Field study of the performance of visibility sensors

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1. INTRODUCTION

Visibility is an important meteorological quantity for weather reporting and forecasting. Traditionally, visibility is assessed by human observer by observing the landmarks around the weather stations. It is more common now to use visibility sensors for automatic observation of visibility. There are two major types of visibility sensors in the market, namely, transmissometers that measure the extinction of a light beam over an extended distance in the air, and forward scatter sensors that measure the amount of light scattered in a small volume of air.

There are various limitations with the two kinds of visibility sensors. Transmissometers are considered to work in a similar principle to human observations with the use of visible light in a larger sampling volume. However, they have non-linear behaviour in the higher visibility (above 3000 m or so) and are subject to various limitations such as lens contamination and off-alignment with the bending of poles due to differential solar heating. On the other hand, forward scatter sensors are linear in behaviour, subject less to lens contamination and without off-alignment problem. But they have small sampling volume only and most of them use infra-red lights instead of visible lights. Moreover, different suspending particulates/water droplets in the air have different scattering properties, and the use of a fixed wavelength of the light and a fixed scattering angle may make a particular forward scatter sensor less suitable for working in certain climatological conditions.

The sensor for runway visual range (RVR) observations at the Hong Kong International Airport (HKIA), namely, the Flamingo transmissometers have been in use for more than ten years. A field study of the latest visibility sensors in the market is thus carried out at the airport to find a suitable replacement visibility sensor. In particular, the performance of the sensors is studied for the climatological condition in Hong Kong, especially for haze (in which the infra-red light forward scatter sensors are considered to behave not so well compared to visible light sensors) and fog/mist in which the amount of suspending particulates in the air could also be quite significant. Both transmissometers and forward scatter sensors are considered. Their performance is studied by using Flamingo transmissometer as a benchmark (for assuring continuity in the measurement). The data from these sensors are also examined using human visibility observations as reference.

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2. VISIBILITY SENSORS UNDER TESTING

The setup of the visibility sensors at the meteorological garden of HKIA is shown in Figure 1. Brief descriptions about the various sensors are given below.

Transmissometers:

Flamingo – It has been in use at HKIA since the opening of the airport in 1998. It is a double-base transmissometer with baseline length of 15 m for the short-base receiver and 75 m for the long-base receiver. The measurement range goes from 10 m to 10 km, but linear behaviour is expected between the visibility of 10 m to 3 km only. White light emitting diode is used with a flash frequency of 2.5 to 3.5 Hz. Lens cleaning and manual alignment have to be conducted carefully and regularly. Bending of the poles occurs in the summertime, leading to off-alignment of the optical path.

LT31 – This is the latest model of transmissometer from the manufacturer. Single-base is used with a baseline of 30 m. The measurement range starts from 10 m to 10 km. The measurement of higher visibility is made possible by equipping the transmissometer with a mini-unit of forward scatter sensor. For the transmissometer part, white light emitting diode is used with a modulation frequency of 1 kHz. There is automatic optical monitoring of lens contamination and alignment. If necessary, automatic compensation of the visibility data is made by detecting the degree of lens contamination, and auto-alignment is made with internal mechanical devices. Auto-calibration of visibility data is achieved with the use of the forward scatter sensor readings in high visibility condition. The sensor is claimed to fulfill the latest accuracy requirements of International Civil Aviation Organization (ICAO) but with no specific accuracy values.

Forward scatter sensors:

FD12P – This sensor has been in use at HKIA for 9 years as reference in the assessment of visibility. Apart from visibility, it gives present weather as well by measuring precipitation amount and temperature. The measurement range of the sensor goes from 10 m to 50 km with an accuracy of 10% from 10 m to 10 km, and accuracy of 20% above. Near infra-red light emitting diode is used with a peak wavelength of 875 nm with a scattering angle of 33 degrees. The modulation frequency is 2.3 kHz.

FS11P – This is the latest model of forward scatter sensor-based present weather sensor from the manufacturer. The measurement range of meteorological optical range goes from 5 m up to 75 km. The measurement accuracy is claimed to be 10% for 5 m up to 10 km, and 20% above, with scatter measurement accuracy of 3%. Near infra-red light emitting diode is used with a peak wavelength of 875 nm and modulation frequency of 2.2 kHz. A scattering angle of 42 degrees is used, which is the major difference from its former version FD12P. There is automatic detection function of lens contamination, and if necessary, compensation for contamination would be applied to the visibility readings.

PWD20 – As indicated by the manufacturer, it is a low-cost version of the forward scatter sensor. It has a measurement range of 10 m to 20 km, with an accuracy of 10% from 10 m to 10 km, and an accuracy of 15% from 10 to 20 km. Similar to FD12P and FS11P, near infra-red light emitting diode is used with a peak wavelength of 875 nm. The scattering angle is 45 degrees. Lens contamination is monitored, but there is no compensation for visibility value.

DF320 – It is a forward scatter sensor with a scattering angle of 35 degrees. Its major differences from the previously mentioned sensors of the same type include: (i) the use of visible light (350 to 900 nm), and (ii) much larger sampling volume of 5 dm^3 (the previously mentioned sensors has a sampling volume in the order of 0.1 cm^3). The light is amplitude modulated at 20 Hz. The measurement range goes from 5 m to 70 km. The accuracy is 10% for visibility up to 5 km, 15% from 5 to 20 km, and 20% for above 20 km.

To ensure the normal functioning of the above sensors, regular maintenance has been conducted. For instance, lens cleaning is performed three times a week. Alignment is conducted every half a year or so. Data from the various sensors are monitored routinely and corrective maintenance is carried out immediately if abnormal data are found.

3. COMPARISON WITH READINGS FROM FLAMINGO TRANSMISSOMETER

The visibility readings from the various sensors are compared with those of the Flamingo transmissometer, in order to ensure continuity of the visibility measurements. They are classified according to the weather reports at the end of each hour as made by the human weather observers at HKIA, namely, haze, mist/fog, and precipitation. Only the sensor readings in the 10 minutes before the end of the hour are considered. The period of study goes from November 2010 to May 2011.

The comparison is made in the form of a box plot: the y axis is the visibility reading from the Flamingo transmissometer as reference, and x axis is the ratio of the reading from the sensor under study to that of the Flamingo transmissometer. In each box plot, the ICAO accuracy requirement of visibility is also drawn as two blue curves. The box plots include the plotting of the median, the 1, 5, 25, 75, 95, 99 percentiles, as well as the minimum and the maximum ratios.

The results for the various weather types are presented in Figures 2 to 4. We would focus on the visibility readings of 3500 m or below because the Flamingo transmissometer is only able to provide reliable readings in this region. For haze, it could be seen that FD-12P tends to over-read the visibility. On the other hand, the other sensors give rather reasonable values. Many of the visibility ratios fall within the ICAO accuracy requirement curves.

For mist/fog, it appears that both FD-12P and DF320 tend to over-read the visibility. PWD20 also tends to have slight over-reading for visibility below 600 m. The performance of LT31 and FS11P appears to be rather satisfactory.

For precipitation, all the sensors have rather large spreads in the ratio for visibility over 1500 m. DF320 has apparent over-reading of visibility. On the other hand, the performance of LT31 and PWD20 appears to be satisfactory.

The performance of the various sensors is presented in Table 1, in which the proportions of visibility ratios falling within the ICAO accuracy requirement are shown. On the whole, it is interesting to note that the relatively low-cost PWD20 performs the best, particularly for haze. LT31 is also performing well, only that the proportion of accurate visibility ratio for haze is lower than that of PWD20 by about 18%. Please note that the comparison period is relatively short (7 months) and the amount of data considered in Table 1 for each sensor and each weather type (haze, mist/fog and precipitation) is in the order of 1000 to 2500 minutes. This amount of data is rather small compared to the minutes of weather observations in one year (87600 minutes).

4. COMPARISON WITH HUMAN OBSERVATIONS

The visibility readings from the various sensors are also compared with the human visibility observations (SYNOP) at the airport. It is noted that the two observations are very much different. The sampling volume is much larger in SYNOP. Moreover, minimum visibility in all directions of observation is taken in SYNOP report. . Therefore, the comparison results are quoted here just for reference only (particularly for visibility higher than 3500 m when the Flamingo transmissometer does not provide reliable readings) and they are not meant to judge the performance of the sensors. In the study period, there are about 200 to 300 readings in the comparison for each of the weather types, viz. haze, mist/fog, and precipitation.

The comparison results are shown in Table 2. Once again, the proportion of visibility ratio falling within the ICAO accuracy requirements is considered. In general, PWD20 has the best performance among all the sensors. For transmissometers, the performance of LT31 is comparable with that of Flamingo, and thus the former may work as a replacement of the latter while preserving the continuity of the visibility readings.

5. CONCLUSIONS

A field study of the latest visibility sensors in the market is conducted at the meteorological garden of

HKIA. Flamingo transmissometer is used as a reference for the assurance of continuity of visibility observation. It turns out that the low cost PWD20 has good performance in the limited period of the study for the various weather types, namely, haze, mist/fog, and precipitation (basically rain). For transmissometer, the latest model LT31 may work as a replacement of Flamingo.

Please note the above results are based on a study period of 7 months only. The field study would continue till the end of 2012. Further comparison results would be presented in future papers.

Figure 1 Setup of the visibility sensors under teseting at the Hong Kong International Airport

	FD12P	LT31	PWD20	FS11P	DF320
Haze	0.044	0.763	0.945	0.603	0.527
Mist/Fog	0.230	0.626	0.623	0.584	0.105
PPT	0.212	0.447	0.452	0.244	0.178
Others	0.047	0.118	0.141	0.070	0.062

Table 1 Proportion of visibility ratios of the various sensors fulfilling ICAO accuracy requirements, under different weather conditions. The Flamingo's visibility data are used as ground truth.

	FD12P	LT31	PWD20	FS11P	DF320	Flamingo
Haze	0.436	0.333	0.505	0.196	0.599	0.475
Mist/Fog	0.207	0.340	0.320	0.303	0.177	0.231
PPT	0.405	0.453	0.484	0.362	0.359	0.372
Others	0.580	0.502	0.705	0.389	0.381	0.378

Table 2 The same as Table 1 but using human observed visibility values as ground truth.

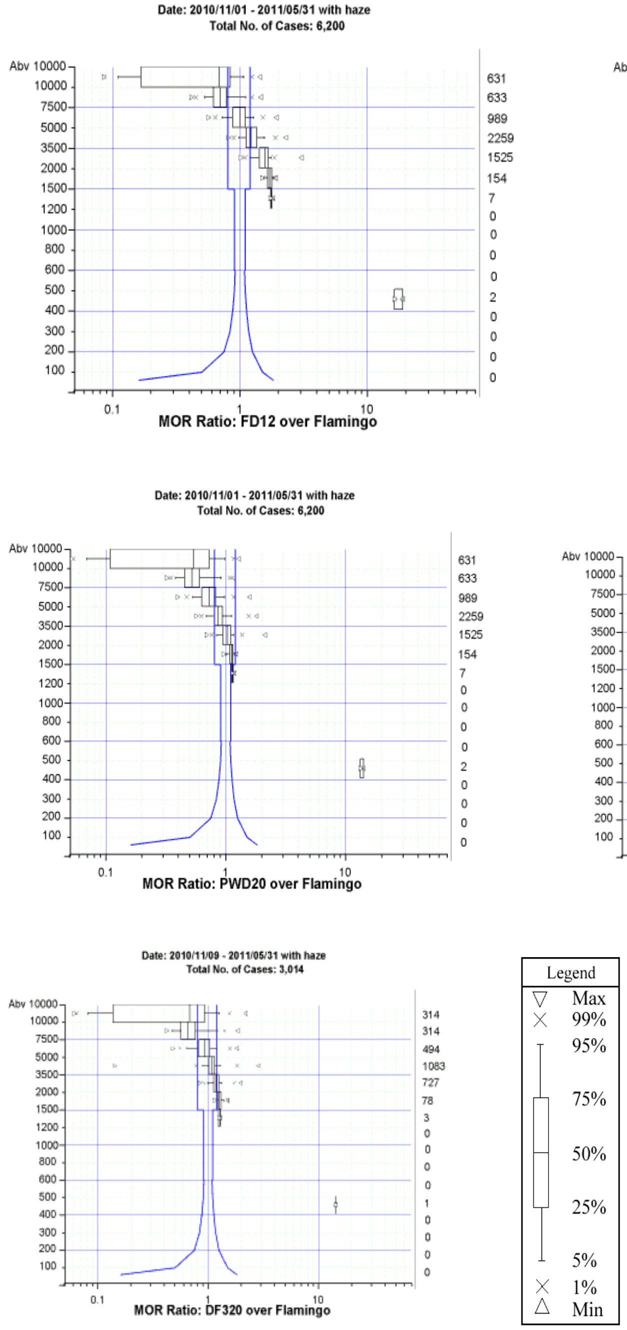

Figure 2   Box plots for the visibility sensors in haze weather.

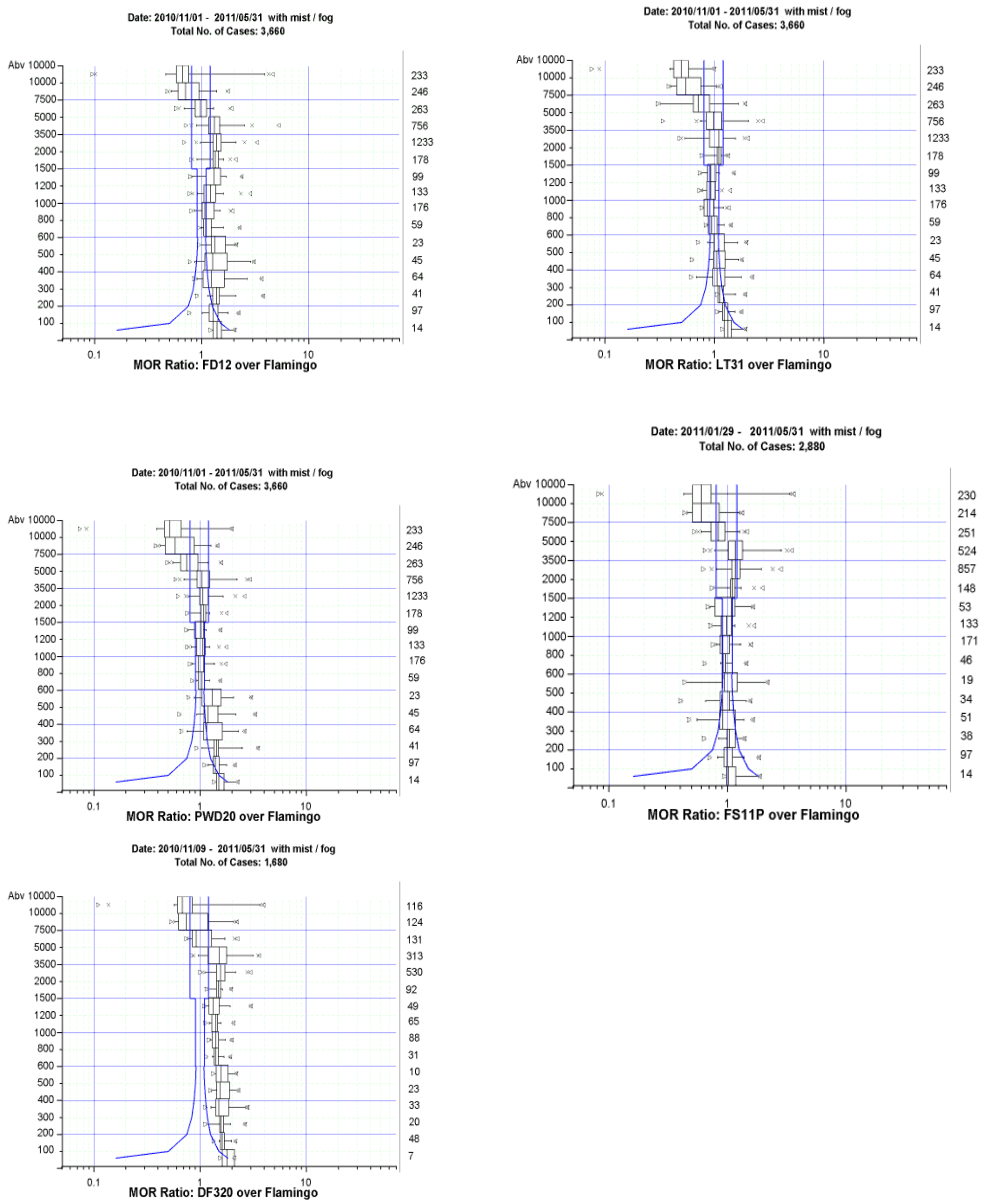

Figure 3 Box plots for the visibility sensors in mist/fog weather.

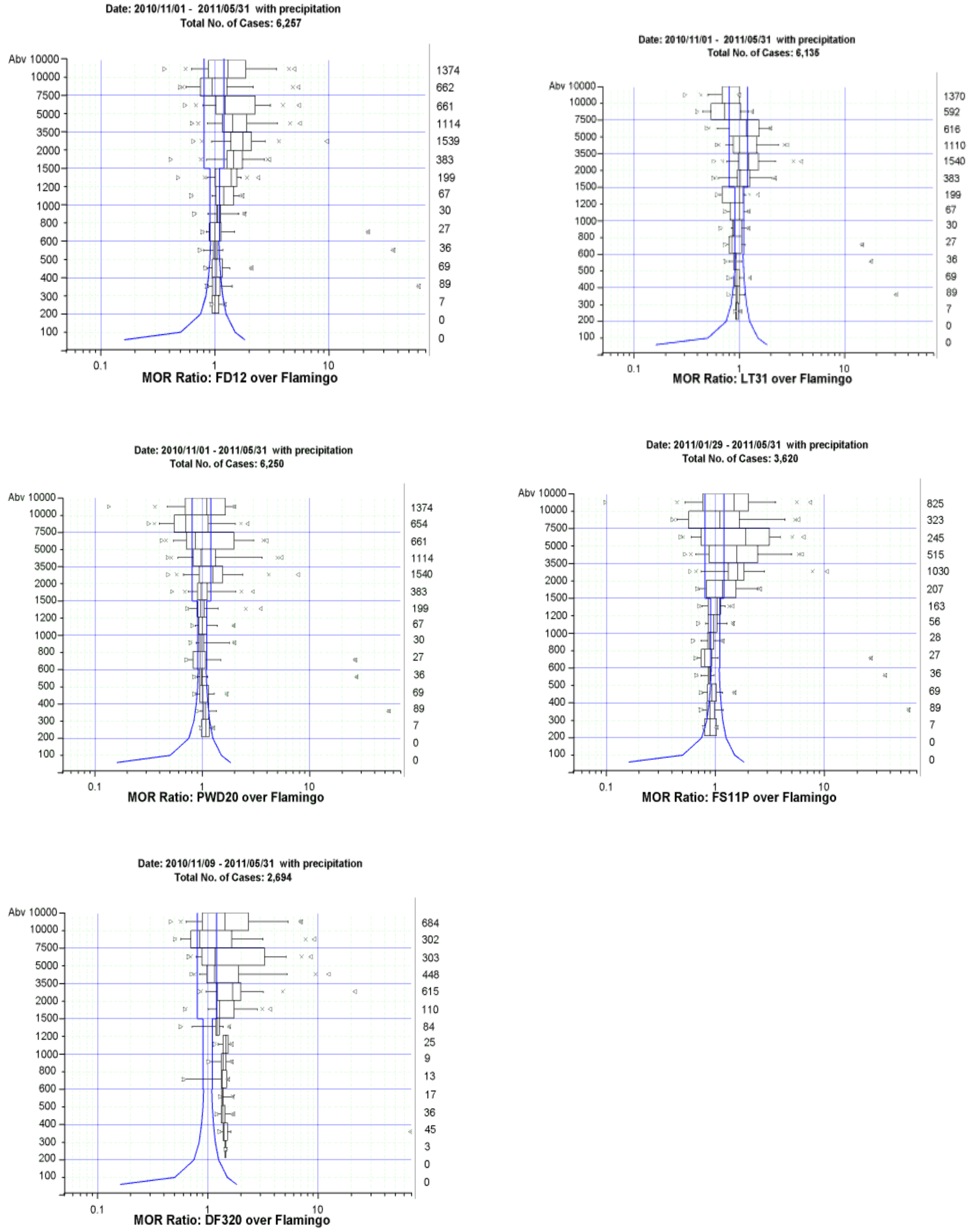

Figure 4 Box plots for the visibility sensors in rain.