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IMPLEMENTATION OF A DOPPLER LIGHT DETECTION AND RANGING (LIDAR) SYSTEM FOR THE HONG KONG INTERNATIONAL AIRPORT

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1. INTRODUCTION

Hong Kong is implementing a Doppler LIght Detection And Ranging (LIDAR) System at the Hong Kong International Airport (HKIA) to supplement the Terminal Doppler Weather Radar (TDWR) in the detection and warning of low-level wind shear under clear-air conditions.

Installed in 1996, the TDWR has proved to be effective in the detection and warning of low-level wind shear in rainy weather. However, reports of wind shear received from aircraft pilots landing at or taking off from the new HKIA since its opening in 1998 indicate that it is possible for low-level wind shear to also occur in clear-air conditions, under which TDWR return signals are not always available. Studies have shown that a majority of these low-level wind shear events were associated with airflow reaching the airport after crossing the hilly terrain of Lantau Island south of the airport. To handle such situations, a new means of detection not dependent on raindrops has to be identified, i.e. a Doppler LIDAR operating at 2-micron wavelength which is capable of receiving return signals from aerosols in clear air to provide Doppler wind measurements in fine weather.

This paper presents the overall plan of the LIDAR implementation in Hong Kong. Installation of the equipment is scheduled for mid-2002, to be followed by evaluation of its performance in the local environment. Important considerations like system characteristics, site selection, scan strategy and laser safety will be discussed. Similarities and differences between the LIDAR and TDWR in respect of low-level wind shear detection will be highlighted.

2. TERRAIN- INDUCED WIND SHEAR

The HKIA at Chek Lap Kok (CLK) has two parallel ENE-WSW oriented runways designated as RWY 07L/25R and RWY 07R/25L. The HKIA was built on reclaimed land to the north of a rather mountainous island, the Lantau Island. Figure 1 illustrates the complex terrain of Lantau Island and location of the HKIA and its approach/departure corridors relative to this terrain. The ENE-WSW oriented island has a width of about 5 km and length of about 20 km. In the middle of Lantau, a U-shape ridge with peaks rising to between 750 and 950 m above mean sea level (amsl) and mountain passes as low as 350 to 450 m amsl separating these peaks. To the southwest of this U-shape ridge, an ENE-WSW oriented ridge rises to between 400 and 500 m amsl at many locations along the ridgeline.

A TDWR was installed at Tai Lam Chung at about 12 km northeast of the airport (see Figure 1 for location of the TDWR) for detecting microburst and wind shear associated with convective storms (Shun and Johnson 1995). A network of ground-based anemometers over and in the vicinity of the HKIA, together with two wind profilers over Lantau, form part of the low-level wind shear detection facilities.

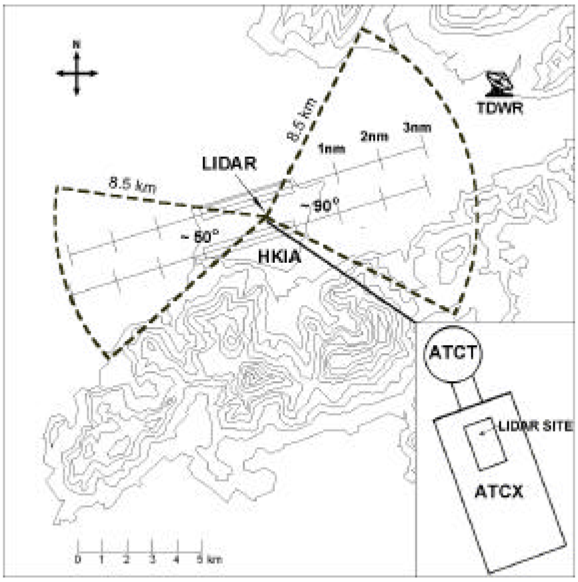

Figure 1. Map of HKIA, its approach/departure corridors and surrounding areas. Terrain contours are given in 100 m intervals. Locations of the TDWR and LIDAR are marked with possible LIDAR scan sectors overlaid. Inset shows the LIDAR site at the roof-top of the Air Traffic Control Complex (ATCX) and its location relative to the Air Traffic Control Tower (ATCT).

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Case studies of wind shear reports received from aircraft pilots landing at or taking off from the HKIA have shown that it is possible for the airflow reaching the airport after crossing the complex terrain of Lantau to be highly three-dimensional with shear in both the horizontal and vertical, and at a spatial scale as small as several hundred metres (equivalent to time scale of several seconds of flight time). The wind shear events also exhibited highly transient and sporadic behaviour, resulting in some aircraft experiencing wind shear, but not others, even though the broad meteorological conditions were the same. The majority of these terrain-induced wind shear events occurred in clear-air conditions. These characteristics of terrain-induced wind shear present the following difficulties in accurate and reliable detection of wind shear over the airport approach/departure corridors:-

(a) Clear-air returns are not always available from the TDWR. Even when they are available, the Doppler velocity data is not of consistently good quality. These often result in substantial difficulties in wind shear recognition under fine weather conditions even by experienced meteorologists;

(b) Installed at an off-airport location, the TDWR radar beam at any given elevation angle (the lowest azimuth scan for microburst detection at 0.6 degree) intersects the atmosphere at different altitudes at different radar ranges. Because of the highly three-dimensional nature of the terrain-induced wind flow, the detected shear along any given radial of the TDWR may not represent the conditions actually experienced over the flight paths; and

(c) Winds observed by the ground-based anemometer network and the two wind profilers do not represent well the conditions actually experienced over the flight paths.

To address these difficulties, a new means of remote sensing designed for continuous autonomous operation has to be found. It should be capable of providing the following:-

(a) Good quality wind data in clear-air conditions;

(b) Good data coverage representative of flight path conditions; and

(c) Data at a high update rate (at least one update per minute).

3. LIDAR TECHNOLOGY

During 5 May – 3 July 1994, a mobile 2.09–micron solid-state coherent Doppler scanning LIDAR (Henderson et al. 1993) was first deployed in Hong Kong as part of a field measurement program to study the wind shear and turbulence conditions at CLK (Neilley et al. 1995). The LIDAR transceiver employed a diode-pumped single-frequency Tm,Ho:YAG laser for the local oscillator source and to seed a flashlamp-pumped Q-switched Cr,Tm,Ho:YAG laser. The Q-switched laser typically produced ~ 28-mJ, 170-ns single-frequency pulses at a pulse repetition frequency (PRF) of ~ 5 Hz. The pulsed output was expanded using a 10-cm-diameter off-axis telescope and directed into the atmosphere using a two-mirror computer-controlled scanner. The entire LIDAR system was contained in a 2.4 m (w) x 3.8 m (l) x 2 m (h) truck-mounted compartment.

During the two-month period in 1994, the LIDAR was able to provide Doppler wind data to 12 km on a majority of measurement days. These Doppler wind data revealed velocity streaks and wind reversal downwind of the Lantau terrain, similar to observations of TDWR collected over the past few years (Hannon et al. 1995; Shun and Lau 2000). However, due to the relatively low PRF of ~ 5 Hz, a full 360-degrees azimuth scan took approximately 15 minutes to complete. Also, routine alignment and adjustments by trained personnel were necessary to maintain the operation of the laser equipment. The LIDAR technology was therefore not yet ready at the time to be included as part of the operational wind shear detection facilities for HKIA.

In recent years, development and improvement of the LIDAR technology resulted in the availability of solid-state coherent pulsed Doppler scanning LIDAR with high PRF designed for continuous autonomous operation. The Hong Kong Observatory (HKO) placed an order in 2001 for a Doppler LIDAR. Its major characteristics are summarized in the following tables:-

Transceiver	
PRF	500 Hz +/- 10 Hz
Pulse energy	2 mJ +/- 0.5 mJ
Pulse duration	400 ns +/- 150 ns
System optical/detection efficiency (electrons/photon)	>10%
Operating wavelength	2022.5 nm (Tm:YAG laser)
Aperture diameter	10 cm
Range resolution	~ 100 m
Maximum unambiguous velocity range	+/- 20 ms^{-1} (extendable to +/- 40 ms^{-1})
Measurement distance Maximum Minimum	 Up to ~10 km 400 m

Scanner	
Aperture diameter	11.6 cm
Azimuth range	Full 360 degrees azimuth scans or sector scans
Elevation	0 to +180 degrees
Maximum scan speed	20 degrees/second
Pointing accuracy	0.1 degree
Position resolution	0.01 degree
Position repeatability	0.05 degree

4. LIDAR SITE SELECTION

For detection of wind shear over the approach/departure corridors of the HKIA, it is necessary to remotely sense low-level winds out to at least 3 nautical miles (nm) (or 5.6 km) from the runway ends. Taking into consideration the runway length (3.8 km) and the small longitudinal displacement of the two parallel runways at HKIA, the normal range of the LIDAR (10 km or less) dictates an on-airport siting near the centre of the runway complex. An on-airport siting also has the benefit of the LIDAR being able to scan directly towards the approach/departure corridors, hence measuring Doppler radial winds closely representative of the head wind conditions of aircraft landing at or taking off from the airport. Also, the compact size of the entire LIDAR equipment, including shelter (2.3 m (w) x 2.9 m (l) x 2.4 m (h)), facilitates its siting within an airport.

The Doppler LIDAR for the HKIA will be installed at the roof-top of the Air Traffic Control Complex (ATCX) which is located between the two parallel runways (see Figure 1). Installed on top of the LIDAR equipment shelter, the LIDAR scanner will be located at an altitude of about 50 m amsl, or around 43 m above the runways. At this height, the possible reduction of signal-to-noise ratio of LIDAR returns due to effects of refractive turbulence generated by solar heating of the aerodrome ground surface is less compared with a ground-level site. Furthermore, blockage of the LIDAR beam by airport structures is minimal at this height with the Air Traffic Control Tower (ATCT) to the immediate NNW of the ATCX (see inset of Figure 1) being the only exception. This blockage is not expected to pose difficulties to detection of low-level wind shear over the approach/departure corridors since the directions blocked are essentially at right angles to the runway orientation. At this site, building infrastructures including electrical power, telecommunication facilities, lightning protection are readily available to support operations of the LIDAR equipment.

5. SCAN STRATEGY

Based on the coherent LIDAR equation given in Targ et al. (1991), taking the refractive index structure constant of the atmosphere to be 10^{-14} $m^{-2/3}$ and the one-way horizontal extinction coefficient of the atmosphere to be –0.3 dB/km, the overall single-pulse system sensitivity will be such that an infinite uniform aerosol target with volume backscatter coefficient of 10^{-6} m^{-1} sr^{-1} (-60 dB β) provides a LIDAR return signal with 0 dB or better narrowband (matched filter) signal-to-noise ratio (SNR_N) at a horizontal range of 8 km. At this level of system sensitivity, the system is expected to achieve accurate estimates of the mean radial velocity at horizontal ranges between 400 m and 8 500 m at a line of sight (LOS) update rate of 10 Hz. With the LIDAR site lying closer to the eastern side of the airport, a Doppler velocity data coverage of 8 500 m will facilitate detection of wind shear out to 3 nm (or 5.6 km) from the runway ends over the western approach/departure corridors and out to about 4 nm (or 7.4 km) from the runway ends over the eastern approach/departure corridors.

Due to the above-mentioned asymmetry of the LIDAR site location relative to the runways, to ensure complete coverage of the airport approach/departure corridors including the touchdown zones, the scan strategy will likely consist of two sectors of different angular widths, with the eastern sector covering roughly 90 degrees and the western sector covering roughly 50 degrees (see Figure 1). By scanning at 10 degrees/second with a LOS update rate of 10 Hz, these two sector scans together will require approximately 14 seconds to complete for any given elevation angle. Within a time period of one minute, this will permit scanning at least two different elevation angles to cover the different flight path angles of approach (~ 3 degrees) and departure (~ 6 degrees). This will leave sufficient time for the LIDAR to scan the other required azimuth angles (at higher scan rates where possible) while maintaining a data update rate of at least once per minute. This data update rate is comparable with the TDWR quick sector scan strategy (known as the “hazardous weather mode”) for microburst detection. At this stage, Range Height Indicator (RHI) scans are not envisaged as part of the routine LIDAR scan strategy but will be conducted on a need basis to probe the vertical structure of the flow disturbances downwind of the Lantau terrain.

6. LASER SAFETY

Another important consideration in operating a LIDAR in an airport environment is laser safety. In accordance with international standards, the transceiver of the LIDAR for the HKIA is classified as a Class 3b laser product as per the American National Standard ANSI Z136.1-2000 (ANSI 2000) and as a Class 3B laser product as per the International Electrotechnical Commission IEC 60825-1 standard (IEC 1998). In particular, if the LIDAR is not scanning, the stationary laser beam may potentially pose hazard to the cornea of the eye for optically aided viewing (i.e. laser beam viewed using magnifying optics such as binoculars) within about 6 km of the LIDAR site. In this connection, laser safety measures including sector blanking, scan rate interlock and physical barrier will be implemented to completely protect airport personnel, pilots, airport users and the public from the LIDAR laser transmission. A laser safety officer has been appointed, and is responsible for ensuring the effectiveness of these safety measures and for the safety aspects of LIDAR operations and maintenance.

7. FUTURE WORK

At the time of preparation of this manuscript, site preparation for installation of the LIDAR at the ATCX has been largely completed and equipment installation has been scheduled around mid-2002. Subject to system acceptance testing, the LIDAR will be put into experimental trial for reference by aviation forecasters in the issuance of low-level wind shear warnings. Graphical user interface (GUI) workstations will be installed at various locations for display of the LIDAR data in real-time and for immediate data archival and playback. High-speed data links will be installed to facilitate transmission of the large volume of LIDAR data to these workstations.

After equipment installation, similar to the TDWR (Johnson et al. 1997), optimization of system parameters including scan strategy, sector blanking settings, scan rate interlock settings, and customization of user-selectable settings such as map overlays, colour scales, etc. will be conducted. LIDAR data will be collected under different meteorological conditions for analysis by meteorologists to evaluate the data quality in the Hong Kong environment. In particular, the assumed values of the refractive index structure constant, one-way horizontal extinction coefficient, and volume backscatter coefficient discussed in Section 5 above will be reviewed on the basis of actual measurements. Subject to satisfactory quality in the data, detailed studies in conjunction with data of the TDWR, surface anemometer network and wind profilers will be conducted to see how new algorithms and software are to be developed to further enhance the low-level wind shear detection and alerting capability under clear-air conditions.

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