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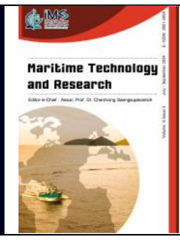

Research Article

A customized drone for ocean and atmospheric measurements and its performances

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Abstract

Drones- Unmanned Aerial vehicles (UAVs)- have become more significant across the world for a wide range of commercial and terrestrial defense applications in recent years. The National Institute of Ocean Technology (NIOT)-Ministry of Earth Sciences (MOES)- is exploring UAVs with a specific focus on maritime applications. NIOT has customized a heavy lift category drone, operable in marine environments and capable of withstanding coastal wind conditions of up to 40 kmph. It can lift and carry an instrumentation payload of 10 kg, conduct ocean data collection, and even take seawater samplings. The 10 kg payload of the UAV might hold a Conductivity Temperature Depth (CTD) sensor, a programmable sea water sampler, and a multi-parameter sensor (MPS) for ocean data collections, and a Light Detection and Ranging (LiDAR) device integrated with a high frame rate camera system for coastal mapping and digital elevation model (DEM) developmental applications. The customized hexacopter UAV is capable of withstanding winds of up to 10 m/s and features a waterproof IPX7 thruster with a maximum thrust of 153 N per axis. The UAV system is also interfaced with a Global Positioning System (GPS), a barometric pressure sensor, a compass, a highly accurate gyroscope, a 15 MP surveillance camera, and an accelerometer sensor connected to a reliable cube orange flight controller module with a redundant 32-bit controller through a serial peripheral interface (SPI). The drone structure and frame is composed of carbon fiber composites to provide an excellent weight-to-strength ratio. This paper presents the outcomes of an initial field test, carried out to ensure the drone's suitability for various marine applications with intended payloads ranging from 5 - 10 kg weight, including coastal demonstrations and ocean data collections performed at Nellore (Andra Pradesh) and Chennai (Tamil Nadu) coastal waters.

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Nomenclature and abbreviations

Abbreviation		Description
AGL	-	Above Ground Level
UAVs	-	Unmanned Aerial Vehicles
DEM	-	Digital Elevation Model
DGCA	-	Directorate General of Civil Aviation
MPS	-	Multi Parameter Sensor
MOES	-	Ministry of Earth Sciences
NIOT	-	National Institute of Ocean Technology
CTD	-	Conductivity Temperature Depth
LiDAR	-	Light Detection and Ranging
IP	-	Ingress Protection
GPS	-	Global Positioning System
SPI	-	Serial Peripheral Interface
SAR	-	Synthetic Aperture Radars
ESC	-	Electronic Speed Controller
BLDC	-	Brushless Direct Current
UART	-	Universal Asynchronous Receiver/Transmitter
IMU	-	Inertial Measurement Unit
IR	-	Infrared
GCS	-	Ground Control Station
AES	-	Advanced Encryption Standard
GNSS	-	Global Navigation Satellite System
RF	-	Radio Frequency

1. Introduction

Drones are more advantageous in terms of the following aspects: reachability- drones can glide over places that are hard for utility workers to get around; increased safety- drones can be easily landed in places with high risk for humans, for example, a methane gas leak; cost reduction- drones can be used as replacements for expensive inspections done using helicopters, drastically reducing the cost; environmental friendliness- the traditionally used helicopters consume much more energy and generate noise, while drones silently give good environmental compatibility with no emissions. Drones are unmanned, pilotless aircraft. They can also be referred to as unmanned aerial vehicles, or UAVs. They vary in their level of independence. A drone may rely on its systems, which are equipped with Light Detection and Ranging (LiDAR) detectors and sensitive sensors (Warwick, 2011; Weisgerber, 2011; Gertler, 2012). These systems are used to compute the drone's motions and surroundings, preventing crashes while it is following its flight plan; this is known as an autopilot. Additionally, it is capable of remotely piloted autonomy, which depends on a person to guide it. Depending on the work they are performing, drones come in a variety of sizes and designs. In terms of the height and distance they can go, they have various powers (Colomina & Molina, 2014). Drones that fly at close range can travel up to three miles. People with hobbies frequently utilize them. Close-range drones, on the other hand, have a range of up to 30 miles. The farthest-reaching drones have a range of 400 miles or more and can fly up to 3,000 feet in the air (Mayer et al., 2012; Merz & Chapman, 2011; Anderson & Gaston, 2013).

To research and monitor water quality, it is important to gather data and observe the shallow ocean areas, since they are the sites of deep-water pollution, ecosystem movement, and marine habitats. Due to the actions of wave breaking activities, which release a tremendous amount of potential energy, monitoring the highly dynamic shallow water zone with the conventional buoy system is particularly challenging. Waves in deep water have longer wavelengths and smaller crests.

Due to variations in the bottom topography, the same wave's wavelength shortens and its height rises as it approaches shallow waters. At this dynamic site, it is particularly challenging to acquire water quality measurements. For this purpose, UAVs are beneficial. Observatories should be designed to resist the harsh maritime environment (Samudranil, 2016; Qasim & Sengupta, 1988). It is extremely difficult to collect real-time observational data in the shoaling zone for ocean observations; hence, this zone requires an innovative way of approach. The shoaling zone, which is mostly found on a continental shelf, combines a transition zone and a shallow zone. Drone-based observation is being studied as a solution to this issue, since it provides real-time data collecting at shallow water zones of higher quality than existing shallow water observations (Koparan, 2016). Today's UAVs are equipped with modern sensors like hyper-spectral imagers, Synthetic Aperture Radars (SAR), and Light Detection and Ranging (LiDAR) scanners, which are starting to revolutionize urban and rural planning, agriculture, and search and rescue operations (Duan & Zhang, 2014). The application of UAV remote sensing applications in the marine sector has increased as a result of all of these technological advancements (Adade et al., 2021; White et al., 2022; Yang et al., 2022; Yuan et al., 2023). NIOT has customized a heavy lift category drone capable of operating in harsh marine environments, withstanding coastal wind conditions up to 40 kmph (Srinivasan et al., 2022a; Srinivasan et al., 2022b; Srinivasan et al., 2022c). It can carry an instrumentation payload of 10 kg, conduct ocean data collection, and even take seawater samplings.

This paper presents the customization of a multipurpose heavy-lift hexacopter drone for ocean observations, the preliminary results of a field test to evaluate the drone's endurance using different payloads weighing between 5 and 10 kg, and the results of a few field demonstrations and data collections carried out in Nellore (Andra Pradesh) Chennai (Tamil Nadu) coastal waters.

Figure 1 Heavy lift hexacopter.

2. Description of the hexacopter system

Figures 1 and **2** shows the hexacopter, a flexible heavy-lift platform. The heavy lift hexacopter is strong and extremely stable. **Table 1** provides information on the hexacopter's technical specifications. It has been built of carbon fiber material, which is lightweight and highly durable. The removable multi-copter arm is fastened using the quick-locking knobs. Because of its portable shape, it is simple to move and quick to assemble. The heavy lift drone can carry a lot more weight than a standard quad copter and its maximum thrust from one rotor may exceed 15.3 kg. It is fitted with an efficient motor and high-efficiency 29-inch propeller to ensure lengthy flying times. **Figure 1** shows the assembled view of hexacopter components, and **Figure 2** presents the detailed dimension of the drone using a CAD model. It contains five subsystems, which are covered in the following subsections: a frame, propulsion, avionics system, electronic system, and power system.

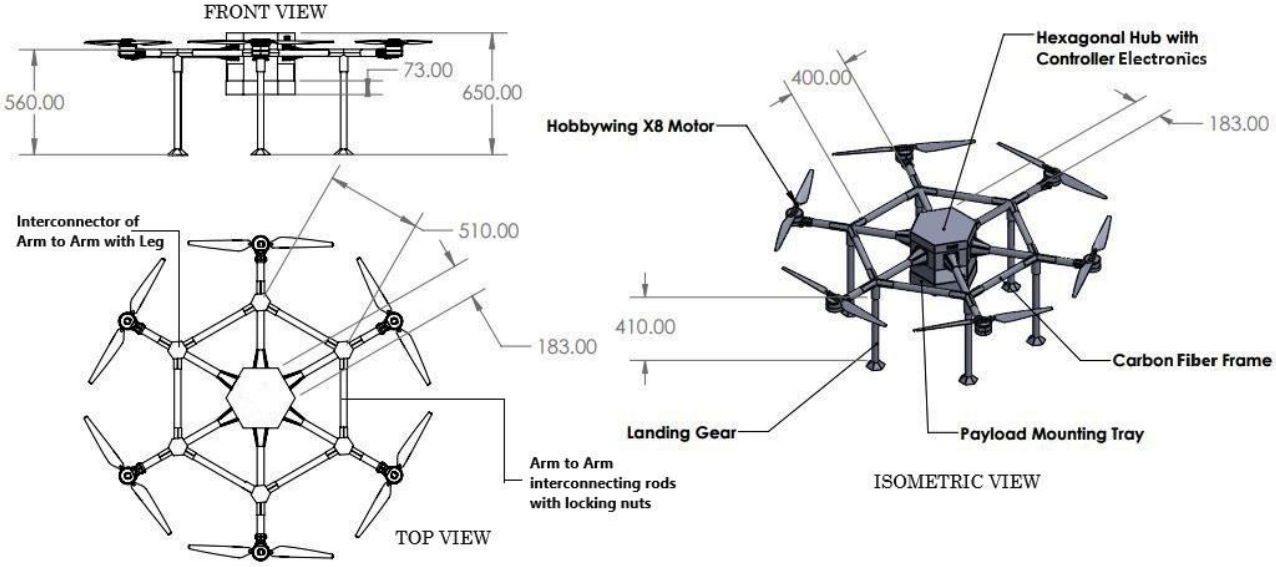

Figure 2 Customized hexacopter CAD model with detailed dimensions.

Table 1 Drone's technical specifications.

Wheelbase	1,830 mm
Material	Carbon Fiber Composite
RTF Weight	23 kg
Max. Take-off Weight	42 kg
Endurance	15 - 20 minutes with a 10 kg payload
Suggested Max Payload	10 kg
Max Cruising Speed	10 m/s
Landing Space	3×3 m^2
Wind Resistance	10 m/s
Operational Altitude	120 m AGL
Max. Takeoff Altitude	3,000 m
Take-off/Landing	VTOL
Working Voltage	48V
Working Temperature	–5 - 55 °C
Deployment Time	30 minutes
Terrain follows	Support with on-board Barometer and Sensor
Power	Battery powered
Range	3,000+ meters
Flight Modes	Fully Autonomous Mode Semi-Autonomous Mode Return to home mode Loiter Mode Altitude Hold

2.1 Frame

A drone's primary structural component is its airframe. The airframe must be suitably designed to handle the stresses that could arise during flight without deforming or vibrating. Typically, four different materials- carbon fiber, aluminum 6061, glass fiber, and steel- are used to make airframes. A carbon fiber composite frame, 3D-printed carbon fiber connecting parts, swipes application mechanisms, and a carbon fiber composite shaft serves as the hexacopter's airframe. These materials were developed and built with industrial-grade requirements, and are corrosion-resistant. To reduce vibrations, a dampening system will be provided to some of the components that are found vibration-sensitive by the inertial measurement unit or sensors. High-frequency vibration will be absorbed by the air-core dampening ball inside the dampers. The Inertial Measurement Unit and gimbals are adequately shielded from the effects of high-frequency vibration.

2.2 Propulsion

Motors, an electronic speed controller (ESC), and propellers constitute the propulsion system. For propulsion, brushless direct current motors (BLDC) are being used. They are made lighter, with excellent efficiency and reliability, by using specialized metals. An electrical circuit known as an "ESC" is used to control and regulate electric motor speed. **Figure 2** displays the BLDC motor and its perspective. It gives speed-related information and improves stability. Hexacopter propellers are used to drive and maneuver the drone by producing thrust and torque. It is constructed of carbon fiber. The 29-inch propellers used in the Hobbywing X8 power systems have a load-bearing capability of 15.3 kg per axis and a maximum thrust of 91 kg. The 100 KV-rated electronically driven BLDC motors power the propellers.

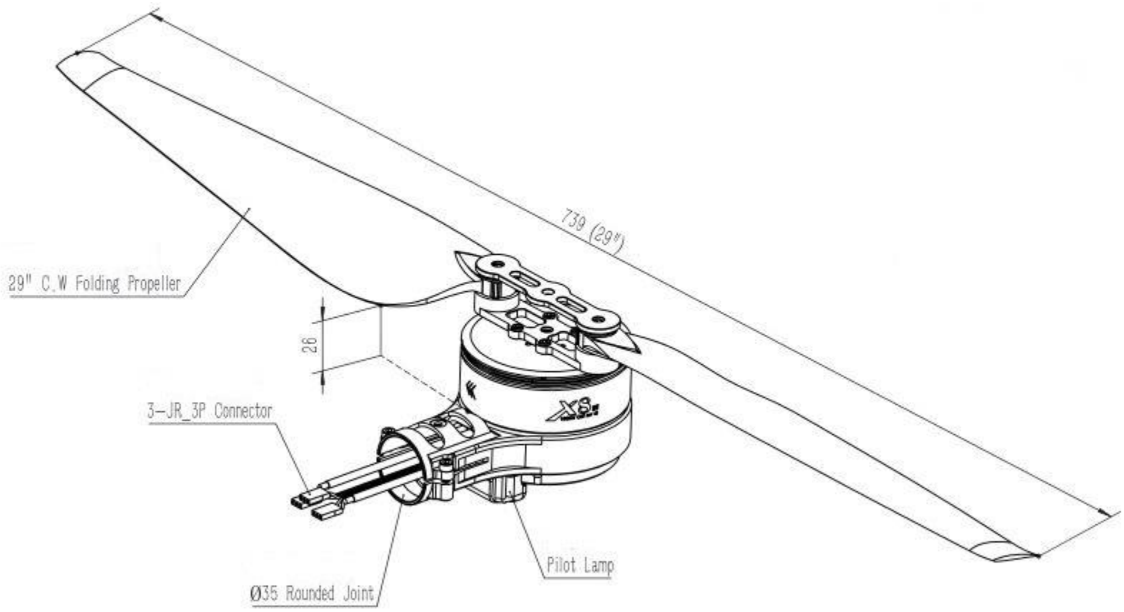

Figure 3 Propellers set.

2.3 Avionics system

To guide the drone in a certain direction, and to regulate its trajectory, an autopilot incorporates an inertial measurement unit. As seen in **Figure 3**, autopilot features a variety of connections, including UART, telemetry, serial communication, etc. The GPS, communication system, camera, and electronic speed controller all interface with each other through these ports in the current drone system. The brains of the system are on autopilot. For improved performance, it is currently connected to several modules. It has an IMU, or inertial measurement unit, which comprises a gyroscope, an accelerometer, and a magnetometer. IMUs are frequently used to control drones and other unmanned aerial vehicles (UAVs). Additionally, it gives the autopilot information on the orientation of the drone. The motor receives regulated outputs from the electronic speed controller (ESC), which is connected to the autopilot. The telemetry port enables communication between the air unit and the ground unit. The drone's location is determined by the satellites tracked with GPS. For a variety of uses, the infrared (IR) cameras are interfaced in the drone to record photos and videos and transmit them through autopilot to the ground control station.

2.3.1 Communication system

Hexacopter uses an advanced autonomous flight control board from STM32 F7 with a 216 MHz CPU, PX4 software support system, 6 PWM I/O ports, 6 Servo I/O ports, and an integrated data recorder. Telemetry-based new parameter sets and assistance software like the mission planner and Ground Control are all feasible. The flight controller module has features like altitude stabilization, fixed height mode, automated return mode, out-of-control return mode, low voltage protection, one button traverse function, etc. Drones utilize air pressure sensors to stabilize altitude, allowing hover capabilities needed for videography or photography. Combined with the accelerometer and gyroscope, barometric pressure sensors enable drones to fly with precision. A ground unit and an air unit make up the communication system. It is the primary relay device that informs the drone operator about how the drone is operating. The ground unit, which consists of a radio controller and a ground station, aids the pilot in comprehending how the drone operates. Video, pictures, and data are recorded and sent to the ground unit via the air unit, which is also used to communicate with the ground unit. The second mode of communication for commanding the UAV is provided by the communication system. It enables the operator to interact in real time with the robust GCS (ground control station). To connect with ground control, the communication system uses radio frequency to convey signals. The receiver receives 2.4 GHz signals from the transmitter and uses them to operate the UAV with very little lag.

Commercial drones operate on four frequency bands: 2.4 GHz, 5.8 GHz, 433 MHz, and 915 MHz. The majority of more expensive commercial drones use GPS L1 and operate on the 2.4 and 5.8 GHz bands, allowing the operator to fly a fixed-wing or quadcopter, hexacopter, or octocopter up to around 5 km distance, with some having a 12 km horizontal range. The drone's map transmission system typically sends radio signals at a frequency of 2.4 or 5.8 GHz to the ground control end to transmit image data. ISM bands- radio spectra internationally reserved for industrial, scientific, and medical purposes- include 2.4 and 5.8 GHz. In this case, 2.4 GHz is the frequency band used.

2.3.2 Global Positioning System (GPS)

A radio navigation system using satellites is known as Global Navigation Satellite System (GNSS). It is used to figure out a vehicle's precise location. The GNSS gives the receiver geo-location and time data from any place on or near the Earth when there is an unrestricted line of sight to four or more GPS satellites. The drone is equipped with HERE 3 GNSS, LH-105A2-B GNSS, and a 12 Channel Drone UAV drone remote control SkyroidT12. To improve the controllability and operation of the drone, we can make use of both a laptop-based Ground Control Station (GCS) and a portable GCS. A single communication system and GCS can manage all radio control, data link, and video link functions; one to two persons are more than enough to run the drone and complete the task. The data sets are secure and protected because of Advanced Encryption Standard (AES) 128 bit encryption. The standard procedure of operations is shown in **Figure 4**.

Although certain drone GPS modules can securely latch on to up to seven or eight different satellite signals for best performance, GPS normally employs three or four satellite signals to determine relative location and speed. Drones with GPS capabilities may determine their location in relation to a system of orbiting satellites by means of a GPS module built within the drone. The drone can carry out tasks including positioning, autonomous flight, return to home, and waypoint navigation when it is connected to the signals of these satellites.

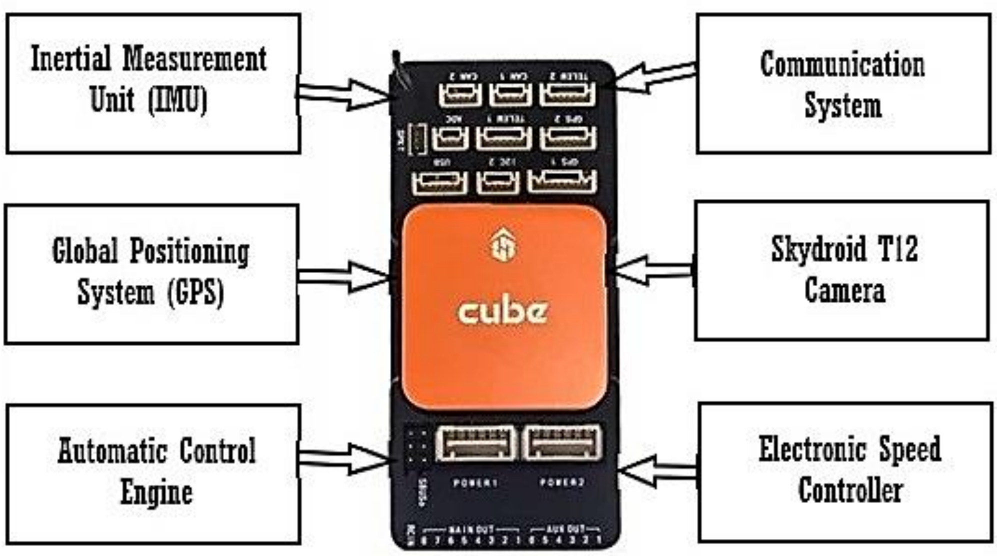

Figure 4 Autopilot block diagram.

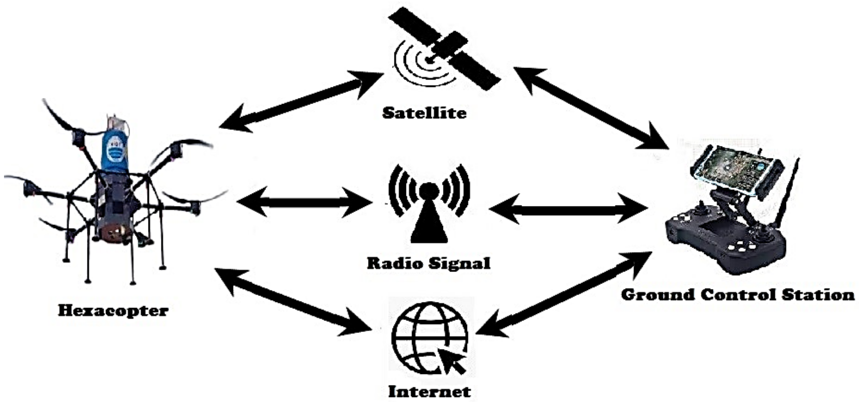

Figure 5 Standard procedures for operating UAVs through ground control stations during manual and autonomous flights.

Figure 6 The sequence of operations performed with CTD attached to the drone.

2.3.3 Camera

The skydroid T12 15 MP Daylight sensor is the camera payload. It is used for several functions, including streaming live to the ground control station (GCS), recording, compression, and snapshots. The operating temperature of the camera is −10 to 50 °C. The camera has an 8w ultra-bright LED for enhanced night time image capturing.

2.4 Anti-collision sensor

The Federal Aviation Administration (FAA) regulates that a drone flown between sunset and sunrise must be equipped with anti-collision lighting. These lights must have a strobe function those strobes between 40 - 100 cycles/minute. They also must be visible from 3 statute miles.

2.5 Power system

The drone is powered by a lithium-ion six battery of 6S3P standard with 50.4 V. The battery is employed as the primary power source and meets all of the system's peak power needs. The backup time for a safe landing in the event of a system breakdown will be 10 minutes through the reserve battery capacity. This guarantees a failsafe mechanism to safeguard the security of drones.

3. Initial field demonstrations- adapting the drone for marine applications

3.1 Field demonstration with CTD sensor- Pond trial at Vijayawada- Andra Pradesh

The drone's stability was studied (static & dynamic) with a CTD sensor and other instrumentation payload as a swing load. This test was carried out by mounting the above-specified sensor payload as swing load in a heavy lift small category drone which can carry a maximum payload of 10 kg. There are two components to this study; the first one is the dry test, which involves using a CTD sensor as the swing load while observing the drone's stability and dynamics. The drone is flown at varied speeds between 3 and 8 m/sec, with the payload hung at a distance of 3 m from the craft. The CTD sensor assembly is submerged in a water body up to a depth of 1 m for the second test, which is an actual measurement cycle test. In this test, the drone is set in an altitude lock position at each measurement site for a period of more than a minute, and the data sets are transmitted through Wi-Fi telemetry. The CTD sensor sampling data is received in real time and graphically updated in a portable device. By operating at various speeds, the lifting, hovering, and static and dynamic stability of the drone are examined. The sequence of operations of the drone attached to the CTD sensor is shown in **Figure 5**. This field research demonstrated the applicability and confidence of modifying an unmanned aerial vehicle (drone) for applications related to ocean monitoring.

3.2 Field demonstration with programmable sea water sampler in Tamil Nadu coastal region

Similar research was done to study whether drones were appropriate for collecting saltwater samples from coastal areas. This study was performed in September 2021 near the Chennai coastal region at Utthandi. A programmable sea sampler having a capacity of 1.7 liter was attached to a heavy lift drone at the central bottom mounting location. Also, the necessary electronic gadgets and Bluetooth devices were built-in with sea water sampler. A thin, 2.5 mm thickness nylon wire was used to dangle the water sampler almost 4 m below the drone, as displayed in **Figure 6**. The drone was flown 12 m above ground level. The drone was flown 300 meters into the sea while maintaining a speed of 4 to 5 meters per second. In relation to the static and dynamic load, as well as the local wind conditions, the functional behavior of the drone with the water sampler was monitored. The sampler weighed 5.2 kg self weight, and around 6.9 kg when it collected the sea water sample. A sample was taken once the water sampler was plunged to a depth of 1 m. The sampler pressure set value controlled the pre-programmed sample depth, and the sampler automatically closed its end caps at both sides when it reached the set depth value; hence, the sample was collected.

3.3 Drone-based ocean data collection

We recently carried out the field tests and ocean data collection trials in the Pamanji coastal regions of Nellore (Andhra Pradesh) as part of the acceptance test of a customized drone developed jointly with the Indian industry (M/s. Enercomp Solutions Private Limited- Ahmadabad). The Director General of Civil Aviation (DGCA) authorized the NIOT drone under small-category drone with the unique identification number UA006SZS1EX.

Table 2 CTD data collection using a drone.

Conductivity readings	Depth	Temperature	Date	Month	Year	Time
5.694986	0.665	29.8031	22	Jun	2023	11:30:36
5.688485	0.913	29.6816	22	Jun	2023	11:31:06
5.672806	0.621	29.6448	22	Jun	2023	11:31:36
5.664808	0.354	29.6509	22	Jun	2023	11:32:06
5.642253	–0.175	30.0257	22	Jun	2023	11:35:06
5.693502	0.349	30.0098	22	Jun	2023	11:35:36
5.678771	0.548	29.8177	22	Jun	2023	11:36:06
5.678771	0.385	29.8220	22	Jun	2023	11:36:36
5.678661	0.479	29.8048	22	Jun	2023	11:37:06
5.679364	0.266	29.7811	22	Jun	2023	11:37:36
5.677996	0.23	29.7933	22	Jun	2023	11:38:06
5.663554	–0.071	29.9044	22	Jun	2023	11:40:36
5.647248	0.376	29.8249	22	Jun	2023	11:41:06
5.669754	0	29.7774	22	Jun	2023	11:41:36
5.678529	0.339	29.8272	22	Jun	2023	11:42:06
5.677258	0.375	29.7518	22	Jun	2023	11:42:36
5.678771	0.049	29.7799	22	Jun	2023	11:43:06

3.3.1 Ocean Data Collections using CTD sensor as payload in drone

The CTD sensor, autonomous measuring equipment weighing about 4.5 kg, was put in the drone as a swing load and suspended 4 meters above the ground. The CTD sensor contained the necessary battery pack and built-in memory for autonomous operations to start taking the specified measurements. From the Pamanji coastal region, a drone fitted with a CTD sensor was flown up to 1.5 km out to sea while maintaining a 10 m vertical height over land. The CTD sensor was submerged up to 1 m into the seawater, and data sets were examined. The same procedure was repeated, and data sets were gathered at distances of 1.0 and 0.5 km. The data sets enlisted in **Table 2** were collected during the first trial observations on June 22, 2023.

3.3.2 Range test- vertical flying of drone up to 500 m above AGL

This test was carried out to make sure that the customized drone would remain stable when flying vertically while enduring the different atmospheric conditions present at the vertical structure. The drone was flown up to an altitude of 500 m AGL. The ascending speed of the drone was nearly 10 m/sec, and its descending speed was approximately 5 m/sec. The drone’s radio frequency (RF) interface to the ground control station (GCS) was constantly monitored. 99 % RF signal strength was observed during the above test. The drone’s stability and dynamics were observed to be excellent in this automatic mode of operation. The drone was operated in autonomous pilot mode during the vertical fly test.

3.3.3 Range test- horizontal fly of drone up to 3.5 km from the coast

By flying the drone horizontally into the sea from the area around the high tide line on the shore, this test was conducted to confirm the Radio Frequency (RF) signal strength between the drone and Global Positioning System (GPS). Here, RF signal strength and other drone properties were measured when the drone was flown 3.5 km offshore (**Figure 7**). The RF signal strength was reported to be 99 % up to a distance of 3.5 km when the drone was maintained at a height of 10 m above ground level. This test provided us with the assurance needed to fly the drone out to the sea while enduring the local wind conditions, etc. At a speed of 10 m/s, the drone dynamics were as expected.

Figure 7 Sea water sampler attached to drone.

Figure 8 Horizontal range fly test image and display results.

Figure 9 Air quality index parameter sensors mounted on top of the drone's central body.

Figure 10 Air quality index parameter sensors mounted at 650 mm elevated point.

3.4 Drone-based Air Quality Index parameters observations

A field demonstration and observation of atmospheric parameters including Air Quality Index parameter sensor, Sonde system and Black Carbon sensor was carried out in support of the Indian Institute of Tropical Management (IITM) Pune. In the aforementioned test trials, NIOT's customized hexacopter drone with the UIN number UA006SZS1EX was equipped with a variety of sensors for air Quality Index parameter measurements and field data collection was carried out in East Coast Road at Thiruvidanthai, Tamil Nadu.

3.4.1 Drone-based atmospheric measurements using sensors mounted at 150 mm elevated from the axis of propellers

The following sensor which measured the Air Quality Index parameters of the atmosphere was mounted on the central top plain surface of the drone assembly (**Figure 9**). The air quality sensors weighed approximately 1.3 kg. All of the sensors had built-in memory and standalone battery for autonomous operations. A drone mounted with an air quality sensor was flown up to 120 m vertical height at the NIOT campus and data sets were collected (**Figure 8**). The above measurement cycle was repeated in three flights. In this test, the drone was operated in altitude position hold mode through manual control.

Black Carbon Aerosol Monitor (micro aeth- model AE51)

1) Sonde-type air temperature, air pressure, and relative humidity sensor (Vaisala)

2) Carbon monoxide (CO), nitrous oxide (NO_2), sulfur dioxide (SO_2), ozone (O_3) + nitrogen (N_2) sensors.

3.5.2 Drone-based atmospheric observations using sensors mounted at 650 mm elevated from the axis of propellers

In this test, the mounting position of Air Quality Index parameter sensors was 650 mm elevated from the axis of the propeller (**Figure 10**) by using the ready-to-pick bucket item which was suitable for fixing to the seating and sensors. The whole setup was mounted on the central top plain surface of the drone assembly and weighed approximately 2.2 kg. This test was performed to ensure the proper functioning of air quality sensors under the influence of heavy-duty propellers. A drone with an air quality sensor mounted at almost 650 mm above the axis of propellers was flown up to 120 m vertical height at Thiruvidanthai near the ECR coast region of Tamil Nadu and data sets were observed. The above measurement cycle was repeated twice. In this test, Air Quality Index parameters were observed at every 10 m height by holding the position for 60 seconds. The drone was operated in position-hold mode through manual control. The drone flew at almost 1m/sec speed while ascending and 3 m/sec while descending. The RF link between the drone and Ground Control Station was checked continuously and remained at 99 %.

4. Conclusions

Beyond surveillance and delivery applications, UAVs are nowadays used for drone journalism, search and rescue, disaster response, asset protection, wildlife monitoring, firefighting, communications relay, healthcare, agriculture, digitization of land topography, etc. NIOT initiated adopting drone technology for marine applications and customized a heavy lift small category hexacopter drone. The initial trials of drone based ocean data collections, seawater sampling, atmospheric observations, and beach mapping activities by NIOT were briefly discussed in this article. The customized drone's stability and maneuverability were observed to be excellent, withstanding the coastal wind conditions. The suitability and the field performance of the customized drone towards the ocean data collection and atmospheric measurements were found to be satisfactory. NIOT will further explore all possible ways of extending drone utility in Marine applications to provide more societal benefits.

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