Interaction-centered Design for Safe Operations of Aerial Robots

Dr. Ming Hou
Defence R&D Canada
Outline

- Background for Interaction-centered Design
- Human Factors (HF) in System Design
- Issues for Unmanned Aerial Robots
- A Solution: Intelligent Adaptive System (IAS)
- An Example of IAS Design
- Takeaway
- Announcement: Canadian IDEaS Program
My Experience in A Manned Aerial Robot Accident

4 years ago, 25 Jan 2015 at Bridgeport, West Virginia

A Disturbing Scene (two months ago)

A Video clip from inside of the aircraft before the crash
157 People KILLED
by An Uncontrollable Aircraft (a flying “Killer Aerial Robot”)

6 mins after Ethiopian Airlines Flt 302 took off from Ethiopian capital Addis Ababa to Nairobi on 10 March 2019.

The deadliest accident for Ethiopian Airlines

theglobalandmail.com  reuters.com
Another: 189 People KILLED by the same type of “Killer Aerial Robot” only 6 months ago

12 minutes after Indonesian Lion Air Flt 610 took off on 29 October 2018, although pilots tried to override the system more than two dozen times. The system (automation/AI) kept engaging nonetheless, most likely because of bad readings from a sensor, until the plane crashed into the Java Sea. (The New York Times).
Same Type of Aircraft (Became A Killer Aerial Robot)

Boeing 737 MAX 8

- Maximum seats: 210
- Engine: LEAP-1B from CFM INTERNATIONAL
- Range: 3,550 nm
- Length: 39.52 m
- Height: 12.3 m
- Wingspan: 35.9 m

Boeing 737 MAX 8 Crashes

October 29, 2018: LION AIR FLIGHT 610
- 189 people killed
- In-operation: Aug 15, 2018 - October 29, 2018

March 10, 2019: Ethiopian Airlines flight 302
- 157 people killed
- In-operation: June 30, 2018 - March 10, 2019

Source: Boeing, Al Jazeera | March 10, 2019
Boeing Reprograms 737 System Linked to Crashes

A software update will prevent a single sensor from activating the Maneuvering Characteristics Augmentation System. The data from both sensors will be considered.

The MCAS system originally was programmed to push the plane’s nose down if a single AOA sensor told MCAS it was in danger of going into a stall.

In that case, it would attempt to push the jet’s nose down by forcing the angle of the jet’s horizontal stabilizer up.

Sources: Boeing, Mentourpilot
On 1 June 2009, Air France Flt 447 from Rio de Janeiro, Brazil to Paris, France crashed into the Atlantic Ocean. The accident is the **deadliest** in the history of Air France, and the **deadliest** aviation accident involving the Airbus A330.

http://www.spiegel.de
What Happened

1. Aircraft crashed after temporary inconsistencies in airspeed measurements (frozen pitot tubes) caused the autopilot to disconnect.

2. In particular, the misleading stopping and starting of a stall warning alarm, which contradicted the actual aircraft status, contributed to the crew’s difficulty in analyzing the situation (Hosford et al., 2012).

3. As a result, and despite the fact that they were aware that their altitude was declining rapidly, the pilots were unable to determine which instruments to trust and did not know aircraft was stalling until it was too late.
A Bad Design for: Human-Machine Interaction

Machine (cockpit)’s representation of the reality did not reflect reality itself: inconsistent airspeed readings led to the crew losing situation awareness (SA) about the aircraft status.

When the crew made a decision to push the nose down and get out of rapid stalling, it was too late and resulted in a deadly crash in the Atlantic Ocean.
10 Years Later: History Repeats Itself

We learn in A **HARD WAY** with the price of lives
A Good Design for: 
Human-Machine Interaction

15 Jan 2009, US Airways Flt 1549 departed LaGuardia Airport in New York City. A min into the flight, the aircraft (Airbus A320) lost engine power due to damaged engines by migratory Canadian geese. The pilot (Capt Sully) made a quick decision to land safely in the Hudson River and all 155 people survived

http://www.reuters.com

Principles, Guidance, and Methods to Design and Test Intelligent Human-Machine Systems

Detailed analysis of two incidents above in 2009 described on pages 7-9
What A Real Life Example in a Hollywood Movie “Sully” Tells?

Human Factors
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About 80% of the aviation incidents are due to human errors.

The most important element is --- the human when assessing factors involved with readiness and performance of any safety-critical systems (e.g., Aerial Robots).

Despite “intelligent systems” and/or “unmanned systems”, much human involvement is still required to achieve desired system safety and effectiveness.
It establishes policy and responsibility for incorporating and coordinating human factors considerations in FAA programs and activities to enhance aviation safety, efficiency, and productivity.

It states “HF shall be systematically integrated into the planning and execution of the functions of all FAA elements and activities associated with system acquisitions and system operations. FAA endeavors shall emphasize HF considerations to enhance system performance and capitalize upon the relative strengths of people and machines. These considerations shall be integrated at the earliest phases of FAA projects.”
A Reminder of Interaction-Centered and Context-Based Design Approach

1. Design around human capacities and limitations
2. Understand consequences of using inappropriate design methodologies for difference domain applications (context-based)
3. Consider optimization of human-machine interactions (interaction-centered)
4. Systems designers should consider not only human capabilities and limitations, technological constraints, and working domain contexts, but also human–machine interaction
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Context for UAS Operations

- What is left behind when human being taken out of the aircraft for Unmanned Aircraft System (UAS)?
- Taking into account...and does it matter?
  - Modality and sensation (speed, sound, pressure, etc.)
  - Design of ground control station (GCS)
  - Automation (performance augmentation)
UAS Issues to Consider

- **Sensory Issues** (HMI: Visual, Auditory, Somatogravic)

- **Physiological Concerns:**
  - Fatigue: sensory underload, repetitive tasks, scheduling
  - Operating environment: crew rest facilities, noise control, temperature control, etc.

- **Remote Operations:** time delay, ‘see and avoid’ operations, radio communications, lack of direct control, etc.

- **Control Issues:** crew change, computer control faults (reset), missed radio calls, missed altitude deviation, sensor output change, engine power setting, etc.
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A Human-Machine System (HMS)

Represented by a human operator (i.e., pilot), a machine (i.e., aircraft), and the interface (i.e., cockpit) that allows them to communicate/interact/work together as partners.

A Conceptualized HMS

(Hou, Gauthier, & Banbury, HCI 2007)
(Hou, Banbury, & Burns, 2014)
Intelligent Adaptive System (IAS)

- A hybrid system that features state-of-the-art interface and automation technologies to *intelligently adjust its behavior* and *adapt* to *dynamically changing* tasks, operator states, and working environments.

- Focus on *dynamic and intelligent adaptation* (e.g., why, who, what, when, and how) to optimize human-machine interaction for safe, effective, and efficient operations.

Hou, et al., 2007 (Journal of Cognitive Engineering and Decision Making)
Hou, et al., 2014 (Intelligent Adaptive Systems – An Interaction-Centered Design Perspective)
A Scientific Solution for: A Collaborative Partnership

“Setting a clear statement of the importance of collaboration and partnership between Human and AI, and outlining how this can be achieved through interaction design…”

Chris Baber, University of Birmingham, Ergonomics, 2017, Vol. 60, No.10, 1458-1459

A must read for any serious professional in academia, government, or industry, interested in building and using twenty-first century human-computer symbiosis technologies...

Dylan Schmorrow
Evolution of Interface and Automation

The technology evolution of IAS:

- **Technology - centered**
- **User - centered**
- **Interaction - centered**

The diagram illustrates the progression from an Interface to an Intelligent Adaptive System, highlighting the evolution in approach from technology-centered to user-centered and finally interaction-centered.
IAS Development Road Map

1. Conduct Taxonomic Analysis
2. Select Framework
3. Select Analysis Methodology
4. Select Design Methodology
5. Select Operator-State Monitoring Approach
6. Comply with Design Guidelines

Hou, et al., 2007 (Journal of Cognitive Engineering and Decision Making)
Hou, et al., 2014 (Intelligent Adaptive Systems – An Interaction-Centered Design Perspective)
Design Issues to Address – W5H1
as an Integrated Design Team (e.g., Project Manager, Design Engineer, or Systems Developer, etc.)

- Why (rationale, perceived need, perceived benefits)
- What (mission, task)
- Where (working environment – context)
- When (timing, frequency, duration)
- Who (intended users/operators)
- How (use case/scenario – interaction)
The NATO Unmanned Aircraft Systems Human Systems Integration Guidebook

“A guide to the Human Systems Integration process for the design and procurement of better performing and safer Unmanned Aircraft Systems”
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A Mission Scenario (context): why, what, where, when, who

Multi-UAVs
Searching for Terrorist Vessels

RCAF Maritime Patrol Aircraft CP140
Selection of Analytical Techniques (How)
Operational Sequence Diagram

<table>
<thead>
<tr>
<th>Part 1</th>
<th>IP/PCT Scenario of UAV Operations</th>
<th>Page 26</th>
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<tbody>
<tr>
<td>Min 1−20</td>
<td>Control of Single VTUAV During Search for Terrorist Vessel</td>
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</table>

**UAV Operator**

- **374** Re-establish CENTERACK of Contact 2
  - 10 Sec (…374) 4.2.5

**UAV Op Up. Level Goals**

- **374** … Contact 2 located on VTUAV radar
- **572** … Contact 2 located on VTUAV radar
- **426** Monitor discussion
  - 20 Sec (…416) 9.2.1

**TACNAV**

- **424** Discuss updated surface plots
  - 20 Sec (…416) 9.4.1.3

- **573** End Goal 374 … Contact 2 located on VTUAV radar
- **576** 386 … Contact 2 is identified using the VTUAV EO suite
- **577** End Goal 386 … Contact 2 is identified using the VTUAV EO suite

**Study radar plot**

- **375** Study radar plot
  - Cont. (…374) 4.2.5

**Determine that radar contact is actually 2 boats**

- **380** Determine that radar contact is actually 2 boats
  - 15 Sec (…380) 4.2.5

**Observe possible contacts using VTUAV EO suite**

- **386** Observe possible contacts using VTUAV EO suite
  - 15 Sec (…386) 7.1.5.1

**Observe that one of the contacts is Contact 2**

- **388** Observe that one of the contacts is Contact 2
  - 10 Sec (…386) 7.1.5.2

**Determine that Contact 2 is not the terrorist vessel**

- **389** Determine that Contact 2 is not the terrorist vessel
  - 30 Sec (…386) 4.4.5
## Goal/Task Analysis

### Level (Indent) & Goal/Objective and Subgoals/Subobjectives

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<thead>
<tr>
<th>Number</th>
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<th>2</th>
<th>3</th>
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<td>... UAVs are employed</td>
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<td>... VTUAV is employed</td>
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<td>... VTUAV navigation is conducted</td>
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<td>... VTUAV destination is determined</td>
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<td>Location</td>
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An Agent-Based Conceptual Framework for IAS Design
A UAS GCS Prototype
Some HF Aspects of Intelligent Systems (e.g., Unmanned / Driverless / Autonomous Systems, AI)

1. Interaction and Transparency
2. Trust and accountability
3. Legal and ethical implications
4. Policy and Regulation
Authority Pathway for Weapon Engagement (APWE)

- An agent-based intelligent decision aid to assist decision-makers in following ROEs and the Law of Armed Conflict (legal, ethical, accountability, and trust) when engaging a target.

- APWE dynamically changes the interface adaptively based on intelligence inputs, external authorities, and AI agents.

- Displays the status of the steps required to release a weapon.

- Integrated with Int’l (US, UK, AUS) C2 systems and tested in an Int’l Joint Service Exercise

“Controlling different autonomous platforms like this is a game changer. Like getting lions, tigers and bears to hunt as one species.”

CMDR Paul Hornsby
Participants Feedback

1. “... brilliant idea (to visualize engagement status for transparency) ...”

2. “... massive fan; logical and great visibility of engagement status...”

3. “... intuitive use for tasking authority to interact (with CDE and AI agents during target engagement) ...”

4. “... supports effective human-autonomy partnerships (teaming) ...”

5. “... the most trustworthy of the whole thing (allied C2 system) because the increased SA and reduced workload (and potential human error) ...”
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Takeaway

- The best technology is NOT necessarily the 1st or the most advanced one (e.g., networking, sensing, and control), but the safest and most effective one.

- Disasters occur repeatedly due to the lack of implementation of HF principles in designing safety-critical HMSs for both civil and military applications.

- What can we do as a society to benefit from HF advancements and mitigate potential risks given the difficulty in designing fully fail-proof systems (e.g., AI, unmanned/driverless/ autonomous systems)?
Rise of AI Machines: the World’s First Robot Citizen

In November 2017, a robot Sophia was given citizenship of Saudi Arabia – the first robot given legal personhood anywhere in the world.

However, this AI robot says that she wants to destroy Humans...

AI Will ‘transform or destroy’ Society

“Success in creating effective AI, could be the biggest event in the history of our civilization. Or the worst. We just don't know. So we cannot know if we will be infinitely helped by AI, or ignored by it and side-lined, or conceivably destroyed by it,...

Unless we learn how to prepare for, and avoid, the potential risks, AI could be the worst event in the history of our civilization. It brings dangers, like powerful autonomous weapons, or new ways for the few to oppress the many. It could bring great disruption to our economy."

Stephen Hawking
IDEaS: An Opportunity to showcase your innovative ideas!

Regardless if you are working from your home, an academic in a university lab or a scientist in a small or a major corporation, the Innovation for Defence, Excellence and Security program is looking for your solutions to help resolve defence and security challenges. Launched in April 2018 with $1.6 billion budget and multiple supporting mechanisms: Ideation, Competitive Projects, Contests, Innovation Networks, Sandboxes, and Innovation Assessment & Implementation.

Thank You!

QUESTIONS/COMMENTS?