NEW TECHNOLOGY FOR FOG AND VISIBILITY OBSERVATION

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1. INTRODUCTION

We provide a novel design of atmosphere visibility measurement system with the contrast principle used in the naked eye visibility observation. The new digital photography visiometer system (DPVS), composed of a CCD camera and two identical targets, utilizes the contrast of dual targets to measure the visibility. The dual targets method, to a great extent, can reduce the errors caused by the drifting of the hardware properties, increase the accuracy of visibility measurement.

2. THEORY OF DPVS

2.1 The mathematical model of DPVS

The basic principle of visibility based on visual contrast that is the relative difference between the light intensity of background and the object. The visual contrast is defined by Equation (1),

$$C_V = \frac{B_g - B_t}{B_g} \quad (1)$$

where B g and B t are the light intensities of the sky background and the object, respectively. When the atmosphere is homogenous, the visual contrast obeys the Beer–Lambert law, therefore we have the relationship between the observed contrast Cv (R) and the original contrast Cv (0), showed in Equation (2),

$$C_V(R) = C_V(0)e^{-\sigma R} \quad (2)$$

where σ is the atmosphere extinction coefficient. The relationship between extinction coefficient and visibility is given by the Koschmieder law, which is Equation (3),

$$V = -\frac{\ln \xi_0}{\sigma} \quad (3)$$

where ξ 0 is the contrast ratio, recommended to be 0.02 by the WMO, or 0.05 by the International Civil Aviation Organization (ICAO). Therefore, the relationship between visibility and contrast is given by Equation (4),

$$V = -\frac{\ln \xi_0}{\ln(C_V(0)) - \ln(C_V(R))} R \quad (4)$$

The Cv (0) is the intrinsic luminance contrast of the object against the sky background when the observer stands just in front of the object, and Cv (R) is the corresponding contrast when the observer is at distance of R from the object. Cv (0) only depends on the radiance of the sky and object itself. For the natural objects, it is difficult to obtain their accurate intrinsic luminance contrast since the albedos of natural objects are variable with many factors. This circumstance stimulates the demand of human designed objects with known albedos to obtain the intrinsic contrast in Equation (4).

The schematic structure of the dual man-made targets system is presented in Figure 1.

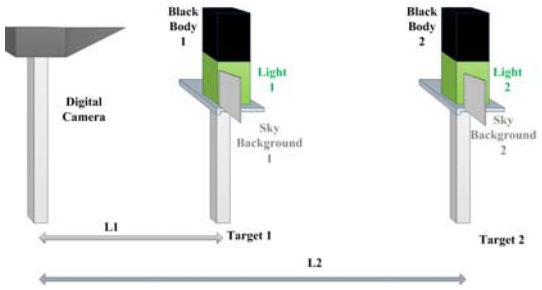


Fig. 1. A schematic structure of the DPVS

3. Configuration of the DPVS

The Physical map of DPVS is presented in Figure 2.

Two operational modes are designed to enable the DPVS to accommodate the lighting conditions of the day and night. Two passive targets, black bodies, are employed for daytime visibility measurement, and two active lights, LED panels, are utilized for nighttime. The mathematical models of the dual targets for both daytime and nighttime are developed.

To evaluate the stability of the DPVS, another field evaluation with 5 days continuous run was made from October 15–19, 2017. The DPVS is compared with two commercial visibility devices, a forward scatter meter and a transmission meter for field validation.

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Fig. 2. The digital photography visiometer system

The 5-day continuous comparison shows promising results, a total of 7200 data points or 120 hours were collected, as shown in Figure 3.

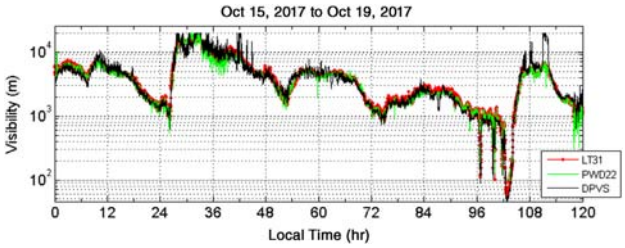


Fig. 3. Five-day continuous observations from October 15 to October 19, 2017 were made by the LT31 (red solid line), the PWD22 (green solid line) and the PDVS (black solid line)

The distributions of the relative biases of the DPVS, the LT31 and the PWD22 were analyzed. Here, we utilize a virtually true visibility that is defined by the average of the three visibilities of the DPVS, the LT31 and the PWD22. The relative bias is computed by Equation (5),

$$\delta_T = \frac{V_T - V_I}{V_T} \qquad (5)$$

where V_T is the true visibility, and V_I is the visibility of the DPVS, the LT31, or the PWD22. The means and standard deviations (SDs) of the relative bias of the DPVS are −0.013 and 0.17, respectively, and the corresponding values are −0.026 and 0.093 for the LT31, 0.040 and 0.11 for the PWD22. For 87% of the data the DPVS, the relative bias lies between [−0.2, 0.2], and the percentage increases to 96% and 92% for the LT31 and PWD22, respectively.

The statistics of the relative biases under different ranges of visibility are compared in Table 1. The correlation coefficient is calculated by virtually true visibility and the observed visibility with the DPVS, the LT31, and the PWD22 for visibility range of 10 m–2 km, 2–10 km and 10–15 km. The overall correlations with correlation coefficients above 0.9 are quite good for all instruments when visibility lower than 10 km. The SDs of the DPVS are close to twice the SD of the LT31 for visibilities from 10 m to 2 km, 2 to 10 km, and the SDs of the PWD22 lie between the DPVS and the LT31. There is relatively larger bias under low visibility for the PWD22.

	10 m – 2 km			2 km – 10 km			10 km – 15 km		
	Mean	STD	Corr.	Mean	STD	Corr.	Mean	STD	Corr.
DPVS	0.018	0.16	0.95	-0.020	0.15	0.92	-0.12	0.33	0.11
LT31	-0.041	0.090	0.98	-0.022	0.084	0.96	0.0085	0.17	0.64
PWD22	0.023	0.13	0.97	0.042	0.087	0.94	0.11	0.18	0.76

Table 1 Statistics Of The Relative Biases Between The DPVS, The LT31, The PWD22 And The True Visibility Ranges Under Ranges Of 10 M–2 Km, 2–10 Km And 10–15 Km

4. CONCLUSION

Our study demonstrates that the new DVPS is superior to the optical visibility instrument and the requirements of the hardware to achieve desired accuracy, especially the DPVS shows good consistency with the LT31 for low visibility range. The SD of the overall bias is not larger than 16% for visibility up to 10 km and suggests that the DPVS is capable for field applications, it can be used for automated visibility observations under all weather conditions. With the development of CCD camera technology, the increased resolution (equivalent to human eyes, 300 dpi) and decreased prices, the DPVS shows bright application promises in weather forecasting, transportation, airport, highways and air quality monitoring.