UAV autonomy

This article discusses the development of Unmanned Air Vehicles (UAVs) from early remote-controlled tele-robotic systems through the increased sophistication afforded by the advances in communications and sensor technologies. The enormous challenges associated with the autonomous operation of UAVs are considered, especially in light of the problems and issues associated with the relationship between the human operator and the UAV.

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Author biography

Since his retirement from Defence Science and Technology Laboratory (Dstl) as a Systems Fellow, Bob Frampton has remained a part time Dstl consultant and continued his involvement with national UAV programmes as one of the judging team for MOD's Grand Challenge and Deputy Chairman of the Bristol UAV Systems International Conferences Committee. His experience on autonomy was gained largely from his time in Dstl (and its DERA predecessor) as the autonomy research lead for advanced combat and small UAV systems. This built on a long career in MOD covering many areas of air/weapons systems research and procurement.

Prior to retirement, in Dstl Bob Frampton was MOD's primary technical focus for UAV research, international collaboration and project support on combat UAV systems with particular responsibilities for technical direction of the UAV autonomy programme. He was appointed a Dstl Fellow in 2003 and his fellowship activities included work with academia on biomimetic systems with a strong interest in insect flight mechanisms and sensing.

Previous experience included Assistant Director UAV Systems in DERA, responsible for UAV research activities and support to UAV procurement programmes, and a four year period in the Directorate of Science (Air) on advanced stand-off missile concepts. As an Applied Physics graduate, much of his earlier professional life was spend within MOD research programmes on navigation systems, including GPS and inertial navigation. He was chairman of the Bristol UAV Systems International Conferences and Committee for five years and a member of the RAeS UAV Committee.

Aviation pioneers have been considering Unmanned Air Vehicles (UAVs) for as long as, and possibly longer than, manned flight. The significant use of UAVs in military operations did not really occur though until the 1960s, when US forces deployed them in large numbers in Vietnam, and Israeli Defence forces integrated them into their operations. Initially UAVs were used for surveillance and reconnaissance tasks, but today armed UAVs are also capable of weapon delivery in complex situations, under the control of remote operators who are able to find, track and identify targets through highly capable sensor systems fitted to the air vehicles. There are many significant technologies and design challenges associated with advanced UAVs. Some of these are common with manned aircraft, and others are specific to unmanned systems. One of the most significant technologies and, perhaps the least understood by many, relates to command and control, and is the concept of autonomy.

It is self evident that the difference between manned and unmanned systems is that the human 'operator' is not within the vehicle. This has advantages and disadvantages. One of the obvious disadvantages is the need for mechanisms to enable the operator to 'control' the activities of the unmanned vehicle which are significantly different to those used when a pilot is on-board.

Many people think of unmanned vehicles as big radio controlled vehicles, an impression enhanced by newspaper reports of "killer drones". In the early days of unmanned systems the concepts were operated exactly that way – as radio controlled "tele-robotic" systems. The operator communicated direct commands to the vehicle via a communications link – "turn left, increase speed…". Operator situation awareness, or knowledge of the vehicle's location and actions, was limited to the information obtained by looking at the vehicle. Anyone who has flown radio-controlled model aeroplanes knows this can be great fun, but it is difficult to get the vehicle to do anything useful. This probably marks the difference between radio controlled toys and serious unmanned systems. The former are recreational and the latter functional.

We have moved on from tele-robotic operation and enhanced functionality considerably. The important steps in generating functionality have been:

- the addition of communications back from the vehicle, which gives the operator enhanced situation awareness;
- the introduction of sensors (e.g. Electro-Optic (EO)/Infrared (IR) cameras) on to the vehicle which now enable a surveillance role; and highly significantly,
- the use of Global Positioning System (GPS) which enable precise navigation.

These steps give us a vehicle with a known location. We can tell it where to go, and it can provide us with useful information. These are the basic essentials for unmanned vehicles.

Unmanned systems have progressively been fitted with more instrumentation and sensor systems so that data on the vehicle systems is available to the operator to the same or higher level than manned aircraft. The sensors provide data on ground surveillance targets at EO, IR and radar frequencies, with the ability to steer the sensor sightline, and zoom into the targets as appropriate. Effectively, a remote cockpit has been generated for some systems. Systems such as the General Atomics Predator UAV have joysticks, throttles, rudder bars and other control inputs to enable the aircraft to be flown remotely if required. This approach makes heavy demands on the communications links and the operators. To alleviate these demands some systems such as the Global Hawk UAV have embodied high levels of 'automation', based on pre-planning activities, through the provision of an autopilot which controls not only the flight trajectory, but also the management of the sensors and contingency plans for malfunctions or flight options. This goes some way to easing communications and operator control pressure, but requires large investment in pre-mission planning, and has an element of inflexibility.

Set against this control background, unmanned vehicle researchers are now providing a paradigm shift in control through the provision of 'autonomy' within the unmanned system. Dictionary definitions of autonomy tend to emphasise it as 'self governing', but what does this mean? Control is about making decisions based on the assessment of information. Autonomy is achieved when the unmanned system is capable of making its own decisions from sensed information, and potentially covers the whole range of vehicle functions. There remain some decisions however, which will still need to be made by a human-in-the-loop. Let us take, for example, the issue of the armed UAV. It is generally accepted that the decision to commit a weapon against a target is made by a human. It is technically quite feasible to give this decision to an unmanned system, but considerations of collateral risk, and rules of engagement, suggest this is generally inappropriate (we do not seek the killer drone image). Depending on the sophistication of the unmanned system, and the circumstances, there will be other decisions left to the

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Level	UCAV Authority	UCAV status	
0	None	Commanded	Supervisor full authority
1	Advice, only if requested	At call	
2	Advice	Advisory	
3	Advice and, if authorised, action	In support	
4	Action unless revoked	Direct support	
5	Full UCAV authority	Fully autonomous	UCAV authority

UCAV autonomy “levels” (based on MOD Pilot Authority Control of Tasks interpreted by QinetiQ).

human. With autonomous systems, therefore, we have a decision partnership between the human and the vehicle.

Implementing this decision partnership invokes another key element of this autonomy paradigm shift – that is, increasing the level of abstraction of the control. With young children you tell them exact sequences of what you want them to do which convey the actions needed to achieve something e.g. “put that pen in the drawer”. However, as they learn skills and gain more experience then the commands can be more task based e.g. “tidy the table”. Eventually, when the children have a skill base and experience you can use high level ‘behavioural’ commands which tell them what you want them to achieve, not how to do it e.g. “this room is a mess – do something about it”. This is the goal of autonomy for UAVs – implementing high level of abstraction behavioural control e.g. operator commands could be “locate a missile launcher in this area”. The goal however goes beyond autonomy in individual UAVs. We are working towards the control of autonomous teams. In this case, a typical command to a team of UAVs could be “locate the launcher last seen at this point at 1030hrs”. In response to this the system would derive a search strategy, and the aircraft would intercommunicate to de-conflict their trajectories, collect and assess data. Once on-board data analysis suggests the objective has been met, the vehicles would transmit images and locations of potential targets to the operator. The trajectories and actions could change in the event of a human over-ride command to take a team member out of the team to do another job, or to reflect issues such as individual low fuel state or attrition.

Why do we want to move to autonomy and behavioural control? One of the main reasons is to reduce the communications demands. The radio frequency spectrum is finite, and subject to increasing use, so it is highly prudent to reduce this dependency. Autonomy also results in reduction of operator workload. We can therefore achieve multiple UAV control per operator. The role of the operators also changes. They are now mission managers, and skills need to match the operational tasks they are trying to achieve. The extent of pre-mission planning drops significantly to reduce the demand on the operators. Autonomy produces a much more responsive system in which operational changes of plan and tasks can quickly be accepted in response to new circumstances. For military systems the big advantage is that they are now far less vulnerable to loss of communications. Autonomy permits easy use of teams to give faster area coverage, and the location of concealed targets through the use of multiple viewing angles and different sensor types.

There are however disadvantages with increasing autonomy. The first of these is that the human operator is still legally responsible for his or her UAV. Autonomy therefore has to be implemented in a way that still provides appropriate situation awareness to the operator, and the necessary level of override control if required. The intelligent software needs to be validated and verified particularly as parts of it could be safety critical. This requires the system architecture designer to recognise the safety requirements and plan for certification.

The decision partnership requires the human to ‘trust’ the UAV – this is a complex relationship. As in human relationships trust is built up from experience, and will need to be generated through operational use. It is envisaged that most of this experience will be gained by ‘flying’ the system in computer based synthetic environments. Trust will also require the human to be aware of the extent of the information held by the UAV (its beliefs) and its intentions. These elements form a significant part of the situation awareness needs of the operator, which must be transmitted from the UAV to the human. Whereas it is possible to consider autonomy as ‘fire and forget’, in reality communications will be required to sustain the safety and decision partnership.

This trust can be illustrated by everyday examples. As stated above, it is possible to have fully autonomous unmanned vehicles which operate with no human intervention but in reality this is only feasible for limited tasks. In unmanned systems such as the Docklands Light Railway, the vehicle freedom is constrained by rails, the numbers of vehicles is limited, and the task and rules are easy to define. Operation is generally routine and any ‘decisions’ are constrained to those associated with reacting to non-routine occurrences such as faults or blocked doors etc. the response to which can be pre-determined. This is perhaps more automated

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JDAM (Joint Direct Attack Munition) release from the J-UCAS (Joint – Unmanned Combat Air System) X-45C air vehicle. © DARPA

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A RQ1L Predator from the 57th Wing Operations Group makes its way back to the hangar at a forward base in the area of Operation Enduring Freedom. © US Department of Defense

than autonomous, nevertheless this system carries human passengers and therefore has to have high levels of integrity, safety and trust. Contrast this with having an unmanned taxi in London which would face a highly dynamic situation with few movement constraints (except in height) and high levels of interaction with its surroundings, which are heavily populated with other obstacles most of which are mobile and 'unpredictable' in their behaviour.

Few passengers would be prepared to accept the risks of this concept. Similarly for air vehicles there are parts of the flight envelope which require minimal human intervention e.g. transit similar to an airliner on autopilot. There are other situations such as operation near an airfield which require significant monitoring and response to external commands. To meet these different circumstances we have 'levels of autonomy'. The levels refer to the freedom the UAV has to make decisions, and vary between full operator control to full computer control. Different functions within the UAV will operate at different levels e.g. the flight stabilisation system will always have full authority whereas the weapon release will be full human authority. Other elements may be at intermediate levels such as the computer recommending a course of action for the operator to accept, or the computer advising its intended actions unless the operator revokes these. The way levels are incorporated and controlled is a research area and inevitably will evolve as intelligent system capability develops and experience is gained.

Finally, this progressive delegation of decisions to the machines may seem a step too far. However, reconsider the taxi or car analogy. Initially, automatic gearboxes were treated with mistrust, but now are universally accepted having developed to the point they change down for bends, have cruise control and can be changed to adapt to driving style (sports mode etc). Anti-lock breaking and power steering are accepted. Satellite navigation systems direct routes giving options. Other cars have suspension and traction control for better road holding. Almost all new cars have fuel management systems, many offer parking aids and climate control options are available. Radar warning detectors can be fitted and so the list of support tools goes on. Admittedly some implementations are not very complex, few are safety critical and there are back up reversionary modes where there is a potential high risk to humans but we have accepted having machines help us on the roads. On a different tack, developments in photography have given us the autostart cameras, auto focus, exposure control based on a range of options etc. The modern world is full of examples of machine decision making and we have learnt to 'trust' them.

UAVs have become an integral part of our military operations and the move to intelligent UAVs working as teams is very close. UK research is well advanced in this area, and Dstl is closely integrated with industry and academia to bring appropriate autonomy into service.

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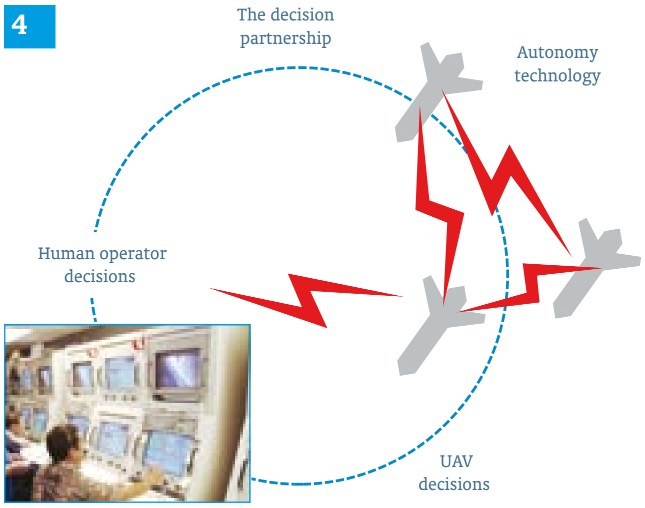

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