THE SIMULATION OF THE HUMAN-MACHINE PARTNERSHIP IN UCAV OPERATION

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Abstract

Nowadays the interaction between human and Unmanned combat air vehicle (UCAV) through mission planning and control station is constrained by levels of autonomy of UCAVs, international legal obligation, communication and human cognitive behavior, so the flexible operational relationship is optimal. This paper proposes an integrated architecture composed of human, intelligent aiding system on control station, and intelligent system on-board UCAV. Based on variable levels of automation of tasks and subtasks, the architecture adjusts cognitive aids for operators and levels of autonomy of UCAVs, and makes it possible that single operator surveillances and controls several vehicles simultaneously. Variable authorization management of tasks is the key of simulation in a scenario which single operator surveillances and controls three UCAVs to perform a Suppression of Enemy Air Defense (SEAD) mission. At last this paper describes the simulation results by several operators in three operational relationships: the flexible operational relationship, high levels of autonomy and maximum manual. The results demonstrate the flexible operational relationship is optimal.

1 Introduction

Unmanned combat air vehicle (UCAV) system is endowed with some levels of intelligence and autonomy along with the development of computer and automation technology. The human's role in UCAV system is variable according to levels of autonomy of UCAV and data communication requirement. Up to now teleoperation and simple pre-program control has been achieved, several operators operating one vehicle and single operator operating one vehicle have been achieved, now study on single operator operating multiple vehicles and relevant interface is developing.

The interaction between human and UCAV through mission planning and control station is constrained by levels of autonomy of UCAVs, international legal obligation, communication technology and human cognitive behavior [1]. It is a result of those factors tradeoff. Level of autonomy of UCAV is the most important one and it influences the revise of international legal obligation. Human cognitive behavior is in a relative fix range to impose on this relationship and communication technology impacts the relationship.

During 2000-2025, the key technology trend is either based on levels of autonomy of UCAV and UCAV centered, or based on human centered on mission planning and control station by data links to command and control UCAV [2]. Abstractly, it is human centered or intelligent machine centered. Shortages of human command and control UCAV are visible. These include the cost of building and maintaining data link for information communication, the cost of potential vulnerability of the data link, the cost of training operators, and the cost of UCAV damage and mission lost by mistakes of human cognitive limitation. Advantages are that human bring intelligent, knowledge and flexible to the course and the international legal obligation and rules of engagement are satisfied. Everybody is asked to be responsible for its behavior, yet UCAV hasn't proved its behaviors are acceptable and responsible.

Along with technology development such as automatic target identify, the command and control of UCAV system finally tends to UCAV centered, especially when UCAV goes into a very complex battle instead manned airplanes, bandwidth is overwhelming for mission planning and control station centered. But now and in not far future, culture, technology and international legal obligation considered, human couldn't absolutely believe UCAV decision on many important areas, and human is required to stay on control loop, mission plan and control station is the only good selection. Like pilot's associate on manned cockpit, MPCS can be developed as a universal operating system to provide decision aid for human to command and control different types of UCAVs on the ground, airborne and marine. The interaction of human, MPCS and UCAV is more complex and changeful, how to integrate them and maximize the strengths of each and therefore the effectiveness of the system as a whole is the key which research laboratory on UCAV system will solve, such as Joint Unmanned Combat Air Systems project of America DARPA, advanced project on UCAV system of China. The coordination relationship of many agents just likes human and human theoretically with delegation interaction and flexible authorization levels is preferable [3~5].

2 An Integrated Architecture Composed of Human, Intelligent Aiding System on Control Station, Intelligent System on-board UCAV

2.1 An Integrated Architecture

Human, MPCS and UCAV compose a distributed intelligent architecture via network and data links. To coordinate well each part must (a) know its role and levels of authority; (b) share the same goals; (c)have access to appropriate knowledge and information; (4)be able to communicate with the other as appropriate to their respective roles and level of authority.[3]. According to human centered concept, the knowledge represents and act characteristic of MPCS, UCAV must match human cognitive features for the harmony of human's behaviors with machine [6].

An integrated architecture of human, intelligent aiding system on control station, intelligent system on-board UCAV likes Fig.1. The command and control system with mixed initiative and bounded autonomy is based on adaptive automation concept. Task manager as the center distributes task, designates executors, plans and shifts execution mode and adaptive range according to the variable situation, and specifies tasks and functions of human, MPCS and UCAV. The variable situation includes communication intermitting and new events which UCAV couldn't deal with. Human can adjust task executor within task authorization and switch protocol through task management entry on MPCS, and the protocol is based on international obligation and levels of autonomy on UCAV system.

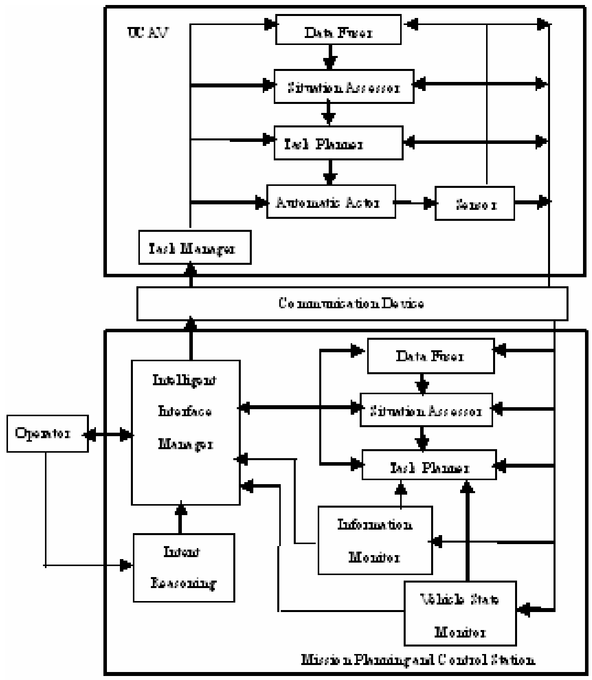


Fig.1 an Integrated Architecture Composed of Human, Intelligent Aiding System on Control Station, Intelligent System on-board UCAV

MPCS will provide decision aid for human on information requirement and analysis, which matches human cognitive requirement to system resources and increases human awareness of battlefield situation, automation mode and capability of system. MPCS aids human in implementing data fusion, gives proposes of situation assessment, aids human in planning and managing tasks, and integrates information and clear interface along with the task process and levels of autonomy on UCAV, even estimates operator's intent and goes by. MPCS includes several displays such as multi-vehicles' tasks monitor, UCAV status monitor and information monitor, which connect through network. Operator revises executable level of tasks, sends command and new mission plan to UCAV, receives information from UCAV, accepts or refuses UCAV suggestions by MPCS.

UCAV will implement autopilot flight, on-board health monitoring, targets detection and identification, flight path planning, information and data simple processing, situation assessment, threaten avoidance and self-protection etc.. Each of these technology developments could induce the interaction mode of human and UCAV to change. When one operator commands and controls multi-vehicles, UCAVs format usually includes head plane and wing planes. The control configuration of a typical format can be composed of four layers: mission management, strategic management, tactical management and coordination action. Mission management is on head plane and others on every plane [7]. Each UCAV can partial optimize oneself behaviors, simultaneity coordinate with others. The interaction of human and UCAVs mainly is distributed decision, including manual, permission, veto and autonomous, like X-45 and other simulating UCAVs [8].

2.2 Task Management

2.2.1 Mission List

Mission list includes flight path points and task operational sequences which mission planning system plans most security and highest performance according to mission goal and commands. Specific control preprogram stowed on UCAV can't respond to all events in complex and variable environment. Operator doesn't control UCAV directly, yet send roughly planning mission list which is composed of some key task and fairway points to UCAV and UCAV controls and adjusts itself according to these lists.

Nodes on mission list are named mission points, includes navigation point, sensor point and communication point etc. Each type of points combines one type of plan like navigation plan, sensor plan, and communication plan. Navigation plan is about flight, sensor plan is about sensors operate, weapon plan is about weapon management, task authorization and shift plan is about task action, system monitor plan is about system monitor and control. After UCAV receives mission list, relevant parts are adjusted according with these plans. Mission list is based on XML.

2.2.2 Levels of Task Authorization

The interaction between human and UCAV system is not either UCAV centered, or human centered, but task performance centered. This interaction includes two features. First, human experts in these domains must work in dynamic, time-pressured environments with large problem spaces characterized by many simultaneous activities. Secondly, complete automation is not an acceptable substitute for human control either because the appropriate behaviors cannot be automated or because there might situations in which a human needs the ability to authorize actions for which the human must be held accountable [8]. Levels of task authorization take four:

Manual: the operator will fully control over the plan's proposal and execution.

Permission: UCAV system proposes and goes to execute plans which is accepted by operators. Operator can accept or reject these plans.

Veto: UCAV system proposes and goes to execute plans which are accepted by operators in limited time. Operator can accept or reject these plans duration of time. If operator doesn't response to this plan in limited time, UCAV system will execute this plan default.

Autonomous: The UCAV system plans and executes proposal autonomously.

Table1 Levels of Task Authorization

levels	depiction	planer	vetor	Information on performance to human	tasks
0	manual	human	human	inform	Weapon authorization
1	permission	human or UCAV	human	inform	Flight way plan
2	veto	human or UCAV	human	inform	Threaten
3	autonomous	UCAV		inform	Flight control

Veto very suits the interaction between human and UCAV system, but takes some risks. Tasks or functions of the level must be designated in task authorization and switch protocol, such as the level of weapon authorization is manual and rarely veto. Level of each task authorization is defined by operator before mission and changed according to situation.

2.2.3 Task Authorization and Shift Protocol

Task authorization and switch protocol is composed of a great deal of rules to define priority of functions and commands to avoid decision confliction. MPCS decision aid and UCAV autonomy is based on same knowledge in order to avoid decision confliction and facilitate operator. The priority of functions and commands is defined according to mission. Now UCAV couldn't accomplish full autonomy, the task plans it planed aren't rounded, yet are emergency plans responded to urgent situation like maneuver routes to avoid threaten. Data fusion by MPCS deals with not only the battlefield information which is from UCAV but also other information from other resources such as air base, ground base, marine base and satellite transmission, so the results are more detailed than by UCAV, and the priority of plans by MPCS is higher than by UCAV. Normally, UCAV flights and executes tasks by the mission list. In an emergency MPCS can send command to directly control UCAV and sensors on-board. Because command is almost real-time and need to immediately execute after received, the priority of command data package is highest. Task manager assesses the battlefield threaten and devices status. When communication link is fine, UCAV sends targets data, vehicles status data, simple fusion data, navigation plans, attack plans etc to MPCS and waits for operator response and command; when communication link is damaged, UCAV becomes a closed loop of information process, levels of some task authorization becomes higher, autonomously collects information, fuses data, assesses the situation, plans tasks and acts.

3 Simulations

3.1Mission Scenario

Simulation system includes command center, mission control center, commander monitor system, operator monitor system and UCAV as Fig.2. The operator operates three UCAVs through information monitor display, status monitor display and multi-vehicles' task monitor display, the commander commands and controls three operators through tactical mission monitor display, multiple formats command and control display and information process monitor display. This paper mainly simulates one operator controlling three UCAVs.

UCAVs will take off from one base each with two guided missiles and suppress enemy air defenses on an island joint manned flight. Enemy defense force includes one fire direction center, three radars and eight surface-to-air missile installations. Fire direction center and radars are primary targets, simultaneously avoiding detection and attack by enemy force.

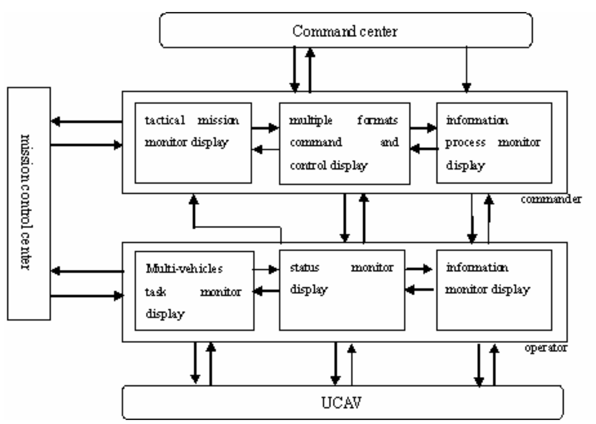


Fig.2 Architecture of Simulation System

3.2 Hierarchical Goal Analysis and Operational Sequence

Mission will be analyzed and decomposed step by step according to subject matter experts and mission scenario from the highest goal to the lowest action until goals couldn't be decomposed, specific operational sequences will be established.

The main goals of SEAD mission include monitoring and controlling vehicles takeoff and landing, detecting, tracking, identifying and validating targets, authorizing weapon, responding to threaten, planning tasks and tactical decision, communicating, controlling and monitoring status in flight.

3.3 Types of Adaptive Tasks

Communication and vehicles flight control will be executed by UCAV system; weapon authorization will accredit to the commander and operator by engagement of rules; battlefield environment and vehicle status monitoring, targets detection and identification, task planning and tactical decision will be shared by operator and UCAV system. When communication link is interrupted, UCAV executes the plan automatically.

3.4 Task Operational Sequence and Authorization List

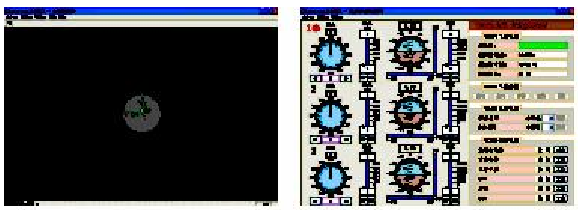
Table 2 Subtasks and Functions Sequence of SEAD Scenario and Authorization Levels (in part)

tasks		Authorization Levels			
		manual	permission	veto	autonomy
Situation assessment			√		√
Appoint area for searching		√			√
Detect target					√
Transmit target information					√
Identify Target			√		√
Appoint attack target		√	√		√
Replan flight path		√	√		√
Authorize attack		√			
Pair weapons and targets		√	√		√
Track and lock target					√
Release missile					√
Hostile threat	Critical				√
	Middle			√	√
	Faintish		√	√	√

3.5 Simulating

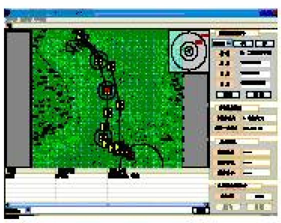
Two dimension and three dimension graphics technology, TCP/IP networks technology, database, Vega and Visual Studio.NET software

are used to design and develop the simulation system. UCAV status monitor display model, multiple task monitor display model, information monitor display model, data communication and management network model, UCAV flight data model are programmed and developed. Interfaces of simulation are as Fig.3.



(a) Information Monitor Interface

(b)Status Monitor Interface



(c)Multiple Vehicles' Task Monitor Interface

Fig.3 Interfaces of Simulation

4 Results and Discussion

Table 3 is a statistical result of objective and subjective evaluation that gained after many test pilots tested the simulation system. The flexible operational relationship, high levels of autonomy and maximum manual is different on task implement time, performance items, yet subjective evaluation of delegation interaction is higher than others.

Table 3 Objective and Subjective Evaluation about Three Interactions

Items/interaction		high levels of autonomy	maximum Manual	Delegation interaction
Objective items	duration	1632	3056	1741
	Target number	2	2	2
	UCAV damage	16	34	12
Subjective items	fatigue	easy	tired	mediate
	acceptance	tired	Very tired	better

5 Conclusions

Results preliminary prove that nowadays the flexible operational relationship between human and UCAV system which integrates intelligent of UCAV and MPCS into human cognitive and operation is superior to high levels of autonomy and maximum manual. Be considerable, the flexible operational relationship is trade-off between flexibility and certainty, development of flexibility of interface requires to collect and extend a great deal of knowledge. Now this simulation system is a bit rough, requires to specific the task management and improve interfaces for refined confirmation made by this system.

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