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ICUAS MAGAZINE

State-of-the-art
and recent developments
in unmanned aviation

In This Issue

EDITORIAL

Dear Readers:

In this 2nd Issue of the eMagazine, we first provide the latest details concerning the upcoming ICUAS 2023. This conference update allows you to plan around the June 6-9 conference dates, whether you decide to attend physically or virtually – our very strong recommendation is to attend physically, and to enjoy what Warsaw has to offer.

This 2nd issue includes three very important and different articles:
- The first article with title "Adopting AI in Defence Organisations Requires Further Focus on Ethical, Legal and Societal Aspects", emphasizes the need for a legal and regulatory framework under which drones will operate. In addition, it raises and makes valid points about AI ethics – note that robot ethics in general is a center stage discussion topic.
- The second article with title "A Novel Remote Water Inspection System based on an Amphibious Drone", centers around the utilization of drones to specific public domain applications.
- The third article with title "Introducing Noise for AirSim 3D LiDAR Sensor to Reduce the Sim2real Gap in Simulated Multi-rotor Operations" centers on the importance of modeling accurately sensor noise, as it may affect the accuracy and reliability of an aerial robot's perception of the surrounding environment.

The issue concludes with recent news and reports on unmanned aviation.

UPDATES ON ICUAS 2023, JUNE 6-9

With respect to this year's conference, the paper review process has been completed and results have been announced. We received a healthy number of 250 contributed, invited session, and poster papers, and, following a very thorough and in-depth peer review process, the committee accepted for presentation and inclusion in the conference proceedings 189 papers, the distribution of which is presented next.

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ACCEPTED PAPERS PER COUNTRY

COUNTRY	SUBMITTED	ACCEPTED	COUNTRY	SUBMITTED	ACCEPTED	COUNTRY	SUBMITTED	ACCEPTED
Algeria	3	2	Germany	9	7	Netherlands	7	7
Argentina	3	2	Greece	4	3	New Zealand	3	0
Australia	2	1	Hungary 3	2		Norway	2	1
Austria	2	1	India	15	9	Poland	10	7
Brasil	19	13	Ireland	1	1	Portugal 1	1	
Canada	12	8	Israel	2	2	Russia	1	0
China	14	12	Italy	17	15	Singapore	5	4
Colombia	1	1	Japan	3	1	Spain	13	13
Croatia	3	3	Kazakhstan	1	1	Sweden	4	4
Cyprus	6	6	Kenya	2	1	Switzerland	4	4
Czech Republic	5	2	Korea, South	5	5	Turkey	3	3
Denmark	6	3	Luxembourg	3	3	United Kingdom	4	4
Finland	2	1	Malta	1	0	USA	34	23
France	9	7	Mexico	6	6			
						Totals	250	189

ICUAS'23 includes the UAV Competition, which is student-focused, offering unique opportunities for students to test and compare their skills with those of their peers, worldwide.

ICUAS'23 offers three pre-conference Workshops/Tutorials that will take place on Tuesday, June 6, and three Keynote/Plenary Talks.

TUTORIALS / WORKSHOPS - TUESDAY, JUNE 6, 2023

LOCATION	TIME	TITLE
ROOM 464	FULL-DAY 9:00 - 18:00	New Developments on Sense-And-Avoid (S&A), Distributed Fault Detection and Diagnosis (DFDD), Fault-Tolerant Control (FTC) and Fault-Tolerant Cooperative Control (FTCC) Techniques Unmanned Systems.
ROOM 465	HALF-DAY 9:00 - 13:00	Review of State-Of-The-Art Deep Learning Approaches for Visual Object Recognition and Tracking: Applications to Unmanned Aircraft Systems.
ROOM 466	HALF-DAY 9:00 - 13:00	Current and Future Surveillance Technologies for Airspace Integration of UAS in Controlled and Uncontrolled Airspace.

KEYNOTE / PLENARY TALKS

DAY	TIME	AULA 58
WEDNESDAY JUNE 7	09:30 - 10:30	**Increasingly Autonomous Perception and Decision Systems for Advanced Air Mobility,** Prof. Ella Atkins, Virginia Tech, USA
	14:00 - 15:00	**Soft Aerial Robots,** Prof. Bego a Chiquinquira Arrue Ullés, University of Seville, Spain
FRIDAY JUNE 9	09:00 - 10:00	**From Competition to U-Space Certification and Implementation - a Story about "What If....?** Panel Korzec, Droneradar Sp. Z. O. O., Poland

All details and logistics about the conference may be found at **www.uasconferences.com.**

ADOPTING AI IN DEFENCE ORGANISATIONS REQUIRES FURTHER FOCUS ON ETHICAL, LEGAL AND SOCIETAL ASPECTS

BENJAMYN I. SCOTT, HENNING LAHMANN, BART CUSTERS

1. INTRODUCTION

On 14 March 2023, two Russian Su-27 jets attempted to intercept a United States MQ-9 Reaper unmanned aircraft in international airspace over the Black Sea, whereby the Su-27 aircraft intentionally flew in front of the Reaper and dumped fuel. Eventually, one of the Russian jets collided with the rear propeller of the Reaper, resulting in the total loss of the Reaper. This recent incident raises questions regarding the legality of the use of both manned and unmanned military aircraft in international airspace, and the right of interception.

International Law makes it explicitly clear, as recognised in Article 1 of the Convention on International Civil Aviation of 1944, that "every State has complete and exclusive sovereignty over the airspace above its territory." As the incident took place in international airspace rather than over the "land areas and territorial waters" (Article 2) of a State, all involved aircraft were lawfully permitted to be in that part of the airspace.

The international airspace is not, as phrased by Prof. Bin Cheng, an "oasis of lawlessness"; international law applies. For example, military aircraft may choose to follow or deviate from civil air law. However, per Article 3 of the 1944 Convention, military aircraft must be flown with 'Due Regard' for the safety of civil aircraft. In addition, each State will have its own rules on the military use of aircraft, which will include procedures on the interaction with other airspace users, including interception of (unmanned) aircraft.

As unmanned aircraft operations fall within the international legal regime, the fact that the US aircraft was unmanned did not pose any specific legal issues in this case. As a result, the use of military unmanned aircraft has produced significant literature on their place in the international legal order. For example, the use of unmanned aircraft for defence purposes by a State must conform to Article 2(4) of the Charter of the United Nations, which declares that "All Members shall refrain in their international relations from the threat or use of force [...]." This obligation must then be balanced against Article 51 of the UN Charter, which codifies a State's "inherent right of individual or collective self-defence" against an armed attack, as well as the rules for international humanitarian law in times of war found in the Geneva Conventions. The fourth Geneva Convention pertains to the Protection of Civilian Persons in Time of War. Thus, public international law dictates how combatants must treat civilians, which also extends to the use of unmanned aircraft. Further, Protocol 1 to the Geneva Convention also covers Methods and Means of Warfare. Nothing in this Protocol precludes the use of unmanned aircraft.

This incident is an example of how applicable legal frameworks generally govern the fielding of unmanned aircraft, but it also illustrates that the current legal frameworks do not provide satisfying solutions and provide only limited guidance. The increasing use of artificial intelligence (AI) in these military systems will further complicate the regulatory picture considerably due to the complexities of human-machine interaction the use of such technologies entails. The development of adequate legal frameworks requires a deeper examination of the issues these military AI raise.

2. THE ETHICAL, LEGAL SOCIETAL ASPECTS LAB

For the armed forces to operate efficiently and effectively in a secure way during both peacekeeping and combat activities, AI technology is becoming increasingly critical. However, while new technological advancements in AI present opportunities for defence stakeholders, they also carry challenges and risks in relation to ethical, legal, or societal aspects (ELSA). To ensure the successful and responsible use of AI technology by the defence stakeholders, ELSA issues need to be evaluated and all concerns must be addressed. This is a continuous and holistic approach, whereby such considerations must take place at the design, manufacturing and maintenance of AI-based systems, as well as its utilisation via appropriate military doctrine and training.

In response to this task, the Dutch Government has established the National Growth Fund (NGF), which is tasked with investing €20 billion between 2021 and 2025 in projects targeting knowledge development as well as research, development, and innovation. Funding is allocated to projects with the highest potential of contributing to durable economic growth, which will bring benefits to Dutch society as a whole. In the first year, around €10 million was dedicated to the so-called ELSA Labs, with more to come.

These ELSA Labs focus on the development and deployment of ‘human-centric AI’ in a way that aligns with the European focus on AI applications that respect fundamental rights and public values. To support and oversee the development of ELSA Labs, the Netherlands Organisation for Scientific Research (NWO) and the Netherlands AI Coalition launched a call for ‘Human-Centric AI for an Inclusive Society: Towards an Ecosystem of Trust’. As a result, five projects were approved at the end of January 2022. One of these was the ELSA Lab Defence (see https://elsalabdefence.nl/).

As ELSA issues are continuously evolving with new developments in technology, this calls into question how defence organisations can maintain strategic competitiveness and be at the forefront of military innovation, while also upholding the values of the citizens they are tasked to protect. In response to this question, the ELSA Lab Defence was established to assess this in an inter-institutional and interdisciplinary setting. The ELSA Lab follows the ‘Quadruple Helix’ model consisting of four actors in innovation: academia, government, industry, and society. The ELSA Lab is focused on giving context-dependent methodology that focuses on the ‘analysis’, ‘design’ and ‘evaluation’ of ELSA issues that arise from AI-based applications within the military context. This necessitates applying the theory to real-world case studies.

3. CASE-STUDY: UNMANNED AIRCRAFT AS NON-LETHAL AUTONOMOUS ROBOTS

There is already considerable literature on autonomous weapon systems, which identify and engage remote targets. However, this is not the totality of AI systems in defensive applications. The use of unmanned aircraft as Non-Lethal Autonomous Robots and as tools for earth observation data collection are highly relevant as well, which makes them an appropriate case study for the ELSA Lab Defence.

Among other possible scenarios, non-lethal unmanned aircraft increasingly play an important role in providing situational awareness, collecting intelligence and fulfilling logistical tasks (e.g., for dirty, difficult or dangerous operations). These types of operations pose ELSA concerns as, for example, human operators hand over a degree of control and responsibility to the AI systems, which in turn impacts human agency and human dignity in warfare. Typical other issues concern security (for people, objects, data or other aircraft), privacy (sensitive data, hindrance, annoyance, data collection, function creep), chilling effects, PlayStation mentality, and PTSD.

Without sufficient consideration of the ethical, legal and societal aspects of the use of AI in the defence domain, risks like losing control, biased decision-making, and decreasing humanity in warfare may result in losing public support. Such detrimental consequences should therefore be avoided.

4. WIDER LEGAL CONCERNS

When discussing the use of AI for defence purposes, concepts like accountability, explainability, governability, reliability, responsibility and traceability are often cited. Furthermore, the AI solutions must be accurate, resilient, robust and trusted. The law plays a central role in guaranteeing and reinforcing these aspects. This takes the discussion beyond the above-addressed international law conversations that dominate aviation law and humanitarian law in the context of the use of unmanned aircraft for defence purposes, and demands that legal questions concerning AI must be considered as well. Here only a few relevant issues are mentioned.

First, privacy is a fundamental right, which is guaranteed, for example, in the United Nations Universal Declaration of Human Rights and the European Union Charter for Fundamental Rights. While the right to privacy initially focused on private and family life, this has evolved as informational privacy has gained importance. Informational privacy is closely related to the protection of personal data and this relates to the developments in AI as violations of privacy may occur (1) when processing personal data and (2) when AI tools disclose privacy-sensitive patterns.

Second, human dignity is inherently and inseparably linked to all the basic human rights (e.g., non-discrimination, freedom of expression, freedom of religion, privacy) and the core values of ethics (e.g., autonomy, non-maleficence, justice). Dignity is the underlying value, whereby interference with basic human rights impacts human dignity.

Third, unmanned aircraft, as well as the systems used to operate them, must be safe. The level of safety is set through strict certification, maintenance, training and operational rules. This must also extend to AI solutions. To promote safety, industry standards, such as those developed by the North Atlantic Treaty Organization (NATO), will also play a key role, whereby interoperability will also be achieved.

Finally, many different stakeholders are involved in designing, manufacturing, putting on the market, and deploying AI systems. This can raise issues of responsibility and liability for damage caused to contractual and third parties. To ensure that injured parties are appropriately compensated, legal clarity is required that takes into consideration the complexity of unmanned aircraft operations that utilise AI solutions.

5. CONCLUSION

It is currently unclear which AI-enabled systems are acceptable from an ELSA perspective, as well as, under which circumstances. This could lead to 'over-use', such as using too many AI systems in too many situations, with a lack of consideration of the consequences, or to 'under-use', such as not using AI, due to a lack of knowledge or fear of consequences. Both reactions could hamper innovation, as over-use could lead to a backlash and under-use to being too cautious. This raises concerns about protecting the freedom, safety and security of society, whereby the suboptimal adoption of AI in the defence organisation carries risks for these values. Here, the law should both facilitate the creation of innovative solutions and contribute to reducing the ELSA risks.

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A NOVEL REMOTE WATER INSPECTION SYSTEM BASED ON AN AMPHIBIOUS DRONE

JONATHAN CACACE, GIANMARCO PADUANO, FABIO PIERRO, FABIO RUGGIERO AND VINCENZO LIPPIELLO
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This article presents an innovative autonomous water inspection system that monitors water regions from the air, underwater, and on the surface. The system includes various modules for extended autonomous inspection missions. The main component is an amphibious aerial vehicle equipped with sensors and probes for monitoring the sea surface and underwater parameters. It also integrates various probes and instruments for analyzing oceanographic and biological parameters. Floating capabilities and inspection system performance were demonstrated through experiments.

1. INTRODUCTION

The increase in pollution, population growth and climate worsened water quality [1]. For this reason, monitoring and analyzing water quality to identify and track contaminants and pollutants has become crucial. Effectively managing water resources, such as rivers, lakes, reservoirs, and estuaries, requires frequent monitoring of their physical, chemical, and biological states. Unfortunately, traditional water quality monitoring methods rely on ex-situ analysis, which involves manual sampling and a plethora of specialized equipment [2]. Since this process is expensive and time-consuming, automatizing the in-situ analyzing process can increase the ease, temporal resolution, and spatial scale of water sampling in locations dangerous to reach for humans. In this domain, using unmanned aerial systems (UAVs) can represent a valuable option. These systems can quickly reach locations and, in obstacle-free and open areas, can be remotely operated and monitored thanks to GPS sensors. The use of aerial systems to evaluate water quality has already been assessed in the literature. In particular, in [3], an autonomous helicopter has been proposed to collect a water sample of up to 500 ml. In [4], a commercial UAV has been used to collect water samples for remote sensing of bacterial flora. Authors in [5] attached a suspended bottle of 1l downward a UAV for water sampling. With respect to these solutions, this work proposes a UAV that can perform in-situ water characterization at different levels of depth over time. The capability of the platform to land on the water surface, allows the drone to preserve the battery lifetime and, simultaneously, increase the water inspection time. While similar systems exist, such as [6], which can sample water during the flight, they are not practical for extended inspection periods or deep water analysis.

In this context, this article reviews the design and development of a water and underwater surface inspection system conducted in the context of the PlaCE project [7]. The PlaCE project aims to develop eco-sustainable solutions for reusing offshore platforms after their production phase ends. In this context, a remote monitoring solution has been explored to assess the environmental impact and sustainability of platform conversion by monitoring the water close to the inspection site acquiring a wide range of environmental parameters in real-time [2]. The main element of the inspection system is the amphibious drone, an aerial platform with water-floating capabilities, able to perform long-term autonomy missions (see Fig.1).

The rest of the paper is organized as follows. In Section 2 the system architecture is detailed with all its components. In Section 3 the software architecture supporting the autonomous inspection system is presented, while in Section 4 the floating capabilities of the aerial system are performed in a controlled, laboratory environment. Finally, in Section 5 a set of field tests have been carried out to assess the effectiveness of the proposed system.

Figure 1

The aerial platform floating on the water surface.

2. SYSTEM ARCHITECTURE

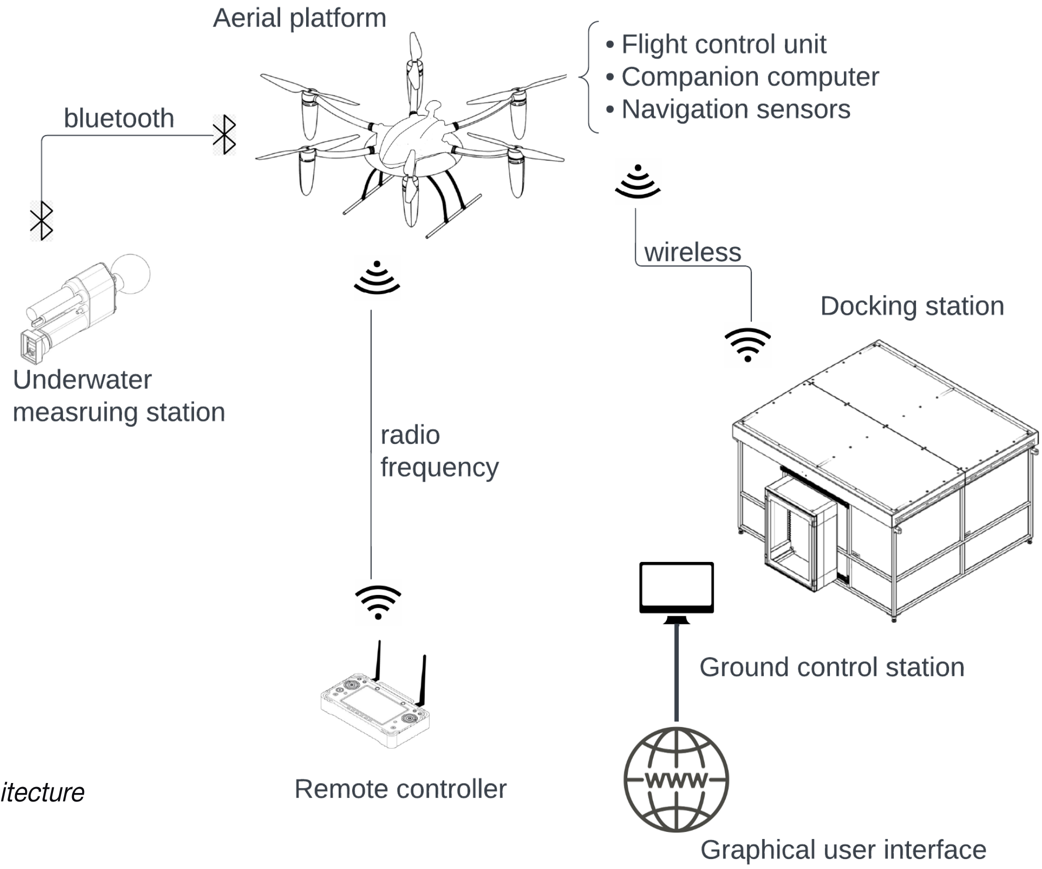


Figure 2

System architecture

2.1 System overview

The aerial system can operate independently, without human intervention or ground station control. To achieve this, different modules have been developed to collaborate in executing and analyzing the collected data. The system architecture, illustrated in Figure 2, comprises three main modules: an aerial platform that carries the measurement tool and permits visual inspection of water regions, a docking station where the aerial platform rests, and an inspection probe, to perform in situ water monitoring at a desired depth. The limited operational capabilities of the drone have been solved with the use of a recovery station, providing mechanical safety during downtime and bad weather conditions. The station includes a battery recharge mechanism and a ground computer that retrieves drone status and collected data, which can be accessed via a graphical user interface (GUI). The interface allows users to set up new inspection missions and issue commands directly to the aerial system. The drone's flight controller unit (FCU) enables autonomous flight by controlling the onboard autopilot, which interfaces with the drone's motors. It incorporates functionalities to convert position control inputs into rotor velocities, stabilize the platform, and implement safety measures for recovering the platform in case of navigation sensor faults or other unforeseen events. While the system is designed to operate independently, a human operator can control the aerial vehicle using a remote radio controller, which communicates with the FCU. The range of the remote controller, used only as a safety mechanism, is limited to 10 km, and environmental obstacles can further restrict the range. The drone carries a variety of sensors to perform water monitoring, including an aerial colored camera, a multi-spectral sensor, and underwater inspection sensors. The companion computer, physically connected to the FCU, enables autonomous behavior and interaction with the ground control station (GCS). It runs on a standard distribution of the Linux operating system and allows inspection missions to be configured and scheduled. Communication between the companion computer and the GCS is only possible when the drone is within range of the recovery station. Overall, the system's design and components are detailed from the drone's structure to its integration.

2.2 Aerial Platform

The aerial platform is a carbon fiber hexacopter with all necessary components for controlling the drone, such as batteries and a computer, stored within a central hollow for an IP66 enclosure. Despite the motors being waterproof, the propellers are positioned away from the center of mass to ensure safety during splashdowns. With a diameter of 158 cm and a weight of 5 kg, the platform is equipped with 28-inch propellers to enhance efficiency and flight autonomy. Based on this configuration, the Aerial Platform can fly for 50 minutes.

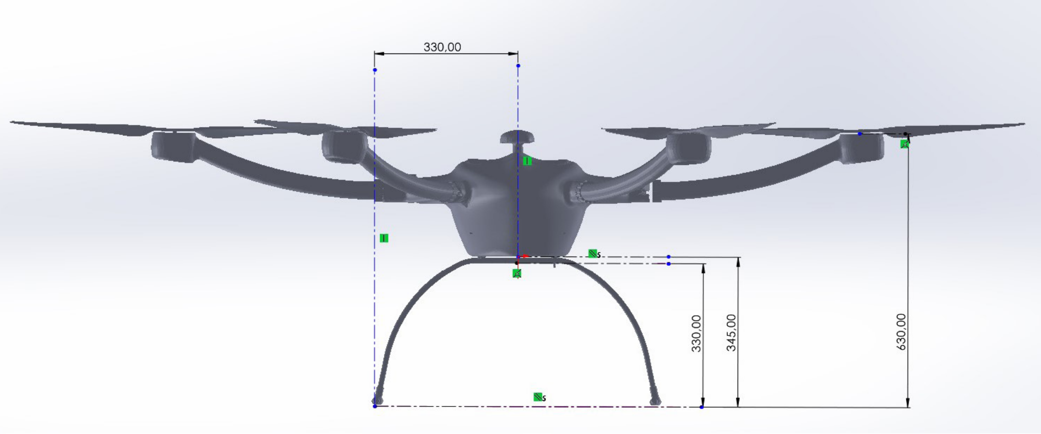


Figure 3 *Hexacopter frame and dimensions.*

2.3 Avionics

The drone's avionics system consists of two main components: the PixHawk-based autopilot with PX4 firmware, connected to six motors enabling different control modes, and two GPS sensors, including an RTK GPS, for improved localization. The lightweight onboard computer communicates with the autopilot through a serial protocol, exchanging telemetry data and navigation actions for the current mission. Python 3.7 and the ZeroMQ library enable intra-process communication for asynchronous data sharing between different clients. Connectivity between the companion computer and the GCS is crucial for reliable communication, established through a standard Wi-Fi access point.

2.4 Floating module

To complete its task, the drone must be able to float on the water surface and roll out the inspection probe at a specific depth. To accomplish this, a floating system has been designed and installed on the aerial platform. The system includes a central module to compensate for the drone's weight and six floating cones to stabilize its attitude in high and irregular waves. The floating module has been designed to specifically fit the frame of the drone and maintain its aerodynamics. To avoid to increase the total weight of the frame, the buoys have been designed in carbon material of 0.6 mm thickness and with empty internal sections.

The system has been carefully designed to fit the drone's external chassis while maintaining aerodynamic efficiency. The Aerial Platform with the floating system is shown in Figure 4.

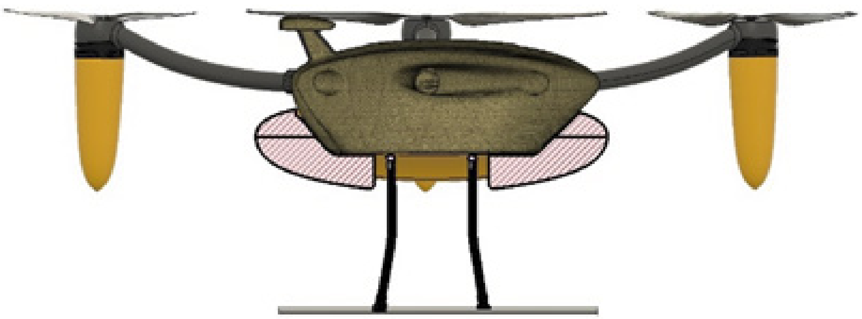


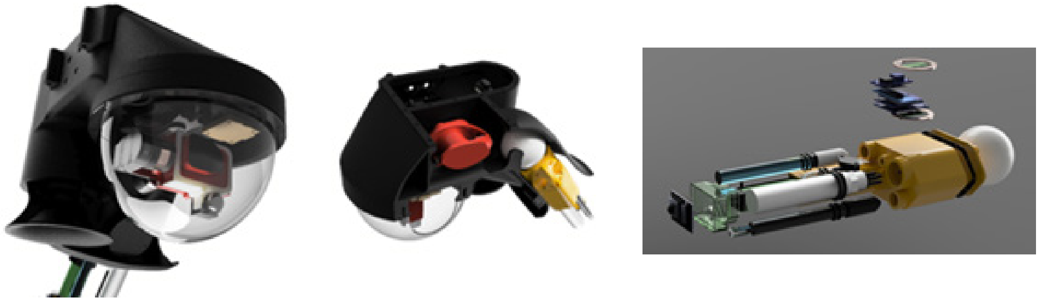
Figure 4 *Floating system*

2.5 Aerial Measuring System

The aerial platform can monitor sea environmental conditions, and to achieve this, it is equipped with a multispectral camera to evaluate water temperature and detect pollutants. To ensure a stable and directed view, the camera is mounted on a 2 DOF gimbal with pan and tilt functions. Additionally, to protect the camera from water, it is housed in a waterproof, transparent casing, as depicted in Figure 5. To geo-reference the captured images, the multispectral camera has an independent GPS sensor. The images are transmitted wirelessly to the companion computer via Wi-Fi. The camera also has a PAR (Photosynthetically Active Radiation) sensor that regulates exposure based on air luminosity. Moreover, a visual high-definition camera is installed in the aerial measuring system and streamed on the GUI and the operator's radio controller, allowing for a real-time view of the inspection scene or the surroundings of the aerial vehicle.

Figure 5

Multispectral camera and gimbal waterproof housing (left), inspection probe (center), and the underwater measuring station (right).



2.6 Underwater Measuring System

The aerial platform has an underwater measuring station with a bell-shaped design to store and deploy inspection probes to depths of up to 70 meters. To allow the descent of the inspection probe, a rod reel has been installed in the upper part of the measurement station (in red in Fig. 8). The reel is controlled with a servomotor, connected to an integrated control board. To decouple the effects of the water current on the aerial system, the inspection probe is attached to the reel with a line and supports up to 70 meters of depth. The station is designed to be waterproof. The probe contains a fluorometer, PAR sensor, CTD (Conductivity, Temperature, Depth), pH sensor, and visual camera, all encapsulated in a waterproof container. Data generated by the sensors are collected by the onboard microcontroller and communicated to the companion computer via Bluetooth. The station has an independent battery and can be recharged wirelessly by the Aerial Platform. In this way, the probe can be directly pulled inside the underwater measuring station without relying on the precise positioning of the probe connectors to the battery charger. The inspection probe is fully autonomous, receiving only the command to start a task and the mission duration.

2.7 Docking Station

To ensure the safety and efficiency of the aerial platform during non-mission periods, a docking station has been developed. This station is intended to be installed offshore and serves the purposes of charging the drone's batteries, uploading mission data, and waiting for the start of a new mission. The design of the station is illustrated in Figure 6 (left), featuring two hinged doors that are opened for drone takeoff or when in close proximity to land. The drone is lowered onto the lift panel, after which the propeller alignment system automatically aligns its propellers. Four independently actuated bars move the vehicle's feet towards the center of the panel (see Figure 6, right part). A dedicated electric panel controls the docking station's automation, and the server computer running the web-based GUI is also housed in the station.

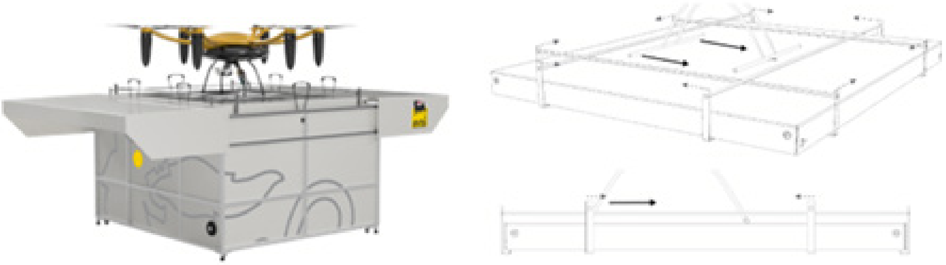


Figure 6 *Recovery station*

3. SOFTWARE ARCHITECTURE

The software architecture is a critical component of the system and it is illustrated in Figure 7. The various software modules communicate with each other through wired or wireless channels to exchange important data. The operator can use the remote controller to directly control the drone's position, which is then relayed to the autopilot. The autopilot provides the drone's telemetry, such as its current position, attitude, and battery level. Similarly, after each inspection mission, the onboard computer receives data from the autopilot and the underwater measuring station. The collected data is then sent to the GCS and stored in its database. The inspection probe is triggered to start a new mission by signals sent from the GCS. The GCS provides access to the stored data and the current state of the aerial vehicle through the web-based GUI.

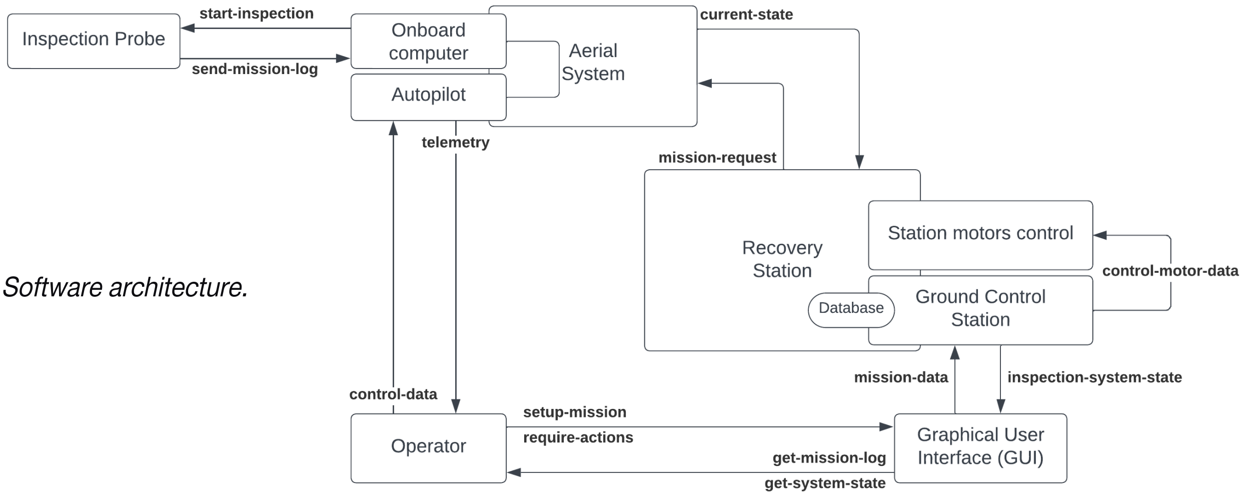


Figure 7 *Software architecture.*

4. SEA KEEPING TEST

A towing tank facility was used to experimentally verify the aerial platform's ability to float in the presence of waves. Due to the tank's relatively low maximum allowable wave height, a scaled model (shown in Figure 8, left part) was used instead of the existing aerial platform. All elements involved in the floating process were scaled down by a factor of 3. During testing, an IMU (Inertial Measurement Unit) logged roll and pitch data generated by waves. The tank measures 147 x 9 x 4.2 meters and is equipped with a dynamometric cart that can generate waves of a desired height. Both regular and irregular waves were tested, with wave heights ranging from 25 to 50 cm and periods of 1.8 seconds to check the model's behaviour under different wave steepness conditions. In all tests, the scaled model successfully followed the wave pattern, with its propellers remaining above the water surface, indicating its capability for safe takeoff. The test conditions, including wave type and period, are listed in Table 1. Among the various tests conducted, Figure 9 illustrates the results of the most significant test, involving waves with a significant height of 48 cm and a period of 1.485 seconds. These waves were the most critical conditions reproducible in the tank area. The wave height is shown in the graph in Figure 9 (top), while the model's pitch and roll are displayed in Figure 9 (bottom). Notably, the model remained stable on the water surface throughout the test, with its pitch orientation never exceeding critical values.

Wave type	Significant Height Hs [cm]	Period T [s]	Wavelength [m]	Steepness [%]
Irregular	48	1.485	3	14.0
Irregular	45	1.856	5	8.4
Irregular	25	1.856	5	5.0
Irregular	27	1.880	6	4.9
Regular	15	1.732	5	3.2
Regular	21	1.732	5	4.5

Table 1: Conditions of the floating test experiments in the towing tank of the University of Naples Federico II

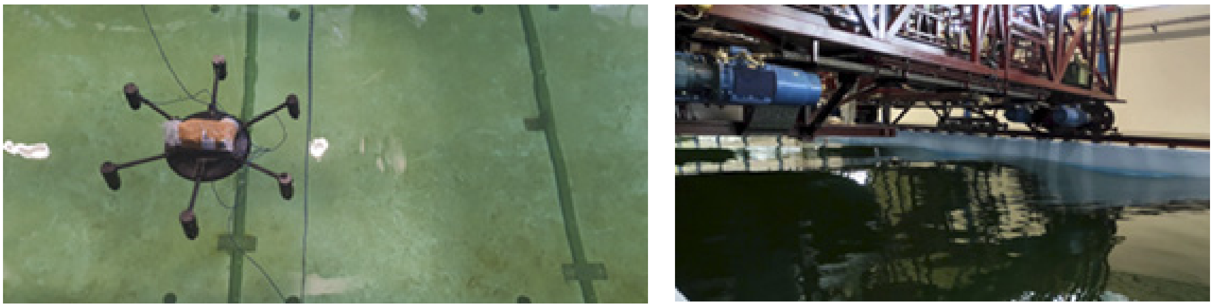


Figure 8 *Aerial platform model (left), 1:3 model in the tank (right)*

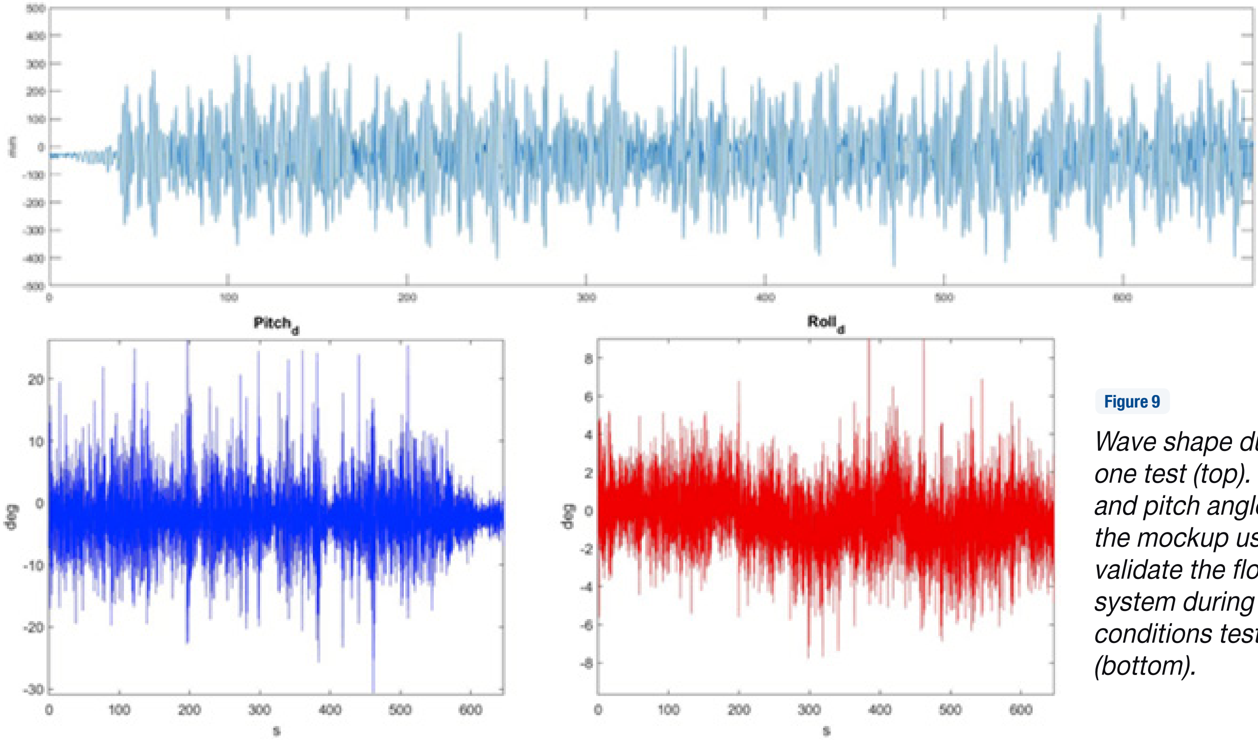


Figure 9 *Wave shape during one test (top). Roll and pitch angles of the mockup used to validate the floating system during worst conditions test (bottom).*

5. FIELD TESTS

Figure 10 *Field test site (left) and trajectory executed by the aerial platform during the mission. Three segments can be distinguished (right).* A video of the experiment can be seen at this link: **https://youtu.be/DzBQ9BVGZiE**

A drone system was tested in July 2022 at the Stazione Zoologica Anton Dohrn in Portici, Naples, as shown in Figure 10. Here, the inspection site with the docking station is reported on the left, while, an example of the path performed by the aerial platform, consisting of three segments, is reported on the right. Different missions were tested, including a set of planned segments and water inspection tasks stored in the onboard computer. The first mission consisted of two segments and one underwater inspection task, covering 288.2 meters in 2.54 minutes. The second mission had five segments and four underwater inspections, covering 420 meters in 6 minutes. The third mission had four segments and covered 410.9 meters in 4.49 minutes. During the first mission, the platform covered 154.6 meters with an average speed of 5.7 km/h, with a maximum speed of 17 km/h. Images captured from the multispectral camera during this mission are reported in Fig. 11. For each frame the multispectral camera can get images at different spectrums. In particular, besides the classical colored image (RGB), the camera considers the red (RED), green (GRE), Near-Infrared (NIR) and red edge (REG) spectrums. These images are georeferenced thanks to the GPS sensor of the multispectral camera. Data collected during the underwater inspection task are reported in Fig. 12.

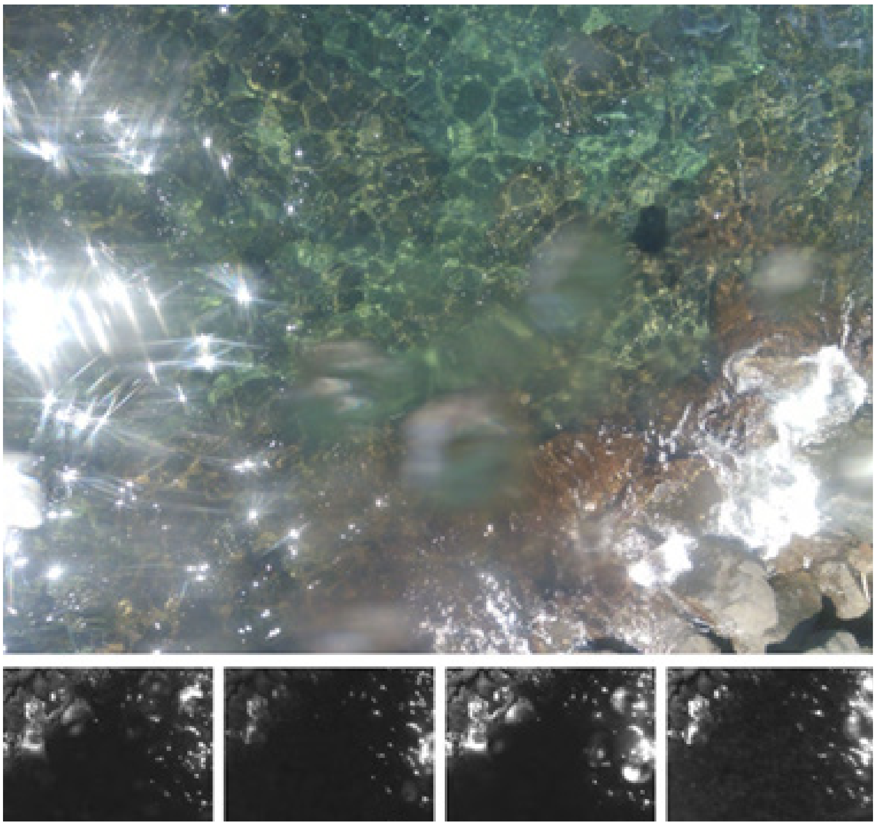


Figure 11

Images from the multispectral camera: RGB (Red-Green-Blue), GRE (Green), NIR (Near InfraRed), RED (Red), REG (Red Edge).

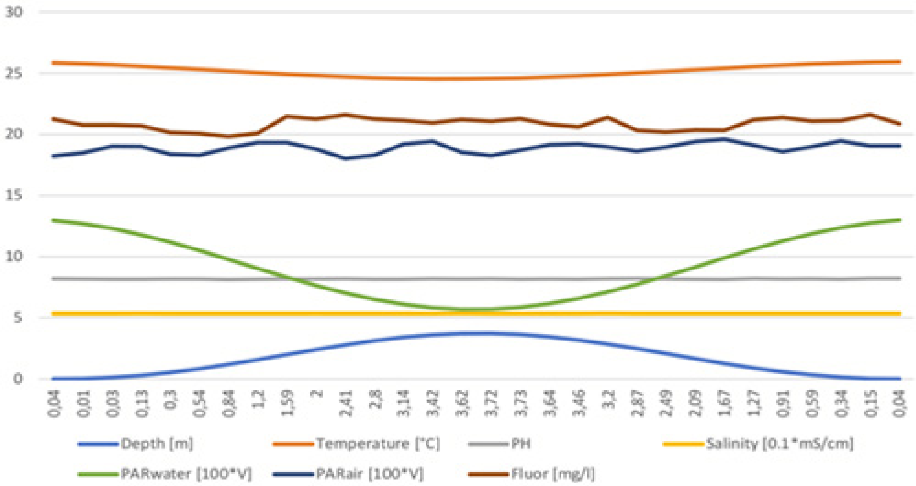


Figure 12

Measures from the inspection probe during a water descent of the field test.

Data collected at maximum depth are reported in Table 2. In particular, the sensor reached a depth of 3.75 meters (blue line in Fig.12). As expected, the PAR (Photosynthetically Active Radiation) of the water decreases proportionally to the depth of the sensor since the light is not able to reach deep water regions. Similarly, the temperature of the water is lower at a lower depth. Differently, the other monitored values were subjected to few variations.

Data	Value
Temperature [°C]	24.5
Depth [m]	3.73
PH	8.2
PAR water [V]	0.057
PAR air [V]	0.18
Chlorophyll [mg/l]	21.06
Salinity [mS/cm]	53.51

Table 2: Water data at maximum inspection depth collected during a field test.

CONCLUSIONS

This paper introduces a novel aerial system designed for surface, aerial, and underwater inspection. The heart of the system is an amphibious drone that can fly over water and land on it or float on the surface. During the floating phase, the Drone employs an underwater inspection probe to assess water quality. When unused, the system returns to a docking station where its batteries are recharged, and mission logs are downloaded. To ensure the system's effectiveness, various tests have been carried out. The floating capability was assessed using simulation tools and validated in a controlled laboratory environment. Additionally, the complete system was field-tested, and various inspection missions were carried out, proving the concept of the developed system.

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INTRODUCING NOISE FOR AIRSIM 3D LIDAR SENSOR TO REDUCE THE SIM2REAL GAP IN SIMULATED MULTI-ROTOR OPERATIONS

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In highly autonomous UAS (Unmanned Aircraft Systems), it is important to model sensor noise because it can significantly affect the accuracy and reliability of the aerial robot's perception of its environment. Modeling sensor noise also allows for more accurate simulations of aerial robotic systems, which can help improve their performance in real-world scenarios. Given the rise in the use of simulation tools for rapid prototyping and iteration of aerial robotic systems, we propose the introduction of a noise model for the LiDAR (Light Detecting and Ranging) sensor that is supported in AirSim, in order to help the community, build more accurate, reliable, and cost-effective solutions.

1. INTRODUCTION

Autonomous robots need to sense the world around them. Sensor noise can cause measurement errors, which could lead to incorrect decisions and actions by the robotic systems [1]. Modeling sensor noise is important in robotics because it helps improve robot sensors' accuracy and ability to perceive the environment. Sensor noise can be caused by several factors, such as environmental conditions, manufacturing imperfections, hardware limitations, and signal processing errors. Some sensors that rely on measuring distances, such as sonar, infrared, and LiDAR (Light Detecting and Ranging) sensors, are known to be particularly susceptible to noise [2].

Modeling sensor noise is crucial for accurate robotic perception regardless of the type of sensor used, since in that way robots can make more informed decisions based on the data they receive from their sensors. This can improve performance in navigation, object recognition, or manipulation tasks.

Modern robotic systems are complex and must be tested in simulations with detailed sensor noise models to verify robotic behavior effectively. Ignoring sensor noise in simulations can lead to unrealistic performance expectations and poor design choices. Using realistic noise models enables the development of more accurate simulations, which can improve the performance of robotic systems in real-world scenarios. The pitfalls of naive robot simulations have been recognized in areas such as evolutionary robotics [3], suggesting that carefully validated simulations can provide a useful tool for testing hypotheses about the behavior of robots in complex environments. Implementing sensor noise in robotics simulations poses several challenges; some of the most important aspects are accurately simulating the physical world, which involves a composition of various models. To address these challenges, researchers continue to develop new methods and models to improve the accuracy and reliability of robotics simulations [4].

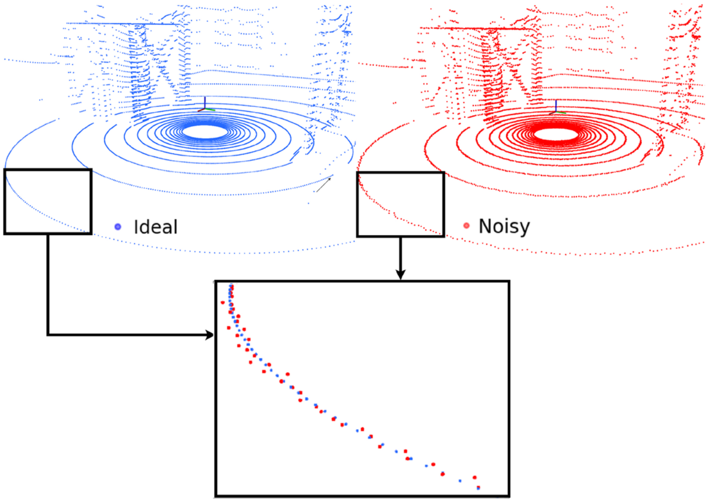

Figure 1 *Simulated lidar point clouds with our proposed noise model.*

Simulation is a highly convenient and useful tool for aerial robotics research. It allows us to conduct a wide variety of tests safely and in a short time, predict system behavior and fine-tune algorithms parameters, given that good models have been derived. For instance, accurate simulations can help identify the impact of sensor noise on the system's overall performance and optimize its design or control algorithms to mitigate the effects of noise. There are several simulation tools available for aerial robotics research [5], such as Gazebo within the Robot Operating System (ROS) [6], Carla which is more focused on autonomous driving [7], or AirSim developed by Microsoft [8]. Nevertheless, using simulation in aerial robotics research has important limitations [9] since real-world dynamics are very difficult to model accurately.

To improve the performance of the algorithms when they are transferred from simulation environments to real robotic systems, we have identified a potential improvement for the sensors supported in AirSim. Currently, the only ones providing some form of noise model are the barometer and magnetometer. LiDAR technology is increasingly used in aerial robotics research, given the reduction in cost, size and weight of available commercial models, which has allowed their integration into a wider range of aerial platforms. This has brought more interest in research based on this technology, which implies a higher importance in how these systems are used in simulation environments. The 3D lidar sensor supported in AirSim allows the configuration of several parameters, but none related to a noise model for the provided measurements.

In this work, we propose introducing a noise model for this sensor corresponding to the specifications of current commercial products, as depicted in Fig. 1, showing results of experiments where such a model brings the simulator closer to a real-world scenario.

The rest of the manuscript is structured as follows. Section II details our AirSim framework and the scenario we have worked with. Section III explains the noise model developed in this context, while Section IV shows some results of its impact in a practical application. Finally, Section V summarizes the outcomes of our approach and future directions.

II. SIMULATION ENVIRONMENT

AirSim is an open-source, cross-platform simulator designed for autonomous systems research. It is built on Unreal Engine [10], a 3D computer graphics game engine developed by Epic Games. The game engine does all the graphical rendering, collision, and vehicle movement simulation. AirSim supports software-in-the-loop simulation with popular flight controllers such as PX4 or ArduPilot, which is very convenient for testing autonomous missions before the deployment on the actual hardware platform. Moreover, it can be easily integrated with ROS through a wrapper, allowing external nodes to work with the simulated data.

To simplify the configuration, installation of dependencies and deployment of this environment on any computer, our framework is based on Docker images. This allows for automating the deployment of applications within software containers, providing an additional layer of abstraction and automation of application virtualization in multiple operating systems. We have also developed scripts to deploy and automatically configure different parameters concerning the simulation and the involved onboard sensors.

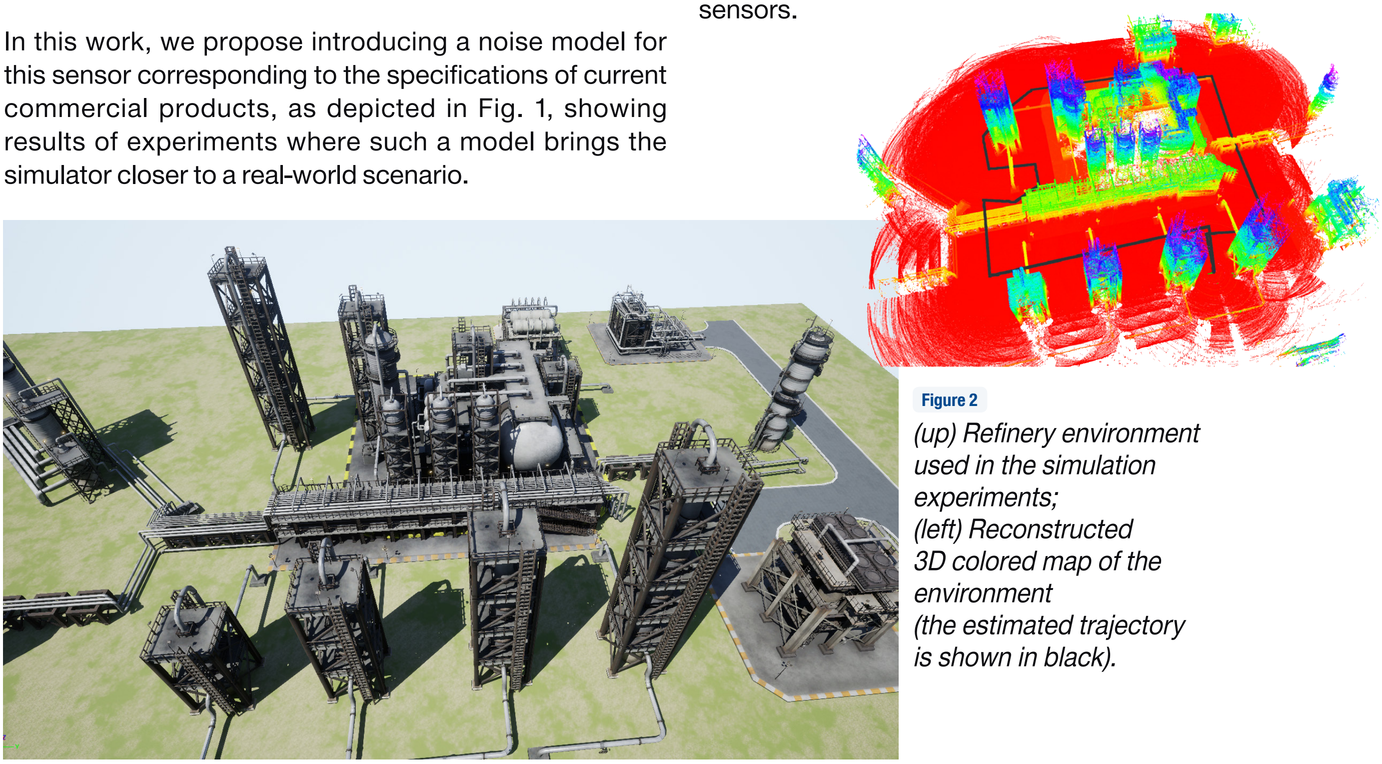

Figure 2

(up) Refinery environment used in the simulation experiments;
(left) Reconstructed 3D colored map of the environment
(the estimated trajectory is shown in black).

Furthermore, to demonstrate the validity of our contribution, we have created a realistic scenario for inspection and maintenance purposes, in this case, a refinery environment, shown in Fig. 2. Oil and gas production plants frequently experience component deterioration due to environmental exposure, or products used within the production process. If pipe corrosion is left unchecked, it can result in accidents, such as devastating explosions and the release of hazardous materials. Consequently, this can affect the safety, environment, and operability of the plant. Aerial robots are a very useful tool for inspection purposes in these plants. To ensure their safe operation, it is essential to have a robust localization system independent of the Global Navigation Satellite System (GNSS) combined with onboard inertial sensors, which can be unreliable in such a cluttered environment full of metallic structures. The proposed virtual world allows evaluation of the performance of algorithms in a complex scenario, where the robot localization needs to be as good as possible. Fig 2-left shows an aerial view of the recreated refinery scenario used in this work.

III. LIDAR NOISE MODEL

The implemented noise model is closely related to how a 3D LiDAR sensor internally works. Most current commercial LiDARs are formed by several vertically arranged laser beams rotating at high speed. The horizontal and vertical angle resolution can be known with high precision, so the directions of the laser beams can be measured with low error. Nevertheless, the measured ranges depend on the beams' time of flight (ToF), which is more susceptible to measurement errors due to environmental conditions or the internal clock resolution. Moreover, these measurement errors are higher in more distant points, causing a worse performance for longer distances. Following the previous idea, instead of adding a random 3D noise for each point, our proposed model will only affect the range and not the direction of the beam it belongs to. The range noise is modelled as a Gaussian noise with a zero mean and a standard deviation which increases linearly with the range.

Since AirSim is open-source, the code for simulating a LiDAR within the Unreal Engine is available, so this noise model has been added to each point in the ray-tracing process. The main parameters which can be modified externally are the standard deviation at zero distance and the maximum range. A linear noise model has been implemented by adapting the AirSim plugin, generating the desired point clouds when the lidar sensors are parameterized, providing such standard deviation values. In contrast to other open-source simulators [7] where the deviation is constant with distance, the proposed noise model increases linearly.

Two commercial lidar models have been studied, the Ouster OS0 and OS1, with 32 horizontal scans, and each of the scans consists of 512 points. The main differences between these two sensors are the vertical Field of View (FOV) and the maximum detection range. According to the datasheets [11][12], the selected OS0 sensor has been parameterized in our simulation with 90 degrees vertical FOV (field of view) and a maximum range of 45 m whereas the OS1 sensor was characterized by 45 degrees vertical FOV and a maximum range of 100 m. The accuracy of both sensor models is 3 cm for Lambertian targets, while their precision is defined by fixed values for the mean and standard deviation for different range intervals, according to Table I.

OS0		OSI	
Range [m]	**StdDev [cm]**	**Range [m]**	**StdDev [cm]**
0.3 – 1	2	0.3 – 1	0.7
1 – 10	1	1 – 20	1
10 – 15	1.5	20 – 50	2
15 – 45	5	50 – 100	5

Table 1 *Precision for Ouster sensors (10% Lambertian reflectivity).*

Based on this data, the values for the standard deviation at minimum and maximum ranges were chosen as follows: 1-10cm for OS0 and 1-15cm for OS1. In this way, the averaged simulated noise in each range is just slightly higher than those provided by the manufacturer and better corresponds with our experience using these sensors in real experiments.

IV. EXPERIMENTAL RESULTS

An open-source localization algorithm was chosen to evaluate the influence of the introduced LiDAR noise. LeGO-LOAM [13] is a lightweight lidar odometry and mapping method that provides real-time six-degree-of-freedom pose estimation. It is specifically optimized for a horizontally placed 3D lidar sensor mounted on a ground vehicle, assuming there is always a ground plane in the scan. Even though these evaluations are based on an aerial vehicle, this assumption holds for our refinery scenario. Only the lidar point clouds are included in the odometry computation, i.e., no inertial data are used. In this way, the odometry quality will strongly depend on the geometry of the point clouds, and the effect of the introduced noise can be clearly assessed.

A benchmark trajectory was defined to evaluate the localization of the aerial robot. A closed trajectory around the refinery environment was designed to emulate a real mission for the general inspection of the plant during a single flight, as depicted in Fig. 2-right and Fig. 3.

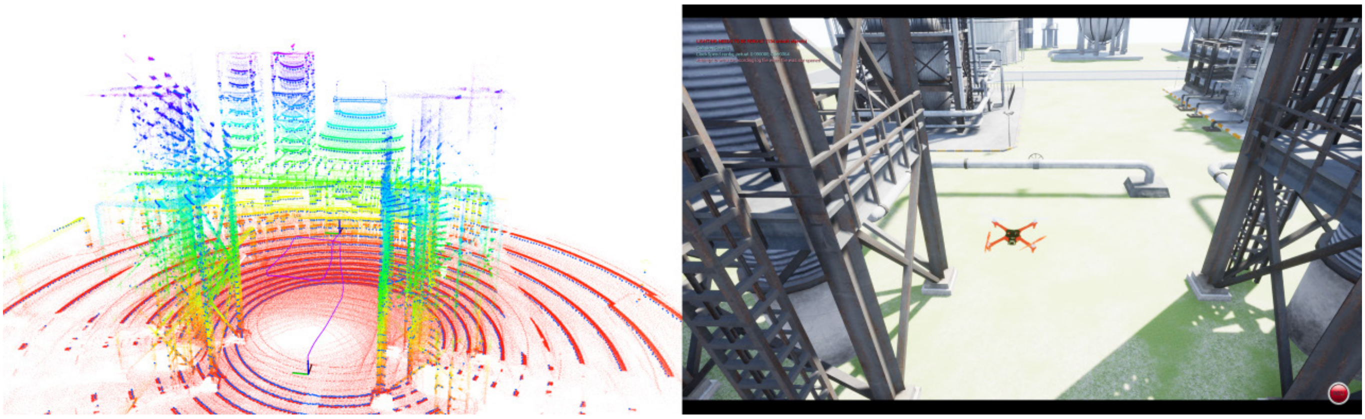

Figure 3 *Aerial robot traversing the simulated environment.*

The comparison between odometries (with and without sensor noise) is carried out by calculating the Absolute Pose Error (APE). This metric evaluates the global consistency of the estimated trajectory by comparing the absolute distances between the estimations and the ground truth. The results have been obtained using the package [14], and an example is shown in Fig. 4.

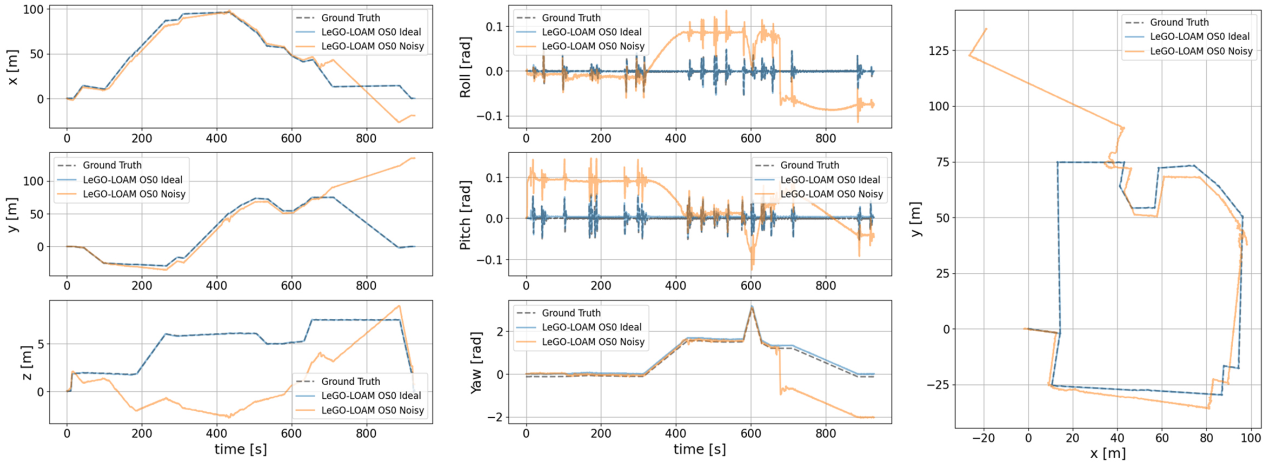

Figure 4 *Trajectories comparison between ideal and noisy OS0 ouster sensor.*

First, the effect of adding noise to the Ouster OS0 sensor model is shown. As it can be seen in Fig. 4 and 5, the effect of the noise is considerable (note the difference in scale) which significantly increases the error in the position estimation.

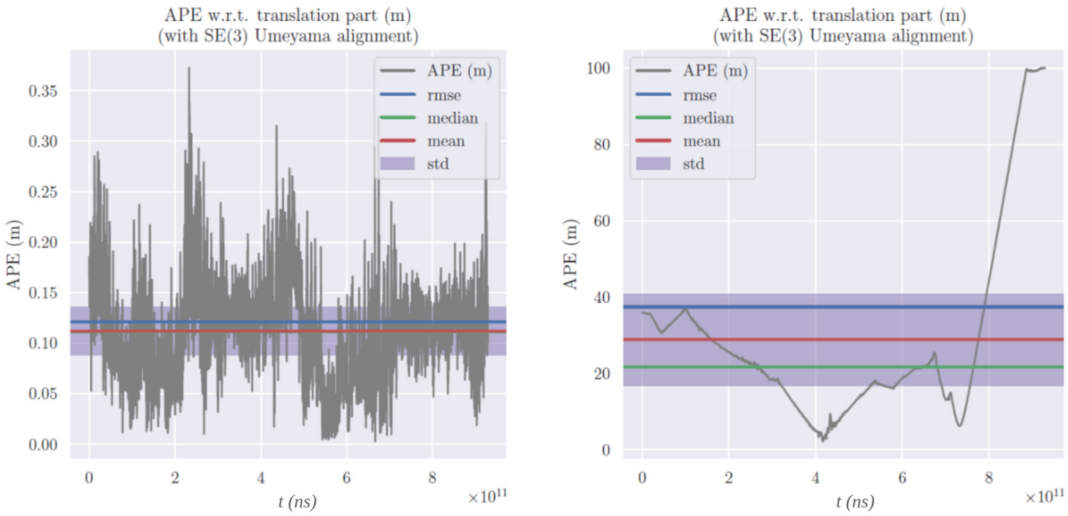

Figure 5 *APE obtained with ideal (left) and noisy (right) OS0 LiDAR.*

While the localization using the ideal lidar resembles the real trajectory with high accuracy, the algorithm faces great difficulties if the proposed noise is introduced. The localization accumulates some drift as the aerial robot moves, especially in yaw and altitude changes. By the last quarter of the benchmark trajectory, there was a turn that caused high drift, completely deviating from the estimation. From this moment, the APE error increases, as can be seen in Fig. 5.

Using the OS1 sensor, as shown in Fig. 6, errors are relatively small with and without sensor noise over the entire trajectory. The fact that the OS1 sensor has twice the range of the OS0 allows to detect more distant objects and spread the noise over the entire range, thus, this is the cause of the improvement in the overall performance of the algorithm. Having a higher range is a differentiating factor, which improves the accuracy of odometry thanks to a more global perception of the scene. The OS1 lidar with the noise model causes much lower drifts compared with the previous noisy OS0.

In this case, both ideal and noisy models of OS1 lidar resemble the benchmark trajectory with acceptable accuracy. Nevertheless, the effect of the noise is not unnoticeable. The APE errors for the odometry corresponding to the noisy OS1 are shakier and have higher values than that produced with the ideal sensor.

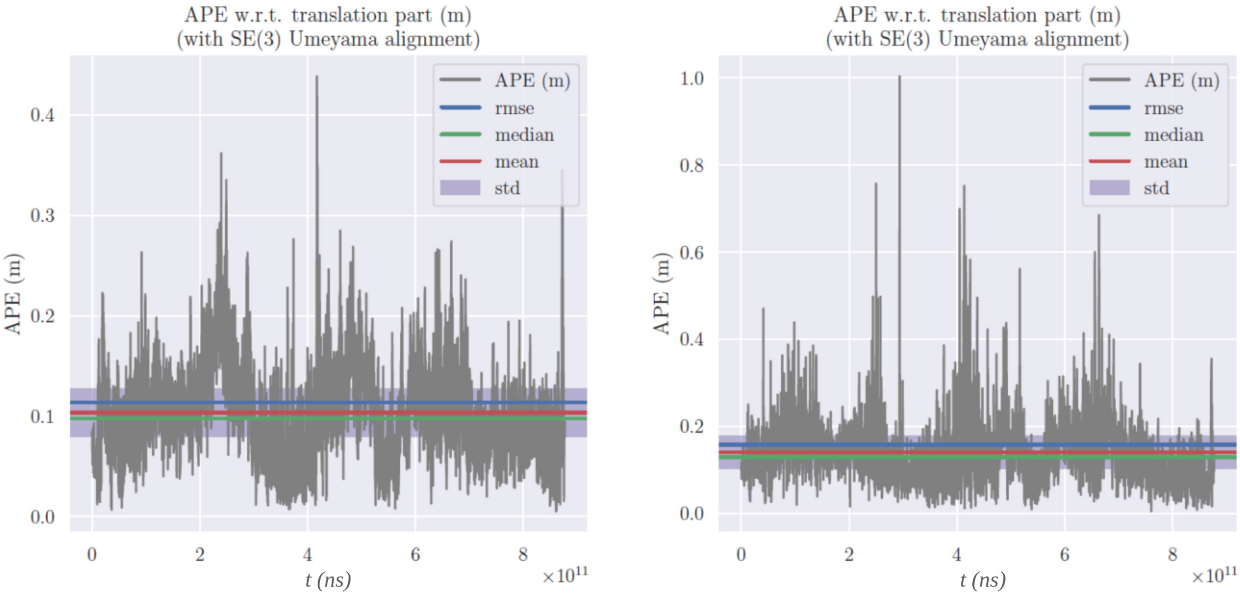

Figure 6 *APE obtained with ideal (left) and noisy (right) OS1 LiDAR.*

Table II compiles the errors obtained for all the simulated experiments. The ideal sensors have similarly low values, causing the lidar-based odometry to perform accurately despite other conditions. However, when the noise model is introduced, both sensors perform worse. This proves the importance of modeling the noise to reduce the gap between simulation and the real world, since the specifications of the real sensor will need to be handled in the developed algorithms.

	OS0 Ideal	**OS0 Noisy**	**OSI Ideal**	**OSI Noisy**
RMSE	0.1213	37.380	0.1137	0.1576
Mean	0.1118	28.8392	0.1034	0.1398
Median	0.1111	21.7313	0.0977	0.1289
Std	0.0471	23.7863	0.0472	0.0727
Min	0.0028	2.1846	0.0053	0.0042
Max	0.3728	100.1327	0.4382	1.0041

Table II APE in squared trajectory for all configurations.

V. CONCLUSIONS

Modeling sensor noise in simulation environments allows to identify its effect on the aerial robot estimation which is closely related to the control performance when implementing the algorithms into the real world. Taking these effects into account contributes to reducing the gap between simulation and real-world experiments, helping to reduce the cost and time required for the testing and development of aerial robotic systems. By introducing a LiDAR noise model using real specifications of currently available commercial products, the algorithms developed considering these measurements will be more robust and reliable, reducing the risk of failure in real-world scenarios. New improved commercial models can be easily integrated to update our contribution.

Future work will consider exploring other noise models using, for example, a continuous piecewise linear function to adjust better to the datasheet values provided for the different range intervals, as well as testing other interpolation methods to resemble the real lidar behavior better. Moreover, a loss function could also be implemented to mimic how some points are not correctly processed due to reflections, environmental conditions, and sensor limitations. Furthermore, an identifier of the hit object could be retrieved for each point thanks to AirSim, so an even more realistic behavior can be modelled by adapting the parameters to the nature of the object's materials.

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