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Human-in-the-Loop Telemanipulation Platform for Automation-in-the-Loop Unmanned Aerial Systems

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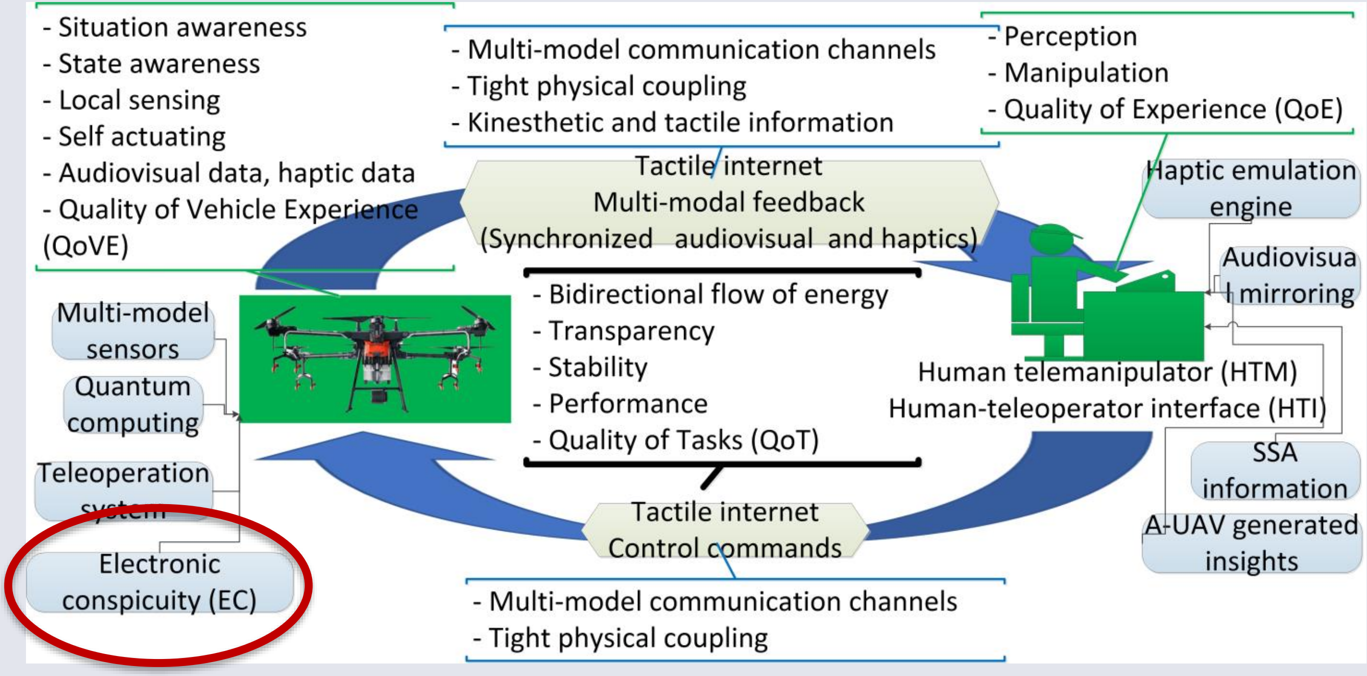
Introduction

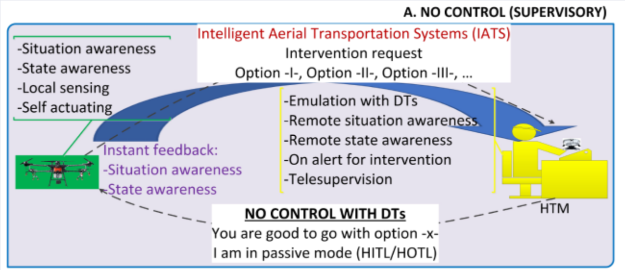
- There are still many limitations with AVs despite several decades of earlier research,
- Many years to come for A-UAVs to become completely self-sufficient,
- HITL telemanipulation to build the required trust in A-UAVs.
- This technical report examines the telemanipulation schemes between two smart agents:
  - ❖human telemanipulators (HTMs) and A-UAVs.
- This work develops a platform to test and evaluate telemanipulation Schemes

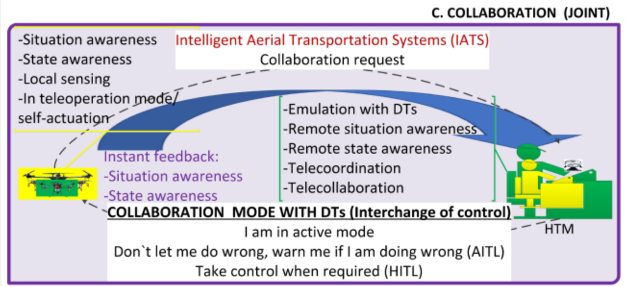
Components of human haptic close-loop telemanipulation of A-UAVs

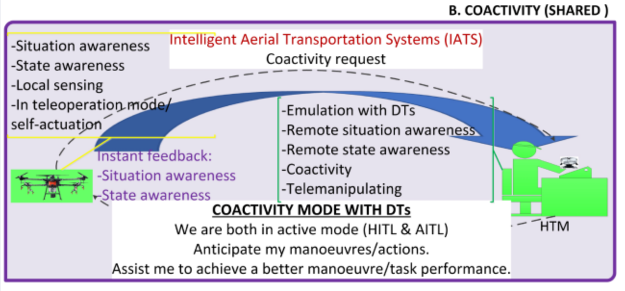


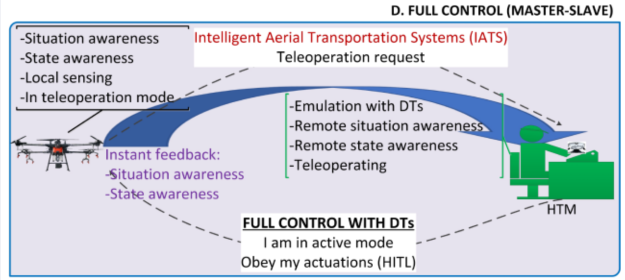
A tight communication channel with high bandwidth capabilities (i.e., ultra-reliable and low-latency communication (URLLC))

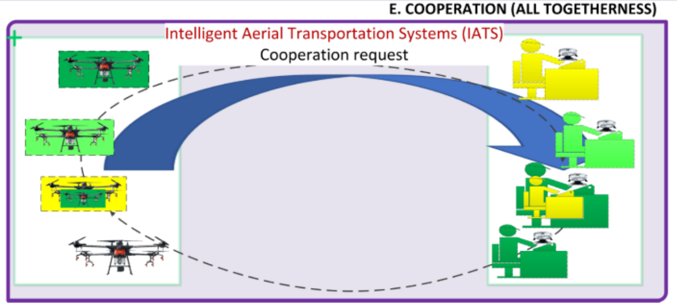
Telemanipulation Schemes with A-UAVs



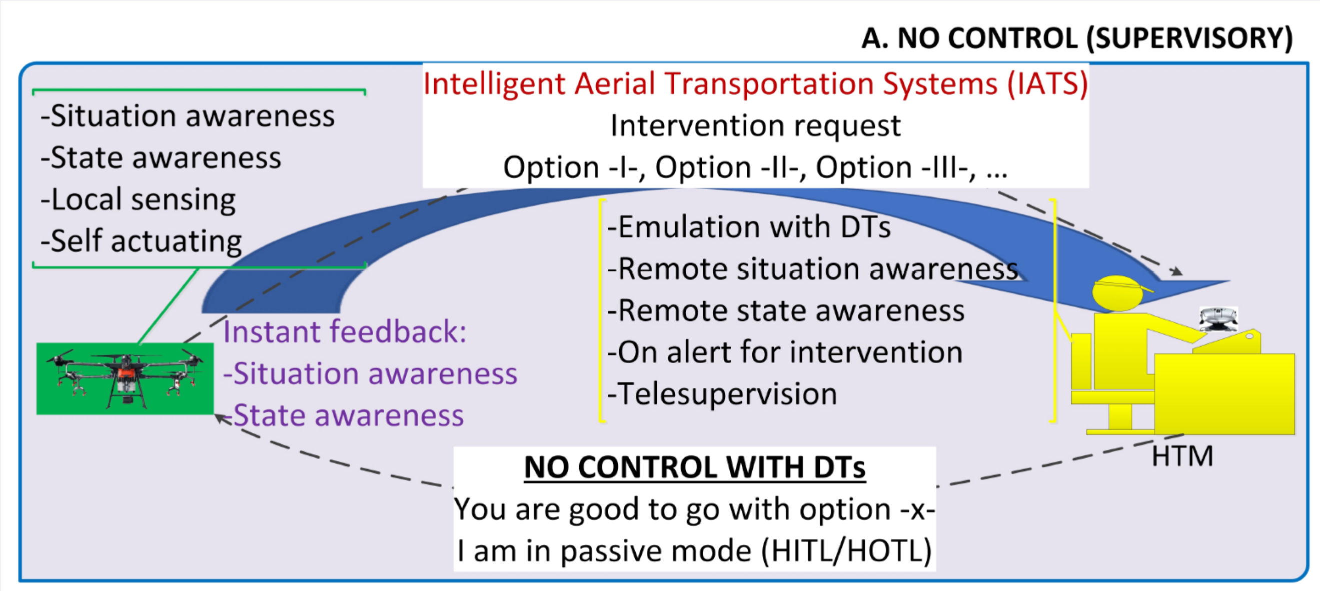








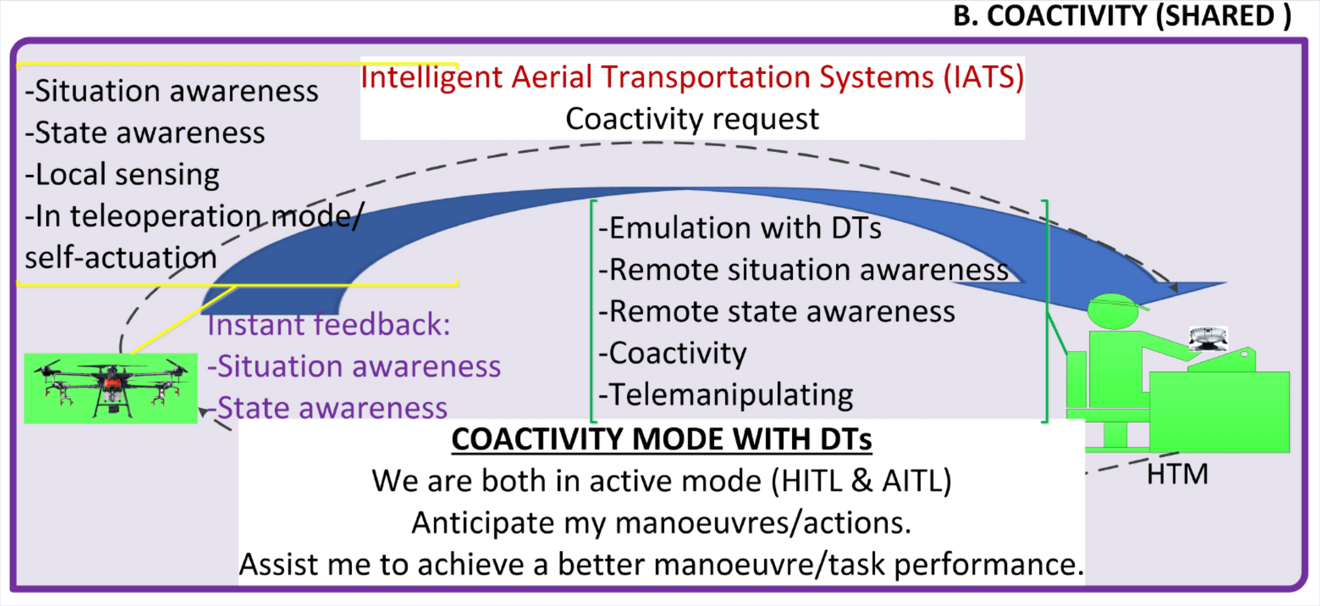
Telemanipulation Schemes with A-UAVs



- The involvement of HTMs minimised.
- A high degree of freedom for A-UAVs.

✓ HTM assists A-UAVs by setting short-range subtasks for the agent to achieve independently.

Telemanipulation Schemes with A-UAVs



- co-activity
- master-master

(i.e. more equal co-worker)

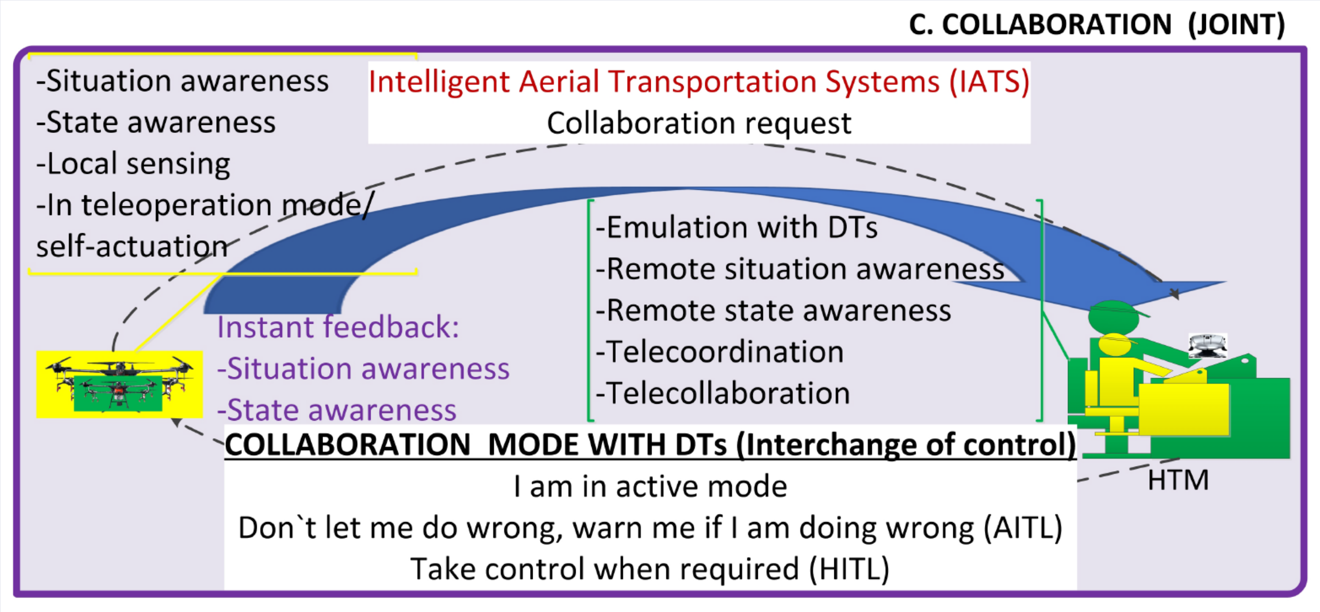
- combined task performance

✓ Roles and responsibilities may not be distinctively assigned.

✓ Human and robot skills combined.

✓ The combined system can outperform both agents.

Telemanipulation Schemes with A-UAVs

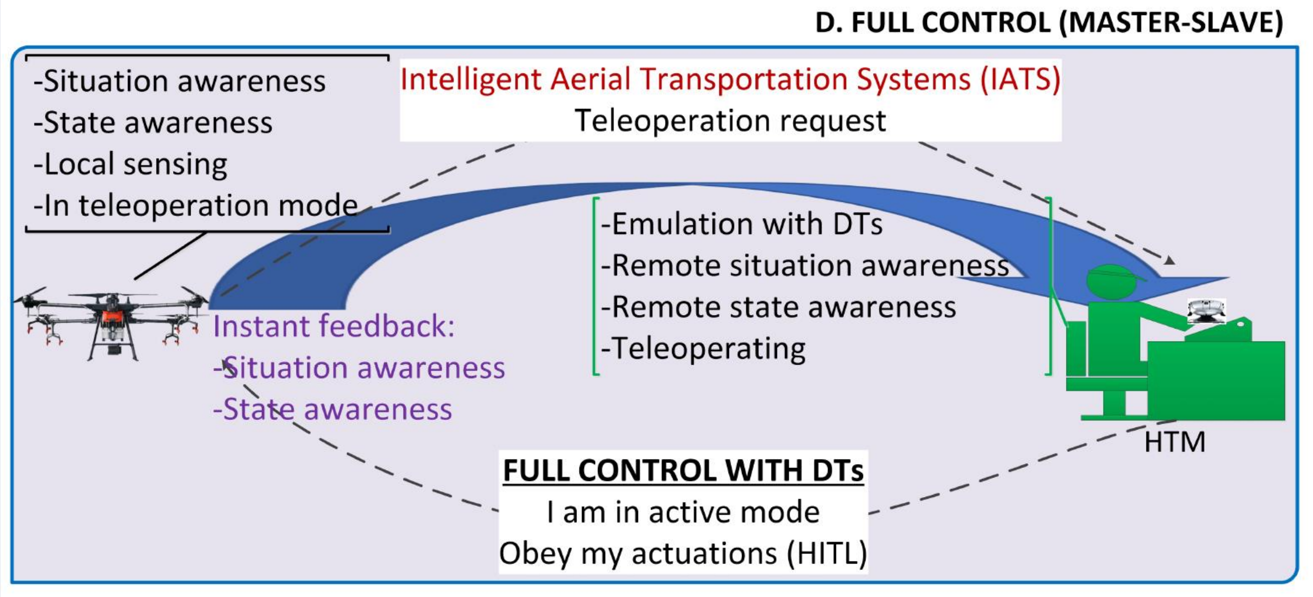


- sub-tasks traded back and forth
- sub-tasks performed individually
- joint task performance

✓ Humans and robots converge to exchange ideas and settle disagreements rather than a superior giving orders to a subordinate.

✓ The robot has more freedom in execution.

Telemanipulation Schemes with A-UAVs

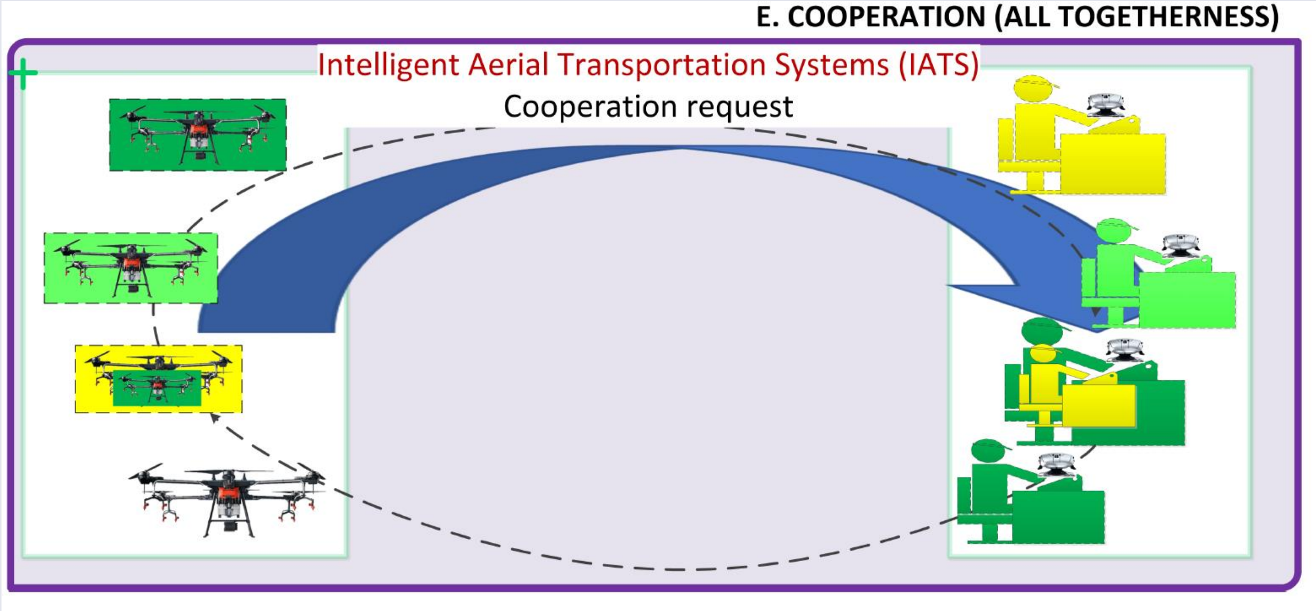


- Onboard sensor failures
- failures of primary actuators

✓ Complete tasks may need to be performed by HTMs alone under extreme conditions in this scheme.

✓ HTMs, as leading agents, take over the control and lead A-UAVs as follower agents.

Telemanipulation Schemes with A-UAVs



- Swarms of A-UAVs
- multiple telemanipulation schemes
- Common goal as a teamwork
- one-to-many or many-to-many human-robot coordination

✓ to accomplish a specific task faster than a single A-UAV or to solve difficult tasks that are beyond a single A-UAV's capability, e.g.

-search and rescue missions,

-transportation of a hefty payload.

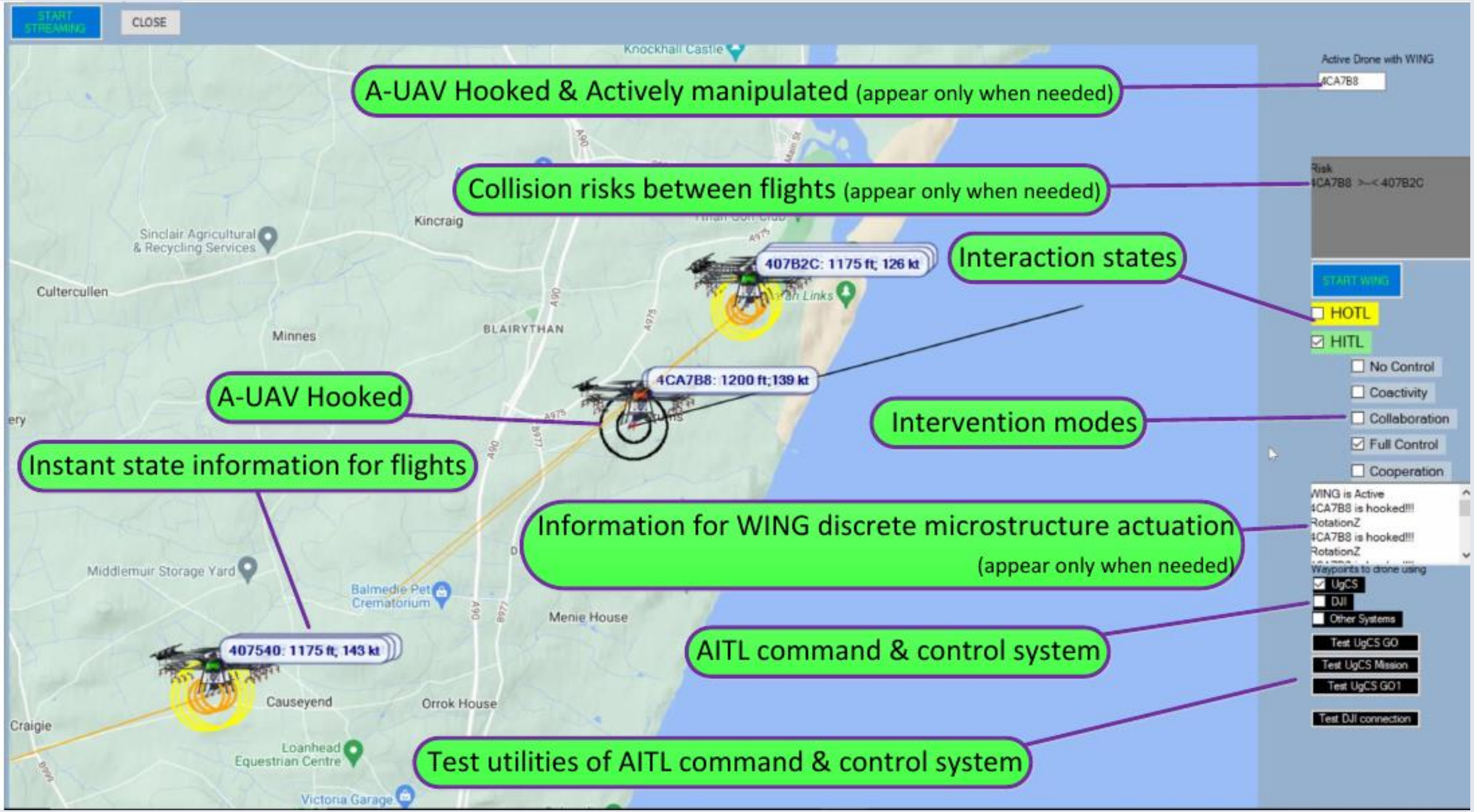
Main properties of the telemanipulation schemes

<table>
<tr><th>Schemes</th><th>Loop</th><th>Decision</th><th>Obedience A-UAV</th><th>Obedience HTM</th><th>Solution for conflicts</th><th>Full control</th><th>Built-in safety</th></tr>
<tr><td>No-control</td><td>HITL</td><td>HTM</td><td>Yes</td><td>No</td><td>N/A</td><td>Yes (A-UAV)</td><td>Operational</td></tr>
<tr><td>Co-activity</td><td>HITL & AITL</td><td>HTM & A-UAV</td><td>No</td><td>Yes</td><td>HTM & A-UAV</td><td>No</td><td>Operational</td></tr>
<tr><td>Collaboration</td><td>HITL || AITL</td><td>HTM || A–UAV</td><td>No</td><td>No</td><td>HTM || A-UAVs</td><td>Partial</td><td>Operational</td></tr>
<tr><td>Full-control</td><td>HITL</td><td>HTM</td><td>Yes</td><td>No</td><td>N/A</td><td>Yes (HTM)</td><td>Inactive</td></tr>
<tr><td>Cooperation</td><td>Mix interactions</td><td>Mix schemes (above)</td><td>Mix schemes (Yes||No)</td><td>Mix schemes (Yes||No)</td><td>Mix schemes (above)</td><td>Mix schemes(above)</td><td>Operational</td></tr>
</table>

Transitional responsibilities of the HITL and AITL agents during the switching

Switching between schemes	Current control	Next control	Current dominance	Next dominance	Switching control
No >>>>co-activity	A-UAV	A-UAV-HTM	A-UAV	A-UAV&HTM	A-UAV
No >>>>collaboration	A-UAV	A-UAV-HTM	A-UAV	HTM	A-UAV&HTM
No >>>>full	A-UAV	A-UAV-HTM	A-UAV	HTM	A-UAV&HTM
co-activity >>>>collaboration	A-UAV-HTM	A-UAV-HTM	A-UAV&HTM	HTM	HTM
co-activity >>>>full	A-UAV-HTM	A-UAV-HTM	A-UAV&HTM	HTM	HTM
co-activity >>>>no	A-UAV-HTM	A-UAV	A-UAV&HTM	A-UAV	A-UAV
Collaboration >>>>full	A-UAV-HTM	A-UAV-HTM	HTM	HTM	HTM
Collaboration >>>>no	A-UAV-HTM	A-UAV	HTM	A-UAV	HTM&A-UAV
Collaboration >>>>co-activity	A-UAV-HTM	A-UAV-HTM	HTM	A-UAV&HTM	HTM
Full >>>>no	A-UAV-HTM	A-UAV	HTM	A-UAV	HTM&A-UAV
Full >>>>co-activity	A-UAV-HTM	A-UAV-HTM	HTM	A-UAV&HTM	HTM
Full >>>>collaboration	A-UAV-HTM	A-UAV-HTM	HTM	HTM	HTM

Platform to Test and Evaluate HITL Telemanipulation Schemes Main Interface



Interface of the co-simulated platform (DTs of aerial traffic)

Platform to Test and Evaluate HITL Telemanipulation Schemes WING Device

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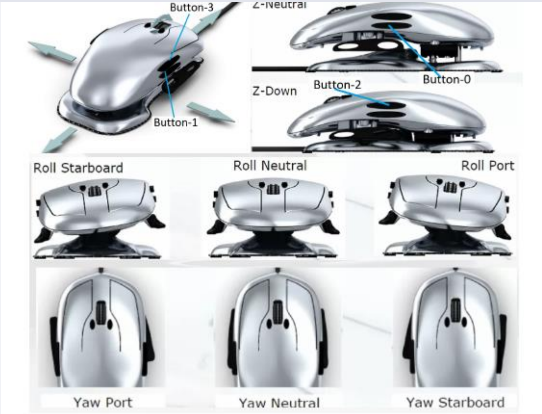


Fig. 4: Essential attributes: The mapping of the WING to the rotational orientations with three degrees– roll (Φ), pitch (Θ) and yaw (Ψ) channels.

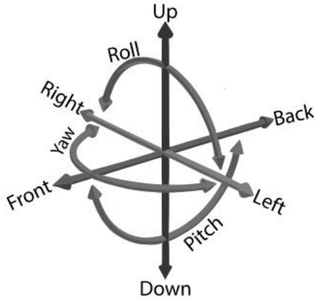


Fig. 5: Conceptualisation of 6DoF (i.e. 3 translation degrees and 3 rotation degrees) of the WING.

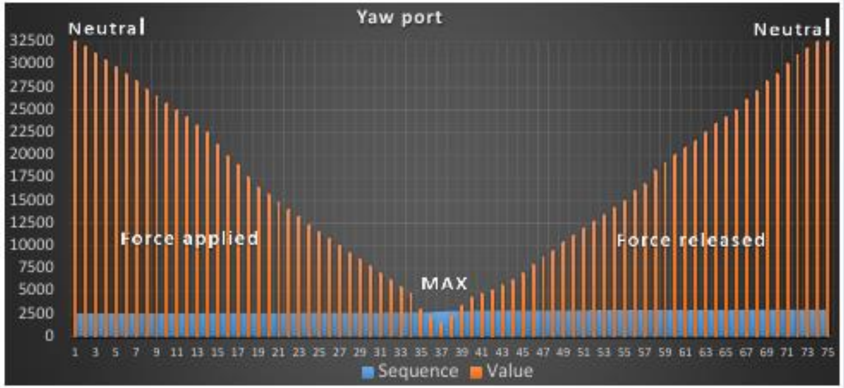


Fig. 6: States of Yaw Port.

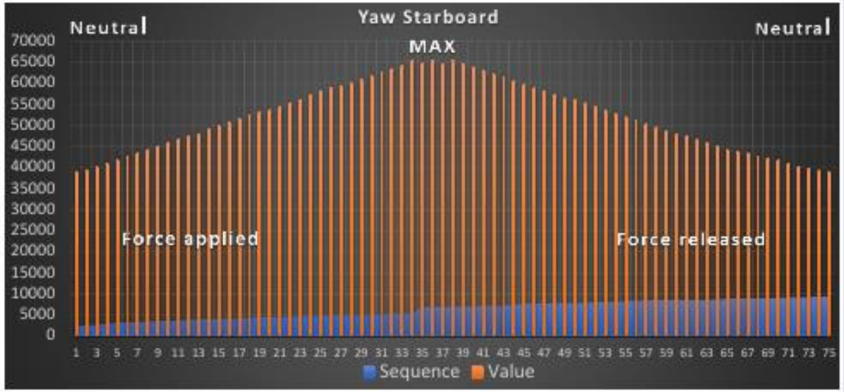
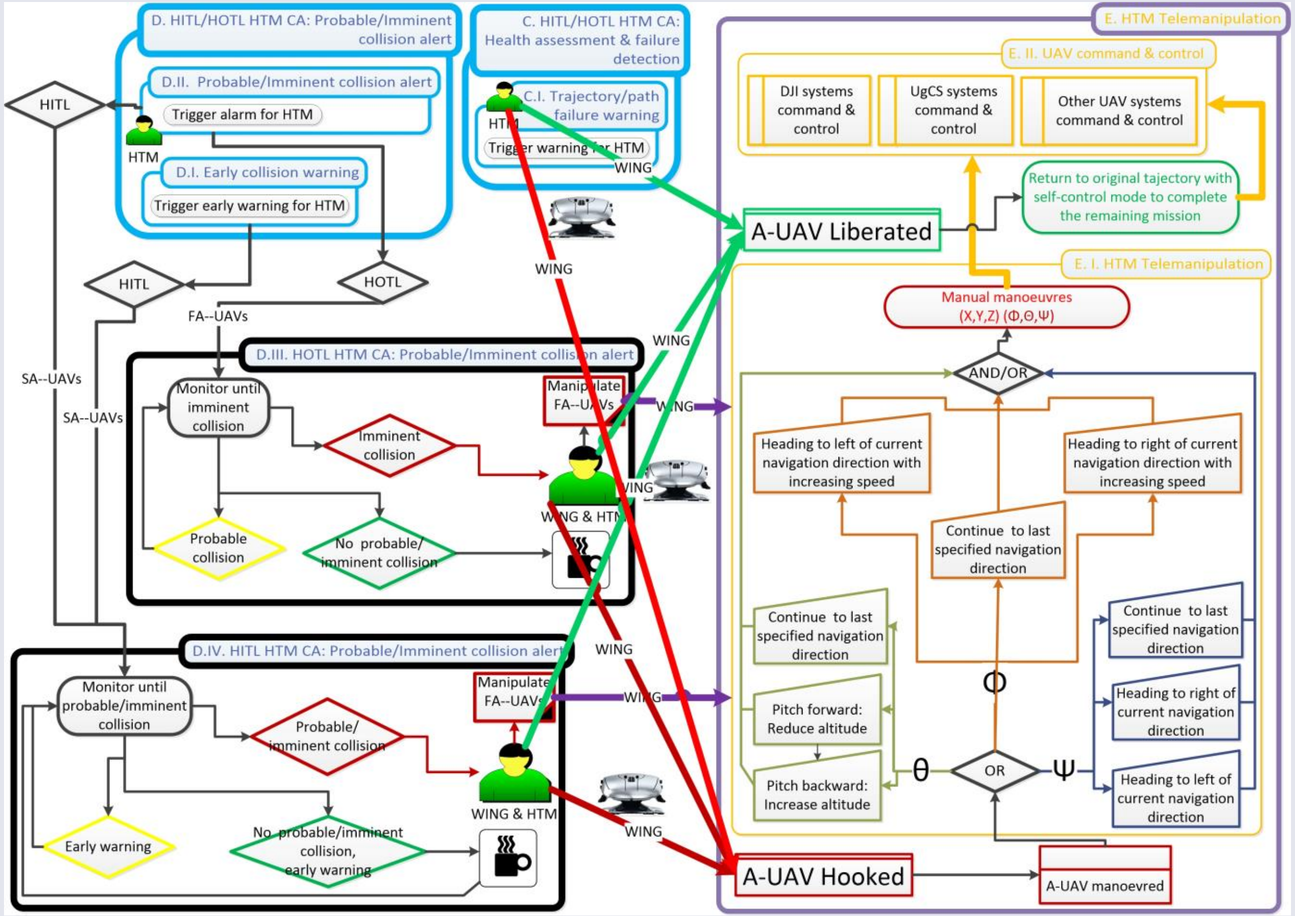


Fig. 7: States of Yaw Starboard.

Platform to Test and Evaluate HITL Telemanipulation Schemes
Methodology: Hooking and manipulation



Platform to Test and Evaluate HITL Telemanipulation Schemes Manipulation of A-UAVs using WING Device

Data: System input: Ψ_{Pmax} & Ψ_{Pmin} & Ψ_{Smax} & Ψ_{Smin} & Φ_{Pmax} & Φ_{Pmin} & Φ_{Pmax} & Φ_{Pmin} & Θ_{Fmax} & Θ_{Fmin} & Θ_{Bmax} & Θ_{Bmin}
Data: Instant input: RoI.flights.Data
Result: $D_H.\Psi$ & $D_H.\Phi$ & $D_H.\Theta$ & D_H.heading & D_H.speed & D_H.alt
=> Create the hooked drone for manipulation & initialise variables;
HookedDrone D_H = new HookedDrone(); $D_H = meD$;
$\Phi_{prev} = 0$; $\Theta_{prev} = 0$; $\Psi_{prev} = 0$; $D_H.\Phi = 0$; $D_H.\Theta = 0$; $D_H.\Psi = 0$;
while *hooked* **do**
  => Inputs from WING;
  if $((W_s == "RotationZ")\&\&((D_H.\Psi > -\pi)||(D_H.\Psi < \pi)))$ **then**
    => Assign the WING value to Yaw (Ψ);
    $\Psi_{cur} = W_{val}$;
    if $(((\Psi_{cur} < \Psi_{Pmax})\&\&(\Psi_{cur} < \Psi_{prev}))||(\Psi_{cur} == \Psi_{Pmin}))$ **then**
      => Heading to left of the curret navigation direction;
      D_H.heading = D_H.heading - $D_H.property(\Psi_{DiffDeg})$;
      $D_H.\Psi = D_H.\Psi$ - $D_H.property(\Psi_{DiffDeg})$;
    else if $(((\Psi_{cur} > \Psi_{Pmin})\&\&(\Psi_{cur} > \Psi_{prev}))||(\Psi_{cur} == \Psi_{Pmax}))$ **then**
      => Heading to right of the curret navigation direction;
      D_H.heading = D_H.heading + $D_H.property(\Psi_{DiffDeg})$;
      $D_H.\Psi = D_H.\Psi + D_H.property(\Psi_{DiffDeg})$;
    else
      => Continue to last specified navigation direction;
    end
    navigateD_H ($D_H.\Psi$, $D_H.\Phi$, $D_H.\Theta$, D_H.heading, D_H.speed, D_H.alt);
    $\Psi_{prev} = \Psi_{cur}$;
  else if $((W_s == "X")\&\&((W_{val} < \Phi_{Smax})||(W_{val} > \Phi_{Pmin}))\&\&((D_H.\Phi > -\pi/2)||(D_H.\Phi < \pi/2)))$ **then**
    => Assign the WING value to Roll (Φ);
    $\Psi_{cur} = W_{val}$;
    if $(((\Phi_{cur} < \Phi_{Smax})\&\&(\Phi_{cur} < \Phi_{prev}))||(\Phi_{cur} == \Phi_{Smin}))$ **then**
      => Roll starboard: Heading to left of current navigation direction with increasing speed;
      D_H.heading = D_H.heading - $D_H.property(\Phi_{DiffDeg})$;
      D_H.speed = D_H.speed + $D_H.property(\Phi_{DiffDeg})$;
      $D_H.\Phi = D_H.\Phi$ - $D_H.property(\Phi_{DiffDeg})$;
    else if $(((\Phi_{cur} > \Phi_{Pmin})\&\&(\Phi_{cur} > \Phi_{prev}))||(\Phi_{cur} == \Phi_{Pmax}))$ **then**
      => Roll port: Heading to right of current navigation direction with increasing speed;
      D_H.heading = D_H.heading + D_H.property(headDiff);
      D_H.speed = D_H.speed + D_H.property(speedDiff);
      $D_H.\Phi = D_H.\Phi + D_H.property(\Phi_{DiffDeg})$;
    else
      => Continue to last specified navigation direction;
    end
    navigateD_H ($D_H.\Psi$, $D_H.\Phi$, $D_H.\Theta$, D_H.heading, D_H.speed, D_H.alt);
    $\Phi_{prev} = \Phi_{cur}$;
  else if $((W_s == "Y")\&\&((W_{val} < \Theta_{Fmax})||(W_{val} > \Theta_{Bmin}))\&\&((D_H.\Theta > -\pi/2)||(D_H.\Theta < \pi/2)))$ **then**
    => Assign the WING value to pitch (Θ);
    $\Psi_{cur} = W_{val}$;
    if $(((\Theta_{cur} < \Theta_{Fmax})\&\&(\Theta_{cur} < \Theta_{prev}))||(\Theta_{cur} == \Theta_{Fmin}))$ **then**
      => Pitch forward: Reduce altitude;
      D_H.alt = D_H.alt - D_H.property(altDiff);
      D_H.speed = D_H.speed - D_H.property(speedDiff);
      $D_H.\Theta = D_H.\Theta$ - $D_H.property(\Theta_{DiffDeg})$;
    else if $(((\Theta_{cur} > \Theta_{Bmin})\&\&(\Theta_{cur} > \Theta_{prev}))||(\Theta_{cur} == \Theta_{Bmax}))$ **then**
      => Pitch backward: Increase altitude;
      D_H.alt = D_H.alt + D_H.property(altDiff);
      D_H.speed = D_H.speed - D_H.property(speedDiff);
      $D_H.\Theta = D_H.\Theta + D_H.property(\Theta_{DiffDeg})$;
    else
      => Continue to last specified navigation direction;
    end
    navigateD_H ($D_H.\Psi$, $D_H.\Phi$, $D_H.\Theta$, D_H.heading, D_H.speed, D_H.alt); $\Theta_{prev} = \Theta_{cur}$;
  else
    => Return to original trajectory after released from hooking;
    hooked = "false";
    ReturnToOriginalTrajectory();
  end
end

Conclusion

- Maintaining trust in autonomous drones can be achieved through human telemanipulation.
- The best possible location-independent co-work between intelligent aerial vehicles and skilled humans is described in this report.
- This research aims to develop an integrated collective approach to make HITL and AITL agents co-work.
- The developed approach enables the global operation of A-UAVs BVLOS.
- BVLOS real-time HITL telemanipulation approaches are expected to expedite the elimination of Visual Line-of-Sight (VLoS) human operators.
- This paper aims to model human-automation interaction (HAI) in autonomous UASs.

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