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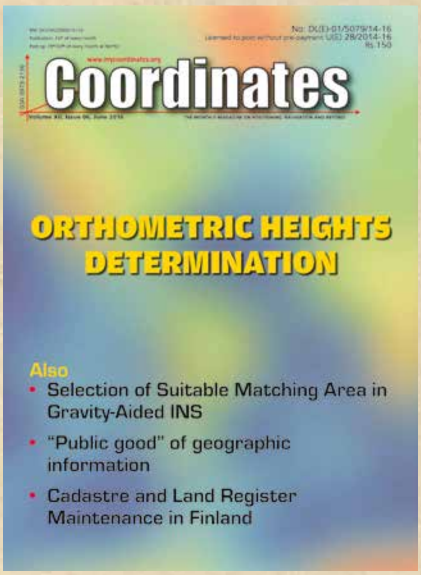
AITL-WING-HITL

Telemanipulation of autonomous drones using Digital Twins of aerial traffic interfaced with WING

Development Communication in Sustainable Land Administration Practices in the Federal Capital territory Abuja

In Coordinates

10 years before...



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Cadastre and Land Register Maintenance in Finland

Ari Tella, Chief Engineer, National Land Survey of Finland Opastinsilta, Helsinki, Finland

Production at the NLS has taken place in processes for the last 15 years, which have ensured a homogeneous mode of action and uniform quality. From the beginning of the year 2014 we develop our process organisation one step further. Now our production operates at a national level without any regional level, and the district survey of¿ces no longer exist. Each national level process is its own result unit which has total responsibility of production regarding result, income, worker resources and quality.

Selection of Suitable Matching Area in Gravity-Aided Inertial Navigation System

DanMei PENG, Master Candidate, Faculty of Geomatics, East China Institute of Technology, Nanchang, China
Cuijun DONG, Master Candidate, School of Geodesy and Geomatics, Wuhan University, Wuhan, China

This paper utilizes PCA method to simplify the selected characteristic parameters into one comprehensive indicator, which can synthesize different information of different gravity field's characteristic with the original information lost within the allowable range.

Comparison of orthometric heights determined by GPS and simple geometric levelling: case studies

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This article highlights the effect of altitude change and baseline length on the differences in orthometric heights between simple geometric levelling and GPS. We have used several experimental tests on three cases of different topography.

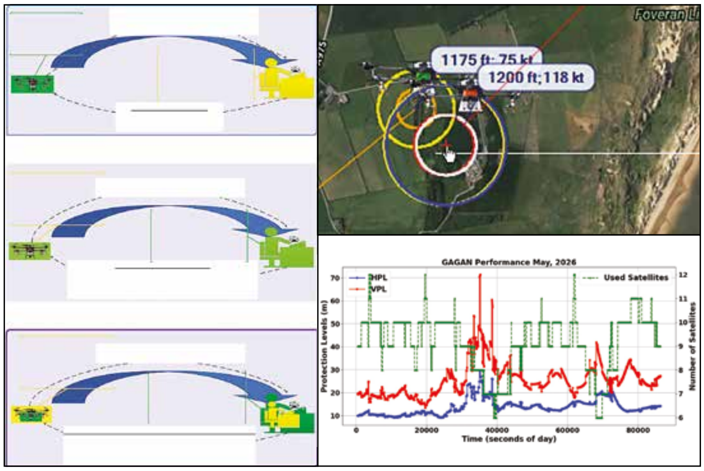
Comparison of orthometric height differences (H_{diff}) using statistical tools allows us to reach the following conclusions:

- - The height difference between leveling and GPS increases very significantly with the length of baseline and depends on the topography of the terrain.
- - The height difference between leveling and GPS is very significantly inÀuenced by the altitude change.

"Public good" of geographic information

Mukund Rao, Member Secretary, Karnataka Jnana Aayoga, India

The GI juggernaut is in motion and "expanding" all over the world (and in India too). The benefit and Public Good of GI is apparent and clear and will become more vivid, visible and all pervading in coming years. The Public Good of GI must not get dismantled or disabled – for the good of society and every citizen, nation and humanity depends upon it.



In this issue

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Articles

Columns

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This issue of Coordinates is of 36 pages, including cover.

Beyond the Epicentre

The images from the Venezuela earthquake are heartbreaking.

Collapsed homes, frantic searches through rubble,
grieving families, and lives transformed in moments.

Every calamity reminds us how fragile human existence truly is.

Nature neither negotiates nor discriminates.

Its forces remain beyond human control.

Each time the Earth trembles,

We watch helplessly as lives are upended and communities reduced to rubble.

Despite all our technological advances,
our belief that we can master Nature is repeatedly humbled.

Technology helps save lives, guide relief, and strengthen resilience.

Yet in the aftermath of every disaster,

It is compassion that transforms response into recovery,

And the resilience of the human spirit that ultimately endures.

Bal Krishna, Editor
bal@mycoordinates.org

AITL-WING-HITL: Telemanipulation of autonomous drones using DTs of aerial traffic interfaced with WING

The system is designed to intervene in scenarios, where an autonomous AI agent – the "new driver" – encounters conditions too complex or unorthodox for autonomy alone to handle. We present here the first part of the paper. The concluding part will be publsihed in July issue

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Abstract

"By touching an instrument placed in the southern gallery, a miniature Spanish cruiser anchored in the fountain lake on the lower floor, 90 ft away, was blown into the air. There was no connection between the transmitter and the vessel in the lake," reported The New York Times in 1898. Though perceived as magic by many at the time, Nikola Tesla had once again pushed the boundaries of technology, becoming the forefather of modern remotely controlled wireless drones. His invention – an early radio-controlled vessel operated via radio waves – was hailed as "the first of a race of robots, mechanical men which will do the laborious work of the human race," and marked a leap far ahead of its time. Since then, human–robot interaction and the telemanipulation of drones have advanced substantially, especially in tandem with the evolution of autonomy. In this context, a scalable, agent-based platform – termed AITL-WING-HITL – was developed for the telemanipulation of Autonomous Unmanned Aerial Vehicles (A-UAVs)

from the perspective of a human–multi-robot architecture, leveraging Digital Twins (DTs) of integrated aerial traffic. This system is designed to intervene in scenarios, where an autonomous AI agent – the "new driver" – encounters conditions too complex or unorthodox for autonomy alone to handle. The platform incorporates a patented, force-sensitive, precision control device known as the WING – an immersive tool tested with participants using measurable parameters to validate the system's effectiveness and identify areas for further improvement. The findings indicate that AITL (Autonomy-In-The-Loop) A-UAV agents and HITL (Human-In-The-Loop) Human Telemanipulator (HTM) agents can co-operate to achieve high-performance, synergistic task execution through a socio-cognitive interaction model embedded in the platform. By addressing current challenges and outlining directions for future exploration, this research not only provides an overview of the evolving landscape of drone telemanipulation but also serves as a roadmap for ongoing and future efforts in this critical field.

1. Introduction

"By touching an instrument placed in the southern gallery, a miniature Spanish cruiser anchored in the fountain lake on the lower floor, 90 ft away, was blown into the air. There was no connection between the transmitter and the vessel in the lake", reported The New York Times in 1898 [1]. Although many perceived it as magic, Nikola Tesla, once again pushing the boundaries of innovation, became the progenitor of modern-day remotely controlled wireless drones by inventing the first radio-controlled vessel using radio waves — an invention well ahead of its time [2]. This small radio-transmitting control box enabled Tesla to adjust the vessel's speed and direction by manipulating on-board mechanisms [3]. When a New York Times reporter described the invention as a device "that could carry dynamite as a weapon of war", Tesla responded: "You do not see there a wireless torpedo; you see there the first of a race of robots, mechanical men – a borrowed mind (the machine's own mind) – which will do the laborious work of the human race" [4]. His vision foreshadowed today's multi-agent autonomous robotic systems, capable of remote operation via distinct frequencies. Tesla's U.S. patent (US613809 A) referred to the invention as a "distant operator" – what we now call a teleoperator [3]. Since then, remote human–robot interaction and telemanipulation have evolved significantly alongside advances in autonomy. Many large-scale and complex tasks now require remote operation supplemented by extended human intelligence and experience. Drones are increasingly deployed by organisations and companies to execute various missions – such as logistics deliveries [5] – and operate in autonomous modes Beyond Visual Line of Sight (BVLOS) along preplanned routes. These missions must be conducted safely, avoiding collisions with other aerial vehicles within integrated Unmanned Aerial Vehicle (UAV) Traffic Management (UTM) and Air Traffic Management (ATM) systems, collectively referred to as the UTM+ATM framework.

In all future visions involving networks of fully autonomous self-driving ground [6] or aerial vehicles [7], some form of remote human intervention is anticipated. Specifically, roles such as "Human-on-the-Loop" (HOTL) and "Human-in-the-Loop" (HITL) for telemonitoring and telemanipulation are expected to foster a desirable level of trust in autonomous vehicles (AVs) as they operate within highly dynamic urban or aerial environments [8]. Ensuring the safe and cost-efficient routing of Autonomous UAVs (A-UAVs) within the integrated UTM+ATM system requires strategic human oversight: HOTL for fully autonomous UAVs (FA-UAVs) and HITL for semi-autonomous UAVs (SA-UAVs), enabling humans to monitor and intervene when necessary (Fig. 15) – particularly when the Artificial Intelligence (AI) agent, acting as the new "driver", encounters unorthodox scenarios beyond the scope of its autonomy. As automation continues to evolve, the nature of human–machine interaction has fundamentally shifted beyond the traditional Humans-Are-Better-At/Machines-Are-Better-At (HABA/MABA) paradigm, in which humans and machines are often seen as competitors [9]. Instead, the Human-Agent-Robot Teamwork (HART) frame-work emphasises collaborative augmentation, where humans and machines co-work by leveraging their complementary strengths to enable practical and profitable applications [10]. This paper examines co-work within this HART-centric framework from the perspective of two intelligent, self-reliant entities: humans equipped with extended intelligence and experience, and A-UAVs operating with a high degree of autonomy. These two entities are critically interdependent for the successful management of rare and complex challenges. Throughout the paper, the "human teleoperator" (i.e. master) and the "in-vehicle teleoperator" (i.e. slave) are referred to as the "Human Telemanipulator" (HTM), acting as the HITL agent, and the "A-UAV" (FA-UAVs and SA-UAVs, i.e. AITL agents), respectively.

Manipulating A-UAVs BVLOS will remain a central topic in the coming years, particularly as autonomous systems increasingly take on indispensable roles in real-world applications. In alignment with this trajectory, the University of Lancashire is actively developing bespoke A-UAVs and AITL systems 3 through various funded projects,4 aiming to tackle a wide range of complex operational tasks using A-UAVs. To support this mission, the University has partnered with PilotAware Ltd. and Worthington Sharpe Ltd. to ensure safe aerial operations, mitigating collision risks while enabling the execution of advanced aerial tasks. The core research question of this study is framed as follows: Can A-UAVs be effectively and efficiently manipulated through the collaborative operation of AITL and HITL agents? To explore this question, the following components were developed and integrated: (i) A Collision Management (CM) system, termed DACM (Drone Aware Collision Management) (Section 3.1.4), which creates Digital Twins (DTs) of aerial traffic through real-time communication with the decentralised PilotAware ATOM-GRID Network (Section 3.1.3); (ii) A patented, advanced force-sensitive control device, referred to as the WING, with 6DoF (Degree of Freedom) (Section 3.1.1), designed as an immersive precision-control interface for remotely operated vehicles (ROVs); (iii) A scalable agent-based platform – AITL-WING-HITL – that integrates these subsystems (Fig. 2) into a cohesive architecture, enabling HTMs to monitor and co-manipulate multiple A-UAVs within non-segregated aerial traffic environments, allowing human omnipresence.

While numerous novel robotic applications are anticipated, a range of emerging challenges must also be addressed — chief among them is ensuring that human–robot interaction remains safe, reliable, and effective [11]. One key question arises: Can the WING device facilitate effective interaction between HTMs and A-UAVs to accomplish tasks safely within the AITL-WING-HITL platform, especially given the potential limitations in human attention and perception when managing multiple A-UAVs simultaneously? To the best of our knowledge, this study represents the first comprehensive investigation into the use of a 6DoF advanced control device for manipulating multiple A-UAVs by a single HTM through digital replicas of aerial traffic, employing human–robot dialogue across several intervention modes (see Section 3.2.1). In addressing this research gap, the primary contributions of this paper are as follows:

(i) This research analyses the simultaneous manipulation of heterogeneous A-UAVs – autonomous aerial robots – by immersing HTMs within a newly integrated multi-agent architecture, termed AITL-WING-HITL.

(ii) The study explores the cooperative interaction between two intelligent entities – HTMs (HITL agents) and AITL AI agents – in performing complex tasks safely, accurately, and efficiently via various intervention modes (Fig. 15). This integration effectively bridges "the remote extension of human intelligence and expertise" with "vehicle autonomy".

The structure of the paper is outlined in Fig. 1 (see Table 1 for the abbreviations used in this paper).

2. Related works

A multitude of state-of-the-art studies have been conducted on the human telemanipulation of robots since the first teleoperator was built in the mid-1940s by Geortz [12]. Telerobotics, particularly bilateral robotic teleoperation activities between humans and robots, have generally been analysed based on the master and slave concept in which the slave side is mapped as "teleoperator" and the master side is mapped as "human operator" [8]. The supervisory role of human control in the remote manipulation of robots was first examined by Ferrell [13] in 1967. Most of the studies in the literature pay particular attention to HITL interactions, usually based on the semi-autonomous mode for human and single-machine hybrid activities to accomplish assigned tasks together, where semi-autonomous robotic systems are mainly designed with reliance on delay-tolerant human assistance [14]. The possibility of having multiple robots controlled by one operator (user) seems to be an additional crucial requirement in collaboration/cooperation [15]. Analysis of human–multirobot or human–multiagent cooperation and collaboration was immensely analysed in the 1990s as in [16–19], in particular, from the perspective of HITL decentralised systems, where the human needs to monitor the system all the time. The research of Nakauchi et al. [16] was the first in this direction in 1992. Laengle et al. [17] in 1997 had envisioned that "On one hand, robots have difficulties coping with unpredictable variations and uncertainties in their environment, which are normally no problem for humans. On the other hand, humans cannot always accomplish a task alone because of their limited force, slow execution speed, limited working area, limited execution time, and low precision. By combining the complementary capabilities of the robot with those of the human within a team, new perspectives for mastering complex systems could be opened". The seeds of HOTL robot manipulation were placed by Suzuki et al. [17] in 1995 while analysing the cooperation between the human operator and the decentralised multi-agent robotic system. The research emphasises several principles of HOTL as "(1) the human operator usually does not control each agent in the system,(2) all information of the system is not concentrated in the human operator, (3)

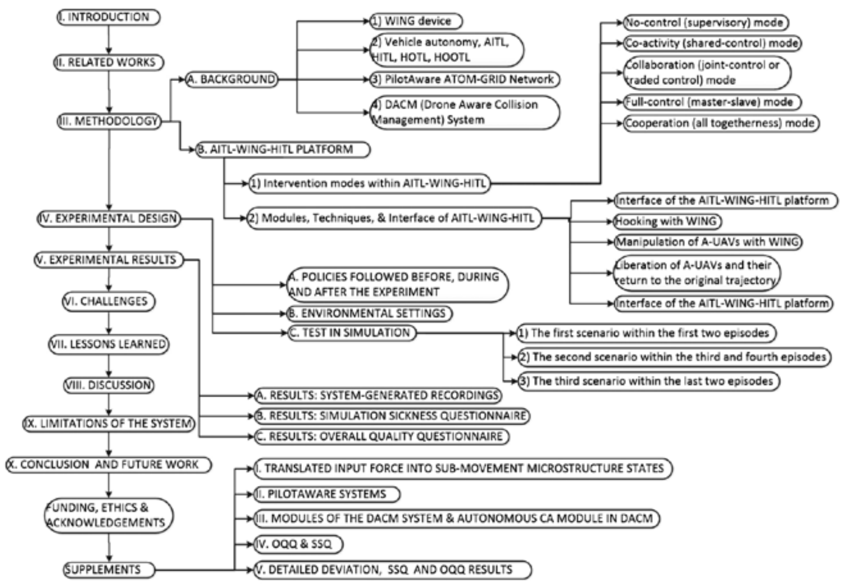

Fig. 1. Organisational structure of the paper.

Table 1
Definitions of abbreviations.

No	Abbreviation	Definitions
1	ADS-B	Automatic Dependent Surveillance-Broadcast
2	AI	Artificial Intelligence
3	A-UAV	Autonomous Unmanned Aerial Vehicle
4	AoE	Automation of Everything
5	AITL	Autonomy-In-The-Loop
6	ATM	Air Traffic Management
7	AV	Autonomous Vehicle
8	BVLOS	Beyond Visual Line of Sight
9	CA	Collision Avoidance
10	CAD	Computer-Aided Design
11	CPS	Cyber-Physical System
12	CM	Collision Management
13	CVP	Cartesian Virtual Point
14	DACM	Drone Aware Collision Management
15	DRONEII	Drone Industry Insights
16	DoF	Degree of Freedom
17	DT	Digital Twin
18	EC	Electronic Conspicuity
19	ECG	ElectroCardioGram
20	EEG	Electroencephalogram
21	ERDF	European Regional Development Fund
22	EASA	European Union Aviation Safety Agency
23	FAUAV	Fully A-UAV
24	FL	Federated Learning
25	FoSR	Flight of Safety Route
26	GUI	Graphical User Interface
27	HART	Human-Agent-Robot Teamwork
28	HABA	Humans-Are-Better-At
29	HITL	Human-In-The-Loop
30	HOTL	Human-On-The-Loop
31	HTM	Human Telemanipulator
32	ICAO	International Civil Aviation Organisation
33	IcRz	Imminent-collision-Risk zone
34	IoE	Internet of Everything
35	ICTZones	Imminent Collision Travel Zones
36	MABA	Machines-Are-Better-At
37	MAV	Manned Aerial Vehicles
38	mm-WAVE	Millimetre-Wave
39	MEDL	Minimum Expected Deviation Level
40	mMTC	Massive Machine-Type Communications
41	PC-UAV	Pilot-Controlled UAV
42	PcRz	Probable-collision-Risk zone
43	PCTZone	Probable Collision Travel Cone
44	RoI	Region of Interest
45	ROV	Remotely Operated Vehicles
46	QoE	Quality of Experience
47	QoS	Quality of Services
48	QoT	Quality of Task
49	OGN	Open Glider Network
50	OQQ	Quality Assessment Questionnaire
51	SA-UAV	Semi A-UAVs
52	SSQ	Simulation Sickness Questionnaire
53	SA	Situation Awareness
54	SSA	State and Situation Awareness
55	SCS	Simulation and Cyber Sickness
56	SS	Simulation Sickness
57	STT	Safety Travel Tube
58	TL	Transfer Learning
59	TS	Total Score
60	UAV	Unmanned Aerial Vehicle
61	UTM	UAV Traffic Management
62	V2V	Vehicle-to-Vehicle
63	WLAN	Wireless Local Area Network

and the human operator needs not always watch over the system'', ''the human operator must know the status of the system when an urgent event occurs in the system and human intervention is required, or he is asked for some cooperation from agents''. In a similar domain, this subject was extensively focused on during the 2000s while a mass number of robotic applications were

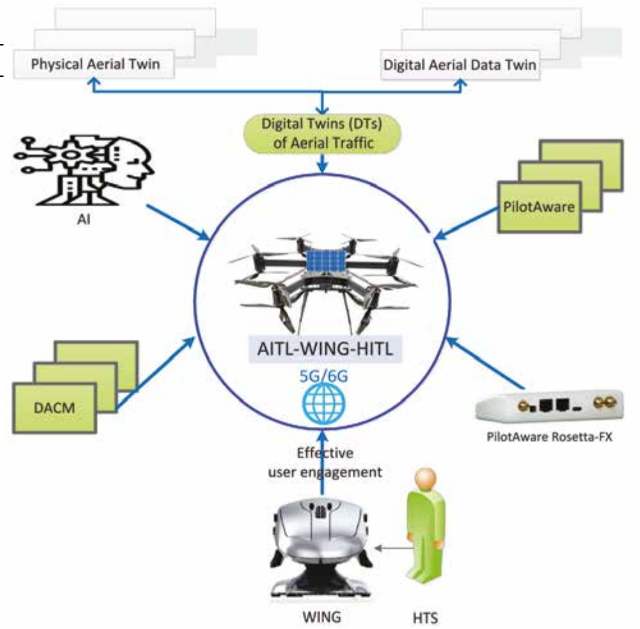

Fig. 2. Main building blocks of AITL-WING-HITL.


Fig. 3. WING device employed for Ground Based WING Station (GBS) using one hand.

taking their indispensable places. Fong et al. [20–23] closely scrutinised this subject and developed a framework in 2003 [21]. In the framework, how a few humans can teleoperate multiple teams of robots to accomplish the targeted task – that is, to assemble large orbital structures – was analysed. Later, human–robot teaming was focused on by Nourbakhsh et al. in 2005 [24] in real-world problem-solving applications, e.g. for urban search and rescue. The research on human–multirobot interaction in many disciplines has increased exponentially to solve real-world problems from the perspectives of HITL and HOTL since these preliminary works. Different types of immersive devices have been developed to interface with remote objects. Today's telemanipulation systems allow the interaction with environments at a distance and can also scale human force and motion to achieve stronger, bigger, or smaller action capabilities [25]. The study by Mithal et al. [26] suggests that joysticks are harder to control than mice. Martins et al. [27] concluded that participants' (with motor disabilities) feedback was more positive regarding 3D optical mice compared to the use of a conventional keyboard+mouse combination for navigation in 3D environments. The WING was tested in controlling 3D objects within computer-aided design (CAD) applications by Turner et al. [28], and by Sandoval et al. [29] in two short papers and found to be efficient in manipulating 3D virtual objects. Sandoval et al. [30], while testing several input devices with varying DoF, concluded that the more DoF available, the more enhanced the control over objects.

Human–drone interaction has been scrutinised by the research community to build easy-to-use interaction interfaces (e.g. natural interaction interfaces [31,32], touch-based [33]). The real-world telemanipulation initiatives with A-UAVs are expanding within the industry with the use of BVLOS, in particular, within the military industry. The aerial industry is partnering with leading telecommunication and technology companies that are experimenting with remote telemanipulation of A-UAVs in stochastic environments. Advanced multi-agent platforms, as well as hefty devices to interface with these platforms, are required to extend human intelligence and experience for tele co-working with multiple A-UAVs to accomplish tasks as desired. In this sense, existing works on drone manipulation need to be extended to mitigate the aforementioned concerns. To this end, to the best of the observed knowledge, having received limited attention in the literature, telemanipulating A-UAVs through different intervention modes has not been analysed in-depth in the sense of establishing a holistic HITL/HOTL approach for improving co-work between humans and multiple A-UAVs, which makes this paper unique, aiming at closing this gap.

3. Methodology

The integration of A-UAVs into non-segregated UTM+ATM aerospace environments necessitates unified platforms that support collective operations to ensure missions are carried out both efficiently and safely. Such platforms are essential for maintaining coordinated control of multi-DoF aerial vehicles while preserving safe separation distances. During the autonomous execution of multiple UAV missions – often orchestrated by different entities – unexpected events may arise, and individual missions cannot be treated in isolation, as they share the same aerospace infrastructure. This study aims to develop an integrated, collective framework that enables HITL and AITL agents to collaboratively manage uncertainty and execute autonomous missions effectively. The proposed approach supports global BVLOS operations by incorporating a comprehensive State and Situation Awareness (SSA) tracking system. The core components of the proposed platform – AITL-WING-HITL (Fig. 16) – for the manipulation of A-UAVs are illustrated in Fig. 2. At its foundation, the platform integrates the PilotAware system (Supplement II, Fig. 1) and the DACM system (Supplement III, Fig. 2) to generate DTs of aerial traffic. These primary components, along with supporting systems, are detailed in Section 3.1, prior to the full presentation of the developed platform in Section 3.2.

3.1. Background

Recent advances in Cyber-Physical Systems (CPSs) within the concepts of Internet of Everything (IoE) and Automation of Everything (AoE) [34] teleport us to teleoperate remote objects using DTs. In this treatise, the components of the designed platform which are depicted in Fig. 2 are explained in Sections 3.1.1, 3.1.2, 3.1.3, and 3.1.4 respectively and then the platform, as a holistic framework, is examined in 3.2.

3.1.1. WING device

The WING, a mouse-like, precision control device, was developed by Worthington Sharpe Ltd. in order to use the human motor system effectively. It is presented in Figs. 3, 4 with its functions. It, by extending the abilities of a mouse, combines the functions of a free-moving isotonic mouse and a free-flowing isometric joystick, leading to unprecedented freedom of movement from a desk-based control system. It enables movements in X, Y

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

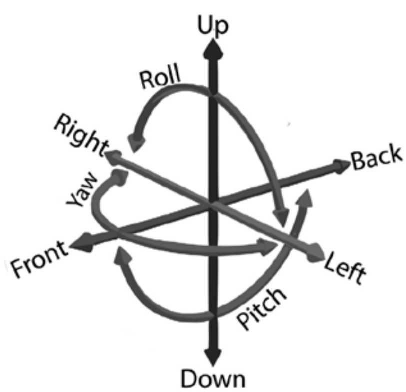

Fig. 5. Conceptualisation of 6DoF (i.e. 3 translation degrees and 3 rotation degrees) of the WING.

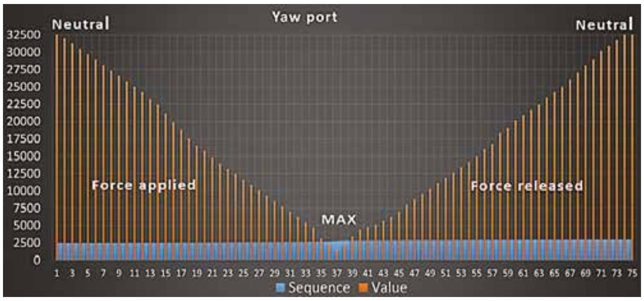

Fig. 6. States of Yaw Port (Table 2).

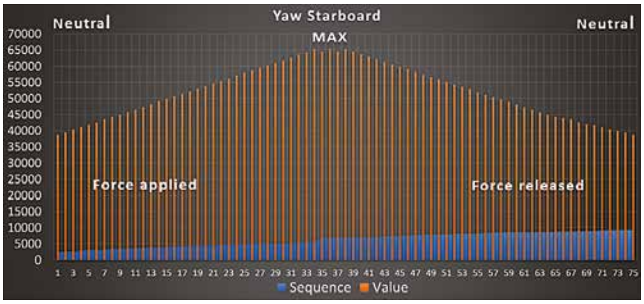

Fig. 7. States of Yaw Starboard (Table 2).

and Z directions as well as a complete precision roll (Φ), pitch (Θ) and yaw (Ψ) joystick functions as delineated in Fig. 5.

The WING aims to create command and control solutions for ROVs and robotic equipment. The lower part contains the laser mouse sensor; the upper part attaches via a precision slide and pivot mechanism to provide pitch, roll and z-height movement. Further control is then added through the under-slung yaw-bar positioned towards the front, giving a total of 6DoF. It, with advanced sensory mechanisms allowing precision control, was designed to address the needs of users who require the speed and accuracy of a high-end mouse for pointing and selection tasks, along with full 3D control. Additionally, it offers a wide range of buttons and a speed wheel that can be further programmed both to perform numerous functions and to map certain actions as we employ in this study. Readers are referred to the video5 to observe how it functions with its particular features. Its particular functionalities regarding the primary objectives of this research can be summarised as follows.

i. Multiple A-UAVs can be hooked and manipulated separately by the same hand.
ii. A-UAVs can be directed using pre-defined navigation waypoints, and their trajectories can be adjusted during the mission.
iii. Integrated 4-axis joystick functionality allows for performing various actions synchronously, such as simultaneous mission planner operation, camera gimbal control, flight path adjustments, or full manual piloting.
iv. Joystick functions can be integrated into APM Planner 2.0, Ardupilot Mission Planer, DJI Ground Station, and any independent Ground Control Station (GCS) that supports standard joystick inputs (Fig. -3).
v. Familiar computer mouse shape, speed, and accuracy

Table 2

Discrete microstructure movement (tele-impedance) of the WING in Yaw channel regarding the time and the subsequent sequences providing more information about the movement velocity over time: Port (Fig. 6); Blackboard (Fig. 7).

N	Yaw Port (RotationZ)			Yaw Starboard (RotationZ)			Force
	Seq	Timestamp	Value	Seq	Timestamp	Value	
1	2495	185 328 531	32 767	2416	266 585 875	38 749	Neutral
2	2496	185 328 537	31 993	2551	266 586 343	39 529	Applied
3	2499	185 328 546	31 219	2668	266 586 734	40 310	Applied
4	2502	185 328 546	30 445	2956	266 587 765	41 090	Applied
5	2503	185 328 562	29 671	3200	266 588 640	41 970	Applied
6	2508	185 328 578	28 897	3209	266 588 671	42 650	Applied
7	2515	185 328 593	28 123	3379	266 589 234	43 430	Applied
8	2520	185 328 609	27 349	3490	266 589 687	44 210	Applied
9	2526	185 328 625	26 575	3579	266 589 984	44 991	Applied
10	2533	185 328 656	25 801	3619	266 590 093	45 771	Applied
11	2537	185 328 671	25 027	3687	266 590 312	46 551	Applied
12	2542	185 328 687	24 253	3841	266 590 843	47 331	Applied
13	2545	185 328 703	23 221	3990	266 591 375	48 111	Applied
14	2548	185 328 718	22 447	4031	266 591 546	49 152	Applied
15	2555	185 328 734	21 141	4056	266 591 656	49 932	Applied
16	2557	185 328 750	19 867	4231	266 592 250	50 712	Applied
17	2559	185 328 750	18 835	4265	266 592 359	51 492	Applied
18	2562	185 328 781	17 545	4323	266 592 562	52 272	Applied
19	2565	185 328 796	16 513	4423	266 592 937	53 052	Applied
20	2566	185 328 796	15 738	4454	266 593 046	53 833	Applied
21	2577	185 328 828	14 706	4579	266 593 406	54 613	Applied
22	2582	185 328 843	13 932	4642	266 593 656	55 393	Applied
23	2589	185 328 875	13 158	4671	266 593 750	56 173	Applied
24	2601	185 328 906	12 384	4685	266 593 812	57 213	Applied
25	2606	185 328 921	11 610	4834	266 594 312	57 993	Applied
26	2610	185 328 937	10 836	4882	266 594 500	58 774	Applied
27	2618	185 328 953	10 062	4907	266 594 593	59 554	Applied
28	2621	185 328 968	9288	5069	266 595 125	60 334	Applied
29	2625	185 329 000	8514	5075	266 595 156	61 114	Applied
30	2632	185 329 015	7740	5086	266 595 187	61 894	Applied
31	2638	185 329 031	6966	5091	266 595 203	62 674	Applied
32	2647	185 329 062	6192	5416	266 596 406	63 455	Applied
33	2654	185 329 093	5418	5425	266 596 468	64 235	Applied
34	2662	185 329 125	4644	5428	266 596 468	65 275	Applied
35	2669	185 329 156	3096	7021	266 602 234	64 495	Applied
36	2676	185 329 187	2322	7024	266 602 250	65 275	Applied
37	2750	185 329 468	1548	7026	266 602 250	64 495	END
38	2828	185 329 687	2322	7031	266 602 281	65 275	Released
39	2832	185 329 703	3354	7047	266 602 343	64 495	Released
40	2833	185 329 718	4386	7094	266 602 531	63 715	Released
41	2836	185 329 726	4782	7188	266 602 890	62 934	Released
42	2839	185 329 734	5160	7197	266 602 906	62 154	Released
43	2841	185 329 742	5676	7203	266 602 937	61 374	Released
44	2843	185 329 750	6192	7526	266 604 062	60 594	Released
45	2847	185 329 765	6966	7638	266 604 453	59 814	Released
46	2856	185 329 781	7998	7694	266 604 671	59 034	Released
47	2860	185 329 796	8772	7795	266 605 015	58 253	Released
48	2864	185 329 812	9546	7837	266 605 140	57 473	Released
49	2868	185 329 812	10 320	7867	266 605 250	56 693	Released
50	2870	185 329 828	11 094	7904	266 605 390	55 913	Released
51	2873	185 329 828	11 868	7976	266 605 703	55 133	Released
52	2881	185 329 859	12 642	8066	266 606 015	54 353	Released
53	2886	185 329 875	13 416	8135	266 606 250	53 572	Released
54	2890	185 329 890	14 190	8148	266 606 296	52 792	Released
55	2896	185 329 906	14 964	8337	266 606 953	52 012	Released
56	2900	185 329 921	15 996	8389	266 607 125	51 232	Released
57	2903	185 329 921	16 771	8517	266 607 593	50 452	Released
58	2907	185 329 937	18 319	8591	266 607 859	49 672	Released
59	2911	185 329 953	19 093	8617	266 607 953	48 891	Released
60	2912	185 329 953	20 125	8619	266 607 968	48 111	Released
61	2913	185 329 968	20 899	8623	266 607 984	47 331	Released
62	2914	185 329 968	21 673	8627	266 608 000	46 551	Released
63	2915	185 329 984	22 447	8638	266 608 031	45 771	Released
64	2920	185 330 000	23 479	8659	266 608 093	44 991	Released
65	2922	185 330 015	24 253	8890	266 608 890	44 210	Released
66	2925	185 330 015	25 027	8912	266 589 687	43 918	Released
67	2931	185 330 046	26 059	8948	266 609 093	43 430	Released
68	2932	185 330 046	27 091	8961	266 609 125	42 650	Released
69	2934	185 330 062	28 123	8997	266 609 317	42 112	Released
70	2935	185 330 062	28 897	9049	266 609 437	41 870	Released
71	2937	185 330 078	30 187	9183	266 609 906	41 090	Released
72	2939	185 330 078	30 961	9254	266 610 187	40 310	Released
73	2940	185 330 078	31 735	9271	266 610 221	39 910	Released
74	2941	185 330 093	32 767	9287	266 610 312	39 529	Released
75	2942	185 331 062	32 767	9296	266 610 343	38 749	Neutral

reduce the learning curve, allowing the operator to focus on the task promptly during telemanipulation.

The min and max values of the rotational orientations — roll (Φ), pitch (Θ) and yaw (Ψ) are shown in Table 3. The WING's motions with discrete microstructure values can be mapped into the manoeuvres of A-UAVs. The Yaw states of the WING detected by the developed application in this research are shown in Table 2, and their graphical representations are depicted in Fig. 6 for Yaw Port and Fig. 7 for Yaw Starboard. The acquired sequences and the time are incorporated to visualise how the velocity varies over the duration of the force applied and released. The readers are referred to Supplement I for all the translated input forces (Fig. 4) into sub-movement microstructure states.

3.1.2. Vehicle autonomy, AITL, HITL, HOTL, and HOOTL

The exponential growth of interest and research in UAVs is strongly pushing for the emergence of autonomous flying robots [35]. 10 control levels of UAV swarms from fully supervisor-controlled to fully autonomous mode between human and machine were analysed in [36]. Drone Industry Insights (DRONEII) categorises the autonomy with 5 levels [37] based on degrees of independence, namely, 1: low automation (i.e. the UAV has control of at least one vital function, with a pilot in control); 2: partial automation (i.e. the UAV can take over heading and altitude under certain conditions with a pilot still responsible for safe operation); 3: conditional automation (i.e. the UAV can perform all functions and a pilot acts as a fall-back system); 4: high automation (i.e. the UAV has back-up systems, so if one fails, the platform is still operational while a pilot is out of the loop); 5: full automation (i.e. the UAV can plan its actions using advanced AI learning techniques) with little to no human intervention in the control loop. As the level of autonomy increases, UAVs can operate in more complex environments and execute more complex tasks with less prior knowledge and fewer operator interactions [38].

Table 3
WING min and max values of the rotational orientations — roll (Φ), pitch (Θ) and yaw (Ψ).

Orientation	WING	WING State	Min/Max	Parameter	Value
Yaw (Ψ)	Yaw Port	RotationZ	Max	$\Psi_{Pmax} =$	32 767
Yaw (Ψ)	Yaw Port	RotationZ	Min	$\Psi_{Pmin} =$	1548
Yaw (Ψ)	Yaw Starboard	RotationZ	Max	$\Psi_{Smax} =$	64 495
Yaw (Ψ)	Yaw Starboard	RotationZ	Min	$\Psi_{Smin} =$	38 749
Roll (Φ)	Roll Port	X	Max	$\Phi_{Pmax} =$	60 074
Roll (Φ)	Roll Port	X	Min	$\Phi_{Pmin} =$	37 189
Roll (Φ)	Roll Starboard	X	Max	$\Phi_{Smax} =$	36 149
Roll (Φ)	Roll Starboard	X	Min	$\Phi_{Smin} =$	3870
Pitch (Θ)	Pitch Forward	Y	Max	$\Theta_{Fmax} =$	37 709
Pitch (Θ)	Pitch Forward	Y	Min	$\Theta_{Fmin} =$	10 836
Pitch (Θ)	Pitch Backward	Y	Max	$\Theta_{Bmax} =$	62 414
Pitch (Θ)	Pitch Backward	Y	Min	$\Theta_{Bmin} =$	39 790

AI agents are now capable of intentionally constraining, complementing, or substituting human involvement in the execution of routine tasks [39]. With Human-out-of-the-Loop (HOOTL) systems, AI agents are expected to execute assigned tasks without human intervention. Humans and machines may need to work hand-in-hand to complete numerous tasks safely, accurately, efficiently, and ethically, in particular, for safety-critical jobs requiring a high level of precision. HITL interaction, requiring active human involvement, is employed for the systems by which a task may not be achieved either by a human or a machine. The concept of HITL dates back to the early 1940s, when humans primarily served as error detectors, monitoring systems and intervening when necessary [40]. HITL, i.e. hands-on, system allows humans to monitor the actions continuously, interact with the system and manipulate decisions that do not seem to be an optimal outcome or situations that involve nondeterministic behaviours of AI. SA-UAVs require humans (HITL) and onboard AI (AITL) to interact with each other continuously, where uncertainty is possible to emerge. In other words, there is always a person or people watching the HITL system actively, in which SA-UAVS are mainly involved, to intervene to fix any problem that is expected to occur. On the other hand, there is no need to employ a person to monitor FA–UAVS. However, it‘s still best to have a person as HOTL passively for remote monitoring to easily step in when alerted by the AI agent and manipulate when autonomy – AITL –encounters uncertainty about what to do next. HOTL interaction turns into HITL when the human agent is alerted. However, HITL is a phase that continues until an alerted uncertainty is handled, and the system turns into the HOTL interaction after the job has been completed. In 2025, the London Office of Technology and Innovation (LOTI) launched a research project to explore the role of HITL, prompted by ongoing questions about what constitutes meaningful human involvement and how effective the designated individual is in mitigating the ethical risks associated with AI [41]. Generally speaking, HOTL/HITL systems are utilised to ensure the expected automated behaviour of A-UAVs and consequently to ensure aerial traffic safety as well as ground-based safety. HOTL systems, while operating with little to no human intervention and not requiring to be alerted all the time, still allow HTMs to perform other tasks while the autonomy level of decentralised agents is relied on to accomplish assigned missions/tasks. HTMs monitor A-UAVs during the progress of the assigned missions within the HITL system. HITL, where a HTM is supposed to be on alert all the time to fix any emerging problem that the vehicle cannot cope with, is commonly used in controlling level-3 and level-4 autonomy. A level-5 autonomy can perform under all predefined circumstances and conditions. In this regard, this paper focuses on both HOTL and HITL with A-UAVs, where the HTM is expected to intervene remotely in rare difficulties that the vehicle cannot tackle under exceptional conditions.

Table 4
Data Streaming from the PilotAware system: Instant flight information. The value of the instant data capture in time, epoch (i.e. Unix timestamp), 162 522 6964, equals "Fri Jul 02 2021 12:56:04 GMT+0100 British Summer Time".

	Time (epoch)	Transponder	Receiver	Latitude	Longitude	Altitude (Feet)	Heading	Speed (knots/h)	Call sign
Example 1	162 522.964	401B8D	ADB	52.08688	0.170053	1100	237	88	GBCOU

Fig. 8. PilotAware small lightweight Rosetta-FX graffiti module, combining all EC technologies together and enabling seamless Flarm Integration, can detect all EC types including ADS-B, Sky Echo, PilotAware, Mode-S with Weather RADAR and Enhanced Traffic Data

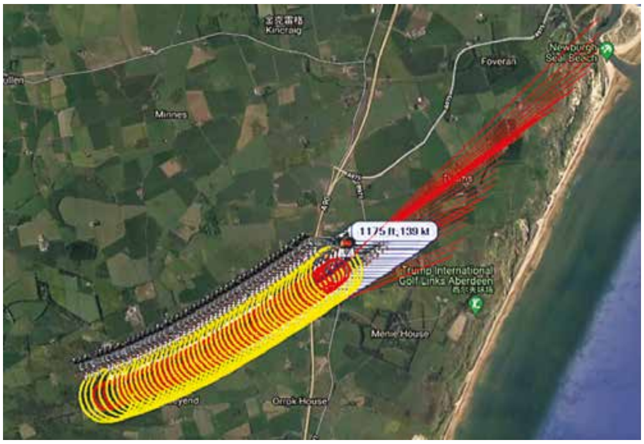

Fig. 9. Generation of future waypoints: safety travel tube with estimationbased predictive display

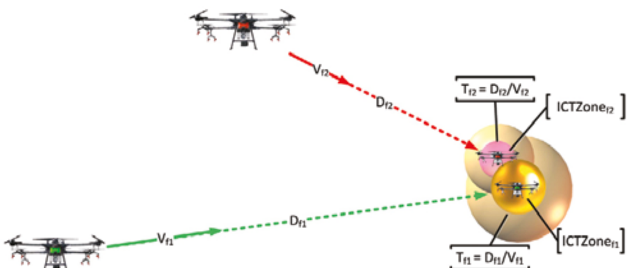

Fig. 10. Estimation-based predictive display: Early warning for a collision risk concerning an impending crossing point (impending crossing within $IcRz$) with two flights that have different velocities and are flying at similar altitudes. V, D and T correspond to "velocity", "distance" and "time to reach the crossing point" respectively.

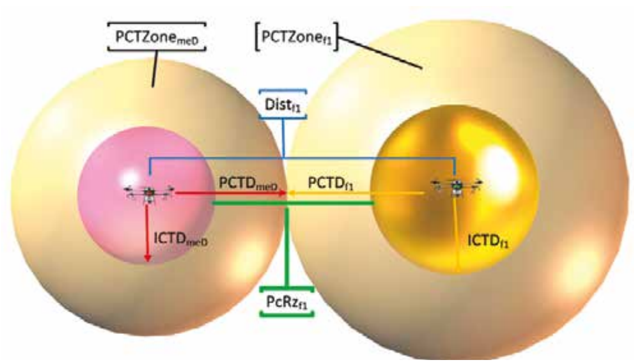

Fig. 11. Alert-YELLOW: Conflict geometry of $PCTD$ and $PcRz$: The yellow zone for each flight represents $PCTZone$. The red zone for meD and the orange zones for other flights represent $ICTZones$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Autonomy has changed the relationship between humans and robots extensively. They are becoming more harmonious while taking part in specific task executions as the level of autonomy increases with further intelligence. This relationship is elaborated in Section 3.2.1 with various intervention modes. It must be noted that the HOTL/HITL manipulation through the intervention modes is performed if necessary, and AITL is expected to take over the HTM completely as soon as possible to realise the main objective of autonomy – self-reliance and self-governing (see Fig. 8 for the EC device and Table 4 for a data instance example acquired from the EC device).

3.1.3. PilotAware ATOM-GRID Network

The PilotAware ATOM-GRID Network (i.e. currently over 320 UK ATOM stations) is elaborated in Supplement II. The network detects aircraft that transmit any of the various Electronic Conspicuity (EC) signals used in Europe. These include ADS-B (Automatic Dependent Surveillance-Broadcast), CAP 1391 and Mode-S signals on the ICAO (International Civil Aviation Organisation) aviation band and Flarm, PilotAware, Fanet + and OGN (Open Glider Network) trackers that use the EASA (European Union Aviation Safety Agency) SRD 860 Band. Aircraft that transmit using the SafeSky mobile app are also detected.

3.1.4. DACM (Drone Aware Collision Management) system

The DACM system was developed to monitor aerial traffic and trigger autonomous cooperative manoeuvres that consider the aerodynamic, flight dynamics and particular features (e.g. physics, kinematics, manoeuvrability) of A-UAVs as mobile aerial agents within a multi-disciplinary joint project [42]. This system is illustrated in Supplement III (Fig. 2). The interface of this system, equipped with simulation capabilities and low-cost equipment, provides us with a full range of testing capabilities in both real-world applications of A-UAVs and co-simulation environments. The DACM – that is tightly coupled with the PilotAware ATOM-GRID Network (Section 3.1.3) – collects instant operational manoeuvre information from all aerial vehicles via simultaneous

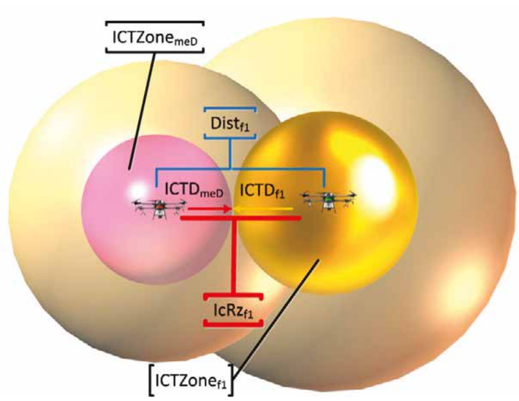

Fig. 12. High-alert-RED: Conflict geometry of $ICTD$ and $IcRz$.

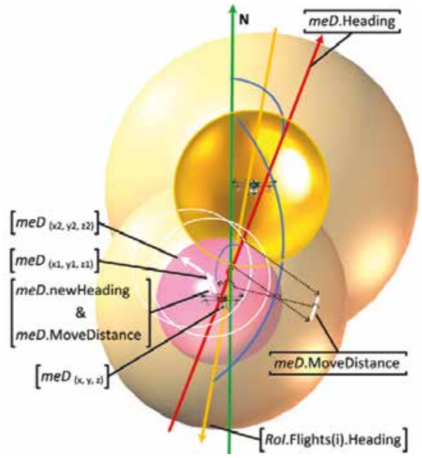

Fig. 13. Geometric illustration of CA manoeuvres (Supplement III, Alg. 2). $meD.MoveDistance$ **is corresponding to the invasion length of the** $ICTZones$**.**

Fig. 14. Self manoeuvring using the simulated and real flight data: Red $ICTZone$ **and heading and yellow** $PCTZone$ **within the original path; white** $ICTZone$ **and heading and blue** $PCTZone$ **within the manoeuvring trajectory. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)**

low-bandwidth data streams from each of the aerial vehicles. The low-bandwidth dual-path data communication is also mainly used in this research for conveying HTM command messages (e.g. new_heading = heading + 15) and necessary telemetry data (e.g. battery level of A-UAVs). The DACM – a digital replica of aerial traffic – integrates all near-real-time streamed data within its DT counterpart for convenient monitoring with more immersive telepresence for HTMs. Autonomous actuation for A-UAVs is performed to avoid emerging hazards in this immersive interface. The DACM supports HTMs to perceive the remote aerial traffic with effective SSA. The main features are outlined as follows.

1) The DACM, equipped with a novel CM methodology within an autonomy control framework using geometry formation of flights, enables BVLOS operations with collision-free trajectories.
2) The system, with (i) perception, (ii) decision-making, and (iii) automated actuation phases, can perceive the surrounding dynamic environment precisely using a global coverage strategy requiring no sophisticated sensors and react efficiently to multiple non-linear collision risks at a time with minimum trajectory deviations, requiring no prior training.
3) The DACM in both air-only and air/ground modes not only implements Collision Avoidance (CA) for FA-UAVs, but also manages Pilot-Controlled UAVs (PC-UAVs) in improving operational safety, where it might be difficult for pilots to detect surrounding close-range/high-speed flights (see Fig. 13 for the geometric illustration of CA manoeuvres).

$$\begin{aligned} PcRz_{f1} &==> (Dist_{f1} \leq PCTD_{meD} + PCTD_{f1}) \ \& \\ &(Dist_{f1} > ICTD_{meD} + ICTD_{f1}); \\ &where\,(0 < P_c \leq 0.5) \ \& \ (PCTD = 2 \ X \ ICTD) \end{aligned} \quad (1)$$

$$\begin{aligned} IcRz_{f1} &==> (Dist_{f1} \leq ICTD_{meD} + ICTD_{f1}) \ \& \ (Dist_{f1} > 0); \\ &where \quad (0.5 < P_c \leq 1) \ \& \ (PCTD = 2 \ X \ ICTD); \end{aligned} \quad (2)$$

$$\begin{aligned} ICTZone &= \frac{4}{3}\pi(ICTD)^3; \\ PCTZone = (\frac{4}{3}\pi(PCTD)^3) - ICTZone &= \frac{28}{3}\pi(ICTD)^3; \end{aligned} \quad (3)$$

$$\begin{aligned} \mathbf{CALatR} &= \sin^{-}\ (\sin(latR) * \cos(distCARadius) \\ &+ \cos(latR) * \sin(distCARadius) * \cos(bearingCAR)); \\ \mathbf{CALonR} &= LonR + \tan^{-1}(\sin(bearingCAR) * \sin(distCARadius) \\ &* \cos(latR))/(\cos(distCARadius) - \sin(latR) * \sin(meCALat)); \\ \underline{\mathbf{meDCALat}} &= CALatR * (180/\pi); \underline{\mathbf{meDCALon}} = CALonR * (180/\pi); \\ \mathbf{where}\, latR &= meLat * (\pi/180); lonR = meLon * (\pi/180); \\ bearingCAR &= newHeading * (\pi/180); \\ distCARadius &= MoveDistance/EarthRadius; \end{aligned} \quad (4)$$

The modules of the DACM, allowing autonomous navigation for A-UAVs with appropriate actuation mechanisms by coordinating the actions of multiple heterogeneous A-UAVs, are introduced in Supplement III, and the methodology using these modules is depicted in Supplement III (Fig. 2). In addition to autonomous actuation mechanisms to avoid any collision risk, the DACM system alerts the HOTL/HITL HTM if any flight is departing from its pre-planned trajectory, where the two control inputs (i.e. pre-planned waypoints and active waypoints) do not agree, considering that a probable failure is causing this unexpected manoeuvre under no collision risk using the health assessment and failure detection module.

The main goal of CM is to keep flights away from hazardous regions with conflict-free solutions at the very early stage by keeping each flight well clear of other traffic, considering their current trajectories and preplanned routes. Currently, A-UAVs do not have a system that will warn an operator of an impending collision with other airborne vehicles [43] using broader local coverage. In this module, SSA through horizontal and vertical planes is provided with the active flights and early collision risk assessment is processed, considering their trajectory predictions. From a linear formulation technical viewpoint, the flights' time-invariant connectivity of previous waypoints, their trajectory headings and their Probable Collision Travel Cone ($PCTZone$) and Imminent Collision Travel Zones ($ICTZones$) are used to

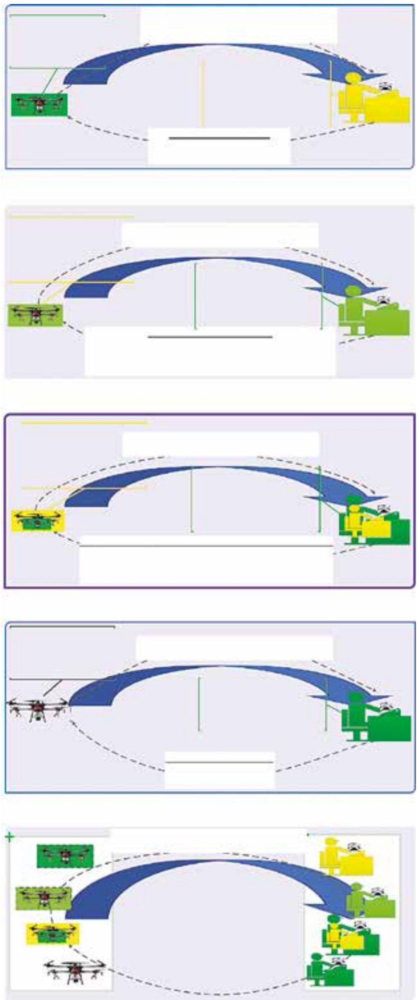

Fig. 15. HITL/HOTL interaction with a high level of transparency. Intervention modes: "No-control (supervisory)", "co-activity (shared)", "collaboration (joint)", "full control (master-slave)", and "cooperation (all togetherness)".

generate the projections of future linear or non-linear waypoints (e.g. kinematic Cartesian Virtual Points (CVPs)), leading to a Safety Travel Tube (STT) using an estimation-based predictive display as depicted in Fig. 9. A-UAVs are said to be within Flight of Safety Route, i.e. $FoSR$, where there are no overlapping STTs as shown in Fig. 10 with estimation-based predictive directions. The DACM is responsible for instructing the flight controller, i.e. HTM, to maintain A-UAV separation from conflicting regions with a conflict resolution mechanism and to avoid imminent collisions autonomously. The HTM with HOTL mode is first informed about the approaching collision risk if STTs of flights are intersecting at a crossing point, considering the conflict geometry regarding the velocities, heading and altitudes. The system turns into the HITL state, where there is a crossing point indicating an impending collision risk. The system, second, warns for the probable collision risks (within Probable-collision-Risk zone ($PcRz$)) as illustrated in Fig. 11. Third, it alerts for imminent collision risks (within Imminent-collision-Risk zone ($IcRz$)) as illustrated in Fig. 12 along with autonomous deconflicting manoeuvres (Fig. 14).

3.2. AITL-WING-HITL platform

Fatigue, lack of concentration, and poor displays all contribute to reduced performance in telemanipulating remote objects, and humans have difficulty building mental models of remote environments [20]. Therefore, these shortcomings must be compensated for with the establishment of easy-to-use interfaces, enabling robust interaction between AITL AI agents and remote human cognitive intelligence. Most importantly, two intelligent nodes – A-UAV and skilled HTM – have to be tightly coupled with human-oriented and vehicle-centric interfaces by exploiting the smartness at the vehicle end. The remote environment of A-UAVs should be observed by HTMs using constant dynamic SSA to generate proper commands at the appropriate time.

The AITL-WING-HITL platform aims to provide a tightly coupled interface between two intelligent agents — HOTL/HITL HTM and onboard aerial AITL AI agent from a multi-agent manipulation perspective. It encompasses a variety of human–robot co-work technologies that enable various interaction modes (elaborated in Section 3.2.1) and guarantee seamless transitions between these modes whenever they are needed. Technically speaking, the platform provides the HTM with a high degree of immersiveness ability with the established DTs of aerial traffic to enable the HTM to both perfectly perceive the remote aerial traffic with a full sense of telepresence (e.g. transparency) and track the results of their manipulated discrete microstructure actuation (i.e. teleimpedance) with back-feeding by incorporating a large set of integrated components as shown in Fig. 2. These integrated components mainly allow the user to interact with precision (e.g. correct aerial information with the PilotAware network (Supplement II, Fig. 1)), real-time user tracking of aerial traffic supported by a large set of proactive AI implementations (e.g. early warning, CA) with the DACM (Supplement III (Fig. 2)) and 6DoF in manipulation with the WING (Figs. 4, 5) as well as its discrete microstructure movement (Figs. 6, 7, Table 2). First, we would like to examine the co-work aspects of two intelligent entities theoretically through different intervention modes (Fig. 15) in Section 3.2.1 before delving into the merits of AITL-WING-HITL in Section 3.2.2.

3.2.1. Intervention modes within AITL-WING-HITL

A-UAVs operate autonomously and need to receive assistance whenever necessary. Time-varying delays are inevitable during the co-work interaction regarding the communication time delay problem, decision-making delays regarding the Quality of Experience (QoE) of HTMs and the evaluation of the voluminous sensor data and actuation time delays; Moreover, human remote intervention is vulnerable to human decision errors regarding incomplete environmental information based on the current state and imminent states of the vehicle concerning the other traffic participants, obstacles and hazards [8]. Even with a high level of SSA, human telemanipulation is strictly dependent on the cognitive and perceptual capabilities, spatial orientation abilities and motor skills of HTMs to avoid risky manoeuvres [8]. To this end, it is important to use the intelligence at the remote site, and it is advantageous to co-work during the execution of the complex tasks that cannot be handled by autonomy.

If A-UAVs are capable of performing on their own, human intervention is not needed, allowing HOTL systems, particularly with FA–UAVs. Otherwise, a remote extension of human intelligence and expertise with HITL interaction may be necessary either for better task performance to avoid disastrous situations during possibly hazardous operations or for executing very complex tasks beyond the capabilities of autonomy. The WING, with 6DoF, allows a HTM, with superior motor capabilities and perception/interpretation/implementation skills, to have partial or total control of A-UAVs to achieve their tasks safely and efficiently. With the help of the WING, HITL HTM inputs range with discrete microstructure values as depicted in Table 2, considering the intervention modes ranging from ''no-control (supervisory) mode'' to ''full-control (master–slave) teleoperation mode'' as delineated in Fig. 15. These intervention modes are elaborated in our previous study in [44]. These modes are summarised below in their dedicated subsections. The WING allows a HTM to switch between AITL and HITL states as well as between the interaction modes. The AITL-WING-HITL platform provides HTMs and AI agents with a high level of transparency through these interaction modes to work together with a high degree of efficacy. The WING, interfaced with AITL-WING-HITL, coordinates the tasks/subtasks by effectively modulating the HTM's hand tele-impedance in a smooth, goal-oriented manner based on the required behaviours of the intervention mode in action and the task to be accomplished. The HTM with the HOTL interaction mode can change the state to HITL to monitor the aerial traffic at any time and take action in one of the intervention modes to ascertain aerial safety or to accomplish any particular tasks. Then, the HITL state can be switched to the HOTL state after any uncertainty is managed successfully. The following intervention modes are analysed within the AITL-WING-HITL framework when continued assistance is critical for A-UAVs.

No-control (supervisory) mode (Fig. 15A): it is a time where the AI can empirically be proved to be on such a high degree of superiority that the human's input may affect the task performance negatively. The involvement of HTMs is aimed to be minimised in this mode. The HTM, as a task-specific HITL, encourages the A-UAV in a non-decisive mood to take either one of the options determined by the vehicle itself or a different predetermined option.

Co-activity (shared-control) mode (Fig. 15B): Some tasks may not be achieved by allocating sub-task responsibilities distinctively between the HTM and A-UAVs, which may lead to compromising task performance. Combining human and robot skills via intelligent interfaces seems very appealing; in this manner, establishing principled co-activity methods to seamlessly blend the control between the human and the robot to enable the combined system to surpass both the robot and human performance with reduced human effort is a prime goal for robotics [45]. This mode assists both intelligent agents – HITL HTM and AITL AI – in achieving the common goal safely.

Collaboration (joint-control or traded control) mode (Fig. 15C): AI-located/assigned series of fine-grained sub-tasks need to be performed individually either by the AITL or HITL agent. Neither the HTM is in full control of the A-UAV nor the A-UAV is in full control of itself, where various specific sub-tasks are allocated between the HTM and A-UAV beforehand. The control is traded back and forth to execute fine-granular sub-tasks, enabling joint problem-solving. Partial control can be mainly used for tightly coupled coordination between collocated HTM and A-UAVs to achieve joint task performance, wherever difficulty that cannot be coped with by the autonomy is alerted. Instead of a supervisor dictating to a subordinate, the human and the robot engage in dialogue to exchange ideas and resolve differences in the collaborative mode [23]. This mode aims to produce a better outcome than either the human or A-UAV performs alone.

Table 5
Main distinctive features of the intervention modes.

	Loop	Decision	Obedience A-UAV	Obedience HTM	Solution for conflicts	Full control	Built-in safety mechanism
No-control (supervisory)	HITL	HTM	Yes	No	N/A	Yes (A-UAV)	Operational
co-activity (shared-control)	HITL & AITL	HTM & A-UAV	No	Yes	HTM & A-UAV	No	Operational
Collaboration (joint-control)	HITL || AITL	HTM || A–UAV	No	No	HTM || A-UAVs	Partial	Operational
Full-control	HITL	HTM	Yes	No	N/A	Yes (HTM)	Inactive
Cooperation (all togetherness)	Mix interactions	Mix modes (above)	Mix modes (Yes || No)	Mix modes (Yes || No)	Mix modes (above)	Mix modes(above)	Operational

Table 6
Transition responsibilities for the intervention mode switching.

Switching decision	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

Full-control (master–slave) mode (Fig. 15D): Complete task may need to be performed by the HTM alone under extreme conditions in this mode. The HTM, as a leading agent, takes over the control and leads the A-UAV as a follower agent. Different from the collaboration mode, the A-UAV, piloted remotely by the HTM, obeys the manoeuvres performed by the HTM under any circumstances.

Cooperation (all togetherness) mode Swarms of A-UAVs sometimes need to interact with each other to accomplish a single 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. carrying a very heavy payload together with a robotic arm or a suspended cable grasped by a fixed gripper, search and rescue by assigning different target Region of Interest (RoI) to multiple A-UAVs.

The main distinctive features of the intervention modes are summarised in Table 5. A merge of these intervention modes can be employed by switching from one mode to another for specific parts of a complicated task to cope with highly difficult challenges. Switching decisions between modes can be determined based on the characteristics and dominance of the modes as presented in Table 6. For instance, the switching decision for ‘‘from no-control to co-activity and then to collaboration and then to full-control and then again back to no-control’’ is controlled and carried out by A-UAV, HTM, HTM and ‘‘HTM & A-UAV together’’ respectively.

3.2.2. Modules, techniques, & interface of AITL-WING-HITL

The main components of the AITL-WING-HITL platform (Fig. 2) are already explained in the related sections of this paper above in Sections Section 3.1.1, 3.1.2, 3.1.3, and 3.1.4. Therefore, we will be focusing on the particular characteristics of the platform in this section to reveal the specific features that are gained from the mould of the aforementioned components. A-UAVs have diverse characteristics, and they are designed with particular features and onboard equipment concerning the missions they are expected to perform [7]. In this regard, 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. 16E.1. Commands generated through the WING are transformed to the hooked A-UAVs using the off-the-shelf drone controlling systems such as UgCS, DJI (Fig. 16E.2.) as elaborated in our previous research in [42].

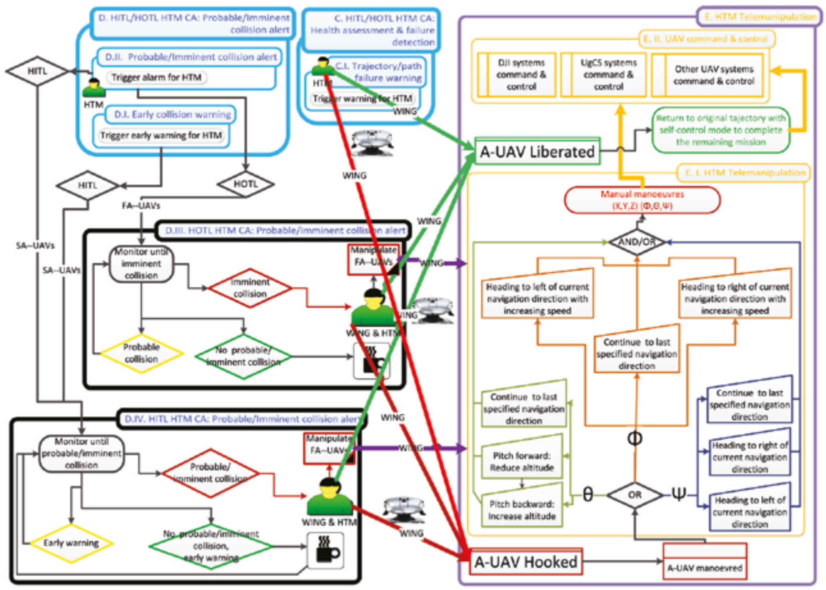

Fig. 16. Methodology of hooking and manipulation of A-UAVs using the WING. The part human intervention, D.1 (Algorithm 1), in this figure is replaced with the autonomous intervention part, D.1, in the DACM system in Supplement III (Fig. 2) when A-UAVs are manipulated by HTMs with the inputs from C.III (HOTL) and C.IV (HITL) (Algorithm 1). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

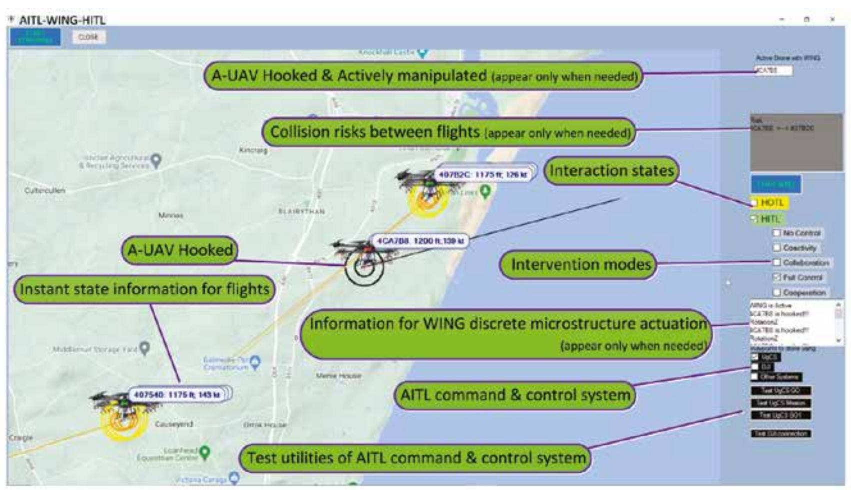

Fig. 17. Interface of the AITL-WING-HITL platform. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Interface of the AITL-WING-HITL platform: The AITL-WING-HITL application provides an improved, easy-to-use Graphical User Interface (GUI) for manipulating A-UAVs in the specified aerial zone using the WING, leading to fine-granular force, direction, and amplitude. The interfaces of intelligent systems are supposed to be considered to reduce the cognitive load to the possible minimum complexity, paving the way for effective human intervention with a high degree of perception. In this direction, the interface of AITL-WING-HITL was designed to be as simple as possible by avoiding HTMs with unnecessary overwhelming information. Additionally, it, as displayed in Fig. 17, 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 $P\ CT\ Zone$ and $ICT\ Zone$ turn black to show that the A-UAV is hooked by the HTM for manipulation. The primary interface elements are (i) DTs of aerial traffic, (ii) the WING 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 the AITL agent determines the intervention mode and transitions between these modes as outlined in Table 6. Either with a button click on the WING 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 intervention modes, namely, no-control (supervisory), co-activity (shared-control), collabo-ration (joint-control), full-control (master–slave), and cooperation (all togetherness) (Fig. 15).

Hooking with WING (Fig. 16C.1, D.III, D.IV): 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 that a specific A-UAV shall be hooked and manipulated during a collision risk by turning its heading line black. 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 over the other fixed-wing drone with a lower battery level, whereas rotary-wing drones with stronger battery levels are proposed against other rotary-wing drones with lower battery levels. Moreover, drones with an air-based mission against drones with a 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 $P\ CT\ Zone$ and $ICT\ Zone$ turn black to denote that the A-UAV is hooked by the HTM for manipulation.

The hooking of a specific A-UAV takes place when the WING-Button-1-clicked point is within the $ICT\ Zone$ of the A-UAV. The HTM remains in the manipulation mode until the hooking is released using the WING-Button-2-clicked point in the same way. The $ICT\ Zone$, $P\ CT\ Zone$, and the heading turn into black colour (Fig. 17) to signify the hooked A-UAVs during the manipulation phase. 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. In this way, multiple A-UAVs can be hooked, which means that they no longer implement their preplanned way-points, velocity, and altitude while the WING is actively manipulating another drone. The actuation per A-UAV is performed using one of the intervention modes (Fig. 15) explained in Section 3.2.1. The liberated A-UAVs from the hooking state return to their original trajectory using the shortest path to implement their pre-planned missions.

Manipulation of A-UAVs with WING (Fig. 16E.1): The mobile Internet with low-latency and high bandwidth capabilities, enabling access to information on an anywhere-anytime basis, has democratised our life in many aspects, in particular, providing fast remote operation abilities [8]. Telepresence of HTMs within aerial traffic is provided by the AITL-WING-HITL platform. The WING offers an intuitive way of controlling multiple degrees of freedom (i.e. multiple axes) simulta-neously, aiming at using the human motor system effectively with a higher information capacity. One hand is in manipulating A-UAVs; the other hand is free to operate aircraft systems through the keyboard or the control panel of the AITL-WING-HITL platform. The mapping of the values acquired from the WING to drone manoeuvres is shown in Algorithm 1. This mapping actuates the hooked A-UAVs appropriately as illustrated in Fig. 16E.1. The user can choose the proper intervention mode within the interface and can translate the inputs of the WING 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 (Fig. 4). The buttons on the WING are employed to switch between several states and actuation functions. The use of the buttons in hooking and releasing A-UAVs is explained earlier.

The SSA of aerial traffic is constantly generated using the global SSA strategy implemented by the PilotAware system (Section 3.1.3). The movements of aerial vehicles are computed by the DACM (Section 3.1.4). The DACM triggers alarms and warnings when the AITL agent experiences a difficult situation or there is a hazard, such as impending collision risks, beforehand for the HTM to take action and manipulate A-UAVs remotely. The HTM within the UTM+ATM system is authorised to intervene in the autonomous actions of A-UAVs. The HTM can adjust the position (longitudinal and lateral), altitude, angular velocity and orientation of A-UAVs concerning their environments with a quick response using the WING. It is worth emphasising that drones can be manipulated with desired navigational actions, considering the dynamic characteristics of the aerial environment and the particular drone physics-based rules defined in the system, such as manoeuvrability, velocity, and acceleration. In this sense, interactions between HTMs and A-UAVs differ depending on the capabilities of A-UAVs. For instance, a drone can accelerate to its maximum allowable speed, but not above it, even if it is forced to a velocity that is above the maximum defined speed. The discrete microstructure values of 6DoF (x, v, z, Ψ, Θ, Φ) (Fig. 5), 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 WING. 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 WING leaves the drone for manipulating other A-UAVs for the sake of simplicity, assuming that the HTM is not required to hold the WING 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 (e.g. Table 2, Figs. 6, 7). 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. The platform reacts to any imminent collision risk. An imminent collision risk can be caused if any required desired action is not actuated by the HTM within the early warning zone (Fig. 10) and the $PcRz$ (Fig. 11) despite the system collision warnings and alarms, which may lead to making drones meet in the $IcRz$ (Fig. 12). An imminent collision risk can also be caused by the instant actions of the HTM during the implementation of any intervention modes. The WING has a significant degree of inertia, which may cause the HTM to overshoot their desired location or move too fast. To avoid unexpected manoeuvres based on the fast-changing microstructure of the WING with a sequence of multiple sub-movements, the directions of the selected intervention mode within 6DoF are taken into consideration along with the

Algorithm 1: Manipulation of A-UAVs (Fig. 16E.1) using the 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 (Table 3)
Data: Instant input: RoI.flights.Data
Result: D_H.Ψ & D_H.Φ & D_H.Θ & 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;
Φ_prev = 0; Θ_prev= 0; Ψ_prev = 0;D_H.Φ = 0; D_H.Θ = 0; D_H.Ψ = 0;
=> Inputs from WING;
while hooked do
    if ((W_s == "RotationZ")&&((D_H.Ψ > −π)||(D_H.Ψ < π))) then
        => Assign the WING value to Yaw (Ψ);
        Ψ_cur = W_val;
        if (((Ψ_cur < Ψ_Pmax)&&(Ψ_cur < Ψ_prev))||(Ψ_cur == Ψ_Pmin)) then
            => Heading to left of the current navigation direction;
            D_H.heading = D_H.heading - D_H.property(Ψ_DiffDeg);
            D_H.Ψ = D_H.Ψ - D_H.property(Ψ_DiffDeg);
        else if (((Ψ_cur > Ψ_Pmin)&&(Ψ_cur > Ψ_prev))||(Ψ_cur == Ψ_Pmax)) then
            => Heading to right of the current navigation direction;
            D_H.heading = D_H.heading + D_H.property(Ψ_DiffDeg);
            D_H.Ψ = D_H.Ψ + D_H.property(Ψ_DiffDeg);
        else
            => Continue to last specified navigation direction;
        end
        navigateD_H (D_H.Ψ, D_H.Φ, D_H.Θ, D_H.heading, D_H.speed, D_H.alt);
        Ψ_prev = Ψ_cur;
    else if ((W_s == "X")&&((W_val < Φ_Smax)||(W_val > Φ_Pmin))&&((D_H.Φ > −π/2)||(D_H.Φ < π/2))) then
        => Assign the WING value to Roll (Φ);
        Ψ_cur = W_val;
        if (((Φ_cur < Φ_Smax)&&(Φ_cur < Φ_prev))||(Φ_cur == Φ_Smin)) then
            => Roll starboard: Heading to left of current navigation direction with increasing speed;
            D_H.heading = D_H.heading - D_H.property(Φ_DiffDeg);
            D_H.speed = D_H.speed + D_H.property(Φ_DiffDeg);
            D_H.Φ = D_H.Φ - D_H.property(Φ_DiffDeg);
        else if (((Φ_cur > Φ_Pmin)&&(Φ_cur > Φ_prev))||(Φ_cur == Φ_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.Φ = D_H.Φ + D_H.property(Φ_DiffDeg);
        else
            => Continue to last specified navigation direction;
        end
        navigateD_H (D_H.Ψ, D_H.Φ, D_H.Θ, D_H.heading, D_H.speed, D_H.alt);
        Φ_prev = Φ_cur;
    else if ((W_s == "Y")&&((W_val < Θ_Fmax)||(W_val > Θ_Bmin))&&((D_H.Θ > −π/2)||(D_H.Θ < π/2))) then
        => Assign the WING value to pitch (Θ);
        Ψ_cur = W_val;
        if (((Θ_cur < Θ_Fmax)&&(Θ_cur < Θ_prev))||(Θ_cur == Θ_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.Θ = D_H.Θ - D_H.property(Θ_DiffDeg);
        else if (((Θ_cur > Θ_Bmin)&&(Θ_cur > Θ_prev))||(Θ_cur == Θ_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.Θ = D_H.Θ + D_H.property(Θ_DiffDeg);
        else
            => Continue to last specified navigation direction;
        end
        navigateD_H (D_H.Ψ, D_H.Φ, D_H.Θ, D_H.heading, D_H.speed, D_H.alt); Θ_prev = Θ_cur;
    else
        => Return to original trajectory after released from hooking;
        hooked = "false";
        ReturnToOriginalTrajectory();
    end
end
```

capabilities of the drones in manipulation. This provides the user with the means to limit movement with more resistance.

A HTM can be cautioned with an alert by the AITL AI agent about the emerging situation. Telemanipulation requests and intervention requirements can be prioritised by the HTM or the system, and several of these can be commanded to take an idle safe position or trajectory (e.g. a circular trajectory as mentioned above) without endangering the vehicle itself and surrounding traffic by hooking multiple A-UAVs simultaneously. They can be handled later in priority scheduling order or hazard states (i.e. red, yellow, green) by a HTM, enabling task allocation. This property enables a single HTM with limited sensorimotor capabilities to manage a large area with heavy aerial traffic.

Liberation of A-UAVs and their return to the original trajectory (Fig. 16C.1, D.III, D.IV): A specific drone can be released from hooking when the WING-Button-2-clicked point is within the $ICT\ Zone$ of the A-UAV. The circles denoting $ICT\ Zone$, $P\ CT\ Zone$, and the heading line turn into their original colour from black (Fig. 17) after the A-UAV is liberated to indicate that they are performing their tasks independently with the AITL agent themselves. A-UAVs orient themselves in Euclidean space by means of the preplanned trajectory after being released from the hook, considering their physical manoeuvring features and the instant SSA environmental inputs.

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To be concluded in next issue.

SPH Engineering Launches UgCS 6.0

SPH Engineering has released UgCS 6.0, a major update designed to resolve critical operational bottlenecks in large-scale drone surveying. The software's new "Large Projects" feature allows operators to import massive polygons and easily split them into smaller sub-areas while guaranteeing perfect grid alignment across the entire site. To further ensure data integrity, it introduces "Tie Lines" for built-in QA/QC data validation directly within the flight plan. Furthermore, a new "Shift Right" parameter enables pilots to adjust current flight grids to precisely match historical survey lines, a critical requirement for long-term mining and geological monitoring. *www.sphengineering.com*

Honeywell launches Kestrel

Honeywell has launched Kestrel, a compact navigation solution designed to help uncrewed aerial systems (UAS) operate reliably in contested environments where GPS signals may be degraded, jammed or spoofed. It combines Honeywell Aerospace's HG3900 MEMS inertial measurement unit with an M-code receiver and a multi-GNSS receiver. The platform is intended to meet the specific needs of Group 2 and 3 collaborative combat aircraft and loitering munitions platforms. *www.honeywellaerospace.com*

FENIX Programme to push UAV swarm technology

Spain's Ministry of Defence has launched the FENIX project to test how groups of UAVs can work together on military missions, particularly surveillance and reconnaissance.

The programme brings together UAV Navigation-Grupo Oesía, Alpha Unmanned Systems, FADA-CATEC and AICIA under the Ministry's COINCIDENTE Programme for defence research. The focus is on "heterogeneous swarms", meaning different UAV types working together instead of relying on a single platform. Each aircraft would carry out tasks suited to its role and capabilities. The project will test how UAVs can operate with greater autonomy and less operator involvement. A key objective is swarm coordination. FENIX will examine how UAVs can react to changing conditions, shift tasks during missions and continue operating with limited human input. The project is also looking at sensor sharing between UAVs to improve detection and situational awareness, particularly in poor weather, low visibility and cluttered environments. *www.armadainternational.com*

42 Technology and Omnisense collaboration

42 Technology (42T) and Omnisense have demonstrated a safer autonomous drone landing system when GNSS signals are unreliable. The system uses a ground-based ultra-wideband (UWB) positioning technology. It was developed by Omnisense through its European Space Agency-supported DroneHome program.

The DroneHome program uses terrestrial radio positioning as a complementary navigation layer within the overall navigation system, so a drone's position remains stable and predictable even in GNSS-challenged environments. In practice, this means autonomous systems can maintain controlled behavior instead of experiencing sudden navigation failures. *www.omnisense.co.uk*

IN-SPACe opens LVM-3 'Bahubali' tech to private sector

The Indian National Space Promotion and Authorisation Centre (IN-SPACe) has invited Expression of Interest (EOI) from private players to transfer technology of its Launch Vehicle Mark-3 (LVM-3), popularly known as Bahubali for its lift of mass of 640 tonnes and its three stage rocket.

This is after IN-SPACe invited EOI for transfer of technology pertaining to PSLV. In September 2025, IN-SPACe and New Space India Ltd signed a technology transfer agreement with Hindustan Aeronautics Ltd (HAL) to transfer SSLV technology. *www.newindianexpress.com*

Development communication in sustainable land administration practices in the Federal Capital territory (FCT) Abuja

The findings of this research will provide valuable recommendations for the FCTA to implement a people- friendly land administration policy.

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Abstract

This study explores the critical role of development communication in promoting sustainable land administration practices within the Federal Capital Territory (FCT), Abuja. As Nigeria's capital continues to expand, the challenges surrounding effective land management have become increasingly complex and contentious. This paper adopts an exploratory approach, drawing insights from both observation and an extensive review of existing literature to investigate the underlying causes of persistent inefficiencies and disputes in land administration across the FCT. The findings reveal that inconsistent policies and abrupt changes introduced by successive administrations, often without adequate consultation or inclusion of key stakeholders, have significantly undermined efforts toward sustainable land governance. These top-down approaches, perceived by many residents and experts as insensitive or disconnected from on-the-ground realities, have led to widespread dissatisfaction, confusion, and in some cases, displacement. The paper argues that incorporating development communication strategies that prioritize dialogue, transparency, and community engagement is essential for creating more inclusive, equitable, and enduring land administration systems in the FCT.

Introduction

The challenges of land administration in Nigeria's Federal Capital Territory (FCT), Abuja, continue to spark pressing debates and generate widespread concern among citizens, policymakers, and development stakeholders. This paper presents a pilot study that explores the role of **Development Communication (DevCom)** in fostering sustainable land administration practices within the FCT. It forms part of a broader inquiry into how participatory communication strategies can address the deep-rooted issues of land governance, equity, and urban planning in the nation's capital. According to Carrilho, et al. (2024) Effective participation of stakeholders is necessary to yield land use plans that address all the social, cultural, economic, environmental and institutional dimensions of sustainability, where the tension between the collective and individual interests manifest. Effective participation in tends to ensure that local constraints and limitations are identified, exclusion areas and easements are correctly understood, making rights recordation informative and able to provide sufficient and informed security of tenure, before fully registered land titles, making pro-poor cadastre a dynamic land administration process.

Over the years, Abuja has grown rapidly from a planned administrative center into a sprawling metropolis, attracting migrants from across the country in search of economic opportunities and better living conditions. However, this growth has come at a significant cost—particularly to the urban poor, who often find themselves marginalized in matters of land ownership and access. Securing land or decent housing within the Area Councils, let alone the city center, remains a herculean task for many, with affordability and accessibility presenting insurmountable barriers for a large portion of the population. On Earth, land is the most vital resource from which living things derive their essential necessities. There are many methods for managing and maintaining this vital resource in a sustainable manner, but it is more important to first understand the root cause of malfunctioning land management strategies (Azadi, et al. 2021).

A critical point of tension lies in the ongoing struggle between indigenous communities and government authorities such as the Federal Capital Development Authority (FCDA) and, at times, the military. These conflicts, particularly in areas along the airport road, have frequently escalated into public demonstrations, road blockades, and even violent clashes. Local media reports have documented several of these incidents, some of which have resulted in tragic losses of life and destruction of property— disrupting not only community life but also daily activities for commuters and residents.

Beyond these confrontations, another major issue affecting land administration in the FCT is the pervasive problem of land racketeering. Dishonest and illegal land transactions—often facilitated by some unscrupulous individuals in the society who takes advantage of the complex land administration in the FCT— This practice have eroded public trust in the system and contributed to a chaotic and unjust land allocation process. Many residents believe that the FCDA and other authorities have failed to adopt a holistic and inclusive approach to governance, one that ensures transparency, accountability, and fairness in land matters.

According to the **Federal Capital Territory Act** of 1976, the ownership of land within the territory is vested absolutely in the Government of the Federation. Despite this legal framework, the reality on ground tells a different story, one marked by inconsistencies, confusion, and a lack of stakeholder inclusion. A significant cause of this disconnect can be traced to frequent **policy summersaults** by successive governments, which have undermined the original vision of the Abuja Master Plan and created uncertainty among residents and landowners alike (Jibril, 2006).

From the 1976 FCT Resettlement Policy, which aimed to enforce "equal citizenship" by compensating and relocating original inhabitants, to the various iterations and reversals in subsequent years—including the partial resettlement of some, integration of others, and abrupt reallocation of resettlement sites—policy decisions have often been made without adequate engagement of the people most affected. For instance, Garki Village, now within the heart of the city, is still home to indigenes left largely to their fate. Meanwhile, places like Jabi, Kado, and Gwarinpa were designated for resettlement, but shifting political priorities saw those areas reassigned to civil servants and security personnel, especially during election seasons (Jibril, 2006).

These inconsistencies and the exclusionary nature of policymaking have hindered the development of a truly inclusive and equitable capital city. Instead of fostering national unity, Abuja has become a contested space where development is perceived by many as imposed rather than participatory. In other climes like Syria, the importance of instituting a knowledge-based land administration system emerges to guarantee housing, land, and property rights issues and support sustainable development. Therefore, the reconstruction process is done by updating geodetic infrastructure to keep in touch with advanced geo spatial technologies and address property-related issues that may hamper economic and social promotion. On the other side, this transition in post conflict Syria requires effective and meaningful participation from all relevant stakeholders to put forth suggestions to solve many legal, political, and technical matters (Maan, 2022).

It is against this backdrop that this paper advocates for the integration of **Development Communication (DevCom)** as a strategy to improve land governance in the FCT. DevCom emphasizes dialogue, mutual understanding, and the active participation of all stakeholders—particularly marginalized groups—in shaping policies that affect their lives. By applying these principles, government institutions can move beyond top-down decision-making and begin to cultivate trust, transparency, and shared ownership of development outcomes.

Ultimately, the aim of this study is to demonstrate how Development Communication can serve as a transformative tool in creating a more sustainable, inclusive, and humane approach to land administration in Abuja. Through meaningful engagement, the people of the FCT—whether native or settler, poor or elite—can contribute to building a capital city that reflects the collective aspirations of all Nigerians. This is further supported by the work of Akintunde (2025), were he recommended that the Nigerian government should going forward adopt the principles of democratic land governance by giving voice to the citizens through their representative in the administration of land. Deploy the instrumentality of technology towards achieving a seamless land administration process, particularly the internet. Addressing the inequalities in the rights, duties and obligations of property owners under the extant laws. Reduce the financial burdens and multi-taxational dimensions to land administration process. Work towards a unified land right and administration, e,g, express/deemed rights; state/local government dichotomy. Review the administration of the revocation and compensation regime under the present laws. Look towards state-backed title registration process rather than the current deed registration system for title reliability and validity.

Statement of the Problem

In theory, the Federal Capital Territory (FCT), Abuja, was envisioned as a symbol of unity and a model city representing Nigeria's national aspirations. However, in practice, its land administration system has become a troubling reflection of deeper governance challenges that continue to hinder inclusive and sustainable development. At the heart of this problem is a persistent disconnect between government institutions and the very people whose lives are most affected by land policies and planning decisions.

For many residents of the FCT—especially the urban poor and original inhabitants—access to land and housing has become increasingly difficult. The cost of securing land legally is often out of reach, and alternative methods are frequently blocked by bureaucracy, corruption, or even force. Numerous reports have emerged detailing conflicts between indigenous communities and government authorities such as the Federal Capital Development Authority (FCDA) and the military, especially in high-value areas along the airport road. These conflicts have resulted in protests, road blockades, prolonged traffic disruptions, and, tragically, at times, loss of lives and destruction of property.

Beyond physical clashes, another layer of complexity is introduced by the widespread issue of land racketeering—where land is fraudulently sold or allocated, often with the involvement of insiders within government agencies. Such practices have further eroded public trust in the institutions responsible for urban planning and land governance. For many, the idea of fairness and transparency in land allocation feels like a distant dream.

One of the most pressing issues is the frequent *policy summersaults*—sudden and often unexplained changes in land policy by successive governments. These policy shifts have ranged from full resettlement strategies to partial integration, and back again—leaving residents confused, displaced, or trapped in legal limbo. Communities like Garki, Jabi, and Kado have experienced first-hand the human cost of inconsistent policymaking, with resettlement plans abandoned mid-way or co-opted for other purposes, including political patronage and security accommodation (Jibril, 2006)

What is glaring in all of this is the lack of *participation*. Land administration decisions are too often made behind closed doors, with minimal input from affected communities, local leaders, or civil society actors. People are told what will happen to them—rather than being part of the conversation about what should happen. This top-down approach fuels resentment, deepens inequality, and weakens the potential for sustainable, people-centered urban development.

This study recognizes the urgent need for a new approach—one that centers **Development Communication (DevCom)** as a strategic tool for bridging the gap between government agencies and the communities they serve. Development Communication, rooted in participation, dialogue, and mutual respect, has the potential to transform the way land governance is carried out in the FCT. By genuinely listening to people, involving them in decisions, and building policies that reflect shared goals, the FCT can begin to address the root causes of its land administration crisis.

Research Objectives

This study sets out to achieve the following objectives:

1. To explore and analyze the root causes of poor land administration in the FCT, with a focus on how inconsistent government policies and lack of stakeholder involvement have contributed to the current challenges.
2. To understand the real-life experiences of residents affected by land conflicts, including indigenous communities, low-income earners, and others who face barriers in accessing and securing land legally.
3. To investigate the extent to which Development Communication can be used as a strategic tool to foster more inclusive, transparent, and participatory land governance in the FCT.
4. To examine past and present land-related policies and their impact on community relations and urban planning, with particular attention to how decisions were communicated and received by the public.
5. To propose a communication-based framework that places communities at the center of land administration decisions, encouraging dialogue, accountability, and shared ownership of urban development initiatives.

Research Questions

Based on the context and objectives outlined above, the study seeks to answer the following key questions:

1. What are the fundamental challenges affecting land administration in the Federal Capital Territory, and how do they impact different groups of residents—particularly the marginalized?
2. How have successive government policies on land resettlement, integration, and compensation contributed to confusion, conflict, and distrust among stakeholders in the FCT?
3. To what extent are residents and stakeholders currently engaged in the processes of land policy formulation, implementation, and monitoring in the FCT?
4. How can Development Communication strategies, such as dialogue, participatory planning, and community consultation be applied to improve land governance in the FCT?
5. What would a sustainable, communication-driven model of land administration look like in the FCT, and how can it be implemented in a way that respects

local knowledge, promotes equity, and builds long-term trust?

The role of development communication in sustainable development

Before the move of the Federal Capital Territory from Lagos to Abuja, Development Communication has been used in various places to assist in the realization of sustainable development. DevCom as a field started in the early 1960s and it was first applied to "nation building" rural development, agricultural extension, health and sanitation, as well as family planning. It is the planned use of communication processes and media products to support effective policymaking, public participation and project implementation geared towards social, economic, political and ecological development. It provides opportunity were two-way social interaction process enables the people concerned to understand key factors and their interdependencies and to respond to problems in a complete manner (Manfred, 2006).

Best practice all over the world for a campaign were people would be informed about initiative at hand, its goal, ways of working, its benefit and the way through which local people and groups can become involved and gain from it wrong perception about the initiative should be dealt with first. The expected cost and information about what the initiative will and will not do should be incorporated with local institutions, schools NGOs, women's group, community based organization, government, and cultural and religious institutions. In fact, to derive home the message, community meetings, street theater or political posters. It is observed that freely distributed information can help build trust between the management of the concept and local stakeholders, this will give rise to increase in the level of local awareness not just about the initiative but about the general state of local resources (Manfred, 2006).

Land governance for sustainable development

Study shows how despite the uniqueness of local system, the range of cognitive framework about land, and difficulties in transferring institutions, design of robust and successful Land Administration system is possible. Among the ten universally applicable principles for Land Administration system that stood out for this piece is about the engagement of people within unique social and institutional fabric of each country. This principle allows for an encompasses good governance, capacity building, institutional development, social interaction and a focus on users, not providers, a sustainable Land Administration should be re-engineered to better serve the needs of users, such as citizens, government and business. Engagement with the society, and finding out how the people think about their land, are core to a successful Land Administration anywhere in the world. And in most parts of the world this can be done through good governance in decision making and implementation (Williamson, et al. 2010). Land is an essential component of household socioeconomic capital, especially in Africa, where agriculture supports most households. More importantly, secure access to land is critical. Long-term investments in sustainable livelihoods by rural households are required for sustainable agricultural development. Most African communities rely on land for survival, and land resources are the cornerstone of achieving many of the UNSustainable Development Goals (SDGs) . Moreover, securing land rights has been identified as an important strategy for achieving SDGs. The 2030 United Nations Development Goals, specifically Goal 1 (poverty), Goal 2 (hunger, food security, nutrition, and sustainable agriculture), Goal 5 (addressing gender equality and the empowerment of women and girls), and Goal 15 (issue on life on land), emphasize the importance of access to and control over land, as well as sustainable land management and associated resources. As a result, a modern land administration system, including formal land registration, titling, and certification, has been viewed as a prerequisite for ensuring property rights and agricultural development. Land tenure should be properly administered for positive societal changes by establishing formal land titling procedures. It is argued that tenure security has a positive impact on land investment by improving holding rights and providing a sense of stability, which encourages farmers to make sustainable land investments and increase yield (Gedefaw, 2023).

Theoretical framework

This study adopts the **Participatory Communication Model** as its guiding theoretical framework. Rooted in the broader philosophy of *Another Development* and the concept of *multiplicity*, this model emphasizes the centrality of people—their voices, cultural identities, lived experiences, and rights—as vital drivers of sustainable development. Unlike traditional top-down approaches to communication, the participatory model insists that development must be inclusive, people-centered, and shaped by those who are most directly affected by it. During the Nigeria's national sodium reduction program, participants were invited through a purposive sampling of identified key actors at the federal, state, or local level who were knowledgeable or influential regarding dietary intake of the Nigerian population and were involved in various components of the priority actions. Participants were recruited from two states (Kano and Ogun) in Nigeria and the Federal Capital Territory (FCT), Abuja. These states were chosen to align with states where the Nigerian Federal Ministry of Health (FMoH) and the WHO were already working to pilot the implementation of selected National Multi-Sectoral Action Plan (NMSAP) priority actions. Data were collected through focus group discussions (FGDs) and in-depth interviews (IDIs) between January 2021 and February 2021. Twenty three IDIs and 5 FGDs (n = 11) were conducted with health professionals (n = 10), federal, state, and local policymakers (n = 9), community leaders (n = 3), food industry (n = 3), inter national non-governmental organization (n = 3), food retailers/restaurant owners (n = 3), aca demia (n = 2), and food and drug regulatory body (1) (Sanuade, et al. 2023).

At its core, this model highlights the importance of democratization and engagement across all levels of society—international, national, local, and individual. It challenges the notion that communication should merely be used to transmit information to passive recipients. Instead, it advocates for strategies that emerge organically from the people themselves—the so-called "receivers" of development initiatives—who are, in fact, co-creators of progress.

This idea is powerfully captured by Paulo (1983), who argued that everyone has the right to "speak their word," both individually and collectively. According to Paulo, this right is not a privilege reserved for a few, but a fundamental expression of human dignity. As he puts it, "no one can say a true word alone, nor can he say it for another in a prescriptive act which robs others of their words." Development, therefore, must begin with listening—truly listening—to the people.

In any meaningful development effort, communication must foster trust, transparency, shared knowledge, and mutual respect. As emphasized by the **International Commission for the Study of Communication Problems** (1980), development requires new attitudes—ones that move beyond stereotypes and embrace diversity and pluralism. People must be seen not as passive beneficiaries, but as active participants with unique insights and experiences that can enrich the process.

Development Communication, through the participatory model, encourages **reciprocal collaboration** at all levels. It is not about "talking at" people or even "talking to" them—it's about *talking with them*. It is about creating space for real dialogue, where community members, stakeholders, and change agents share ideas, voice concerns, and jointly decide on the best way forward.

Supporting this perspective, the **Xavier Institute (1980)** argues that genuine development must be anchored in faith in the people's capacity to know what is best for themselves. Communities are not empty vessels waiting to be filled with knowledge—they carry generations of wisdom and resilience. Our role is to draw on that strength, not to override it.

Mayan-Julia, et al. (2020), also affirm that when beneficiaries are actively involved in all stages of a project—from planning to execution—they are more likely to take ownership. This sense of ownership transforms the perception of development initiatives from being "government-owned" to being *community-owned*, increasing the likelihood that such projects will be protected, maintained, and sustained in the long run.

Okunna (2002), reinforces this view by insisting that participation should go beyond sending feedback—it should involve people in *decision-making* itself. Development meetings, she argues, should not be platforms for announcing pre-decided plans, but interactive forums for co-creating solutions. True participation means giving communities the power to shape the outcomes that affect their lives.

Finally, **Mefalopulos (2008)**, reminds us that even the most advanced technology or expertly packaged messages cannot achieve meaningful results unless stakeholders are actively engaged in the process. Sustainable development, he asserts, is not about how loudly we broadcast information, but about how deeply we listen and collaborate.

In sum, the participatory communication model offers a compelling framework for this study. It redefines development as a shared journey—where communication is not a tool for persuasion, but a bridge for understanding, empowerment, and lasting change.

An Empirical Study on Stakeholders' Perspectives about the National Target Program for New Rural Development in Vietnam

This empirical study aims to shed light on the practical application of **Development Communication** as a strategy for **participatory development**, demonstrating how it has been successfully implemented in other parts of the world and how it has had a positive impact on rural areas. The study particularly focuses on the context of rural Vietnam, where the government launched a comprehensive **National Target Program for New Rural Development**. This program involved various stakeholders, ranging from government authorities at the national and local levels, to grassroots organizations such as the **Youth Union, Women's Union, Farmers' Union**, and local households and businesses, all of whom worked together to drive the successful execution of the program.

One of the primary findings of the study is the distinction between two broad groups of stakeholders involved in the project: **the state actors** (representing government authorities) and **the people**, which include local households and enterprises. The **Resolution of the 7th Conference of the Central Party Committee** on agriculture, farmers, and rural areas set the framework for implementing the national target program. This resolution emphasized the critical importance of **local community participation** as a key principle in the program's execution.

From the perspective of government officials, the state plays an orienting role by establishing criteria, standards, policies, support mechanisms, staff training, and providing implementation guidance. However, it is the **villages** and **commune-level communities** that engage in democratic discussions, planning, and conducting specific activities in alignment with the central guidelines. Notably, the study revealed that the role of rural households, while important, does not always reflect the extent of their financial contributions to public-private partnership programs. Instead, the study advocates for a more comprehensive approach, recognizing the value of household participation in both the d**ecision-making** and **implementation processes**.

Several examples cited in the study illustrate how households have actively participated in various aspects of the new rural development initiative. This includes **proposing community needs, supervising and implementing activities, sharing benefits, and reviewing performance indicators**. The research also highlights that in some regions, the level of people's participation has had a direct and positive effect on their contributions. For instance, communities that engaged in discussions, planning, and monitoring activities found that their participation led to higher levels of commitment, reducing costs and improving the quality of infrastructure built through the program (Nguyen, 2012).

Furthermore, the study draws upon the work of Doan (2017), who observed the varying levels of participation among residents in the **Northern mountainous areas**. In some places, participation ranged from simply attending project meetings (without being involved in decision-making) to more active roles, such as **engaging in the decision-making process, providing labor, supervising projects**, and even participating in the **management and maintenance** of infrastructure. These activities contributed to **reducing construction costs**, lowering the state's financial burden, and ensuring that the constructed works met the actual needs of local communities.

However, the study also acknowledges that in some localities, the participation of people remains **superficial**, and the potential for full engagement has not yet been realized (Pham, 2017). This is particularly true in the pilot areas where the new rural development program has been implemented for several years, but **awareness** and **understanding** of its full scope remain limited. The study stresses that the objectives of the program should be extended to **all localities** across the country, not just the initial pilot areas. In certain regions, there has been a lack of consensus among stakeholders, leading to suboptimal outcomes in the implementation of the program.

According to a report by the **Ministry of Agriculture and Rural Development (MARD, 2019)**, the efforts to **mobilize** and **engage** people in the program have been **insufficient**. One of the slogans, "the farmer is the subject," has not been fully communicated or understood by many stakeholders. As a result, people have not been actively involved in the process or have waited for **state support** without fully participating. Similarly, the research of Duong (2014) highlighted that, in some regions, local officials and residents still do not fully appreciate the importance of the new rural development program or recognize the **critical role of the people** in its success.

A survey conducted by the **Institute of Policy and Strategy for Agriculture and Rural Development (IPSARD, Hoang, 2014)** further revealed some concerning statistics regarding **people's rights** in the program. The survey found that only **68.1%** of households reported having the right to voice their opinions about local planning and development schemes; only **55%** felt they had the right to comment on the selection of projects; and **66.9%** claimed to have the right to monitor project implementation. In some cases, even communes that met the official new rural standards were unaware that they had done so.

Additionally, research by **Do (2016)** pointed out that the **low level of education** in some rural areas remains a significant barrier to effective participation. Many people in remote locations lack access to communication tools or the necessary skills to express their views or understand complex processes, resulting in limited involvement in planning and implementation. **Decentralization** of decision-making from the central government to local levels, if properly executed, could help address these issues, increasing **democracy** and improving the overall effectiveness of the program (Nguyen and László, 2020).

In conclusion, the study underscores the importance of **awareness**, **education**, and active **participation** from all stakeholders for the successful implementation of the new rural development program. Stakeholders, particularly at the local level, need to better understand the program's objectives, and their roles in it, to contribute meaningfully to its planning and implementation. Properly engaging communities and ensuring their involvement at every stage of the development process will be key to the program's long-term success and sustainability.

Second empirical study that underscore the relevance of development communication in land management in Bhiwandi Mumbai

Datta and Hoefsloot (2025) assert that in 15 December 2023, citizens in the small textile town of Bhiwandi, located on the northern outskirts of Mumbai, gathered outside the Municipal Corporation building to demand the revocation of the Development Plan (DP) 2023–43. This plan, which had been developed following two years of consultation and assessment by private consultants, was still awaiting approval by the Bhiwandi Municipal Corporation. However, the process leading to its creation had been shrouded in secrecy – citizens, community leaders and local professionals had no opportunity to observe or provide feedback on the plan. Despite this, the municipality claimed to have conducted a comprehensive consultation process that resulted in the zoning and criteria for Bhiwandi's future development. The DP 2023–43 was a significant milestone in Bhiwandi's history and a source of pride for the municipality, which for several decades had been bypassed by Mumbai's regional development plans. The corporation had struggled to cope with rapid 'unplanned' urbanisation in and around the town and often attributed this to its inability to 'see' territorial expansion using simple analogue survey methods. For the first time, the Bhiwandi Municipal Corporation had produced a DP (albeit with the help of private consultants) using relatively sophisticated digital technologies such as drones, remote sensing and geographic information system (GIS) mapping. These new spatial planning technologies were a watershed for a relatively small corporation that had been plagued by decades of mismanagement, resource shortages and limited capacity. So why were the citizens agitating? This development led to the study on informational peripheries. The month-long protests and sit-ins by citizen groups in Bhiwandi were directed at the informational gaps and inaccuracies in the DP that directly affected their lives and livelihoods. Their grievances were related to the use of digital technologies, which they claimed had misrepresented existing land use in Bhiwandi. Private consultants recruited by the municipality had used drones and camera-equipped cars to map the area, but they had been unable to enter the narrow alleys and lanes, leaving parts of the city unmapped and invisible in the DP. Further, they had relied on the outdated 2003 DP as the foundation for the new plan, despite the fact that Bhiwandi's rapid urbanisation had not followed any of the zoning and development stipulations set out in earlier plans. Citizens demanded a return to physical survey methods of mapping existing land use in Bhiwandi and a process of citizen consultation to plan Bhiwandi's future. The events in Bhiwandi illustrate the ways in which control over informational flows determines how territories are seen, represented and governed. Who has access to information, who gets to direct informational flows and who determines what sorts of information will flow – these are forms of power that are crucial to determining how urban futures will unfold. Informational power is arguably more significant than other forms of social, infrastructural or territorial power since it can be exerted simultaneously across physical, social and digital realms. Informational power is infrastructural, social, physical, representational and territorial. Those without informational power are peripheralised – they are denied agency over the urban transformations unfolding around them. In this book we refer to the diverse processes of peripheralisation evident in a digital age with the term 'informational peripheries'. Following Datta (2023; 2024b, as cited in Data and Hoefsloot, 2025) we define 'informational peripheries' as a combination of digital, material, territorial, infrastructural and social marginalisations that emerge from informational control, redlining, manipulation and blockading. We argue that in a digital age, the periphery is more than just a geographical location. Seen through an informational lens, it emerges as a temporal construct that continually evolves across virtual and analogue spaces. Informational peripheries are determined by a lack of access to informational flows, as well as a relational positionality of expulsion from crucial informational exchanges across geographic space-times. They emerge from the residual spaces of flows, circuits and networks of information and the laws, policies and governance systems that channel information away from particular geographies. The informational periphery is fragmented, diffuse and dispersed and cannot be fixed or determined through simple cause-and-effect analysis. Secondly, informational peripheries It is entangled with regimes of capital, land transformations and infrastructural disconnections across several scales. The informational periphery, then, is a heuristic that stands for the digital-urban condition today. Because it cannot be fixed in location or time, informational peripheries are multitudinous, diverse and continually shape-shifting. The agitations of Bhiwandi's citizens remind us that across the world, peripheral spaces and communities are becoming the experimental testbeds of new smart technologies for visualisation, mapping and urban governance. The rapid rise of sophisticated data-based technologies in public services in recent decades has been accompanied by skyrocketing investments in data-driven administrative reforms and an incredible growth in companies specialising in facilitating these services, including software developers, system architects and geo-information consultants. These reforms and investments are rationalised by calls to speed up service provision, achieve greater efficiency and gain deeper knowledge to anticipate future challenges (Coletta and Kitchin, 2017, as cited in Data and Hoefsloot, 2025) But the reach of these tools and their impacts often coincide with increased surveillance of the poor, the curtailment of opportunities to audit policies (Eubanks, 2018, as cited in Data and Hoefsloot 2025) and exploitation of people on the social-economic-geographic margins. This is not a coincidence, and the technologies for urban governance are not neutral. They emerge out of techno-capitalist projects and shape the politics and experiences of being and becoming 'urban' in a digital age. This book presents a case for 'informational peripheries' as an analytical lens for understanding the new configurations of urban digital peripheralisations. While the information revolution infiltrates all processes of governance and planning, informational peripheries become both drivers and outcomes of uneven urbanisation processes. The informational periphery is fraught with tensions between erasure/inscription, inclusion/exclusion, (in)visibility and (dis)connectivity in an era when new digital technologies are seen as the future of planning and governance. In the informational periphery, social exclusions are marked by both geographic and informational distance from the state; it includes subjects that are uncountable as well as territories that are unmappable – digitally, socially and geographically. The informational periphery intersects with urban peripheries but also straddles geographic and informational spaces. It attends to diverse and heterogeneous forms of digitalised urbanisation that are taking shape across metropolitan regions in the Global South. The paper argues that, despite the challenges faced by those denied informational power, peripheralisation nonetheless offers possibilities for producing informational flows from below. For instance, during the COVID-19 pandemic, a collective of citizens living in Kibera, Nairobi's largest informal settlement, formed Community Mappers. Initially focused on conducting community needs assessments and gauging the impact of the pandemic on young women, Community Mappers has grown beyond these goals. It is now a partner in generating data for infrastructural management within Kibera and has assisted in classifying satellite images to model deprived neighbourhoods across the city. The data collected by Community Mappers literally and figuratively puts Kibera on the map, drawing the attention of the state and supporting its claims to welfare provisions. In the case of Bhiwandi, the absence of spatial data leads to the exclusion of citizens from its urban futures represented on a map; in the case of Kibera, networked connectivity brings a marginal group within a geographic periphery closer to the state. Informational peripheries, then, are paradoxical spaces that are at once marked by invisibility, exclusion and marginalisation while at the same time being targeted for incorporation into the territory of the metropolitan city. They are materially and epistemologically located in the intersections of multiple imaginaries of the urban, the desire for governability and expansion. The periphery and processes of peripheralisation are not points on the map or linear transformations but anchors of the urban condition at different moments in time. From this perspective, urban spaces and urbanisation are shaped by global political economies, as well as by the small but continuous actions of people, as citizens, as engineers, or through the routine tasks of bureaucrats at work. This urges us to take a deeper look at the practices of accommodation and subversion in the making of the periphery. Data-based systems are ubiquitous in all these spaces, especially in the offices responsible for land, property and resource administration, low-wage and gig workplaces, and the management of public services and infrastructures. This requires thinking about urban transformation not as a singular or linear event but as a temporal and irregular process, oscillating in pace and progress. This book is a study of this fluid notion of informational peripheries emerging at the nodes of urbanisation, digitalisation and networked societies. As compared to a more topical subject – data – we suggest that informational peripheries are more than data marginalisations. Rather, we approach information as data that has been organised – to which certain logic has been applied to carry meaning and serve a purpose. In the current digitalising moment, the periphery is produced not just by data flows and blockades, but also by how information is leveraged towards political ends. Collectives of government, local consultants and global companies make maps of new regions for development based on data collected by digital technologies. Digital platforms and integrated databases store and analyse personal data, labour information and register records to control movement, calculate welfare and tax lands, often with poor safeguards regarding privacy and data security (Masiero and Das 2019; Hoefsloot and Gateri 2024, as cited in Data and Hoefsloot, 2025). These systems are being integrated into peripheral spaces at an astounding pace, with little political discussion about their impacts and who they serve. We suggest here that the periphery in a digital age needs to be understood through the lens of information – encompassing both its politics and its flows through people, spaces and technologies. This 'urbanization of information' (Shaw and Graham 2017, as cited in Data and Hoefsloot, 2025) means that informational power is simultaneously urban, social, political and technological – producing specific inequalities and exclusions across digital and analogue spaces. It fundamentally alters how we might begin to think about the notion of the periphery itself in a digital world. Periphery in a 'digital turn' There has been a renewed focus in urban and regional studies on the concept of 'periphery' and the processes of peripheralisation (Gururani 2024; Hauswedell et al. 2019; Phelps et al. 2023 as cited in Data and Hoefsloot, 2025). Stemming from Wallerstein's world systems theory, which aimed to capture the geographical dualisms of the Global North versus the Global South, the urban core versus the periphery, and international divisions of labour within extractive and capitalist globalisation, the concept of the periphery has been translated, redefined, localised and critiqued within urban and development studies, research on knowledge production, sociology, and far beyond (el-Ojeili 2015, as cited in Data and Hoefsloot, 2025). In the Global South, conceptualisations of the periphery.

Methodology

The paper adopted the exploratory methodology, including comprehensive reviews of existing literature, to identify the gaps in knowledge. This emphasizes that the exploratory method involved a review process to pinpoint areas where further research is needed.

Conclusion

The current management approach to land administration by the Federal Capital Territory Authority (FCTA) in Abuja highlights a pressing need for a more inclusive strategy that addresses the aspirations of the urban poor regarding land ownership. The prevailing mindset that the government can single-handedly resolve these issues has marginalized the voices of key stakeholders, including local communities and ordinary citizens, in the decision-making processes related to development projects in the FCT. Recognizing the substantial financial burden on the government to develop the city, the FCTA has opted to sell land to estate developers. Unfortunately, this has led to the construction of properties that are often unaffordable for the average Nigerian, particularly civil servants. The high costs associated with renting or purchasing these properties have created a significant barrier to housing access for many residents.

In light of the current economic challenges facing the country and the specific context of Abuja, this research proposes the exploration of Development Communication strategies as a means to foster sustainable land administration in the FCT. The goal is to facilitate collaboration among various stakeholders, enabling them to contribute to the formulation of policies that prioritize the needs of the community and promote equitable access to land.

The findings of this research will provide valuable recommendations for the FCTA to implement a people-friendly land administration policy. By fostering a collaborative environment where stakeholders can share their insights and experiences, we envision an FCT that residents can take pride in, one that reflects their needs and aspirations, as supported by empirical evidence indicating that stakeholder awareness and understanding are crucial for the successful planning and execution of development programs. This research aims to contribute to the ongoing discourse on land administration in the Federal Capital Territory by advocating for a more participatory approach. By leveraging Development Communication strategies, we can work towards a sustainable and inclusive land administration system that empowers all residents of Abuja.

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GNSS (SBAS) Constellation Specific Monthly Analysis Summary: May 2026

The analysis performed in this report is solely the author's work and his opinion.

Narayan Dhital
Actively involved to support international collaboration in GNSS-related activities. He has regularly supported and contributed to different workshops of the International Committee on GNSS (ICG), and the United Nations Office for Outer Space Affairs (UNOOSA). As a professional employee, the author is working as GNSS expert at the Galileo Control Center, DLR GfR mbH, Germany.

Introduction

This article continues the monthly performance analysis of the GNSS/SBAS constellation. Readers are encouraged to refer to previous issues for foundational discussions and earlier results.

Satellite Based Augmentation Systems (SBAS) enable highintegrity GNSS navigation for all phases of flight, including precisionlike approaches with vertical guidance. In the Asia–Pacific region, several SBAS implementations are progressing at different maturity levels. This article presents a consolidated analysis of four systems—GAGAN (India), MSAS (Japan), KASS (Republic of Korea), and SouthPAN (Australia/New Zealand). The study combines (i) observed Horizontal and Vertical Protection Level behavior from a representative day in April 2026, (ii) officially declared SBAS service capabilities and supported aviation procedures, and (iii) spaceweather conditions on the analysed day.

The results provide a coherent view of current SBAS readiness across the Asia–Pacific region, excluding the mature WAAS and EGNOS systems. In the coming month's issue, further analysis on the topic of clock and orbit corrections of SBAS systems and DFMC will be provided.

1. Observed Performance Analysis

The GAGAN performance during a random day (day of year 138) May 2026 reveals a relatively stable HPL behavior, with values generally remaining between 10 and 20 meters and only occasional increases toward 25–30 meters. This stability indicates that satellite geometry remains largely sufficient throughout the day. In contrast, VPL exhibits pronounced variability, with fluctuations typically between 15 and 40 meters and a significant spike exceeding 70 meters around mid-day (~35,000 seconds of day).

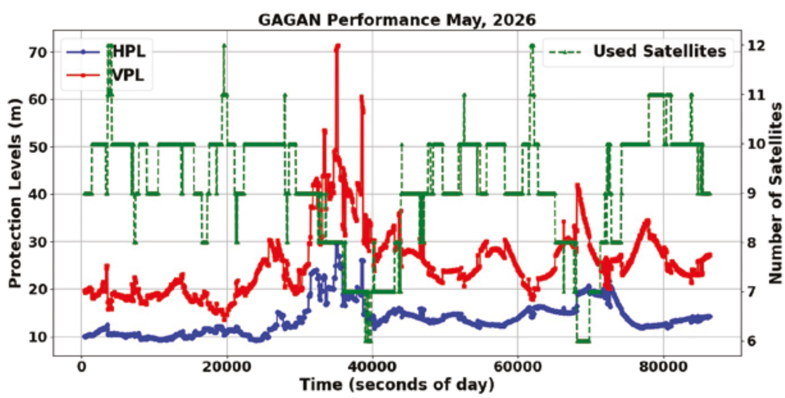

Figure 1: GAGAN performance in terms of achieved protection levels throughout the day of year 138, 2026.

This sharp VPL increase occurs despite a relatively stable number of satellites, indicating that the degradation is primarily driven by ionospheric effects rather than geometry limitations. The timing of the spike corresponds to the period when the equatorial ionosphere is most dynamic due to the Equatorial Ionization Anomaly (EIA), which introduces steep electron density gradients. These gradients are difficult to model accurately within the SBAS framework, leading to increased uncertainty and inflated protection levels. Overall, GAGAN demonstrates a characteristic equatorial response, where performance is generally stable but highly sensitive to localized ionospheric disturbances.

The performance of KASS in May 2026 presents a different behavior compared to GAGAN, reflecting its mid-latitude operational environment. HPL values remain mostly stable in the range of 10 to 20 meters, with occasional peaks reaching approximately 50 meters. VPL values are generally confined between 20 and 35 meters but exhibit a major spike close to 95 meters toward the end of the day (~78,000 seconds).

Unlike the GAGAN case, this late-day VPL spike clearly coincides with a reduction in satellite availability to as few as four satellites. This strong correlation indicates that the degradation is primarily geometry-driven rather than ionospheric-driven. With fewer satellites, the positioning geometry weakens significantly, resulting in increased dilution of precision and inflated protection levels. Therefore, KASS performance is characterized by relative robustness under normal conditions but vulnerability to periods of poor satellite geometry, highlighting the importance of constellation availability and redundancy for maintaining integrity.

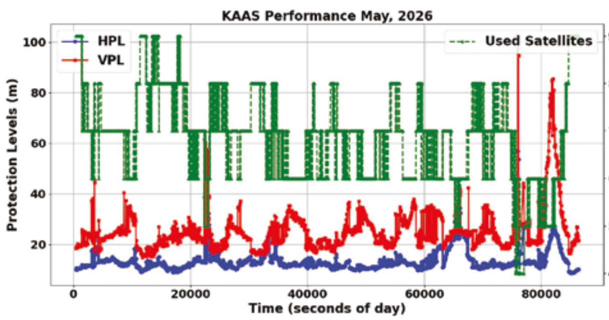

Figure 2: KASS performance in terms of achieved protection levels throughout the day of year 138, 2026.

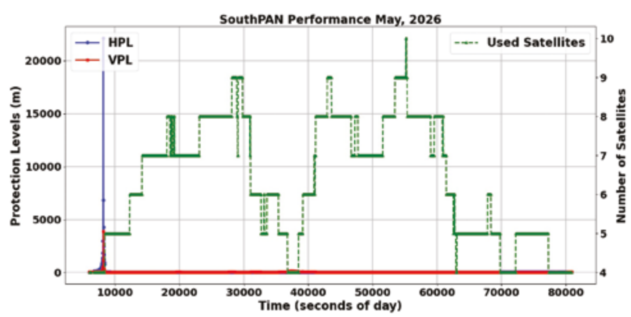

Figure 3: SouthPAN performance in terms of achieved protection levels throughout the day of year 138, 2026.

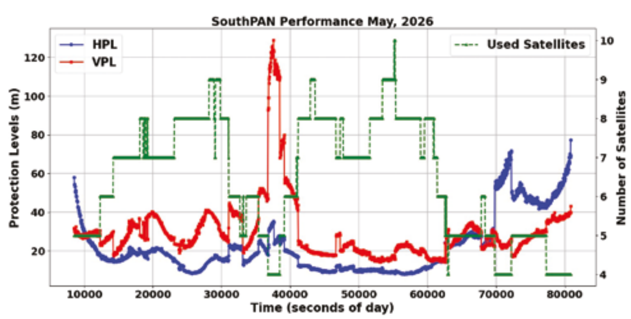

Figure 4: Removing the first 8500 seconds from the analysis, the performance of SouthPAN for day of year 138, 2026.

The SouthPAN system exhibits the most complex and unstable behavior among the three SBAS systems analyzed. One of the most striking observations is an extreme HPL anomaly early in the day in the broader dataset, where the horizontal protection level exceeds 20,000 meters. Such a large value is indicative of a severe failure, likely caused by a loss of valid corrections or a temporary divergence in the integrity algorithm.

In the refined performance plot excluding those impacted epochs, SouthPAN shows a significant VPL spike exceeding 120 meters around mid-day (~38,000 seconds), followed by continued instability throughout the day. Later in the day, HPL values increase to approximately 60–70 meters, coinciding with a reduction in satellite availability. These observations suggest that SouthPAN is affected by both ionospheric disturbances and geometry limitations. The combination of strong ionospheric variability in the region and relatively sparse monitoring infrastructure likely contributes to the observed instability. Compared to the other systems, SouthPAN appears to be less reliable for this day. It was providing better results in last months. There will be a dedicated analysis to understanding and troubleshoot this anomaly.

2. Officially Declared Performance and Supported Procedures

GAGAN is officially certified for RNP 0.1 and APVI with declared APV availability over most of the Indian landmass. MSAS supports enroute and limited terminal operations but does not declare APVI or LPV nationwide. KASS officially supports RNP APCH including LPV with published horizontal and vertical alert limits of 40 m and 50 m respectively. SouthPAN is designed to support APVI, LPV, and LPV200 and has published target VPL values below 35 m over its primary service region.

3. Conclusions

The analysis of May 2026 (DOY: 138) SBAS performance demonstrates that significant degradation can occur even under moderate space weather conditions. GAGAN shows strong sensitivity to equatorial ionospheric dynamics, KASS performance is primarily influenced by satellite geometry constraints, and SouthPAN exhibits both ionospheric and system-level instabilities. Among the three systems, SouthPAN experiences the most severe anomalies, indicating a need for further analysis. This will be provided in next month's issue.

The results confirm that VPL remains the primary limiting factor for aviation operations, as it is highly sensitive to ionospheric uncertainty. Additionally, satellite availability plays a critical role in maintaining system robustness, emphasizing the importance of multi-constellation integration and redundancy.

Data sources and Tools:

https://cddis.nasa.gov (Daily BRDC, RINEX OBS); http://ftp.aiub.unibe.ch/CODE_MGEX/CODE/ (Precise Products); BKG "SSRC00BKG" stream; IERS C04 ERP files

SBAS Mentor, ESA

gLAB GNSS, https://gage.upc.edu/en/learning-materials/software-tools/glab-tool-suite

serenad-public.cnes.fr (SBAS data)

Galileo signal updated for internet-of-things use

The European Space Agency and its industrial partners have developed a solution targeted at mass-market applications that require low power: E5a-QP, a Quasi-Pilot (QP) signal component transmitted in Galileo's E5 band. The signal component is broadcast free of charge and now available for implementation in both new and upgraded chipsets, enabling all users of the Galileo Open Service to benefit from its capabilities.

'Quasi-Pilot' means a pilot signal that retains its intended role but also carries a small amount of data, including the time information necessary for a first fix. This time information is fully predictable at user level. A Quasi-Pilot signal component is also characterised by a tailored signal structure that simplifies the acquisition process, which reduces the power consumption on the receiver's end. Test campaigns have demonstrated that E5a-QP can reduce signal acquisition time by a factor of three, while substantially lowering the number of operations required for acquisition by a factor of eight.

The introduction of this new Galileo signal component follows an extensive series of design, testing and validation that demonstrated the value of the signal and the feasibility of implementing new signal components on current Galileo satellites. *www.esa.int*

Qualinx and EUSPA complete Galileo OSNMA support

Qualinx has integrated support for the Galileo OSNMA (Open Service Navigation Message Authentication) on its QLX3Gx Series ultra-low-power GNSS receiver.

Developed with the support of the European Union Agency for the Space Programme (EUSPA), the integration makes the QLX3Gx a GNSS receiver purpose-built for ultra-low-power markets to deliver hardware-native OSNMA support as a standard feature across the entire product family. *www.qualinx.io*

Norway boosts GPS jamming detection

For Norway, persistent GNSS jamming and spoofing are disrupting a broad range of civilian operations, including air traffic. Interference is now being detected increasingly farther inside Norwegian airspace. Three dedicated monitoring stations to detect GNSS interference have already been established near the Russian border. This year, the Norwegian Communications Authority (Nkom) plans to add two more stations. *www.thebarentsobserver.com*

Lockheed Martin secures $514m U.S. Space Force contract

Lockheed Martin has announced that the U.S. Space Force has awarded the company a $514 million contract to build Global Positioning System IIIF Space Vehicles 23 and 24, bringing its total GPS IIIF commitment to 14 spacecraft. The 14 upcoming GPS IIIF satellites will deliver advanced, reliable positioning, navigation and timing capabilities for both military and civilian users. *https://news.lockheedmartin.com*

Focal Point Positioning launches Precise+

FocalPoint, UK announced Precise+, a new technology that delivers reliable high-precision positioning in the tough environments where conventional carrier phase tracking fails. It extends the benefits of the company's patented Supercorrelation® platform into the carrier phase domain. It directly targets the cycle slips that cause RTK and PPP systems to lose lock in challenging environments. *focalpointpositioning.com*

Pole mount controlled reception pattern antennas launched

Calian has introduced two pole mount variants of its controlled reception pattern antenna (CRPA) line. The new models support L1/E1 + L2/E5b (CR8894PXF+) and L1/E1 + L5/E5a (CR8854PXF. This new architecture increases installation flexibility across critical infrastructure, timing, marine and defence environments while maintaining Calian's CRPA and extended filtering plus (XF+) interference mitigation performance. With dual band options, the platform aligns with modern multi frequency GNSS architectures, improving accuracy, robustness, interference rejection and compatibility with current and next generation receivers. *www.calian.com*

Development of national heat network zoning model

Arup and Ordnance Survey (OS) have hit a major milestone in the roll-out of national heat networks in England with a major update to the national heat zoning model. The model will support at least ten English towns and cities to begin establishing their heat network zones later this year, with further zones to follow.

Arup, a global engineering and sustainability development consultancy, and OS were first appointed as consultants by the Department for Energy Security and Net Zero (DESNZ) in 2024 under the Heat Network Zoning Consultancy Framework to provide technical and consulting services to help identify and develop heat network zones in England.

As part of the framework, they have been working on the design and management of the national heat zoning model, which helps decide where large, low-carbon heat networks should be built across England. The model is underpinned by OS building and address data, which provides the core inputs for assessing heat network development costs, alongside OS roads and rivers data. Accurate building classification data is critical to the model, as it informs heat demand assumptions and improves the reliability of outputs. The potential use of the OS National Geographic Database (OS NGD) is also being evaluated, with potential value in new building attribution and more comprehensive site-level data. *www.arup.com*

New era of Earth Intelligence from space

Satellites have watched Earth for decades. In that time, they've accumulated a staggering archive of images. Yet, faced with intractable datasets and cloud-covered images, scientists have struggled to convert the massive data troves into actionable insights about the planet.

That has changed with Tessera, an artificial intelligence model that distils millions of images captured by European Space Agency satellites into a format that is easily used by researchers. The model has been developed by a team led by the University of Cambridge. The software can be used to reveal crop patterns, habitat loss, deforestation, and even environmental impacts of conflict, said Srinivasan Keshav, professor at the Department of Computer Science and Technology and one of Tessera's lead investigators.

Tessera is a type of generalized AI known as a foundation model. As it churns through petabytes of satellite data, it learns to recognise patterns and how they change over time. It also fills in missing values for cloud-covered images. The result is an uninterpreted sequence of 128 numbers for every 10-by-10-metre area of land. *www.cst.cam.ac.uk*

LYNRED launches SPIRIT

LYNRED, AIM and EXOSENS, Europe's three leading suppliers of infrared detectors, have decided to join forces under the SPIRIT project, a strategic European initiative designed to further develop the fundamental technology building blocks for the next generation of infrared sensors. *www.lynred.com*

KONGSBERG accelerates seabed mapping

KONGSBERG and the Ocean Exploration Trust (OET) are set to dive deeper than ever before in a new expedition to map vast areas of previously unexplored seafloor in the Central Pacific.

The Pacific Mapping (NA178) expedition, running 10–24 June, sees OET Exploration Vessel Nautilus deploying KONGSBERG's EM 304 MKII multibeam echo sounder for the first time. Three KONGSBERG engineers will be embedded aboard Nautilus for the full 14 days, using the mission as a critical real-world testing platform for advancing multibeam technology and helping to raise standards across the global mapping community.

Despite covering more than 70% of the planet, huge swathes of the ocean remain uncharted at high resolution. The challenge is particularly acute in deep ocean environments, where access, cost and technical limitations typically constrain survey efforts. The EM 304 MKII is designed to tackle these pain points head-on. Capable of operating at full ocean depth, it combines wide swath coverage with consistently high resolution, enabling survey teams to map larger areas more efficiently without compromising data quality. *www.kongsberg.com*

Kalogiannakis elected FIG president

Michalis Kalogiannakis of Greece has been elected president of the International Federation of Surveyors (FIG) for the 2027 to 2030 term, following a vote held at the XXVIII FIG Congress in Cape Town, South Africa. In a separate vote, Qingdao, China secured the right to host the XXIX FIG Congress in 2030.

Esri's Jack Dangermond receive award from IFCE

At the 2026 Shanghai Green Development Innovation Summit Forum, the International Fund for China's Environment (IFCE) recognized Esri president Jack Dangermond with the 30 Years of International Green Development Influential Figures Award. Created to coincide with IFCE's 30th anniversary, the award is presented to leaders who have made outstanding achievements in addressing climate change and advancing sustainable development over the past 30 years. *esri.com*

Taoglas launches ultra-compact dual-band high-precision GNSS antenna

Taoglas has launched the GVLB208 series, an active and passive dual-band GNSS L1/L5 stacked patch antenna. Combining a tiny package with concurrent L1/L5 support and stable right-hand circular polarization (RHCP), the antennas deliver reliable centimeter-level positioning in a compact 20 x 20 x 8 mm footprint. *www.taoglas.com*

Safran and SatSure forge a strategic partnership in India

Safran Electronics & Defense and SatSure have signed a Memorandum of Understanding (MoU) to formalize their collaboration in Geospatial Intelligence (GEOINT). The partnership aim to develop end-to-end GEOINT solutions combining satellite imagery, advanced AI models, and operational intelligence delivery, with a particular focus on the Indian market. These solutions will enhance situational awareness, accelerate intelligence processing, and support faster, more informed decision-making across defense, environmental monitoring, and other critical applications. *www.safran-group.com*

Surveying total station with dual displays

SingularXYZ has added the STS1 total station to its range, bringing a combination of precise measurement capabilities with intuitive software.

It provides 2″ angular accuracy with mm-level distance measurement, making it highly suitable or land surveying, construction layout and site mapping. It supports measurement distances of up to 1,000 metres without a prism and up to 5,000 metres with a single prism. *asmmag.com*

Leica launches Leica RTC series

Leica Geosystems, part of Hexagon, launched the all-new Leica RTC series of terrestrial laser scanners: the Leica RTC300, 500, and 700. The new series delivers substantial improvements in scanning speed, accuracy, and range, while introducing real-time workflow connectivity that keeps field and office teams aligned from first scan to final deliverable.

The new RTC series combines the speed, capability and versatility of the Leica RTC360 with the robustness and superior accuracy of the ScanStation P-Series, enabling specialised workflows across surveying, construction, industrial plants, public safety, and infrastructure. It includes three performance tiers based on the same platform: As projects grow in size and demand, users can upgrade to a higher performance tier without replacing their system. *leica-geosystems.com*

New navigation technology available from HRL Laboratories

HRL Laboratories introduces a new inertial measurement unit (IMU) that provides near navigation-grade accuracy in a palm-sized package. HRL's AXI-R100 delivers range-extending accuracy for GPS-contested navigation.

Using silicon micro-electro-mechanical systems (MEMS) technology, HRL's gyros exceed current state-of-the-art tactical-grade levels of performance in the same or smaller package size and is manufactured in high volumes at wafer-scale. *hrl.com*

Telit Cinterion launches SE869eK2L GNSS Module

Telit Cinterion has announced the SE869eK2L, a single-frequency L1 GNSS module designed to help device manufacturers upgrade legacy positioning designs with improved performance and cost efficiency, while preserving design continuity. It supports GPS, GLONASS, Galileo, BeiDou and QZSS for reliable multi-constellation positioning and has approximately 1.5-meter accuracy and update rates of up to 10 Hz *www.telit.com*

Viavi launches GNSS-disciplined oscillator

Viavi Solutions has launched the µPNT GDO-1000, a GNSS-disciplined oscillator built in the M.2 B-key form factor. Measuring 22 x 42 mm (the size of a postage stamp) and weighing less than 4 grams, the GDO-1000 is designed for platforms requiring accurate timing in places where traditional timing modules do not fit or are too power-hungry, including defense and airborne platforms, unmanned systems, data center cards, and communications equipment. *www.viavisolutions.com*

Oscilloquartz launches ruggedSync Series OSA 5510

Oscilloquartz has launched its ruggedSync Series OSA 5510, a ruggedized timing and synchronization platform. It is designed for deployment in tactical communications networks, mobile command centers, aviation systems and other highly demanding operational environments. It combines PTP grandmaster and NTP server functionality with synchronization assurance and resilient holdover in a compact military (MIL)-qualified platform. *www.oscilloquartz.com*

TimePictra 12 platform released

Microchip Technology has released the TimePictra 12 platform, a major software upgrade to its synchronization management software to help critical-infrastructure operators manage advanced timing architectures with greater visibility, automation and control. The platform is designed to strengthen GNSS visibility and resiliency by monitoring using BlueSky technology. It helps operators better understand GNSS conditions, identify anomalies, and manage timing infrastructure in environments where GNSS availability, integrity and security are critical. *www.microchip.com*

V2X deployment in US

The Maricopa County Department of Transportation (MCDOT) has selected Cohda Wireless to support delivery of the Connected Vehicle Acceleration Zone (CVAZ), a USDOT-backed deployment designed to accelerate interoperable vehicle-to-everything (V2X) technology across key corridors in the county. Under the project, Cohda will supply MK6 Road-Side Unit (RSU) kits and MK6 On-Board Unit (OBU) kits across the CVAZ application zones.

CVAZ forms part of the Federal Highway Administration's Saving

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www.isprs2026toronto.com

Esri User Conference 2026
13 - 17, July
San Diego USA
www.esri.com

August 2026

13th IGRSM Conference 2026
05 - 06 August
Kuala Lumpur, Malaysia
https://conferences.igrsm.org

September 2026

Esri India User Conference
2 - 3 September 2026
New Delhi, India
www.esri.in

ION GNSS+ 2026
14 - 18 September
Orlando, Florida, USA
www.ion.org

Intergeo 2026
15 - 17, September
Munich, Germany
https://dvw.de/intergeo/en

21st International 3D GeoInfo Conference
28 - 29 September
Sofia, Bulagria
https://gdmc.nl/3DCadastres/workshop2026

October 2026

14th International FIG Workshop on the Land Administration Domain Model & 3D Land Administration
1 - 2 October
Sofia, Bulagria
https://gdmc.nl/3DCadastres/workshop2026

3rd Annual International Geotechnical Innovation Conference
12 - 13 October
Jeddah, Saudi Arabia
https://geotechnicalinnovationconference.com

November 2026

United Nations World Geospatial Information Congress (3rd UNWGIC)
16 - 19 November
Jeddah, Saudi Arabia
https://ggim.un.org/3UNWGIC

Geoworld
23 - 26 November
Dubai, UAE
https://www.geoworldevent.com

Pacific Islands GIS & Remote Sensing User Conference
30 November - 4 December 2026
Suva, Fiji
https://pgrsc.org

Lives with Connectivity: Accelerating V2X Deployment program, which is supporting national models for connected vehicle deployment in Arizona, Texas and Utah. The Maricopa County project will rely primarily on 5.9 GHz communications and is expected to connect up to 750 physical and virtual roadside units with approximately 400 onboard units across transit, emergency response and freight fleets.

The deployment will support Emergency Vehicle Pre-emption, Vulnerable Road User alerts, Transit Signal Priority and Freight Signal Priority in Phoenix, Tolleson, Avondale and unincorporated Maricopa County, as well as along ADOT's US 60.

GMV will develop Satellite Control System for CAMILA

Developed in collaboration with the European Space Agency (ESA), the CAMILA Earth Observation program will deploy a constellation of four observation satellites to strengthen Poland's national Earth observation capabilities and increase its independence in access to geospatial data.

CAMILA, which stands for Country Awareness Mission in Land Analysis, was established under an agreement between Poland's Ministry of Development and Technology and the ESA. The system will consist of two main segments: a space segment comprising four Earth observation satellites and a ground segment responsible for mission control and management. Its objective is to provide high-resolution geospatial information to public administrations, emergency management services, and organizations responsible for spatial planning and environmental protection.

GMV is responsible for the design, development, and implementation of the Flight Operations Segment (FOS), the software system that will enable operators to control the CAMILA satellite constellation from the ground.