Whose Goal is it anyway? User Interaction in an Autonomous System

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Abstract

We describe how establishing goals at different levels of abstraction helps a human operator to supervise/control a system consisting of multiple unmanned air vehicles. In particular we focus on the importance of including Human Machine Interaction within the design of an autonomous system. Important lessons include being explicit about the level of authority to delegate to the automated part of the system and viewing the interaction between the human and the automated planning / execution system as a partnership, thus facilitating a shared awareness of, and commitment to, joint goals.

Introduction

For a number of years QinetiQ have been involved in developing and testing technologies to allow a human operator to control a team of unmanned air vehicles (UAVs) [Platts 2004]. This has included an agent based planning and execution system to control the vehicles based on high level goals given by the operator and several different Human Machine Interfaces (HMI).

The design approach adopted by QinetiQ has ensured that the intelligent system was developed in tandem with the HMI. Over a number of years a regular series of trials has been undertaken whereby human operators were tasked to validate the approach and provide feedback on both the HMI and the behavior of the system. These trials have been a mixture of simulations and flight trials with the operator in a variety of different situations. At one extreme the operator was controlling a team of vehicles while flying his own fast jet aircraft (Baxter, Horn and Leivers 2008) and at the other from a Control Station on the ground (Richards, Howitt, White & Dickson 2005).

This experience has allowed us to develop ways of representing and expressing the goals held by the operator and explaining the current goals of the system. Our approach has been to focus on trying to ensure that the human operator and the intelligent system can communicate effectively in order to achieve mission objectives. Viewed from the operator's perspective they have a set of changing high level goals which they want to achieve and they wish to achieve these goals in as short a time as possible by making use of the system to assist them. To do this they need to be able to express their goals to the system and to get enough information back so that they believe that the system is correctly pursuing those goals. As importantly, they need to be convinced that the system is not going to carry out an action which impedes their goals or violates the restrictions they are operating under.

Typically an operator in our system has a variety of tasks to achieve, usually involving one or more UAVs searching for particular vehicles or activities in a defined area and tracking or gaining close up imagery of those vehicles. Additionally the operator may wish to gather specific images of locations on the ground or to respond directly to requests for support from others in the area in which the UAVs are operating. The operator and the system therefore have to balance a variety of tasks, composed of differing durations, involving one or more UAVs in each task.

Related work

Considerable attention has been given in the computer science literature to models of co-operation between intelligent agents such as Joint Intentions (Levesque, Cohen and Nunes 1990) and Shared Plans (Grosz and Sidner, 1990). Consideration has also been given to variable levels of autonomy, controlling how users can vary the level of interaction and delegate or receive goals from an intelligent system (Maheswaran et al 2004). Additionally the psychological literature has produced much more complex models of co-operation between groups of people (Axelrod, 1984) and the way that people react to automation (Sarter and Woods, 1995).

The importance of displaying information effectively and its impact on performance has been widely studied.

For example, head-up displays in cockpits have been criticised for inducing information overload on many occasions (Lintern et al, 1999). Other studies have found that poorly designed interfaces result in inefficient search behaviour (Goldberg et al, 1999). The use of graphical user interfaces is thought to reduce the complexity of the operating system and make it easier to use and learn (Wiedenbeck, 1999). As a result, any new format of interface that represents the point of contact for a new system is crucial in terms of the usability of such a novel system.

Our system is a good example of Collaborative Discourse Theory (Rich, Sidner and Lesh 2001) being applied, whereby the human and intelligent system co-ordinate their actions toward achieving a shared goal. The communication observed between humans in a shared context to achieve goals outlines the importance in the discourse required to address the task. The intelligent System model and User mental model must achieve a level of synergy in order for the collaboration to be successful in achieving the goal. This synergy between user and system builds on the concept of a state of shared awareness (White, Richards and Diethe, 2005).

While the work described here has some similarity to mixed initiative planning (for example Burstein et al, 2000) it differs significantly in that it is designed for mixed initiative execution in real time. The user of the system interacts at the goal and resource allocation level but does not dynamically alter or edit plans.

The Intelligent System

The Intelligent System consists of four distinct types of agents illustrated in Figure 1. User Agents act as the interface to the operator, receiving commands, making requests for authorization and informing the operator of the current state of the system and vehicles. Group agents are responsible for specific joint goals held by a (temporary) group of agents. They are responsible for achieving the goal, producing a suitable joint plan and for maintaining the necessary communication between agents to ensure that the plan is progressing appropriately. UAV agents are responsible for controlling the individual UAVs to match their role in any joint plan. They plan the detailed flight path of the UAV, control its sensors and distribute status and sensor information. Specialist planning agents wrap a range of different domain specific planners which can be called on by other agents.

The main design rationale behind the multi-agent system was the need to continually monitor the progress of existing plans and goals so as to be able to identify and address any problems as quickly as possible. This is in turn conveyed to the Operator in order to facilitate trust in what the system is doing. The resulting framework allows for the mixing of different types of planners for specialized tasks in a single system and allows tasks to be jointly pursued by a variable number of vehicles acting in close co-operation.

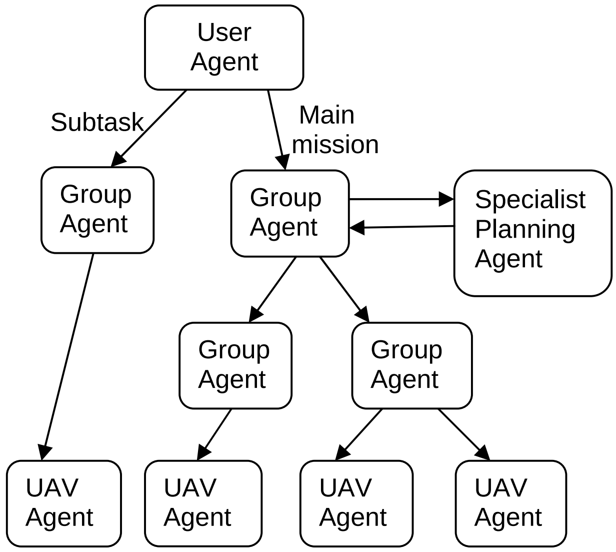

Figure 1 The internal structure of the multi-agent system

User Agent

The User Agent has control of all of the UAVs in the package. It accepts specific (but possibly very high level) goals from the operator and attempts to use the available UAVs to achieve those goals. The User Agent has a notion of a 'Main mission' task to which all assets are assigned by default. The User Agent has full control over the task and may change the assignment of any of the UAVs involved in it. In addition to this default task, the operator may specify a number of 'subtasks' which the User Agent is also responsible for trying to achieve. A subtask represents some specific action which the operator may require to be undertaken in addition to the default task, such as observing a specified location. The User Agent can select the assets to carry out each subtask, or they can be specified by the operator. When the User Agent has identified the UAV assets required for a task these assets are assigned to a Group Agent. Group Agents can be created by the User Agent or existing Group Agents can be re-used. The User Agent therefore controls a number of concurrent tasks on behalf of the user and uses the Group Agents to plan and supervise these tasks.

Group Agents

Group Agents are designed to control a team of UAVs for a single task. Group Agents may either control UAV Agents directly or may control other Group Agents. For example, if a task requires the UAVs to operate in two pairs, a Group Agent will control the group of four by tasking two Group Agents (each of these will control a pair of UAVs). Group Agents embody the knowledge of how to plan and execute coordinated team tasks using a framework based on Joint Intentions theory. This provides a solid grounding for the required communication necessary to keep a team task coordinated. Given an assigned task and assets a Group Agent makes a plan to achieve the task. It may call on additional specialist planning agents to do this. The plan is structured so that the roles which need to be fulfilled are clearly identified and UAVs are assigned to these roles. The plans include the coordination necessary to execute the plan. These plans then form the tasks for subordinate Group or UAV Agents and are sent to them for further planning and execution.

Specialist Planning Agents

One way of incorporating other Artificial Intelligence (AI) techniques for planning actions for the UAVs is to wrap them inside specialist planning agents. For example one such agent was used to provide access to a planner that produces search routes. The planner (Strens and Windelinckx 2005) is provided with a set of possible target positions and expands them into regions that could be reached by a moving target in the next few minutes. The search routes are designed to allow the UAVs to search these regions with short-range sensors and take images of potential targets that will be classified by the operator. The search agent maintains and updates the possible target locations, removing potential targets if the operator classifies them as non-targets.

UAV Agents

A UAV Agent exists for each UAV platform. It sends commands to the sensors, weapons and autopilot via a lower level platform controller. The UAV Agent monitors the status of the vehicle and sends sensor and state information to the other agents. The UAV Agents can plan and execute single vehicle tasks, such as taking images of a specified ground entity, and can try different actions until they achieve the tasks set by the Group Agent.

Operator Interface

The operator interface was designed and developed with the aim of aligning the system model and the user's mental model in order to attain a degree of cognitive compatibility. This is extremely important when considering critical systems (Rushby, 2002). Figure 2 shows the role of the HMI in aligning the user's model of the system and the system's internal model. Effective operation is only possible if the two models are kept aligned, otherwise the operator and system will not share the same view of the current environment and goals. A key aspect of our HMI design is therefore to keep the internal models of the system and user aligned.

The interface enables the operator to understand the state of the Agents at all times, and provides the operator with the means to select and modify goals as well as monitor and approve (or reject) decisions. The HMI provides a

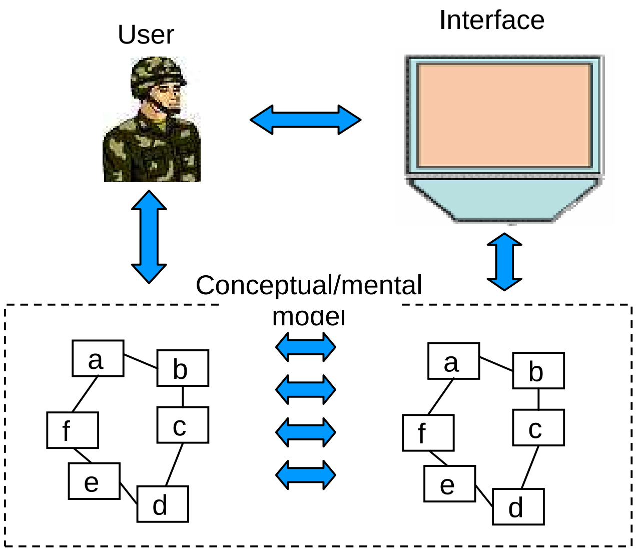

Figure 2 User – System shared mental model

formal representation of the discourse between operator and intelligent system, whilst also providing a framework for allowing goals to be realized. .

The interface therefore provides a number of different views onto the problem space and current goals to allow the operator to build up their awareness of the state of the UAVs and their environment. Multiple views can be displayed simultaneously to allow the operator to focus on one particular aspect while being easily able to monitor others. Consistent colour coding is used to identify different UAVs and goal types across displays allowing the operator to quickly confirm how each goal is being tackled and which individual actions relate to which goals.

A group view shows the high level allocation of groups of vehicles to goals (the number assigned to each goal) and allows the operator to increase or reduce the number of vehicles working to achieve each goal. A vehicle centric view gives summary information about the state of each vehicle and the goal it is contributing to. A map view shows the location of the UAVs and any detections made by their sensors. Multiple zoom levels and filtering / clustering options allow the operator to rapidly switch between monitoring the entire mission and looking at a single vehicle or detection. A dedicated imagery view displays the pictures gathered by visual sensors and allows the operator to annotate them to indicate their relevance to current goals. Finally a message window provides progress information from the intelligent system and allows the agents to seek permission for actions depending on the variable level of autonomy allocated to them.

Use of PACT

Variable autonomy is achieved by adopting the framework of PACT (Pilot Authorisation and Control of Tasks). This was originally developed for UK MoD for use within a fast jet environment in order to alleviate workload from the pilot and delegate some elements of decision support to a level of dynamic assistance (Howitt and Richards 2003). The PACT levels of automation, as shown in Figure 3, range from fully manual to fully automatic, with four levels of automation assistance, which can be changed dynamically by the system or by the pilot. In the context of a variable autonomy system, PACT provides a framework through which the goals adopted by the intelligent system can be both notified to, and, if necessary, authorised by, the operator. From a system design point of view it gives an explicit way of recognising the points where interaction with the operator may be required.

Shared Goals

When analyzing the goals in our system we recognize that in most cases they are hierarchical. That is, a goal is simply a task placed on the system as part of the achievement of some higher level goal. However there are three distinct types of goal within the system depending on the degree of autonomy the system has in dealing with them.

1. User specified goals
2. User delegated goals
3. System internal goals

A user specified goal represents the highest goal that the agents in our intelligent system are aware of, that is a goal derived directly from a command sent by the operator. As far as the system is concerned it must try to achieve this goal and inform the operator if it believes it has been achieved or is impossible.

A user delegated goal is one which has been generated by an agent within the system but which has been identified as including aspects over which the operator may wish to have direct control. In general these goals are associated with the PACT process, identifying that depending on the level of autonomy granted by the operator, they may require additional authorization before they can be adopted. However, as system generated goals they can be dropped if the system believes they are no longer appropriate.

System internal goals are generated by the system as needed and require no further authorization from the operator other than that given to the higher level goals from which they have been derived..

Operator's perspective

From the operator's perspective the three types of goal (user specified, delegated and system internal goals) differ quite substantially. User specified goals are the result of direct interaction with the system and the operator expects to get regular feedback on their progress. This includes being able to simply and easily identify which asset(s) are involved in the particular goal (via color coding of the display) and being able to influence the achievement of the

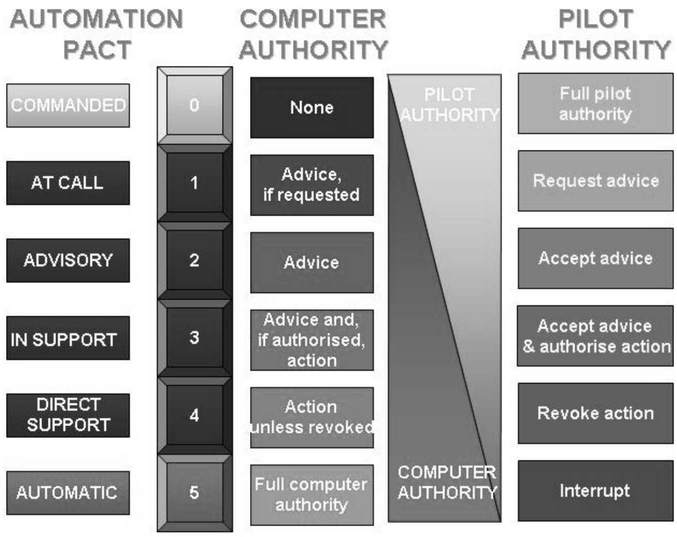

Figure 3 the PACT levels, showing how the level of user / system authority can be varied

goal directly. The operator can directly cancel this type of goal, increase or decrease the number of UAVs assigned to achieving the goal and if desired specify exactly which UAVs should be selected for the task. The operator needs to know both that the goal is actively being addressed and that it is happening in a manner which both the operator and the system understand and agree.

User delegated goals are primarily those initiated as part of a user specified goal. This is where the operator is confident enough in the system to expect the agents to propose that a particular goal should be adopted, based on their interpretation of the current situation, but not confident enough to allow the system to act on the new goal without further authorization. There are a number of reasons for the operator wishing to retain control in this way. While an operator is building up a level of trust in the system they like to retain as much control as possible. In order to maintain their own understanding of the state of the system and the tasks it is undertaking, an operator may wish to specify that the system inform them of specific goals it initiates so that the operator will not miss them (and potentially become confused as to the state of the system). Finally, adoption of particular goals, for example to use specific sensor or weapon systems, may require direct operator intervention for legal reasons.

System internal goals, from an operator's point of view, should be relatively simple and self explanatory. The operator does not need direct control over them but would like to be aware of the decisions taken to increase their confidence that the high level goals are being achieved. In our system this would encompass, for example, the detailed routes flown by a specific UAV, which UAV is selected for particular roles in a plan and individual sensor tasks. While an operator may be able to achieve these goals by direct intervention, to do so would be likely to increase their workload above the level at which they could command all the assets available to them.

To the operator therefore, the three types of goal are quite distinct and this helps to maintain their mental model of the state of the system, what it is doing now and will do in the future.

Intelligent System Design Perspective

The core system views all goals in essentially the same way. Goals give a desired state of the world the system has to achieve. Planners provide plans to achieve those goals under a set of assumptions and constraints. Executing a plan gives an ordered set of goals to achieve. The system iterates, over several levels of planning to arrive at atomic actions for individual vehicles.

Where a user delegated goal is involved the operation becomes rather more complicated. Given that permission to adopt a particular goal has to be sought from the operator (via the PACT framework) the system has to allow for this fact. Initially we implemented a block and request mechanism whereby the system would identify that it believed the conditions for a new goal were met and it would ask for permission to adopt that goal. Depending on the PACT settings this might be automatically approved, approved after a delay or rejected after a delay. This mechanism provided the basic control needed to ensure that a goal which the operator wished to approve could not be adopted automatically. However it posed several additional questions about the interaction. What should be done about refused requests? How should the delays be allowed for? What if a goal was only relevant for a limited time window?

The initial design to deal with these issues was reasonably successful. PACT requests could be issued with a timeout to indicate to the operator for how long the particular goal would remain valid.. Planners were provided with an 'operator delay' parameter which allowed a period of time for gaining approval to be factored into plans. Finally goals for which a request had been made were suppressed, so that a request would not be regenerated immediately if it had been rejected.

In trials with operators using the system, several issues emerged. In cases where the system made a request, the operator felt under pressure to respond (even if no time limit was given). If they were unsure about an action they would reject it but would subsequently be annoyed that the system would not then propose the same goal, requiring the operator to do it manually. Operators also found it frustrating that the system would effectively pause, waiting for them to say yes and not gather any new information. In response to this we reviewed the way we were dealing with operator interactions within the intelligent system. We realized that the way the system dealt with user delegated goals was effectively to believe that the system was right and expect the operator to approve the decision. A more fruitful approach we believed was to model the approach to the user delegated goals in more detail and to recognize their joint status.

A Joint Perspective

Rather than have the system wait for the operator to confirm the potential goal and if that did not happen, reject it, we found it much more productive to view the user specified goals as *Joint Persistent Goals* held between the operator and the system (Jennings 1995). Based on this theory, in order to adopt a goal, all parties need to agree that it is necessary and to do so on the basis of mutual belief. This provided a useful model for the system to adopt with respect to the operator. In order to get the operator to agree to the new goal proposed by the system, the operator needs to have the information on which the system based its decision. The system can therefore reason about what information it would need to supply in order to convince the operator that the decision is correct, or to allow the operator to update that information so that the system recognizes why the operator is refusing the goal.

We therefore enhanced the system so that planners linked to user delegated goals could consider whether enough data had been gathered and sent to the operator to allow them to assess whether a goal should be adopted, and if the operator did not approve the request, to identify what information would most likely be needed by the operator. In our system this is primarily linked to the taking and transmitting of images to the operator. Considering the value of a particular image with respect to adoption of a particular goal allows us to consider which new images to acquire and which images to send (down a restricted capacity link) to the operator. As part of a feedback mechanism operators establish a goal related classification for vehicles. The classification is used to link the sensor system's interpretation of the vehicle type (based on real or simulated image recognition algorithms) with the operator's belief, based on looking at images of the vehicle and its behavior.

The interaction of the operator with the intelligent system over user delegated goals is therefore much more indirect than simply issuing or cancelling a goal. The generation of user delegated goals typically involves a two stage process. At first the current goal drives the collection of images, prioritized by the importance of the vehicle being imaged to the current goal and the likelihood that those images will affect the classification of the vehicle. The operator has a variety of supporting tools and filtering mechanisms allowing review of current and historical images and to request images from the UAVs which have been taken but not currently sent. Based on one or more images of a vehicle the operator can classify the vehicle with respect to the current task. This classification is used by the agents in the system to propose new goals (for example tracking, or ceasing to track a particular vehicle). By using this shared belief mechanism there is a higher chance that the proposed goals will be accepted by the operator and if the operator disagrees, by changing the image classification, this can be 'explained' to the system.

Conclusions

We have described a research system for controlling multiple UAVs with a single operator. The development of the system has had to consider both the needs (and cognitive capacity) of the human operator and the ability of the intelligent system to plan and execute the tasks as set by the operator.

We have found it beneficial to regard many of the goals generated by the system as being 'Joint Goals' (using definitions drawn from both the psychological and computer science literature) owned by both the operator and the agents. The operator therefore has three ways of interacting with the system. Directly placing goals on the agents, approving or rejecting goals proposed by the agents and enhancing the mutual beliefs held between the system and the operator. In our system this has primarily been done by classifying images of vehicles which have been detected and / or tracked by the sensors on the UAVs.

We believe that regarding goals as jointly held between the operator and the system and providing both the agents and the operator with the means to share the beliefs which support the adoption of those goals, has made the system much more flexible and easy to use.

Such a system, where the operator and the agents act in partnership, necessarily requires that the design of the human machine interface and the agents are carried out in tandem and necessarily have a strong influence on each other.

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