting areas for moving targets are essential to facilitate UAV mission planning and execution, and this will be an important application in the CAS-scenario described below.

In this paper we will focus on the first level of Endsley's situation awareness level, that of perception of the elements in the environment.

A typical close air support scenario involves a Forward Air Controller (FAC), a fighter aircraft and an Air Operation Center (AOC). The FAC essentially requests a service from a fighter aircraft, given sensor information from a UAV (here a rotor aircraft). Central to this division of labor is video links, high-accuracy targeting, and semi-autonomous UAV functions for reconnaissance, multi-target detection and tracking.

2 Scenario: Close Air Support

In the following scenario, the Gripen aircraft will be called the "aircraft", to distinguish it from the unmanned aircraft "UAV". AOC is "Air Operation Center" and UCS is the UAV ground control station, in effect acting as a FAC.

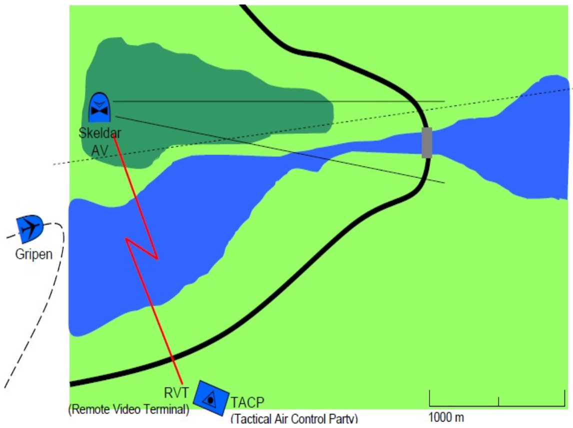

Figure 1. A Close Air Support scenario: TACP is a UAV control station, for the UAV that requests air support from a Gripen Aircraft.

A ground reconnaissance patrol launches a rotor-UAV to scout the terrain. The UAV mission has been planned on a mobile UAV ground control station using high-level commands to search, detect and follow multiple targets within a specified area. Video streams are down linked to the patrol over a video link, which means the UAV is within line-of-sight control of the UCS. The UCS station uses a moving target indication (MTI) software module to detect moving targets in the video stream, and high accuracy track coordinates are calculated from the geocoded video sequence, using high accuracy 3D reference maps[1]. Alternatively, geocoded track data can be derived using a laser designator on the UAV, often a part of modern EO/IR tracking systems. The MTI module detects and signals movements, and the UCS operator detects and initiates a tracking of vehicles along a road. Changing to a higher zoom factor leads to the conclusion that it is a military convoy, further supported by an IR image processing threat library.

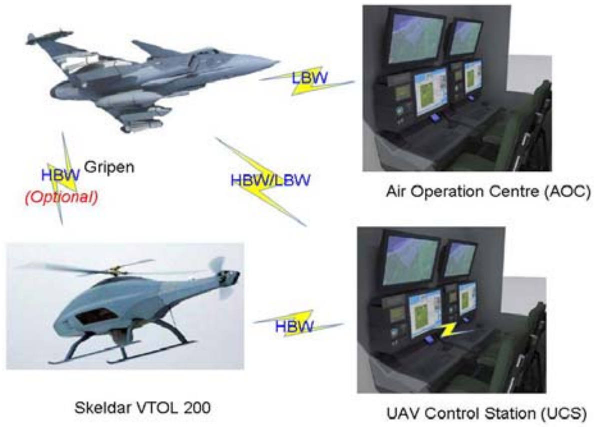

Figure 2. Example of actors in the CAS scenario: A manned A/C, UAV and ground control stations (AOC + UCS). HBW=High Bandwidth, LBW=Low Bandwidth

The reconnaissance patrol FAC calls for air-support from a patrolling Gripen aircraft and uplinks track information of the convoy to the aircraft. The aircraft in turn reports the request for CAS to the Air Operation Command (AOC) and is cleared for the mission. AOC reports possible hostile areas (no-fly zones) to the aircraft, and the onboard decision support system uses this information to automatically plan a route to the mission waypoint.

Meanwhile, the ground control uses the UAV-sensor to take a series of close-up photos and uplinks them to the aircraft (no video link

[1] Many sensors today include MTI modules, but the geocoding is still a computationally heavy process better suited for a ground station. With the new avionics suite in the Gripen aircraft, however, geocoding can be readily done in near real time.

necessary). The track data from the UCS is used to initiate a slaving of an aircraft laser designator pod when the target is in sight (this task may also be performed by the UAV). The pilot switches to video tracking mode based on the uplinked coordinates, makes final slewing adjustments, aims the laser designator and initiates weapon engagement. The FAC reports engagement to the AOC and aircraft, and the UAV performs a damage assessment. Alternatively the aircraft performs the battle damage assessment, reports back to the FAC and AOC and returns back to base.

This scenario highlights a number of basic decision support elements:

- Cooperation between manned, unmanned aircraft and ground control station coordinated by the FAC
- Image, video and track support for visual identification of threats
- High level UAV commands and intelligent UAV reactive reconnaissance functions
- Advanced geo-coding techniques

3 Decision support elements

3.1 Video & data links

The UAV in this scenario can be seen as an extended sensor, and the reconnaissance group as a FAC. Cooperation between the FAC and the aircraft involves standard com-radios, a two-way video data link for visual identification and clearance from Air Operation Center is usually necessary.

3.2 Image Processing

The aircraft needs display surfaces and functions that allow for display of both external video feeds and images, as well as own aircraft sensors. Typical image processing functions are standard zooming and panning, readily done with HOTAS functions. Comparison of own and external sensor feeds are important, and split-screen functionality will be important.

Assisted target recognition functions may be available on reconnaissance sensors, but more realistically they will reside as back-end applications in the aircraft, and pre-programmed with threat libraries and user-defined algorithms. ATR critically depends on the data quality, the sensor properties and – most importantly – the expected threats. When performing wide area reconnaissance and multiple object tracking, data association becomes an issue and here pattern recognition methods must be used. Advanced learning methods and robust feature extraction methods must be used to achieve a robust ATR, and this is an area of active research. For sensors like synthetic aperture radar and infrared imagery, physics based methods are usually more robust than pure bottom-up image processing methods. Identifying a target for weapon delivery, however, requires a human in the loop.

Figure 3. Cockpit display of simultaneously uploaded video feed from a UAV Skeldar (left display surface) and onboard video from a laser designator device (right).

3.3 Geocoding

In the above scenario it is assumed that track data are reported as absolute geographical coordinates. These can be derived using either active measurements – laser designators – or passively. If coordinates are measured passively for high precision target acquisition, the video stream needs to be geocoded, typically a computationally heavy process. Geocoding – sometimes called Orthorectification - can be achieved in different ways, but typically assumes the existence of high-precision reference map data, texture (images) and high resolution terrain models.

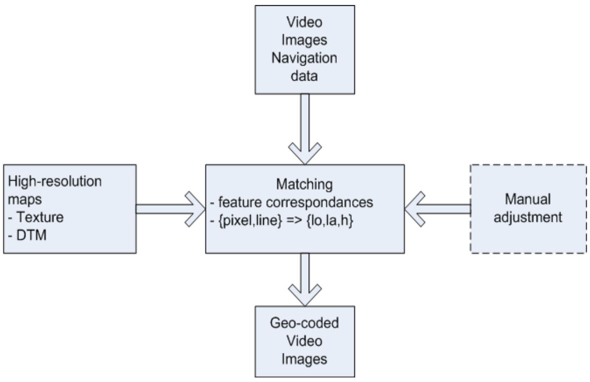

Figure 4. Geo-coding is typically done automatically using 2D or 3D input data. For some types of reference data manual adjustment may be needed. The process typically requires powerful CPU resources, and is best performed in the ground segment (with the new Gripen avionics suite the process may be done on-board).

Traditional methods use 3D image texture to map the data with existing geocoded reference images and a digital elevation model. More advanced methods use on-line 3D mapping, where the sensor directly delivers a 3D map using ego-motion to get a stereo baseline. This 3D map is then rectified using a high-resolution 3D map using a combination of 3D and texture data. As a general rule, laser designators are best in oblique geometries, whereas as automatic geocoding of image/video is more robust at angles normal to the ground plane.

4 Technologies

4.1 Geocoding

Geocoding an image using texture data only requires in principle three major steps:

- Detection of feature correspondences between the present and existing reference images
- Derivation of a mapping from {pixel, line} to {lat,lon,elev}
- Warping/re-sampling of the image/video data

The first step – finding feature point correspondences – is the most difficult part, and in most traditional remote sensing systems this is a manual process, although many software system are now pursing automatic methods[17][18]. The image processing community has made substantial progress here [19][20] using scale and rotation invariant feature vectors and advanced outlier detection methods. The process can be aided using navigation heading information, to make a rough estimate of the rotation angle between the current and reference image. An interesting example of this process in action can be seen on the web-site http://photosynth.net.

The last step is mostly used for creating large image mosaics on image servers, and is typically performed by high-performance software on specialized image servers. This step can be omitted if the objective is to be able to acquire coordinates from the video feed using the mapping function.

An essential component here are the statistical errors introduced in the derivation of the mapping: Each coordinate is associated with an error field over the image/video. The extent of the error depends on the nature of terrain (rugged, shadows, flat, etc) and mathematical functions used to model the mapping. When acquiring coordinates from the display it is essential that the pilot be aware the total error in each pixel: This will ultimately determine whether or not a weapon engagement can be performed.

In some cases automatic geocoding may not be possible because of lack of available of image map data (texture + terrain). Assuming the existence of vector data, it is still possible to use fixed reference points and corresponding points in the sensor data to make a *locally* well-defined mapping between pixels and geographic coordinates. Several tests at Saab have verified the practicality of this using the cockpit existing interface.

For high-precision geocoding to work, reference data must be derived with a high absolute geographic accuracy. Many efforts are being made to derived high-accuracy terrain data using e.g. LIDAR measurements from low-flying A/C. Other efforts are devoted to deriving simultaneous texture and terrain data using standard SLR cameras and high-precision navigation systems and phase differential GPS correction [22].

4.2 UAV autonomous functions

It is essential that UAV:s can be controlled using high-level commands and simple and intuitive high level commands and interfaces. This requires a sufficient level of autonomy - independence of direct control - that enables the operator to focus on tasks rather than flying. We make a difference between Core Autonomy and Tactical Autonomy: The former deals with safety aspects relating basic flying, the latter concerns the mission critical parts. The UAV needs to handle High Level Commands (HLC) from external actors, some examples of HLC:s are (here assuming both fixed-winged and rotor UAV:s):

- Loiter/Hover (CA)
- Set Course/Speed (CA)
- Landing (CA)
- Mode logic (CA and TA)
- Wide area search (defined by map) and report “interesting” targets, e.g. moving targets, road search, etc. (TA)
- Manual sensor slewing and slaving to given geographic coordinates (TA)
- Video tracking (TA) and geocoding

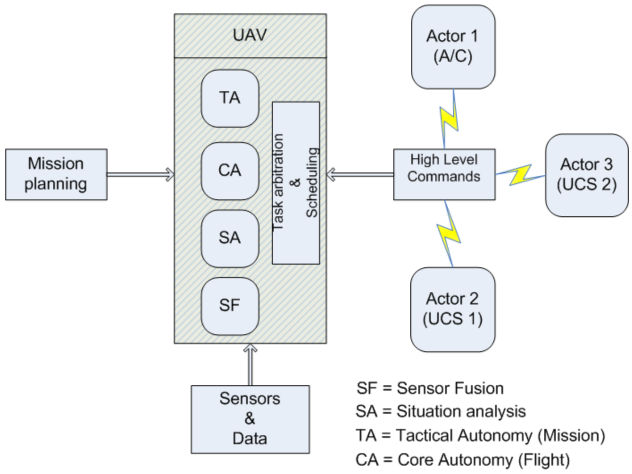

Figure 5. Several types of actors may control UAV:s using high level commands and pre-defined mission programs. Conflicting requests are handled by arbitration and scheduling. For the present CAS mission, only one actor and one UAV is present.

In the scenario above, the FAC needs to reconnoiter an area for moving vehicles. Assuming there is no GIS or map information on the existence of roads (where vehicles travel), the UAV needs to somehow find roads using e.g. computer vision techniques (see e.g. [21]). The reconnaissance can be performed using a simple comb-like pattern as in classical remote sensing mapping, or a more reactive approach, where the UAV uses a multiple target planning and search approach. This can be done using a model predictive control approach (“Receding Horizon”) with information filters (a version of the Kalman filter) and a reward function based on the cumulative probability of detection [23].

Some UAV functions may be deployed in the ground segment (UCS), others in the air-segment on board the aircraft. For example, contingency plans for fault mitigation (such as loss of C2 link) must be present on the UAV, whereas geocoding of video may be done on the UCS.

The deployment of high-level commands has to be handled by a module capable of translating intentions to a series of tasks. The complexity of this operation depends critically on the type of commands, and may involve a simple state-machines and traditional control theory guidance functions, to a generation of task-trees, planning and scheduling using a multi-agent system [24]. The choice ultimately depends on the application, rules of the air and the rules of engagement.

5. Discussion and conclusions

This paper has discussed some issues related to the collaboration between a manned fighter aircraft and an unmanned aerial reconnaissance vehicle. We propose that semi-autonomous reconnaissance functions on UAV:s together with advanced video and tracking methods on fighter aircraft can be a powerful joint system for CAS scenarios.

If collaboration between manned and unmanned aircraft systems will grow in the future, this will most likely have an impact on fighter aircraft support systems. In the fighter aircraft domain, we expect that more emphasis will be based on situation awareness, and automation of “standard” tasks such as multi-sensor control and threat analysis. A relatively high degree of automation and the use of high-level commands for UAV control are also necessary.

The acquisition of high resolution reference data in military contexts used to be surrounded with top secrecy; the maps from Napoleons expedition to Egypt were regarded as top secret for over a century. Today many online search engines have street-view and map functions that allow for sub-meter precision coordinate acquisition. For military operations, however, publicly available data is usually not an option because of legal aspects, the need for up-to-date information, and – more importantly – the knowledge of position uncertainties and the exact details of the measurements process.

The lack of safety regulations for UAV:s have so far made combined missions with both manned and unmanned aircraft difficult. Program such as the MIDCAS [25] program will address the problems of mixed aircraft in civilian non-segregated airspace, but will not primarily address conflict theatre sense and avoid actions. In a close air support scenario UAV:s and manned aircraft both operate within a FAC-controlled local airspace. In a conflict situation it is usually very difficult to concentrate on both air space sensor & avoid and solving the mission task, and there is a need for more automatic airspace deconfliction systems.

Experience from conflicts in the 1960s and 70s showed that the use of fast fighter aircraft for CAS was less than optimal, and slow-moving school aircraft were often chosen for the task. Today, technology (UAV:s, high-bandwidth data links and sensors) and standardized theatre procedures has enabled a division of labor between the ground and air segments, which will enable a fast flying fighter A/C to perform well in a CAS mission. In this light, it is not surprising that live video and high-bandwidth communication links have been identified as mission and safety critical technologies in modern conflicts.

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