Human Interaction with Teams of Autonomous UAVs

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Section 1 - Introduction

Background

• Series of studies for UK MoD investigating system requirements of sophisticated UAVs for offensive missions

• Research Objectives
  – Manned/UAV interaction
  – UAV intelligence & autonomy requirements
  – Inter-UAV co-ordination & co-operation requirements
  – UAV integrated system architecture & vehicle management requirements
  – **HMI issues for control of multiple UAVs from**
    • single-seat manned combat aircraft
    • ground control station
  – Datalink & sensor requirements
Section 2

User Requirements
Section 2 – User Requirements

Who is the user?

- Strategic decision-maker
- Tactical decision-maker
- UAV Operator
Section 2 – User Requirements

What are the requirements?

• Operational flexibility
  – Multi-mission

• Complete mission successfully
  – Command team
  – Review sensor data
  – Meet RoE
  – Kill target
Section 3 – System Requirements

Top-Level System Requirements

• System managers & controllers
• On-board intelligence
• Datalinks
• Physical interface
Section 3 – System Requirements

Top-Level HMI Requirements

• Assess current situation
• Assess intent of team/individuals
• Command team/individuals
• Assess status of team/individuals
• Respond to team/individual requests
• Manage autonomy of team/individuals
• Manage sensor product
• Respond to emergency situations
• Share information and/or control with other assets
Section 5 – Implementation

Lower-Level HMI Requirements

- Operator interaction with package & individual UAVs
- UAV status display
- Sensor output display
- Message display
- Levels of autonomy interface
- Mission re-planning interface
- Information sharing
- Control sharing
- Handover between operators
Section 4 – Design Criteria

Influencing Factors on HMI Design

- Division of Responsibility
- Rules of Engagement
- UAV's Environment
- UAV Intelligence
- UAV Autonomy
- Presentation of Information
- Information Parameters
- Supervisor's Environment
- Level of Interaction Requirements
- Information Requirements
- Human Cognitive Behaviour
- Software Interface
- Hardware Interface

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Section 4 – Design Criteria

HCI & Autonomy

- Theoretical foundation for design
- Platform
- Research development and concept testing
- Dealing with autonomous systems and intent
Section 4 – Design Criteria

Theoretical Foundation for Design

User

Interface

Multiple UAVs

Conceptual/mental model

Johnson & Mervis (1998):
The more expert the individual, the more elaborate the mental model

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Section 4 – Design Criteria

Research, Development & Concept Testing

- Random presentation of information on interface can lead to increase in mental workload (Verves & Wickens, 1987)

- Gestalt approach dictates visual elements are grouped together into perceptual groupings (Koffka, 1935)
  - Desire to divide visual regions into meaningful units
  - Perceptual cues can include: organisation, proximity, similarity, surroundedness, continuation, etc.
Section 5

Implementation
## Section 5 – Implementation

### Levels of Autonomy

<table>
<thead>
<tr>
<th>AUTOMATION PACT</th>
<th>UAV AUTHORITY</th>
<th>OPERATOR AUTHORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTONOMOUS</td>
<td>Full UAV authority</td>
<td>Interrupt</td>
</tr>
<tr>
<td>DIRECT SUPPORT</td>
<td>Action unless revoked</td>
<td>Revoke action</td>
</tr>
<tr>
<td>IN SUPPORT</td>
<td>Advice and, if authorised, action</td>
<td>Accept advice &amp; authorise action</td>
</tr>
<tr>
<td>ADVISORY</td>
<td>Advice</td>
<td>Accept advice</td>
</tr>
<tr>
<td>AT CALL</td>
<td>Advice, only if requested</td>
<td>Request advice</td>
</tr>
<tr>
<td>COMMANDED</td>
<td>None</td>
<td>Full operator authority</td>
</tr>
</tbody>
</table>

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Section 5 – Implementation

Ground-based Interface
Section 5 – Implementation

Reconfigurable Layout

(a) Dynamic C2 Taskbar
   SA Display

(b) Dynamic C2 Taskbar
   SA Display
   IMG
   MSG

(c) Dynamic C2 Taskbar
   SA Display
   IMG

Bialystock & Olson (1987):
“…spatial categories were the manifestation of mental structures in the form of spatial propositions.”
Section 5 – Implementation

Navigation: Map Manipulation
Section 5 – Implementation

Image Selection

Track or image selected
Section 5 – Implementation
Dealing with Autonomous Systems & Intent

• To understand why a UAV is behaving in a certain way, an operator needs to know what it believes, what it is trying to achieve and how it is planning to achieve it.
Section 5 – Implementation

Task Schedule Display

- Makes task allocations visible
- Shows what the UCAVs are currently doing and will be doing next
- Offers the potential for operator intervention

![Diagram showing task schedule for UCAVs](image-url)
Section 5 – Implementation

Predictive Behaviour

Select UCAV tasks to be displayed from here

UCAV 3 selected
Section 5 – Implementation

Conveying UAV Intent

• Plans will need to be presented in a way that conveys how the goals are to be achieved
  – How are the assets organising themselves?
    • Which asset is doing what task?
  – How long will tasks take to complete?
  – When will operator interaction be required?

• Greater scope to achieve this with large-screen displays
Section 5 – Implementation

Trajectory Projection

De-cluttered

Time-based

Task-based
Section 5 – Implementation

Presentation of Intent

• Important to maintain alignment (and operator visibility) of Beliefs, Desires and Intentions

• Consequences of not doing so include
  – Operator exclusion
  – Operator confusion

• Benefits of doing so include
  – Better Situational Awareness
  – Operator able to anticipate events
  – Greater operator trust in the system
Section 5 – Implementation

Airborne HMI
Section 5 – Implementation

Situational Awareness Display
Section 5 – Implementation

Team Display
Section 5 – Implementation

Status Display

Granite24 has entered Waypoint mode, 800 secs
Section 5 – Implementation

Message Display

- AUTO BIL
- ACPT
- RJCT
- DEL

BIL Picture received from UAV 00201
10 Secs

- BIL Picture received from UAV 00205
- UAV 00203 ABOUT TO GOTO POI 01

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Imagery Display

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Human in the Loop Trials
Section 5 – Implementation

Workload Assessment for Trial 2004

• Operator A had lower workload than Operator B
  – Differences in training & experience with system
• Operator A focused on information acquisition
  – System familiarity
  – Limited information availability from agents
• Operator B focused on responding to demands from agents
  – Lack of familiarity with mission, potential requests, & UAV behaviours
Section 5 – Implementation

Situation Awareness Ratings for Trial 2004

- supporting evidence
Section 5 – Implementation


- Distribution for 2003 similar to 2004
  - Slight increases due to increased mission complexity & addition of package command window without incorporating UAV intentions
- Distribution significantly changed in 2003 from 2000
  - Reduced in Search & Verify due to advances in
    - UAV intelligence
    - ATR
    - Image management
  - Increase in Attack due to
    - Increase in amount of information available
    - Need for operator to monitor progress of weapon & abort attack
Section 5 – Implementation

SA Ratings Comparison: Trials 2003 & 2004

- Command process improved
  - Enhancements to UAV co-ordination
  - Addition of package command window

- Package command window
- Enhance SA

- Access to information improved
  - Add weapon range info
  - Limited by lack of supporting evidence on decisions

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Trial Summary

• Operator understanding of UAV behaviours desirable
• Dichotomy between operator control & fully autonomous systems
• Poor subjective ratings at beginning of research driven by poor design of HMI
• Subjective ratings limited by
  – Poor understanding of UAV decision process & intentions
• Single-seat combat aircraft control is viable (in simulation)
Support to UAV Systems & Demonstration

Developing dedicated UAV test bed capability in form of piloted surrogate to facilitate cross-programme development of UAV technologies

- Practical demonstration of advanced UAV autonomy & $C^2$ technologies
- Providing UK MOD with increased credibility in UAV development & demonstration

- Auto-coupled flight guidance from post-launch to pre-recovery
- Autonomous behaviours, under control of single-seat fast jet operator
- Co-ordination of vehicle systems to achieve safe & effective mission performance
Section 6 – Future Direction

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ASTRAEA

Developing & demonstrating technologies, rules, & regulations to enable routine flight in all classes of UK, European, & Global airspace

Benefits

- Positions UK at forefront of push to open up airspace to UAVs
- Provides UK industry with key technologies needed to open up marketplace
- Provides guidance to regulatory authorities

Outcome by Dec 2008

- Demonstration of entire system in SE
  - Take off Aberporth, fly through all types of airspace, & land Sumburgh
- Demonstration of individual technologies in SE, Surrogate platforms, & UAVs
Section 7

Conclusions
Conclusion

• Results indicate that capability management not platform management can
  – improve SA
  – lower workload
  – facilitate information sharing
  – facilitate control sharing