Unmanned Aircraft Systems against Air Threats: The Semi-Direct Control System

Frank Tempelman, Hans Heerkens

Abstract

In this paper, we propose a new control system for unmanned combat air vehicles (UCAVs), enabling these to engage in air-to-air combat. UCAVs could be very effective in air-to-air situations, mainly because manoeuvrability and endurance are no longer limited to those of the human body. Our Semi-Direct Control System (SDCS) eliminates a number of problems, preventing UCAVs being used against air threats nowadays, mainly with respect to bandwidth, latency, and situational awareness. In the SDCS, commands are supplied to the UCAV separated by intervals. In between these intervals, the UCAV has to sort things out for itself, but because of the relative shortness of the intervals, the amount of artificial intelligence needed in the UCAV is limited and feasible given today's standards. The SDCS additionally offers new possibilities for the Human-Machine Interface, further increasing operational effectiveness, and, although a number of research questions have yet to be answered, opens up new possibilities for operational use of unmanned aircraft.

1 Introduction

1.1 Background

Due to the introduction of new technologies, the effectiveness of manned fighter aircraft will probably decrease in the next twenty years. The range of air missiles increases, as well as their manoeuvrability: avoiding them may become almost impossible. The added value of stealth technology for manned aircraft will, according to the US Air Force, decrease due to the development of anti-stealth technology. Increasing flight performance of manned aircraft hardly decreases their vulnerability, and reaches its limits, due to physical limitations of the air crew. Laser and energy weapons increase the vulnerability of the human senses. Focus will move to long-distance or long-duration missions, pushing the limits on human stamina.

The obvious solution is the use of unmanned aircraft. For reconnaissance and the attack of ground targets, their use is fairly common nowadays, and development of unmanned fighter-bomber aircraft is on-going (e.g., the development of the Unmanned Carrier-Launched Surveillance Strike (UCLASS) aircraft by the US Navy (Rosenberg (2013), Majumdar (2013b)). Unmanned aircraft, probably co-operating with manned aircraft, will change warfare in many respects (Work & Brimley (2014)). Aircraft, much like the current ones, but in which the pilot is optional, are in research (Anonymous (2010)). However, attacking air-based targets using unmanned aircraft is, although slowly getting some attention (Robinson (2009)), still considered impractible for now, because of insufficient situational awareness for the pilot, and limitations in data links. The data link, necessary for a 'traditional' human pilot on distance, usually satellite-based, will probably have a delay of tenth of seconds. Such a delay is unacceptable in air-to-air combat, or in avoiding air-to-air missiles or energy weapons. The Semi-Direct Control System (SDCS) proposed here mitigates, and perhaps solves, these problems

1.2 Overview of this paper

In this paper, we will first discuss the advantages of using unmanned combat air vehicles (UCAVs) against air threats, leading to the logical question: why is it not done today? This is because it appears that there are a number of problems to overcome. We will discuss these problems, and propose a solution in the form of the SDCS. Its main principles are discussed and an example is given. An important aspect is the Human-Machine Interface for the SDCS, and we will give some special attention to ideas on that subject. After the conclusions, a number of steps to be taken and questions to be answered to make the SDCS feasible are outlined.

2 UAS against Air Threats

2.1 Advantages

The main advantage of using unmanned instead of manned aircraft in situations against air threats lies in overcoming the limitations of the human body. Humans can only handle a certain amount of G forces (in the order of 9 to 12G), limiting the manoeuvrability (acceleration and turn rate) of combat aircraft. Unmanned aircraft of course do not have a pilot on board. Hence, manoeuvrability is less limited (handling forces from 20 to 30G should be possible, giving the aircraft a manoeuvrability comparable to that of guided missiles), offering a better possibility to be a more worthy adversary to the increasingly effective enemy air threats. These air threats may even be unmanned themselves, and supplied with self-defence equipment. The development of UCAVs by adversaries, e.g., with a small high-tech sector but extensive resources and depth of defence, offers them the possibility for long-range strike and counter air, keeping war at a distance. There is a real danger expected that against unmanned fighter aircraft, only other unmanned aircraft can stand a reasonable chance of prevailing in an engagement.

Furthermore, both endurance and range of unmanned aircraft are potentially superior to those of manned aircraft, thanks to their lower empty weight and higher fuel fraction, and because of their optimized aerodynamics (no canopy etc.). Again, due to the limitations of the human body, a pilot can only be in an aircraft for a limited amount of time. Removing the pilot will increase the endurance of the aircraft, thus also extending the operational range where the aircraft can be deployed.

Humans are also more vulnerable to emerging types of threats, like the use of laser weapons, or directed energy weapons. Unmanned aircraft are less susceptible to these kinds of threats because of their manoeuvrability, redundant sensors and absence of physical risks for the pilots like blinding. This offers an additional possible increment of operational effectiveness.

Controlling UCAVs impose other physical requirements to the pilot as compared to manned aircraft. Manned aircraft require physical and mental characteristics that are found in only a small proportion of aspiring pilots. It is expected that, certainly in this age of computer technology and gaming, the pool of possibly appropriate UCAV pilots is larger than that of prospective manned aircraft pilots, and their training may be less costly since it can be done largely in simulators.

Finally, the lack of limitations due to the presence of a human on board the aircraft opens up new possibilities, like short or vertical take-off and landing, or operating at great altitudes. Even attacking low-flying satellites may be a possibility for unmanned aircraft.

2.2 Current problems

The foregoing raises the question why is it not done right now. Why are UCAVs not being used in air-to-air missions yet, as it, as we have shown, offers numerous advantages? The reason is that there are several serious problems to overcome when wanting to apply UCAVs in air-to-air combat.

In these types of situations, quick reactions are needed by a human pilot on the ground, based on proper situational awareness (SA). To obtain that SA, lots of sensor data has to be sent to the pilot on the ground. Bandwidth is however limited and data links are vulnerable to jamming or forging.

Furthermore, and maybe even more important: there is always latency in data links. This latency is at the very least in the order of tenths of seconds, which is, in air-to-air combat, far too much.

These problems could be solved in principle by applying totally *autonomous* UCAVs in air-to-air engagements. Latency problems and bandwidth limitations disappear when the UCAV can do most or all of its tasks on its own. However, despite the large amount of research that is done in the area of autonomy and Artificial Intelligence, the progression that is made thanks to this research, and that our optimism in this field of research is shared by others (e.g., Robinson (2009)), it will take decades to be able to send UCAVs on a mission with ‘destroy all enemies you encounter’ given as the only command. There are also ethical issues to consider: who is, or should be made, responsible for the act of a machine? For now, ‘full autonomy’, if existing at all, is not feasible, and an intermediate solution has to be found.

3 The Semi-Direct Control System

3.1 Explanation

The core of SDCS is that an Unmanned Combat Aerial Vehicle (UCAV) is operated by sending control commands in short intervals (varying from one to a couple of seconds). These commands do not directly steer the UCAV, but supply it with waypoints or commands instead: fly in a certain direction, fly to a certain position, approach a certain target, follow under a certain angle, avoid an air missile using a certain manoeuvre, attack an aircraft and so on. A Combat Manoeuvring Management System (CMMS), supplied with some intelligence and autonomy, calculates the optimal way to get from the current to the designated parameters (position, velocity, weapons and systems configuration). This is done by analysing position and movements of both aircraft and target, prediction of changes by using extrapolation techniques, and using these to calculate and execute the necessary direction changes. Although full autonomy may be a few steps too far for now, methods and techniques to locally detect obstacles and avoid collisions in a limited space, are getting more and more advanced (see e.g., Kelly (2010)) and can be applied to this end. In Figure 1, a stylistic impression is given of the SDCS, showing the commands, separated by intervals, and the manoeuvring in between these commands.

The pilot determines the tactics to be used, and can continuously modify the flight path, weapons deployment etc. based on the opponent's behaviour. The SDCS executes the pilot's commands. Expectations are that the SDCS can react in terms of milliseconds (not taking the delay caused by mechanical rudder movements and the like into account): sufficient for both in air-to-air combat and to avoid imminent threats like missiles.

The SDCS is positioned in-between direct control systems, in which the pilot directly controls the control surfaces and other devices (thrust vectoring) of the aircraft, and interval control, in which the pilot, using intervals varying from minutes to hours, directs the aircraft on a two-dimensional map, without being able to execute combat manoeuvres. SDCS eliminates the drawbacks of both 'classic' systems: there is limited data exchange, the volume of data exchange is small, but despite that combat manoeuvres can be executed. Furthermore, SDCS overcomes the problem of needing too much intelligence in the UAV: because the tasks the UCAV is ordered to do are relatively simple and easy to assess, only a limited amount of intelligence is needed. If some tasks, projected for the SDCS to execute, prove to need too much intelligence, the task can probably be split up into separate, less complex, tasks.

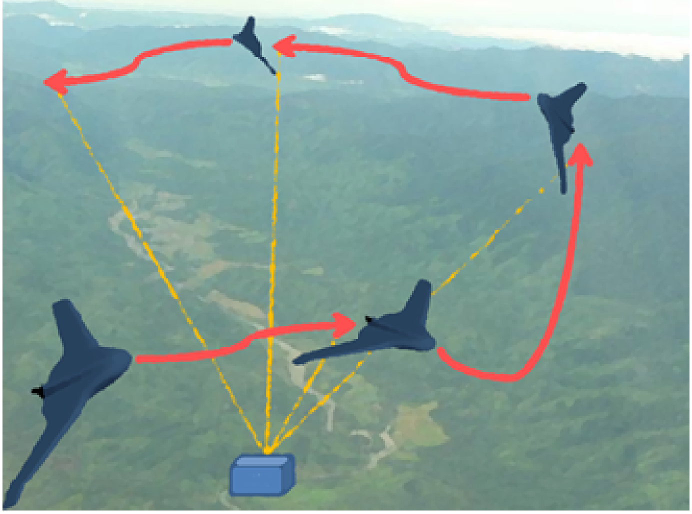


Figure 1 Stylistic impression of the SDCS

In general, one can say that there is a trade-off between the length of the interval and the complexity of the commands on the one hand and the intelligence, needed in the CMMS, on the other hand. One can imagine that over time, when artificial intelligence and autonomy options further improve, the intervals will lengthen and the commands will become more complex, or abstract, an abstract type of command being something like ‘get into good position’, a more concrete command ‘get to that-and-that position’. In the meantime, the SDCS offers, when varying on the interval time, an interesting research vehicle on autonomy and artificial intelligence.

The SDCS is especially suited for situations in which quick reaction is needed because of obstacles or threats, and where direct joystick control is not feasible or precise enough. Furthermore, the predictability of totally autonomous behaviour in for instance dogfights can be avoided. Direct control requires detailed situational awareness, SDCS requires much less.

3.2 The Human-Machine Interface

The SDCS control can take place in a traditional Human-Machine environment. However, we see additional, more advanced, opportunities to increase the effectiveness of the SDCS, by locating the controller in a Virtual Reality (VR) environment.

In this environment, a synthetic picture, based on data, video, audio and other sensory cues from the UCAV and other platforms, and probably with real-time simulation data added, is created. The environment can possibly be presented in a way that the pilot has a virtual view from inside the UCAV. Of course, also data like speed, altitude etc. can be shown. It is possible for the pilot to 'step out of the cockpit' and view the airspace with both his/her own vehicle and opponents. Think for instance of a 'dome' on the wall in which synthetic representations of goals are shown in more detail than a pilot of a manned aircraft would see, or a Virtual Reality helmet. This results in improved situational awareness as compared to the current indirect control systems, in which the UAV is usually a dot on a two-dimensional map, and may make the UCAV usable in a more high-risk environment than is considered acceptable right now (Majumdar (2013a)).

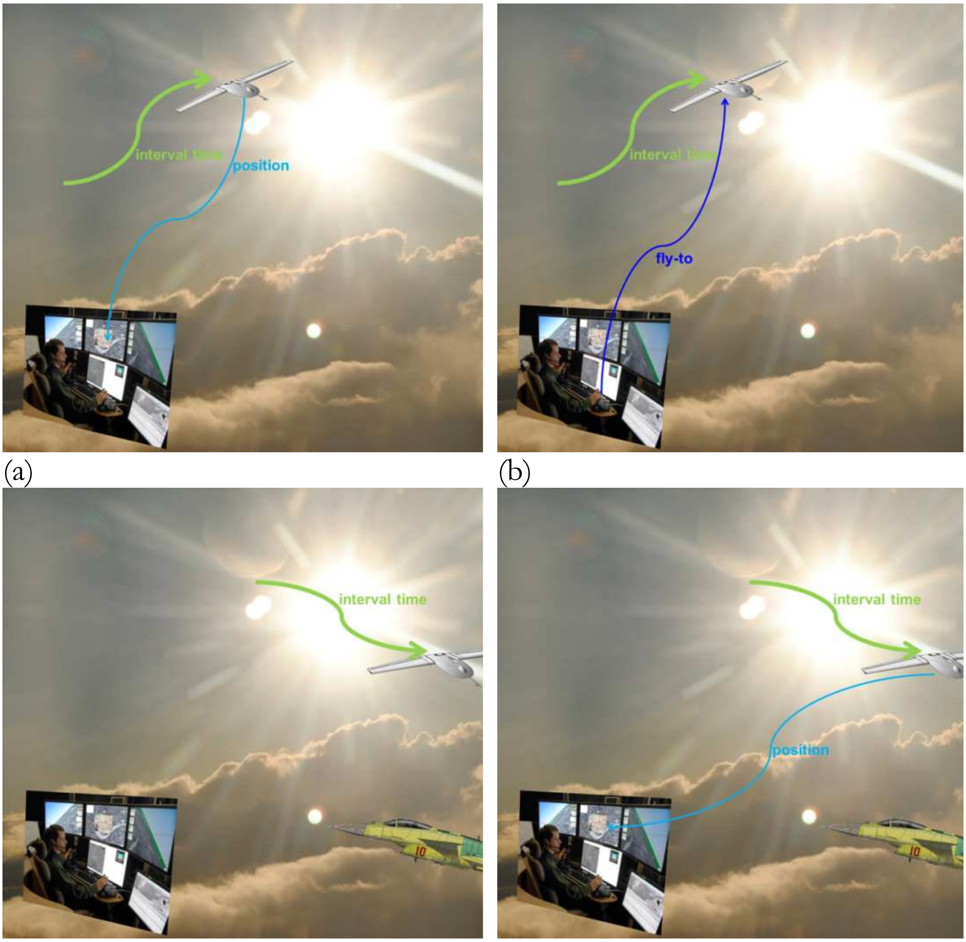
To create this synthetic environment, fewer sensors are needed than in situations where real imagery is combined into a situational awareness picture. Fewer sensors means a possibly smaller, more agile UCAV, more silent in different senses (less visible for detection systems), and easier to make stealthy. So, even if the stealth advantage is decreasing, its advantages will continue to hold for some time for these kinds of aircraft.

The controller can using pick-and-move techniques to command the UCAV, picking it up with special virtual reality gloves from where it is and moving it to the desired location, which is probably easier, more flexible and faster than more traditional ways of issuing commands.

The synthetic VR environment offers additional possibilities, once again improving operational effectiveness. One can think of the visualisation of the (expected) course of potential targets, or the visualisation of no-escape zones. Tasks can be distributed between two or more controllers, and it is easy to control more than one UCAV by only one operator, avoiding coordination problems. Furthermore, the SDCS allows leaving the aircraft alone for a moment or two.

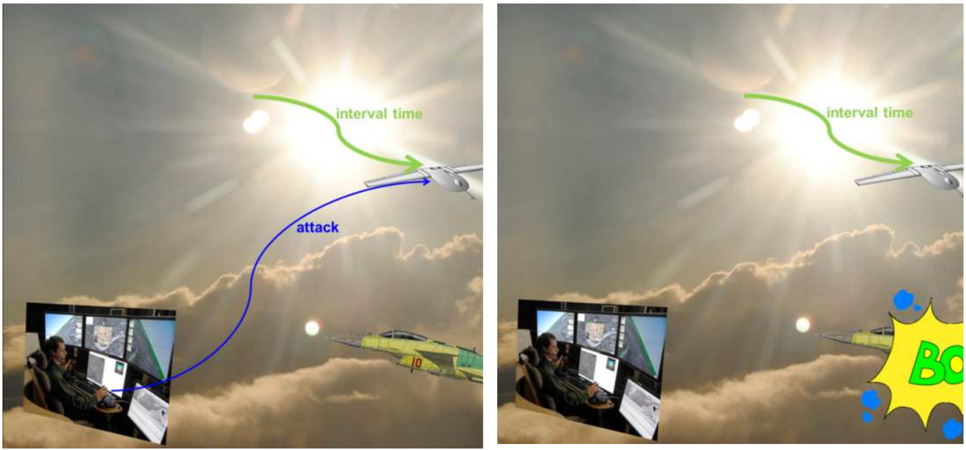
3.3 An example

In Figure 2, a small example is supplied of the SDCS in action. It depicts a situation in which an UCAV, controlled by a pilot on the ground, using a rather classic Human-Machine Interface, engages an enemy aircraft and it is an excerpt of a larger scenario.



(a) (b)

(c) (d)



(e) (f)

Figure 2 An example

In Figure 2 (a), the UCAV has just finished its commanded manoeuvre, and sends his new position, possibly accompanied by the detected position of the enemy aircraft, to the controller on the ground. In Figure 2 (b), the controller sends a new command to the UCAV, ordering it to fly to a new position in order to get attacking chances against the enemy aircraft. Figure 2 (c) shows the UCAV, flying to its new position. Meanwhile, the enemy aircraft has moved too, of course. In Figure 2 (d), the UCAV sends his new position to the ground, after which in Figure 2 (e), the controller commands the UCAV to attack, which it successfully does in Figure 2 (f).

4. Application areas

In general, the SDCS is especially suited for situations in which quick reaction is needed because of obstacles or threats, and where direct joystick control is not feasible or precise enough. Furthermore, as mentioned, the SDCS opens new possibilities in air-to-air situations. In this section, we will give some examples of possible operational application areas where the SDCS may prove its use.

Air defence

Air defence, defined as 'all measures designed to nullify or reduce the effectiveness of hostile air action' (NATO Standardisation Agency (2012)), can also contain air-to-air components. However, most air forces choose to augment airbase defence with surface-to-air missile systems as they are such valuable targets and subject to attack by enemy aircraft. The use of UASs reduces the disadvantages of using air assets in air defence, with respect to vulnerability of pilots, and costs, and the SDCS also opens up possibilities to operate in a wide area.

Cruise missile and UAS defence

Possibly the only way to use air assets in the defence against enemy cruise missiles and hostile UCAVs, is the use of UCAVs by own forces. The SDCS opens up this possibility, and offers, as an additional advantage, the possibility to operate much further away than what is possible now with the currently preferred defence against such threats, being either surface-to-air defence, , or manned aircraft. As compared to the latter, UCAVs of course can be much longer on-station.

Escorting

Using a UAV to protect other air assets during a mission is also possible. One can think of escorting bombers, transport aircraft, tanker aircraft and AWACS. It may even be possible to control the UAV using the SDCS on-board the aircraft it protects.

Counter-air and interdiction

Air interdiction is the use of aircraft to attack tactical ground targets that are not in close proximity to friendly ground forces. It differs from close air support because it does not directly support ground operations and is not closely coordinated with ground units. Unlike strategic bombing, air interdiction is not meant as an independent air campaign, as its ultimate purpose is to aid ground operations rather than to defeat the enemy by air power alone. The purpose of air interdiction is to delay, disrupt, or destroy enemy forces or supplies *en route* to the battle area before they can engage friendly forces.

Using UCAVs controlled by the SDCS opens up the possibility for more effective air interdiction, because it can be applied deeper into enemy territory than what is possible now, for a longer consecutive time, as compared to using manned aircraft, and without the risk of losing pilots.

Ship defence

The additional technical possibilities of using UCAVs instead of manned aircraft include technical possibilities, not available for the latter. One can think of Short Take-Off and Landing (STOL), or Vertical Take-Off and Landing (VTOL), without having to take the human on-board into consideration, opening up the possibility to operate from small ships. This for instance enables the defence of groups of small ships, where the SDSC is stationed and controlled on board of one of these ships.

The edge of space

The ability to make use of the extreme manoeuvrability and flight performance may even be relevant if the continuing militarization of space leads one day to air combat at the edge of space.

5. Conclusions

Applying the SDCS to control UCAVs opens up new operational possibilities, mainly because of the lack of the restrictions a pilot on-board implies. Air-to-air operations requiring long endurance, e.g., deep into enemy territory and operations requiring extreme manoeuvring become possible. A number of application areas have been identified for the SDCS.

Using the SDCS removes the need for full autonomy, removes the need for large bandwidths, and overcomes the latency problem, present when steering a UAV directly. The envisioned synthetic Human-Machine Interface offers new possibilities in controlling, possibly multiple, UCAVs, in a Virtual Reality environment. The trade-off between interval length and artificial intelligence needed offers the possibility to gradually make the vehicle more autonomous, when AI research advances, and also offers a research vehicle to AI and autonomy.

With the West having the ultimate manned fighter, the Lockheed Martin F-22A, available at present, the time is right to start development of air-to-air UCAVs. The security risk if development problems are encountered is manageable with the F-22A at hand, and maturation of UFAVs will likely take so long that, if they are to be the eventual successors of the F-22A, development should start in the next ten to fifteen years. This means that the basic technologies need to be developed sooner. In the meantime, UFAVs can be a useful addition to the somewhat limited air-to-air capabilities of the F-35 Joint Strike Fighter (JSF). Since there are less than 300 F-22A's available at present and there will likely be thousands of JSFs, additional air-to-air capabilities may be welcome, especially in the later years of the operational life of the F-35.

6. The way ahead

Technical challenges for the SDCS are, next to the development of the 'intelligent' CMMS, the realization of an effective Human-Machine interface, probably in a VR environment. To determine the feasibility of SDCS, at least the following questions have to be answered:

What information does the pilot need to effectively give input to the CMMS?

What SA is necessary for the pilot? How does it depend on the operation? Does it depend on the phase in the operation? Does it depend on the length of the intervals between commands?

How can this information be generated?

How do we obtain that SA? How much does it depend on sensors in the UCAV? Does this actually solve the bandwidth problems? Are additional sensors necessary? Is the use of real-time simulation an option?

What is the effectiveness of various ways to present the information to the pilot?

What possibilities are there, and in what timeframe? Does a VR environment improve mission effectiveness? Is a 'classic' HMI adequate for testing the SDCS concept?

What information should be given in the control commands?

What types of commands are possible? How does the length of the interval determine the complexity of a task? How does the information, available in the control room, determine the possible types of commands that can be given? What is, given these various possibilities, the level of intelligence/autonomy needed in the intervals between the control commands? Is this level of autonomy feasible?

Are the demands, imposed on the pilot using SDCS, feasible?

What abilities does a controller have to have, to control a UCAV? How does this depend on the HMI? How does it compare to the abilities of pilots of manned aircraft? Is it expected that there are sufficient controllers available? Is specialization (e.g., in mission phase) an option?

It is expected that most of these questions can, in essence, be answered using simulations. The results will show whether or not the SDCS is a solution to overcome the previously mentioned drawbacks of UCAV in use presently, and if it offers the possibility to use UCAVs in air-to-air situations, without unrealistically high data link or autonomy requirements..

The acquired knowledge can also be of value in the development of other types of unmanned aircraft, especially because considering the shift from more and more tasks from manned to unmanned aircraft. Examples are rescue UAV's that can, for example, evacuate people from ships in distress. SDCS par excellence expands the possibilities for UAV use.

References

Anonymous (2010). "Boeing unveils strike fighter options", in *Flight International*, 11-17 May 2010.

Kelly, Emma (2010). "Australia senses breakthrough on airspace sharing", in *Flight International*, 25-31 May 2010.

Majumdar, Dave (2013a). "UAVs 'irrelevant' over Pacific", in *Flight International*, 18 December 2012-7 January 2013.

Majumdar, Dave (2013b). "Access denied", in *Flight International*, 6-12 August 2013

NATO Standardization Agency (2012). *AAP-06 Edition 2012 Version 2. NATO Glossary of Terms and Definitions.* http://armawiki.zumorc.de/files/NATO/AAP-6.pdf. Retrieved 27 Nov 2014.

Robinson, Tim (2009). "Man vs. Machine", in *Aerospace International*, September 2009.

Rosenberg, Zach (2013). "US Navy releases requirements for carrier-launched UAV". Flightglobal, 17 Jun 2013. Retrieved 21 Nov 2014.

Work, Robert O. & Shawn Brimley (2014). *20YY. Preparing for War in the Robotic Age*. Center for New American Security, January 2014.