The Development of the Research in Digital Visibility Instruments and the Related Comparative Experiments

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Abstract—The observation automation of cloud, visibility, and weather phenomena are principal issue to solve in the modern meteorological observation field. In the late 20th century, scientists have started to develop a kind of digital visibility automatic monitor, which has adopted advanced digital photographic technology and image recognition technology, based on the definition of visibility and fully imitating the human eye observing visibility principle （Steffens C，1949）. Undoubtedly, the digital visibility automatic monitor is the best instrument to replace the manual observation of visibility （homas 1994）. This article briefly introduces the methods of visual and instrumental observation of visibility, and elaborates the basis of the Digital Photograph Device System （Xingsheng，1999）, its latest development, and the comparative results between Finnish Vaisala visibility instrument and manual observation （Jingli，2002）. In the end, the article reaches an error analysis conclusion and discusses about the problems and further improving measures.

Keywords: Digital Photograph Visibility Device System (DPVS); Visibility; Digital Photography; Comparative Experiment.

1. INTRODUCTION

At present, China's meteorological station still adopts the traditional manual observation method to observe the basic meteorological elements such as clouds, visibility, and weather phenomena. This kind of method is very subjective and non-complete, thus it is hard to apply it to quantitative / model system. In the instrumental observation of visibility, the main equipments adopted include transmission visibility meter, automatic laser visibility observational instrument, and forward scattering visibility instrument. Atmospheric transmission instrument is used to measure attenuation coefficient, that is, to let a light beam run through the atmospheric column between two fixed points to measure the transmittance of the atmospheric column, thus to assess its visibility value. In this sort of measurement, the light beam is supposed to run through an atmospheric column that is sufficiently long. However, in rainy, foggy and other low-visibility days, there will be a greater error due to water vapor absorption and other complex conditions, thus it has very big limitation1.. While automatic laser visibility observational instrument is to extrapolate visibility from the atmospheric light extinction coefficient measured by laser, which is relatively more objective and accurate. But this method is still limited to a small number of research departments, because the laser radar is very expensive, and its maintenance cost is high too; the operation of the equipment is complicated, and in rainy and foggy days, it is also difficult to carry out normal observation.

Considering the visibility observation status at home and abroad mentioned above, it is imminent to develop an automatic visibility observational instrument to fully replace the manual observation. In the late 20th century, in China, scientists have started to develop a kind of Digital Photograph Device System(DPVS), that is, digital visibility instrument, which has adopted advanced digital photographic technology, fully imitates the human eye observing visibility principle, and is designed based on the definition of visibility. Undoubtedly, digital visibility instrument is the best instrument to replace the manual observation of visibility （Jingli，2006）. With the rapid development of digital photography technology, especially that the pixel of the CCD camera has earlier reached the resolution of the human eye (10 million pixels), while the price is in freefall, it is certainly a general trend to use digital photography technology to measure atmospheric visibility.

2. INSTRUMENTAL VISIBILITY OBSERVATION

Definition of Visibility that is the maximum distance from which in a weather condition the human eye(standard visual acuity) can see and identify a target's contour (black, with appropriate size, and a general view of 0.5 to 5 °) in the background of sky. Figure 1 shows that Visibility Differences
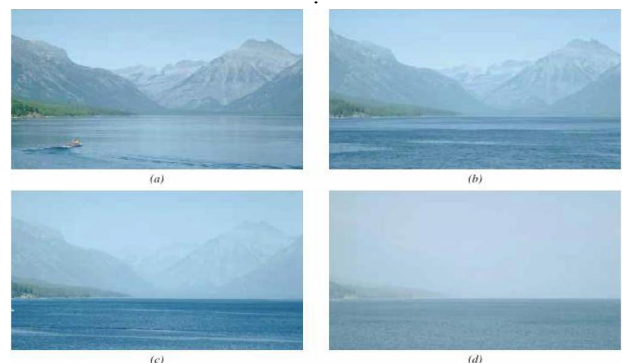

Figure 1. Visibility Differences.

2.1 Transmission visibility meter

Transmission visibility meter is to measure directly the transmittance of the atmospheric column between two fixed points when a collimated light beam runs through, and estimate the average extinction coefficient from the transmittance, thus obtain the visibility value, that is, the meteorological optical visual range. It is obviously accurate to infer the visibility within a distance of about several kilometers or dozens of kilometers from the transmittance of the atmospheric column that has only a limited base length of dozens of meters. (In this method, the light beam is supposed to run through an atmospheric column that is sufficiently long). And in the rainy, foggy and other low-visibility days, there will be a greater error due to water vapor absorption and other complex conditions, thus it has very big

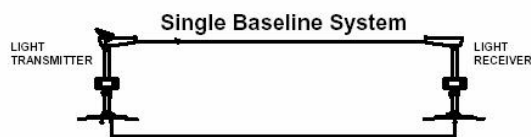limitation. Figure 2 shows that schematic for Transmission visibility meter.

Figure 2. Schematic for Transmission visibility meter

2.2 Laser Visibility Instrument

Automatic laser visibility observational instrument is to measure the echo energy of the laser in the process of transmitting in the atmosphere. Therefore the extinction coefficient can be calculated due to the fact that the extinction coefficient is in proportion to the echo energy. In turn, the visibility can be inferred from the extinction coefficient. The atmospheric extinction coefficient obtained here is based on the premise that the air on the optical transmission path is evenly distributed, and the molecular and aerosol absorption is negligible. As the baseline is longer, the observation is relatively more objective. However, as the absorption is neglected, in rainy and foggy days, the accuracy of the observation will certainly be affected. The laser radar is very expensive, and its maintenance cost is high too; the operation of the equipment is complicated; therefore this method is still limited to a small number of research departments, and in rainy and foggy days, it is also difficult to carry out normal observation. Figure 3 shows that schematic for Laser Visibility Instrument.
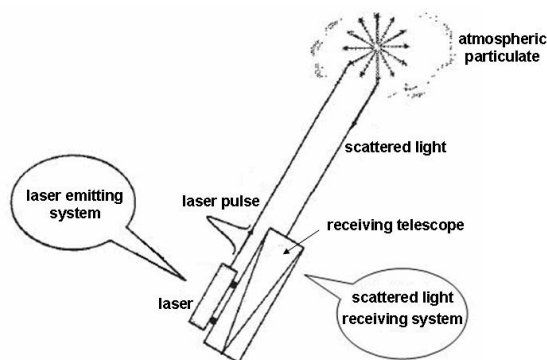

Figure 3. Schematic for Laser Visibility Instrument

2.3 Scattering visibility instrument

Scattering visibility instrument is to measure the scattered light intensity of a limited volume (small volume) of air, and then estimate the atmospheric light extinction coefficient to figure out the atmospheric visibility. The calculation of extinction coefficient is based on the following three assumptions: ①the atmosphere is homogeneous, that is, the atmosphere is uniformly distributed; ②atmospheric light extinction coefficient R is equal to the scattering of fog, haze, snow and rain in the atmosphere, that is to say, molecular absorption, scattering, or the interactive optical effect within the molecule is zero; ③the scattered light intensity measured by the scattering instrument is in direct proportion to the scattering coefficient. Under normal circumstances, select an appropriate angle, scattering signal is approximately in direct proportion to the scattering coefficient[2]. Apparently all the three assumptions mentioned above are untenable in the actual observation environment. Uniform air distribution is impossible, and it is unreliable to extrapolate the atmospheric visibility of a distance around a few or even dozens of kilometers from the extinction coefficient of a limited volume of air. Atmospheric light absorption can not be ignored, especially in rainy, foggy and other low-visibility weather; a bigger error will be caused by the water vapor

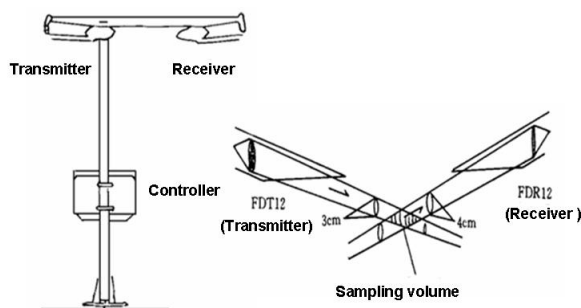absorption and other complicated conditions. Figure 4 shows that schematic for Scattering visibility instrument

Figure 4. Schematic for Laser Visibility Instrument

2.4 Digital Visibility Meterr

Digital visibility meter is a new instrument which adopts digital photographic method to measure visibility. The design idea is proposed by Mr. Zhou Xiuji, academician of Chinese Academy of Sciences, renowned atmospheric physicist. It is entirely developed from the principles of manual visibility observation. According to manual visibility observation method, first, choose several targets which are clear and can be identified by CCD in normal weather conditions, and then use CCD to take photos of the selected targets to get the images which are then conveyed to computer through image acquisition card. Computer will then analyze and deal with the image data of the targets respectively, substituting the image data into the relevant formulas to work out the observational visibility value according to the principles of manual visibility observation and the definition of visibility. Figure 5 shows that schematic for Digital Visibility Meter.

Figure 5. Schematic for Digital Visibility Meter

3. ASSESSMENT OF INSTRUMENTAL OBSERVATIONAL VISIBILITY VALUE AND ERROR ANALYSIS

As noted above, the former three devices are to estimate the visibility value by speculating atmospheric extinction coefficient indirectly. Transmission visibility meter is to measure directly the transmittance of the atmospheric column and estimate the extinction coefficient from the transmittance, thus obtain the visibility value. Automatic laser visibility observational instrument is generally to measure the latter-part scattering coefficient to infer the extinction coefficient and in turn obtain the visibility value. Scattering visibility meter is usually to measure the scattering light intensity of a limited volume of air directly and thus estimate the atmospheric extinction coefficient to figure out the visibility value. Digital visibility meter is based on the principles of manual visibility observation and the definition of visibility, and it is to figure out the visibility value from the target distance and clarity, which is therefore the best instrument to replace manual visibility observation.

4. COMPARATIVE EXPERIMENTS

In 2008, Institute of Urban Meteorology, Beijing, China Meteorological Administration, has transformed and laid five sets of automatic digital photographic visibility monitors. from January 1, 2009 to March 17, 2009, comparative experiments

between DPVS and Finnish Vaisala visibility meter as well as manual visibility observation have been carried out for 75 days during daytime simultaneously in five stations. In Miyun station, comparative experiments between DPVS and Vaisala FD12 visibility meter are carried out. The results of the comparative experiments show that the relative standard deviation between DPVS and Vaisala FD12 visibility meter is 20% or close to 20%. Table 1 shows the comparative result of the relative standard deviation between the visibility observed by DPVS and FD12. Formula (1) is the relative standard deviation calculation formula:

$$\sigma_{rd} = \sqrt{\frac{\sum_{i=1}^{N}[(X_i - Z_i)/Z_i]^2}{N}} \times 100\% \qquad (1)$$

In formula (1), X_i represents the observational visibility value of DPVS , Z_i represents the standard FD12 observational visibility value, and N represents the times of observations. σ_{rd} represents the relative standard deviation between DPVS and FD12.

TABLE I.   THE COMPARATIVE RESULT

Comparative Result	Visibility Scope(km)				
	Below 2	*2-5*	*5-10*	*10-20*	*Above 20*
number	116	692	1628	1222	2262
σ_{rd} [a] (%)	11.5	17.8	21.7	23.1	2.1

a. Relative Standard Deviation

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