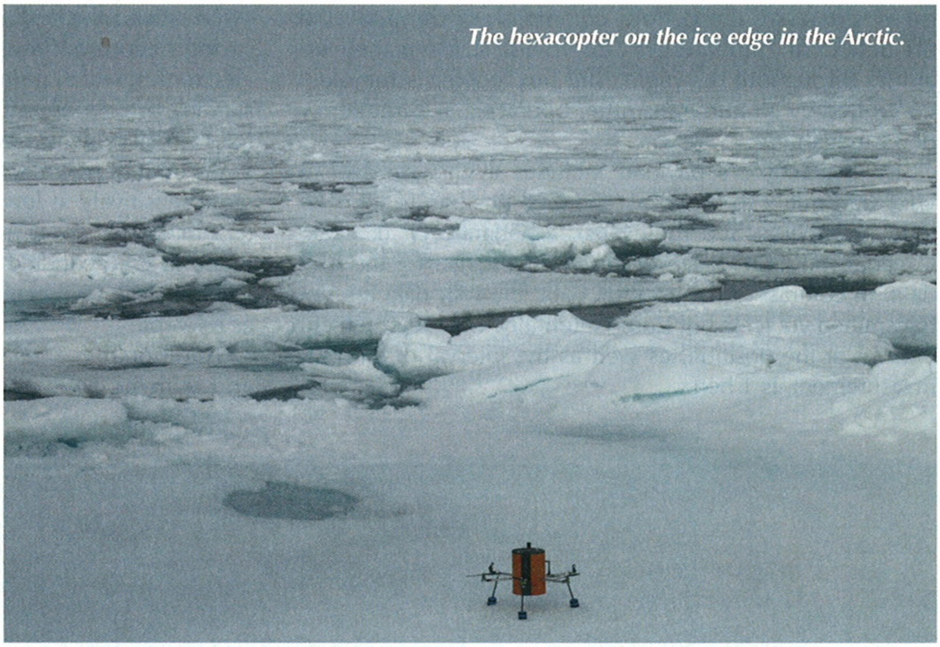
Flying Drone for AUV Under-Ice Missions

Remotely Controlled Drone Aids Arctic Measurements, Ice Tracking

By Sascha Lehmenhecker • Thorben Wulff



The hexacopter on the ice edge in the Arctic.

Starting in 2010, the Alfred Wegener Institute (AWI) has deployed a Bluefin Robotics Corp. (Quincy, Massachusetts) Bluefin-21 AUV in several dives under Arctic sea ice. All dives were conducted close to AWI's deep-sea observatory, Hausgarten, which is located west of the Svalbard Archipelago in the ice-margin zone of the Fram Strait.

Since the ice-margin zone is a highly dynamic environment, it is crucial to track the position of the ice edge to define the AUV's mission parameters. In 2011, a GPS-based tracking system was developed to mark the ice edge and to observe the ice drift before and during an under-ice dive.

However, deploying the transmitters on the ice turned out to be risky and time-consuming. To facilitate the deployment of the tracking system on the ice, a remotely controlled flying drone was developed for polar operations.

Basic Conditions

The major goal was to design a vehicle able to carry a GPS transmitter along with other instruments onto the ice and back without using, for example, a rigid inflatable boat (RIB) for deployment. Conceptual plans considered the flying drone as a transporter that deploys instruments on the ice and then flies back to the ship. After completing all the measurements, the drone would return and recover the instruments from the ice. However, fog and the ice drift could cause difficulties in finding the location again.

Thus, it was decided the drone would land on the ice and stay there to act as a GPS transmitter. Along with the GPS transmitter, a sensor for photosynthetically active radiation (PAR) would be integrated to measure light on the ice and represent a surface reference for the AUV's PAR sensor. As AUV dives may take up to 10 hours, an operational time of 14 hours on the ice was considered to be mandatory for the drone.

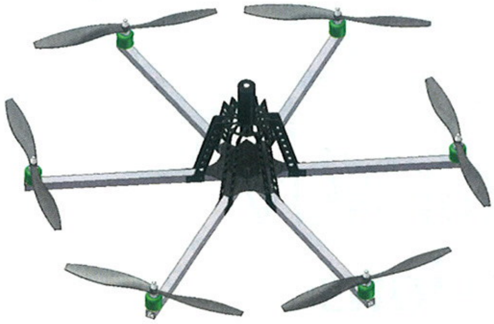
Functional Principle

Preliminary tests conducted with a four-engine drone, or quadrocopter in harsh conditions such as crosswinds proved reduced in-flight stability compared to a six-engine drone concept, or hexacopter. A hexacopter can also lift larger weights than a quadrocopter of the same size and offers bigger safety reserves. For example, a hexacopter is able to compensate for the stability problems caused by an engine failure, whereas a quadrocopter would suffer an uncorrectable thrust imbalance and most likely a crash.

The hexacopter's mainframe consists of an aluminum frame with six arms arrayed radially outward from a center point. The arms are made of square tubes (15 millimeters by 15 millimeters) and have a length of 350 millimeters each. At the center point, the entire electronics of the hexacopter is mounted in a lightweight carbon structure. For insulation, the hexacopter is protected by a 3-centimeter-thick Styrofoam hull. Only the ends of the aluminum arms and the PAR sensor stick out of the hull. Additionally, the insulation offers sufficient buoyancy to make the hexacopter float in case of a crash or an emergency landing.

For visibility reasons, the outer hull of the hexacopter is painted in bright orange. Only a vertical line at the rear side of the hexacopter and the upper side of the hull are painted in black. With the black line, the pilot can determine the hexacopter's orientation. The black topside of the hull is to minimize the reflection of incoming sunlight so that the PAR sensor measures the downward radiation flux exclusively.

Six brushless motors with a shaft power of 110 watts are mounted at the end of the arms and point upwards. All motors have 12-inch-by-4.5-inch fixed-pitch propellers. With this propeller size and the engines running at a maximum speed of 10,000 revolutions per minute, the thrust of the hexacopter is approximately 47 newtons. As the hexacopter itself weighs about 3 kilograms, or 29 newtons, the remaining 18 newtons can be used for dynamic flight control. Roll, pitch and yaw rate of the hexacopter are controlled exclusively via motor speed. A microcontroller processes the control commands of the pilot and the data of an onboard gyro to provide stable maneuverability throughout the flight. The hexacopter is remotely controlled by a radio transmitter operating at a frequency of 35 megahertz.



A computer-aided design model of the hexacopter.

The hexacopter's payload includes a GPS receiver, a UHF transmitter to broadcast the GPS position to the ship (869 megahertz, 500 milliwatts), a Satlantic LP (Halifax, Canada) PAR-LOG-S sensor and a data logger for the PAR data. In contrast to the position data, the PAR data are not transmitted via UHF but stored internally. The measurement interval of the position, as well as the interval of the PAR measurement, is 1 hertz.

The hexacopter's power supply consists of three Hacker Motor GmbH (Ergolding, Germany) TopFuel LiPo 30C-LIGHT 4,000 milliampere-hour 3S lithium polymer batteries, with 11.1 volts, 45 watt-hours and an overall nominal capacity of 12 ampere-hours. Two of the batteries (8 ampere-hours) are assigned to the engine circuit, providing power for flight electronics and engines.

With an average power consumption of 32 amperes during flight, the hexacopter is able to fly for about 15 minutes. One battery (4 ampere-hours) is assigned to the payload circuit, providing power for the GPS receiving-transmitting unit, the PAR sensor and its data logger.

To extend the endurance of the hexacopter, an energy-saving sleep mode was implemented. In this mode, flight electronics, which normally consume up to 0.4 amperes in standby, are almost entirely switched off and only the payload circuit remains powered.

As lithium polymer cells are commonly known to react quite sensitively at low temperatures, and as the hexacopter's interior is not actively heated, the batteries had to be tested in cold conditions. Cooling the cells down to -4° C resulted in a 10 percent capacity loss, which was defined as tolerable.

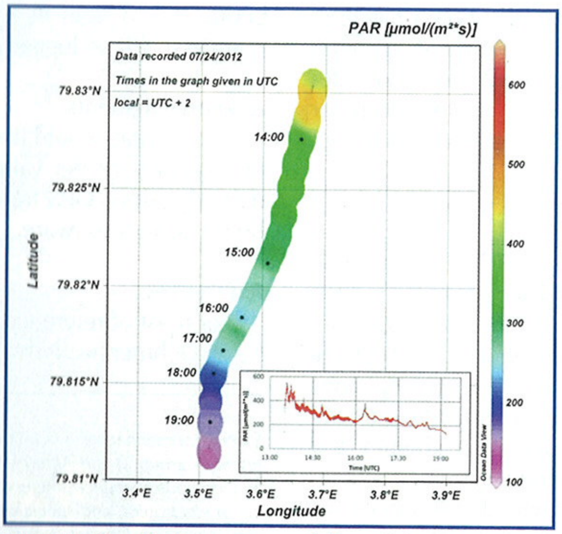
Additionally, after spending several hours on the ice and with its cells entirely cold, the hexacopter has to take off from the ice again, forcing the cells to cope with high currents of up to 68 amperes during launch phase. Tests with the hexacopter at temperatures of -7° C proved the currents to be unproblematic.

Arctic Deployment

Initial Arctic deployment of the hexacopter took place in the Fram Strait in July 2012 during expedition ARK-XXVII/2 using the RV *Polarstern*.

In order to mark the ice edge and prepare an under-ice dive of AWI's Bluefin-21 AUV, the hexacopter was deployed at a position close to 79 degrees 50′ north and 03 degrees 40′ east. The ice field consisted of fast moving, different-sized, separate ice floes. *Polarstern*'s radar was used to determine the general orientation of the ice edge and to find suitable floes to mark the field.

Eventually, the hexacopter lifted off from *Polarstern*'s stern deck and landed on the ice within sight range. An additional GPS transmitter was deployed using an RIB 1 kilometer further east to clearly mark the ice edge's orientation. With *Polarstern* leaving the area, the hexacopter started to transmit its position and gather PAR data.



Map showing the hexacopter's drift and the development of PAR values over time.

Meanwhile, the AUV was deployed and the inertial navigation system alignment procedure was started, giving the operator time to observe the ice drift and adjust the AUV's mission file accordingly.

After two dives in the ice-margin zone and a total mission time of about 3.5 hours submerged, the AUV was recovered and *Polarstern* approached the position of the hexacopter.

When the hexacopter came into sight, it was woken up from sleep mode and flown back to *Polarstern*. It landed back safely on the vessel after having spent 5.5 hours on the ice. Waking up the hexacopter from its sleep mode and lifting off from the ice were carried out without any problems.

During a second deployment on the following day, the hexacopter logged another 5.5 hours on the ice. The maximum distance between the hexacopter and *Polarstern* while still receiving a signal was 3 kilometers. The hexacopter drifted to the southwest following a heading of roughly 247 degrees at an average speed of about 1 kilometer per hour. The orientation of the ice edge was almost 90 degrees, with the ice in the north.

Data acquisition with the PAR sensor worked flawlessly. As it was a day with scattered clouds, the PAR diagram showed the expected spikes and dips, with a smooth decline towards the evening. Nevertheless, due to the polar day, the PAR values remained relatively stable throughout the day.

Future Prospects

The hexacopter is a platform that could be useful to all kinds of experiments. By marking the ice edge and conducting PAR measurements, expedition ARK-XXVII/2 demonstrated only one way that marine operations could benefit from flying drones. The plan is to enlarge the working range of the hexacopter significantly with, for instance, camera-controlled flights, improved communication abilities and more autonomy via an automatic homing system.

At least for 2013, the scientific payload will remain the same. However, the type of PAR sensor will be changed from one with logarithmic output to a sensor with linear output (Satlantic's PAR-LIN-S). Within the range of the measured PAR values, which were relatively high on the surface of the ice, a linear sensor offers a higher resolution, whereas a logarithmic PAR sensor is used on AWI's AUV to make use of its high resolution at low PAR values.

Additionally, since PAR sensors are equipped with a cosine collector, the inclination of the hexacopter with respect to the sun is important. Especially as the hexacopter is operated in high latitudes where the sun remains low above the horizon, the resulting error caused by a tilted and moving sensor, for example, due to waves under the ice, is relatively big. To correct the data, the inclination angles of the hexacopter (taken from its gyro) and its orientation (using the compass) will be logged in the future.

Acknowledgments

The authors would like to thank Kimberly Shurn of Bluefin Robotics for her valuable assistance in feeding the signals of various GPS transmitters into Bluefin's AUV Dashboard control software.

References

For a list of references, contact Sascha Lehmenhecker at sascha.lehmenhecker@awi.de. ■

Sascha Lehmenhecker is a member of the deep-sea research group at the Alfred Wegener Institute. He is a computer science engineer with special training in electronics, and specializes in microcontroller applications and circuit design. He has a bachelor's degree from the University of Applied Sciences in Bremerhaven, Germany.

Thorben Wulff is a Ph.D. student at the Alfred Wegener Institute. He has a bachelor's and master's in mechanical engineering, both from the University of Applied Sciences in Mannheim, Germany. Funded by the European Union in the frame of project EUROFLEETS, he is working on interoperable payloads for European AUVs.