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Platform To Test and Evaluate Human-Automation Interaction (HAI) For Autonomous Unmanned Aerial Systems

1st Kaya Kuru
School of Engineering and Computing
University of Central Lancashire
Preston, UK
https://orcid.org/0000-0002-4279-4166

2nd Sam Worthington
Worthington Sharpe Ltd.
Preston, UK
sam@worthingtonsharpe.com

3rd Darren Ansell
School of Engineering and Computing
University of Central Lancashire
Preston, UK
https://orcid.org/0000-0003-2818-3315

4th John Michael Pinder
School of Engineering and Computing
University of Central Lancashire
Preston, UK
JMPinder@uclan.ac.uk

5th Benjamin Watkinson
School of Engineering and Computing
University of Central Lancashire
Preston, UK
BJWatkinson1@uclan.ac.uk

6th David Jones
School of Engineering and Computing
University of Central Lancashire
Preston, UK
DJones38@uclan.ac.uk

7th Claire Tinker-Mill
School of Engineering and Computing
University of Central Lancashire
Preston, UK
CLTinker-Mill@uclan.ac.uk

***Abstract*—In recent years, remote multi-agent human-robot communication and remote agent telemanipulation have thrived considerably in line with the rise of autonomy since Tesla‘s invention of the “distant operator” with a patent (US613809A) in 1898 for controlling wireless drones remotely. As a result of taking on more and more tasks that require decision-making skills, vehicles are becoming more and more automated using intelligent control systems that are getting better with advanced sensors and actuators using AI. While the ultimate goal of these systems is full autonomy, it may take years/decades to make these systems thoroughly integrated into mixed traffic due to the varying expectations of stakeholders and their level of trust in autonomous vehicles (AVs). To expedite this integration and consequently exploit the benefits of these automated systems, in all future scenarios of fully autonomous ground or air vehicle networks, human intervention is expected to take place in the form of “human-in-the-loop (HITL)” remote immediate involvement. In this direction, a scalable agent-based platform was designed for the telemanipulation of autonomous unmanned aerial vehicles (A-UAVs) from the perspective of human-multi-robot architecture by which various HITL telemanipulation schemes can be tested, evaluated and improved.**

***Index Terms*—Telemanipulation, teleoperation, human-in-the-loop (HITL), human–vehicle co-activity, autonomous unmanned aerial systems (UASs), digital twins (DTs).**

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I. INTRODUCTION

The “everyday things” in our environment have been getting more intelligent in recent years thanks to CPSs and improved AI techniques, allowing them to make decisions for themselves with a growing degree of autonomy with little to no assistance from humans [1]. The audacious goal is for all vehicles to be controlled centrally by 2040 [2]. Manipulating autonomous unmanned aerial vehicles (A-UAVs), i.e. unmanned aerial systems (UASs), beyond visual line of sight (BVLOS) operations will be an influential subject over the next few years while autonomous tasks are playing a crucial role in practical applications such as in [3], [4], [5]. Research and commercial interest in A-UAVs is growing exponentially in a diverse range of fields [6], which is driving the development of autonomous flying robots [7]. Readers are referred to [8], [9] for the detailed analysis of the classified autonomy levels with UAVs ranging from fully controlled level to fully autonomous level. UAVs can perform more complex tasks and function in more intricate environments with less operator interaction and less prior knowledge as their level of autonomy rises [10] due to intelligent control systems that are getting better with advanced sensors and actuators using AI. Fully autonomous vehicles (AVs) in the future are anticipated to involve human intervention in the form of a remote supervisory role [11]. With the use

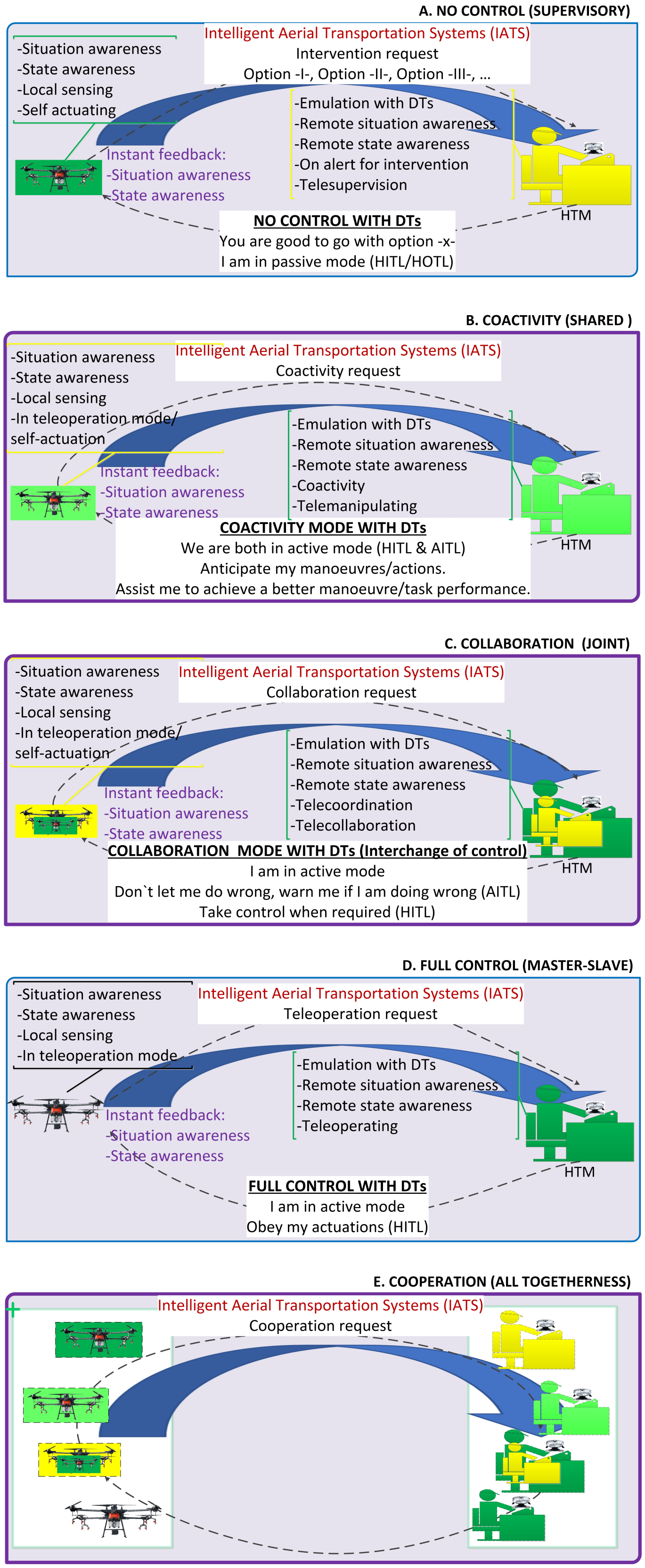


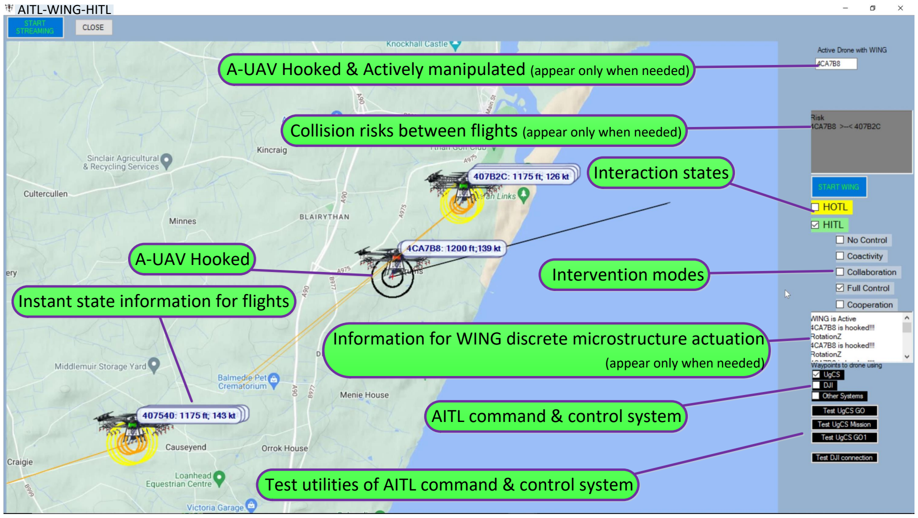
Fig. 1: HITL telemanipulation Schemes: “No-control (supervisory)”, “co-activity (shared)”, “collaboration (joint)”, “full control (master-slave)”, and “cooperation (all togetherness)”.

of cyber-worlds implanted in the real world, or digital twins (DTs), we can now teleoperate distant objects thanks to recent advancements in cyber-physical systems (CPSs) in the aspects of Automation of Everything (AoE) and Internet of Everything (IoE) [12]. A-UAVs are expected to be readily integrated into mixed aerial traffic thanks to location-independent remote real-time human-in-the-loop (HITL) approaches that use human telemanipulators (HTMs) in a supervisory role. Real-time HITL telemanipulation approaches during BVLOS operations are expected to expedite the elimination of Visual Line-of-Sight (VLoS) human operators with increased trust in A-UAVs equipped with their advancing automation-in-the-loop (AITL) abilities. There are still many limitations with AVs despite several decades of earlier studies and a renewed focus from the scientific community and major technology companies, which is what makes the HITL concept a reasonable remote involvement in managing AVs [13]. In this regard, remote involvement of human telemanipulation expertise, just in case, would increase the confidence of the general public, involving all stakeholders, in A-UAVs [14].

When the new operator – AI/AITL agent – experiences an unusual adverse condition that the autonomous capabilities are unable to handle, HITL telemanipulation, which extends human sensing and control capabilities, can aid in overcoming difficult tasks [15]. DTs facilitate the mapping of physical assets’ dynamic real-time properties into the counterpart cyber-world in multidimensional space [16]. HTMs can monitor, communicate with, and modify the states of remote aerial robotic vehicles appropriately thanks to DTs of aerial traffic [17] by leveraging two analogous remote environments [18] — the actual AV ecosystem and the cyber-world mirroring of this ecosystem, i.e. augmented DTs of aerial traffic. A human telemanipulator (HTM) can be coupled with these DTs to co-work with A-UAVs. The report in [19] examines the telemanipulation schemes with A-UAVs whereas the report in [20] explored the telemanipulation schemes with ground-based self-driving vehicles (SDVs). In the context of human-vehicle teamwork, this report elucidates the development of a telemanipulation platform that enables real-time remote human involvement with various HITL delay-sensitive telemanipulation schemes with A-UAVs during BVLOS operations. “In-vehicle teleoperator” and “human telemanipulator” are referred to as “A-UAV or AITL agent” and “HTM or HITL agent” respectively in this report. The following section summarises the telemanipulation schemes with A-UAVs before scrutinising the developed platform in Section III to be able to understand the infrastructure and the functions of the platform better.

II. TELEMANIPULATION SCHEMES WITH A-UAVS

A-UAVs operate autonomously and need to receive assistance whenever necessary. Sole human teleoperation without using local vehicle intelligence is dependent on motor skills, spatial orientation abilities and perceptual and cognitive capacities of HTMs to avoid risky adverse conditions, even with an intact state and situation awareness (SSA) [21]. To this end, it is important to use the intelligence at the remote site



AITL-WING-HITL

Active Drone with WING: 4CA7B8

Risk
4CA7B8 >--< 407B2C

☐ HOTL
☑ HITL
☐ No Control
☐ Coactivity
☐ Collaboration
☑ Full Control
☐ Cooperation

WING is Active
4CA7B8 is hooked!!!
RotationZ
4CA7B8 is hooked!!!
RotationZ

Waypoints to drone using
☑ UgCS
☐ DJI
☐ Other Systems

Fig. 2: Interface of the co-simulated platform (DTs of aerial traffic). The logic of telemanipulation is illustrated in Fig. 3

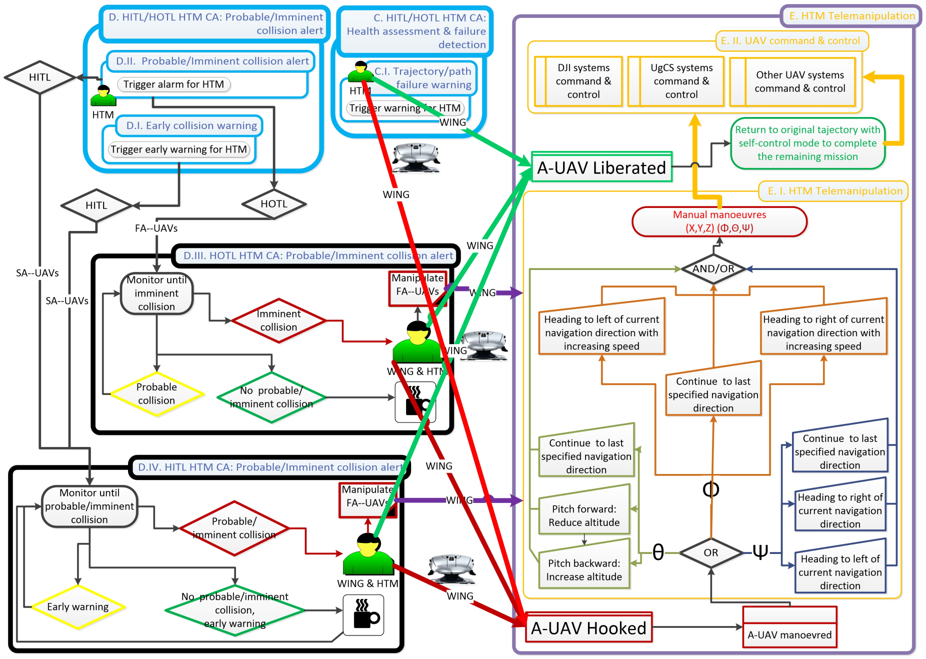


Fig. 3: Methodology of hooking and manipulation of A-UAVs through the interface in Fig. 2 using Algorithm 1 with an immersive device.

and it is advantageous to co-work during the execution of complex tasks that cannot be handled by autonomy. If A-UAVs are capable of performing on their own, human intervention is not needed, allowing human-on-the-loop (HOTL) systems by which HTMs are not required to monitor the system. Possible HITL micromanipulation schemes are "No-control (supervisory)", "co-activity (shared)", "collaboration (joint or traded control)", "full control (master-slave)", and "cooperation (all togetherness)" as illustrated in Fig. 1. Readers are directed to [19] for the comprehensive analysis of the possible telemanipulation schemes with A-UAVs. These schemes are summarised as follows:

No-control (supervisory) Scheme (Fig.1 A): This is a time when AI's superiority over humans can be demonstrated empirically to such an extent that human direct operational inputs could have a negative impact on task performance. The involvement of HTMs is aimed to be minimised in this scheme. As a task-specific HITL, the HTM encourages the indecisive A-UAV to choose between options determined by the HTM or those determined by the vehicle itself. The HTM assists A-UAVs by both setting short-range sub-goals/subtasks for the AITL agent to achieve independently to reach the final goal and giving A-UAVs a high degree of freedom.

Co-activity (shared-control) Scheme (Fig.1 B): It's possible that some tasks cannot be achieved as desired by distributing subtasks between HTMs and A-UAVs, which may lead to compromising task performance. A simultaneous synergistic tighter one-to-one or one-to-many co-activity, i.e. master-master (i.e. more equal co-worker), needs to be built within a simultaneous, reciprocal interaction with mutual trust and shared effort to complete the task satisfactorily. The notion of "shared autonomy" stems from the combination of human operator inputs and autonomous system computation to generate the desired robot behaviour [22].

Collaboration (joint or traded control) mode (Fig.1 C): A series of assigned or distributed fine-granular sub-tasks need to be performed individually either by the AITL agent or HITL agent. HTMs do not have complete control over A-UAVs, and A-UAVs do not have complete control over themselves where these sub-tasks are traded back and forth between them to enable joint problem-solving. Partial control can be mainly used for tightly coupled coordination between collocated HTMs and A-UAVs to achieve joint task performance. In the collaborative scheme, humans and robots converge to exchange ideas and settle disagreements rather than a superior giving orders to a subordinate [23].

Full-control (master-slave) mode (Fig.1 D): 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. Different from the collaboration scheme, A-UAVs, piloted remotely by HTMs, comply with HTMs' manoeuvres under all conditions.

Cooperation (all togetherness) mode Swarms of A-UAVs sometimes need to interact with each other 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 where each A-UAV assists in the accomplishment of the desired goal considering its specific capabilities, e.g. deploying several A-UAVs for search and rescue missions, each with a distinct targeted Region of Interest (RoI), or transporting a hefty payload.

III. MODULES, TECHNIQUES, & INTERFACE

The interface of the platform developed in this study was designed to be as simple as possible by avoiding overwhelming HTMs with unnecessary information. The interface of the developed platform is depicted in Fig. 2. The SSA of aerial traffic is constantly generated using the global SSA strategy implemented by the DACM system in the DTs of aerial traffic using electronic conspicuity (EC) as explained in our previous work inin [24]. Telepresence of HTMs within aerial traffic is provided by the platform. The primary interface elements are i) DTs of aerial traffic, ii) the immersive device that is coupled between HTMs and A-UAVs within DTs, iii) the interactive interface control elements, and iv) informative elements. Either the HITL agent or AITL agent determines the intervention mode and transitions between these modes as outlined in [20]. Either with a button click on the immersive device or with a selection from the interactive interface control elements, the HTM can switch between the interaction states (i.e. HOTL and HITL) and the telemanipulation modes, namely, no-control (supervisory), co-activity (shared-control), collaboration (joint-control), full-control (master-slave), and cooperation (all togetherness) (Fig. 1). The infrastructure of the platform provides an improved easy-to-use graphical user interface (GUI) for manipulating A-UAVs in the specified aerial zone using an immersive device leading to fine granular force, direction, and amplitude. Additionally, it provides HTMs with effective perception capabilities which allow HTMs to focus on the particular sections of the interface with which they are supposed to interact. For instance, the colour of an A-UAV's heading line turns black when that UAV is suggested to the HTM to be hooked and manipulated during a collision risk. The circles of probable and imminent collision risk zones turn black to show that the A-UAV is hooked by the HTM for manipulation. The manipulation of different types of A-UAVs requires particular control parameters representing the particular features of A-UAVs. The HTM can manipulate the speed, altitude, and heading of A-UAVs considering the other aerial vehicles in the environment both to avoid instant collisions and not to cause new collision risks with the generated manoeuvres as illustrated in Fig. 3 E.1. Commands generated through the immersive device with 6DoF (Degree of Freedom) such as a joystick or a force-sensitive mouse (e.g. WING (https://www.worthingtonsharpe.com/wing)) are transformed to the hooked A-UAVs using the off-the-shelf drone controlling systems such as UgCS, DJI (Fig. 3 E.2.) as elaborated in our previous research in [11]. The mapping of the values acquired from the immersive device to drone manoeuvres is shown in Algorithm 1. This mapping actuates the hooked A-UAVs appropriately as illustrated in Fig. 3 E.1. The HTM can choose the proper intervention mode within the interface and can translate the inputs of the immersive device into a particular transfer function that manipulates A-UAVs accordingly. HTMs are immersed with A-UAVs through force/torque applied or released to the rotational orientations – roll (Φ), pitch (Θ) and yaw (Ψ) channels).

HTMs may need to intervene in the current actions of A-UAVs for better task performance or to avoid hazards. The flights that indicate a collision risk are highlighted in the interface and the system turns into HITL state from HOTL state. A HTM can hook one of these flights using the immersive device to manipulate its actions. The interface may suggest a specific A-UAV be hooked and manipulated during a collision risk by turning its heading line black (Fig. 2). More specifically, the system can recommend a specific A-UAV to be hooked if there is a collision risk between that A-UAV and Manned Aerial Vehicles (MAVs) where there is no possibility to hook MAVs. Similarly, fixed-wing drones are recommended by the system against rotary-wing drones while the battery constraint feature of rotary-wing drones is evident. In the same manner, the fixed-wing drone with a stronger battery level is advised against the other fixed-wing drone with less battery level whereas rotary-wing drones with stronger battery

```
Data: System input: $\Psi_{Pmax}$ & $\Psi_{Pmin}$ & $\Psi_{Smax}$ & $\Psi_{Smin}$ & $\Phi_{Pmax}$ & $\Phi_{Pmin}$ & $\Phi_{Pmax}$ & $\Phi_{Pmin}$ & $\Theta_{Fmax}$ & $\Theta_{Fmin}$ & $\Theta_{Bmax}$ & $\Theta_{Bmin}$
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 ($\Psi$);
        $\Psi_{cur}$ = $W_{val}$;
        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
        navigate$D_H$ ($D_H.\Psi$, $D_H.\Phi$, $D_H.\Theta$, $D_H$.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 ($\Phi$);
        $\Psi_{cur}$ = $W_{val}$;
        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
        navigate$D_H$ ($D_H.\Psi$, $D_H.\Phi$, $D_H.\Theta$, $D_H$.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 ($\Theta$);
        $\Psi_{cur}$ = $W_{val}$;
        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
        navigate$D_H$ ($D_H.\Psi$, $D_H.\Phi$, $D_H.\Theta$, $D_H$.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
```

Algorithm 1: Manipulation of A-UAVs using the immersive device, WING (Fig. 3 E.1).

levels are proposed against other rotary-wing drones with less battery levels. Moreover, drones with the air-based mission against drones with the ground-based mission are selected by the system for hooking where drones with air-based missions are not required to turn to their leaving point at the original trajectory. Likewise, the slower drone can be recommended against the faster one while the manoeuvring may be easier with the slower drone. The circles of the probable and imminent collision risk zones turn black to denote that the A-UAV is hooked by the HTM for manipulation. The HTM can hook and manipulate multiple A-UAVs simultaneously. While an A-UAV is implementing the last command in the hooked state, e.g. heading to a new direction with a new altitude, the HTM can hook other A-UAVs to manipulate their actions. The actuation per A-UAV is performed using one of the intervention modes (Fig.1). The liberated A-UAVs from the hooking state return to their original trajectory using the shortest path to implement their pre-planned missions.

The discrete microstructure values of 6DoF $(x, v, z, \Psi, \Theta, \Phi)$, corresponding to the geospatial orthogonal axes (i.e. three state variables – translational coordinates (x, v, z) and rotational coordinates (Ψ, Θ, Φ), are mapped to the manoeuvrers of A-UAVs. The translational coordinates are very much dependent on the angular coordinates in our model as formulated in Algorithm 1. Taking this into consideration, the maximum manoeuvrability of the A-UAVs is determined according to the yaw, pitch and roll orientation as $(-\pi \leqslant \Psi \leqslant \pi)$, $(-\pi/2 \leqslant \Theta \leqslant \pi/2)$, and $(-\pi/2 \leqslant \Phi \leqslant \pi/2)$. The A-UAV changes its trajectory as the HTM applies the desired force on the immersive device. The A-UAV follows the latest action taken by the HTM if the HTM releases the force completely. In other words, the A-UAV follows the heading with specified altitude and velocity directed by the HTM even though the immersive device leaves the drone for manipulating other A-UAVs for the sake of simplicity assuming that the HTM is not required to hold the immersive device for same actions at a specific trajectory for a specific drone. In this way, multiple A-UAVs can be hooked simultaneously. The A-UAV follows similar actions continuously where the HTM applies the maximum allowed force on the device. For instance, the heading can change to the left or right of the original direction by 15°, which results in a circular trajectory. The relationship between the inputs and outputs is managed by mapping interactions' inputs to desired outcomes concerning the particular manoeuvrability capabilities of each A-UAV. The number of actions in the specified direction (i.e. roll (Φ), pitch (Θ) and yaw (Ψ)) executed by an A-UAV leading to the change of rotation angles of the X, Y, and Z axis is dependent on the DoF, the number of sequences executed by the HTM and their values and timestamps. The hooked drone has to co-work with the HTM by following the actions directed by the HTM to increase its task performance and avoid hazardous situations. Readers are referred to the 7-minute recorded videos, namely, "01_No-intervention-no-CA.wmv", and "02_No-intervention-with-CA.wmv" in [25] to observe merits of the platform. A specific drone can be released from hooking when the specific button of the immersive device is clicked at a point near the A-UAV. The circles denoting probable and imminent collision risks and the heading line turn into their original colour from black (Fig. 2) after the A-UAV is liberated to indicate that they are performing their tasks independently with AITL agent themselves. A-UAVs orient themselves in Euclidean space by means of the preplanned trajectory after being released from the hooking considering their physical manoeuvring features and the instant SSA environmental inputs.

IV. Discussion and Conclusion

The use of A-UAVs in the non-segregated UTM+ATM aerospace requires integrated platforms for collective movement to accomplish missions efficiently and safely. These platforms can provide the desired cohesion to maintain multi-DoF aerial vehicles with an acceptable distance in between. Any unexpected event can be encountered during the autonomous implementation of multiple UAV missions organised by various entities where each mission cannot be considered in isolation as they are using the same aerospace. In this regard, this research aims to develop an integrated collective approach to make HITL and AITL agents co-work in tackling uncertainties and efficient implementation of autonomous tasks. The developed approach enables the global operation of A-UAVs BVLOS using a global state and situation awareness (SSA) tracking system. BVLOS real-time HITL telemanipulation approaches are expected to expedite the elimination of Visual Line-of-Sight (VLoS) human operators with increased trust in A-UAVs.

Utilizing the principles of biological brains and human cognition for learning, recent groundbreaking developments in cognitive science have propelled artificial intelligence (AI). Specifically, Deep Reinforcement Learning (DRL), which leverages the self-learning properties of RL and the potential generalization capabilities of data-hungry Deep Neural Networks (DNN), has been developed and applied across multiple domains [26]. The near future will show whether DRL equipped with Federated Learning (FL) [27] can emulate human cognition to the extent necessary to enable A-UAVs to perform tasks at human and even higher levels.

References

[1] K. Kuru and D. Ansell, "Tcitysmartf: A comprehensive systematic framework for transforming cities into smart cities," *IEEE Access*, vol. 8, pp. 18 615–18 644, 2020.

[2] S. Liu, J. Peng, and J. Gaudiot, "Computer, drive my car!" *Computer*, vol. 50, no. 1, pp. 8–8, 2017.

[3] K. Kuru, D. Ansell, D. Jones, B. Watkinson, J. M. Pinder, J. A. Hill, E. Muzzall, C. Tinker-Mill, K. Stevens, and A. Gardner, "Intelligent airborne monitoring of livestock using autonomous uninhabited aerial vehicles," in *The 11th European Conference on Precision Livestock Farming*, 2024.

[4] K. Kuru, D. Ansell, B. Jon Watkinson, D. Jones, A. Sujit, J. M. Pinder, and C. L. Tinker-Mill, "Intelligent automated, rapid and safe landmine and unexploded ordnance (uxo) detection using multiple sensor modalities mounted on autonomous drones," *IEEE Transactions on Geoscience and Remote Sensing*, 2023.

[5] K. Kuru, A. Sujit, D. Ansell, B. Jon Watkinson, D. Jones, J. M. Pinder, and C. L. Tinker-Mill, "Intelligent, automated, rapid and safe landmine and unexploded ordnance (uxo) detection using maggy," *IEEE Transactions on Geoscience and Remote Sensing*, 2024.

[6] K. Kuru, D. Ansell, W. Khan, and H. Yetgin, "Analysis and optimization of unmanned aerial vehicle swarms in logistics: An intelligent delivery platform," *IEEE Access*, vol. 7, pp. 15 804–31, 2019.

[7] S. Bouabdallah, M. Becker, and R. Siegwart, "Autonomous miniature flying robots: coming soon! - research, development, and results," *IEEE Robotics & Automation Magazine*, vol. 14, no. 3, pp. 88–98, 2007.

[8] M. Radovic, "Tech talk: Untangling the 5 levels of drone autonomy," 2019.

[9] G. Coppin and F. Legras, "Autonomy spectrum and performance perception issues in swarm supervisory control," *Proceedings of the IEEE*, vol. 100, no. 3, pp. 590–603, 2012.

[10] K. Nonami, "Present state and future prospect of autonomous control technology for industrial drones," *IEEJ Transactions on Electrical and Electronic Engineering*, vol. 15, no. 1, pp. 6–11, 2020.

[11] K. Kuru, "Planning the future of smart cities with swarms of fully autonomous unmanned aerial vehicles using a novel framework," *IEEE Access*, vol. 9, pp. 6571–6595, 2021.

[12] K. Kuru and H. Yetgin, "Transformation to advanced mechatronics systems within new industrial revolution: A novel framework in automation of everything (aoe)," *IEEE Access*, vol. 7, pp. 41 395–41 415, 2019.

[13] B. Goldfain, P. Drews, C. You, M. Barulic, O. Velev, P. Tsiotras, and J. M. Rehg, "Autorally: An open platform for aggressive autonomous driving," *IEEE Control Syst. Mag*, vol. 39, no. 1, pp. 26–55, 2019.

[14] K. Kuru, "Trustfsdv: Framework for building and maintaining trust in self-driving vehicles," *IEEE Access*, vol. 10, pp. 82 814–82 833, 2022.

[15] K. Kuru and W. Khan, "A framework for the synergistic integration of fully autonomous ground vehicles with smart city," *IEEE Access*, vol. 9, pp. 923–948, 2021.

[16] K. Kuru, "Metaomnicity: Toward immersive urban metaverse cyberspaces using smart city digital twins," *IEEE Access*, vol. 11, pp. 43 844–68, 2023.

[17] K. Kuru, S. Worthington, D. Ansell, J. M. Pinder, A. Sujit, B. Jon Watkinson, K. Vinning, L. Moore, C. Gilbert, D. Jones *et al.*, "Aitl-wing-hitl: Telemanipulation of autonomous drones using digital twins of aerial traffic interfaced with wing," *Robotics and Autonomous Systems*, vol. 180, 2024.

[18] K. Kuru, "Technical report: Essential development components of the urban metaverse ecosystem," *Central Lancashire online Knowledge*, 2024.

[19] ——, "Human-in-the-loop telemanipulation schemes for autonomous unmanned aerial systems," in *2024 4th Interdisciplinary Conference on Electrics and Computer (INTCEC)*, 2024, pp. 1–6.

[20] ——, "Technical report: Analysis of intervention modes in human-in-the-loop (hitl) teleoperation with autonomous ground vehicle systems," *Central Lancashire online Knowledge*, 2022.

[21] ——, "Conceptualisation of human-on-the-loop haptic teleoperation with fully autonomous self-driving vehicles in the urban environment," *IEEE Open J. Intell. Transp. Syst.*, vol. 2, pp. 448–69, 2021.

[22] P. Marion, M. Fallon, R. Deits, A. Valenzuela, C. Pérez D'Arpino, G. Izatt, L. Manuelli, M. Antone, H. Dai, T. Koolen, J. Carter, S. Kuindersma, and R. Tedrake, "Director: A user interface designed for robot operation with shared autonomy," *J. Field Robot.*, vol. 34, no. 2, pp. 262–80, 2017.

[23] T. W. Fong, "Collaborative control: A robot-centric model for vehicle teleoperation," Ph.D. dissertation, Carnegie Mellon University, Pittsburgh, PA, November 2001.

[24] K. Kuru, J. M. Pinder, B. J. Watkinson, D. Ansell, K. Vinning, L. Moore, C. Gilbert, A. Sujit, and D. Jones, "Toward mid-air collision-free trajectory for autonomous and pilot-controlled unmanned aerial vehicles," *IEEE Access*, vol. 11, pp. 100 323–100 342, 2023.

[25] K. Kuru, "Telemanipulation of autonomous drones using digital twins of aerial traffic," *IEEE Dataport*, 2024.

[26] ——, "Definition of multi-objective deep reinforcement learning reward functions for self-driving vehicles in the urban environment," *IEEE Trans. Veh. Technol.*, vol. 11, pp. 1–12, Mar. 2024.

[27] ——, "Management of geo-distributed intelligence: Deep insight as a service (DINSaaS) on forged cloud platforms (FCP)," *Journal of Parallel and Distributed Computing*, vol. 149, pp. 103–118, Mar. 2021.

[28] W. Khan and K. Kuru, "An intelligent system for spoken term detection that uses belief combination," *IEEE Intelligent Systems*, vol. 32, no. 1, p. 70–79, Jan. 2017.

[29] K. Kuru, D. Ansell, M. Jones, B. J. Watkinson, N. Caswell, P. Leather, A. Lancaster, P. Sugden, E. Briggs, C. Davies, T. C. Oh, K. Bennett, and C. De Goede, "Intelligent autonomous treatment of bedwetting using non-invasive wearable advanced mechatronics systems and mems sensors: Intelligent autonomous bladder monitoring to treat ne," *Medical & Biological Engineering & Computing*, vol. 58, no. 5, p. 943–65, 2020.

[30] K. Kuru *et al.*, "Iotfauav: Intelligent remote monitoring of livestock in large farms using autonomous uninhabited aerial vehicles," *Computers and Electronics in Agriculture*, 2023.

[31] K. Kuru, A. Sujit, D. Ansell, J. M. Pinder, B. Jon Watkinson, D. Jones, R. Hamila, and C. Tinker-Mill, "Iintelligent, automated, rapid, and safe landmine, improvised explosive device and unexploded ordnance detection using maggy," *IEEE Access*, 2024.

[32] K. Kuru, "Technical report: Analysis of intervention modes in human-in-the-loop (hitl) teleoperation with autonomous unmanned aerial systems," *Central Lancashire online Knowledge*, 2024.

[33] K. Kuru, O. Erogul, and C. Xavier, "Autonomous low power monitoring sensors," *Sensors*, vol. 21, 2021.

[34] K. Kuru, "Use of autonomous uninhabited aerial vehicles safely within mixed air traffic," in *Proceedings of Global Conference on Electronics, Communications and Networks (GCECN2024)*, 2023.

[35] ——, "Sensors and sensor fusion for decision making in autonomous driving and vehicles," 2023.

[36] ——, *A Novel Hybrid Clustering Approach for Unsupervised Grouping of Similar Objects*. Springer International Publishing, 2014, p. 642–653.

[37] ——, "Optimization and enhancement of h&e stained microscopical images by applying bilinear interpolation method on lab color mode," *Theoretical Biology and Medical Modelling*, vol. 11, no. 1, 2014.

[38] K. Kuru and K. Kuru, "Urban metaverse cyberthreats and countermeasures to mitigate them," in *Proceedings of IEEE Sixth International Conference on Blockchain Computing and Applications (BCCA 2024)*, 2024.

[39] ——, "Blockchain-enabled privacy-preserving machine learning authentication with immersive devices for urban metaverse cyberspaces," in *2024 20th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA)*, 2024, pp. 1–8.

[40] K. Kuru, B. J. Watkinson, D. Ansell, D. Hughes, M. Jones, N. Caswell, P. Leather, K. Bennett, P. Sugden, C. Davies, and C. DeGoede, "Smart wearable device for nocturnal enuresis," in *2023 IEEE EMBS Special Topic Conference on Data Science and Engineering in Healthcare, Medicine and Biology*, 2023, pp. 95–96.

[41] K. Kuru, "Technical report: Big data-concepts, infrastructure, analytics, challenges and solutions," 2024.

[42] K. Kuru, D. Ansell, D. Hughes, B. J. Watkinson, F. Gaudenzi, M. Jones, D. Lunardi, N. Caswell, A. R. Montiel, P. Leather, D. Irving, K. Bennett, C. McKenzie, P. Sugden, C. Davies, and C. Degoede, "Treatment of nocturnal enuresis using miniaturised smart mechatronics with artificial intelligence," *IEEE Journal of Translational Engineering in Health and Medicine*, vol. 12, pp. 204–214, 2024.

[43] K. Kuru, M. Niranjan, and Y. Tunca, "Establishment of a diagnostic decision support system in genetic dysmorphology," in *2012 11th International Conference on Machine Learning and Applications*, vol. 2, 2012, pp. 164–169.

[44] J. Lowe and K. Kuru, "Design & development of a smart blind system using fuzzy logic," in *2024 20th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA)*, 2024, pp. 1–8.

[45] ——, "Development of machine intelligence for self-driving vehicles through video capturing," in *2024 20th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA)*, 2024, pp. 1–8.

[46] K. Kuru and K. Kuru, "Urban metaverse cyberspaces & blockchain-enabled privacy-preserving machine learning authentication with immersive devices," in *Proceedings of IEEE Sixth International Conference on Blockchain Computing and Applications (BCCA 2024)*, 2024.

[47] ——, "Urban metaverse cyberthreats and countermeasures against these threats," in *Proceedings of IEEE Sixth International Conference on Blockchain Computing and Applications (BCCA 2024)*, 2024.

[48] K. Kuru, M. Niranjan, Y. Tunca, E. Osvank, and T. Azim, "Biomedical visual data analysis to build an intelligent diagnostic decision support system in medical genetics," *Artificial Intelligence in Medicine*, vol. 62, no. 2, p. 105–118, Oct. 2014.

[49] K. Kuru and W. Khan, "Novel hybrid object-based non-parametric clustering approach for grouping similar objects in specific visual domains," *Appl. Soft Comput.*, vol. 62, pp. 667–701, Jan. 2018.

[50] K. Kuru, S. Clough, D. Ansell, J. McCarthy, and S. McGovern, "Wildetect: An intelligent platform to perform airborne wildlife census automatically in the marine ecosystem using an ensemble of learning techniques and computer vision," *Expert Systems with Applications*, vol. 231, p. 120574, Nov. 2023.

[51] ——, "Intelligent airborne monitoring of irregularly shaped man-made marine objects using statistical machine learning techniques," *Ecological Informatics*, vol. 78, p. 102285, Dec. 2023.

[52] K. Kuru, "Joint cognition of remote autonomous robotics agent swarms in collaborative decision-making & remote human-robot teaming," *Proceedings of The Premium Global Conclave and Expo on Robotics & Automation (AUTOROBO, EXPO2024)*, 2024.

[53] N. Caswell, K. Kuru, D. Ansell, M. J. Jones, B. J. Watkinson, P. Leather, A. Lancaster, P. Sugden, E. Briggs, C. Davies, C. Oh, K. Bennett, and C. DeGoede, "Patient engagement in medical device design: Refining the essential attributes of a wearable, pre-void, ultrasound alarm for nocturnal enuresis," *Pharmaceutical Medicine*, vol. 34, no. 1, p. 39–48, Jan. 2020.

[54] K. Kuru, D. Ansell, M. Jones, C. De Goede, and P. Leather, "Feasibility study of intelligent autonomous determination of the bladder voiding need to treat bedwetting using ultrasound and smartphone ml techniques: Intelligent autonomous treatment of bedwetting," *Medical & Biological Engineering & Computing*, vol. 57, no. 5, p. 1079–1097, Dec. 2018.

[55] K. Kuru, S. Girgin, K. Arda, and U. Bozlar, "A novel report generation approach for medical applications: The sisds methodology and its applications," *International Journal of Medical Informatics*, vol. 82, no. 5, p. 435–447, May 2013.

[56] K. Kuru and K. Kuru, "Blockchain-based decentralised privacy-preserving machine learning authentication and verification with immersive devices in the urban metaverse ecosystem," 2024.

[57] K. Kuru and S. Girgin, *A Bilinear Interpolation Based Approach for Optimizing Hematoxylin and Eosin Stained Microscopical Images*. Springer Berlin Heidelberg, 2011, p. 168–178.

[58] K. Kuru, "Use of wearable miniaturised medical devices with artificial intelligence (ai) in enhancing physical medicine," *Proceedings of Enhancing Physical Medicine. In: World Congress on Physical Medicine and Rehabilitation*, 2024.

[59] K. Kuru, A. Sujit, D. Ansell, J. M. Pinder, D. Jones, B. Watkinson, R. Hamila, and C. L. Tinker-Mill, "Non-invasive detection of landmines, unexploded ordnances and improvised explosive devices using bespoke unmanned aerial vehicles," *Proceedings of EEE International Conference on Electrical and Computer Engineering Researches (ICECER'24)*, 2024.

[60] K. Kuru, "Technical report: Towards state and situation awareness for driverless vehicles using deep neural networks," *Central Lancashire online Knowledge*, 2024.

[61] ——, "Technical report: Human-in-the-loop telemanipulation platform for automation-in-the-loop unmanned aerial systems," *Central Lancashire online Knowledge*, 2024.