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UAV-BORNE COHERENT DOPPLER LIDAR FOR MARINE ATMOSPHERIC BOUNDARY LAYER OBSERVATIONS

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ABSTRACT

A compact UAV-borne Coherent Doppler Lidar (UCDL) has been developed at the Ocean University of China for the observation of wind profile and boundary layer structure in Marine Atmospheric Boundary Layer (MABL). The design, specifications and motion-correction methodology of the UCDL are presented. Preliminary results of the first flight campaign in Hailing Island in December 2016 is discussed.

1. INTRODUCTION

Wind profiles and atmospheric boundary layer structure are important for MABL dynamics study. The coherent lidar employing heterodyning technique has been demonstrated to be an effective tool for wind measurements for the marine atmospheric boundary layer where considerable aerosol particles present. The unmanned airborne coherent lidar can help improve the ability of meteorological detection and data assimilation in remote areas, especially for MABL, which compensates for the shortcomings of existing fixed weather stations, buoys and sounding balloons. In order to investigate the capability of automatic observations for coupled ocean-atmosphere dynamics, a compact UAV-borne Coherent Doppler Lidar (UCDL) prototype has been developed by Ocean University of China. Other instruments aboard include a synthetic aperture radar (SAR) for ocean wave measurement and in-situ sensors for temperature and humidity profiling. The UCDL is installed in a small unmanned helicopter which can ben taken off and landed on a research vessel as shown in Figure 1.

Figure 1. Shipborne UAV ocean observation system

2. SYSTEM DESIGN

The UCDL operates at the wavelength of 1.5 μm which is safe for human eyes. A modified Velocity Azimuth Display (VAD) scanning patterns were used, with the maximum measurement range up to 3 km. The Doppler spectral estimates are processed with FPGA and are sent back to the data server in the ship in real time via the UAV datalink up to 100 km. The simplified diagram of UCDL is shown in Figure 2.The system specifications are summarized in

Table 1. Because of the utilization of the robust semi-conductor single frequency laser and the Erbium doped fiber amplifier, the system works stably even under vibration and temperature variation during flight, more than 20 degree from the sea surface to the height of 3500 m.

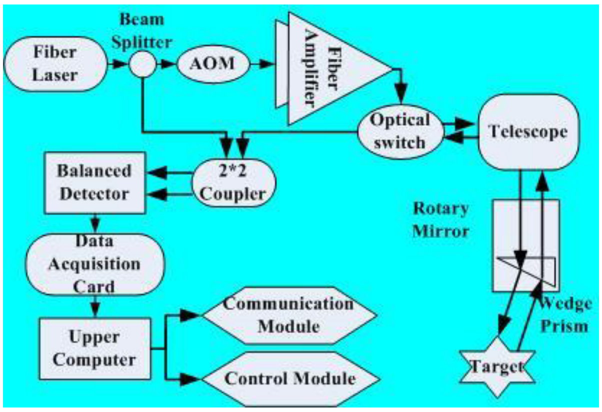

Figure 2. The schematic of UCDL system

Table 1. The specifications of the UCDL

UCDL parameters	
Wavelength	1.5 μm
Pulse Energy	100 μJ
Pulse Duration	200 ns
Pulse Repetition Frequency	10 kHz
Radial Spatial Resolution	30 m
Measurement Range	50 to 3500 m
Wind Profile Average Time	1 min
Velocity Measurement Range	± 60 m/s
Resolution of Velocity	0.3 m/s
Power Consumption	90 w
Weight	23.2 kg
Size	460×370×270 (mm)
Eye Safety Standards	EN60825-1:2007

Before the installation in UAV, all the modules and the lidar as a whole have been tested for the thermal adaptability, the anti-vibration performance, the data link communication, and the electro-magnetic-compatibility test, etc.

3. DATA PROCESSING

The radial velocity is obtained from the peak value of the FFT spectrum data at different range gates. Then the wind speed and direction are determined using VAD fitting method [1]. It is necessary to record and correct the effect of UAV attitude and velocity in real time and calculate the true radial speed. We obtain the UAV attitude and velocity information from the Global Navigation Satellite System (GNSS) and Inertial Measurement Unit (IMU) carried in the UAV, which are used for the retrieval and correction of the UCDL wind speed as listed in table 2.

Table 2. UAV attitude and velocity information

a. Roll angle **α** (IMU)
b. Pitch angle **β** (IMU)
c. Yaw angle **γ** (IMU)
d. Latitude (GNSS)
e. Longitude (GNSS)
f. Height (GNSS)
g. Forward velocity (IMU)
h. Lateral velocity (IMU)
i. Vertical velocity (IMU)

Attitude data (a, b and c in table 2) are used in the calculation of the pointing direction of the UCDL, and the true heading is corresponds to the UAV yaw angle [2]. Longitude and latitude (d and e) provide the geolocation. Amongst others, the height above the sea level (f) is used to determine the location of the UCDL range gates. The velocities (g, h, and i) are the velocity vectors of the UAV. Considering the UAV velocity and the UCDL pointing direction, the components of UAV velocity in each pointing directions could be calculated and corrected, then the real atmospheric wind profile and visualization products is derived based on the algorithm of correction and retrieval, including wind speed and direction information from 50 m above the sea surface to the altitude of the UAV. The height information of MABL could be derived based on the SNR data at the same time.

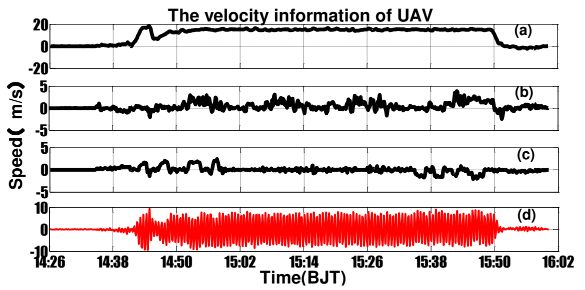

Figure 3. The velocity information of UAV in one flight

Figure 3 is a record of the velocity of UAV by the IMU. Figure 3 (a), (b), and (c) are the forward velocity, lateral velocity, and vertical velocity, respectively. Figure 3 (d) is the projection component of the UAV velocity in the lidar pointing direction, which is used for the velocity correction later on.

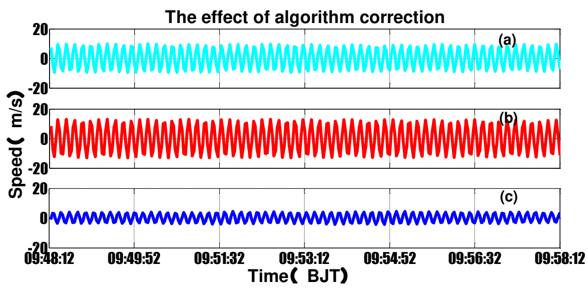

Figure 4. The effect of algorithm correction

Figure 4 shows the measurements and calibration of UCDL. Figure (a) is the raw radial velocity by UCDL, while Figure (b) shows the components of UAV velocity calculated from each pointing direction. The calibrated results of radial wind velocity is shown Figure 4 (c), which is used for wind speed and direction profile retrieval.

4. AIRBORNE EXPERIMENTS

Several field campaigns were conducted at Qingdao and Yangjiang, including the ground measurements, low-altitude flight experiments, and the data link test experiments. The first UAV flight campaign over ocean was carried out in Hailing Island, Yangjiang from November 5 to December 21, 2016. More than ten flights at different heights (800m, 1100m, 1200m, 1500m) from different periods (morning, noon and nightfall) were conducted. Concurrent measurements by in-situ sensors and SAR were performed. Satellite data were also collected as well for further validation analysis.

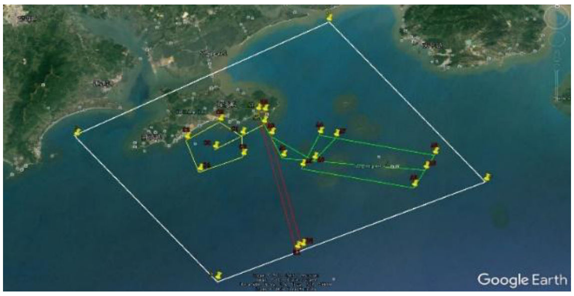

Figure 5. Airspace and flight routes of the first experiment in Hailing Island

Figure 5 shows three flight plans. The experiments consisted of two phases: UAV was flown from the land (Phase I) and from a barge (Phase II). Route A (Green Line): UAV was taken off / landed at point S1 (Ground) to observe the wind profile of over the Nanpeng Island. Route B (Red Line): UAV was taken off/landed at point S1 (Ground) to monitor both the wind file and MABL structures. Route C (Yellow Line): UAV was taken off at point S2 (Barge), observed the wind profile along the coastal area, and landed at point C6 (Barge). Route A (Green Line) and Route B (Red Line) experiments were performed during Phase I; Route C (Yellow Line) experiment was conducted during Phase II. The UAV was taken off/landed on a barge, while the barge was kept moving from point S2 to C6 during the experiment.

5. RESULTS

During the experiments, the wind profile and

MABL were observed, some preliminary results from the first flight campaign are presented in Figure 6.

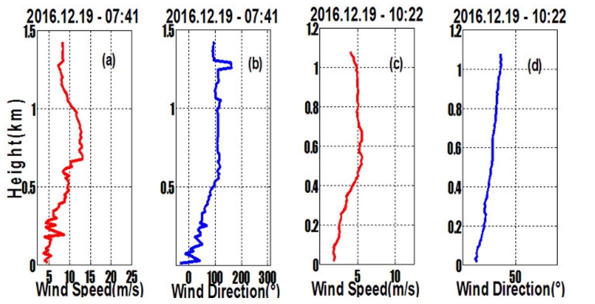

Figure 6 Wind profile measured by UCDL over Hailing Island on Dec 19th, 2016.

Figure 6 (a), (b) are the wind speed and direction profile from 50 m to 1425 m above the sea surface when the UAV was flown at the height of 1500 m at 07:41, December 19, 2016. Figure 6 (c), (d) are the wind speed and direction profile from 50 m to 1125 m above the sea surface when the UAV was flown at the height of 1200 m at 10:22 at the same day. As Figure 6 (b) shows there are wind shear in the direction at the height of 1300 m. During the campaign, a coherent wind lidar, WindPrint S4000 from Seaglet Environmental Technology, conducted ground wind observations for validation.

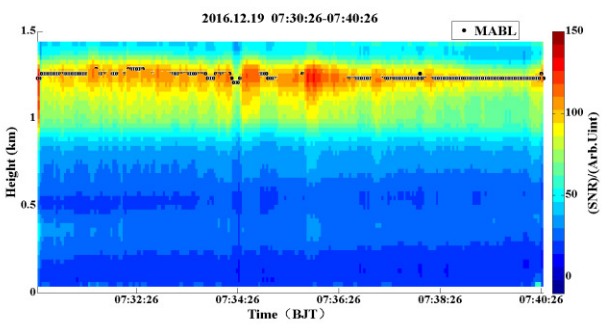

Figure 7 MABL measured by UCDL in Hailing Island on Dec 19th, 2016.

In addition to the wind profile, the MABL structure was derived from the Doppler spectrum of the UCDL. The backscatter signal is retrieved according to the peak height of FFT spectrum and the standard deviation of SNR profile [3]. The MABL height was determined by UCDL from 07:00 to 08:00, December 19, 2016 (as shown in Figure 7). The averaged MABL height is about 1300 m, corresponding to the wind direction shear events shown in Figure 6 (b).

6. CONCLUSION

OUC team developed the UCDL and conducted the first flight campaigns at the coastal area. The wind observation and the velocity correction has been conducted and analyzed. The ground based wind measurements and concurrent atmospheric probing data were obtained for further analysis.

ACKNOWLEDGEMENT

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