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13. ABSTRACT *(Maximum 200 words)*

As part of its effort to automate surface weather observations, the U.S.Air Force funded the development of a visibility sensor that duplicates the function of a trained weather observer: it scans the horizon and estimates the prevailing visibility by the reduction in visibility target contrast in many different directions. Just as for the human observer, the accuracy of this method depends upon the number and quality of visibility targets. Good targets have a known range and a high intrinsic contrast (i.e., close to black) that is stable with time of day and season of year. Methods were developed for assessing time variations in inherent target contrast and for detecting significant simultaneous changes in the inherent contrast of many targets, such as caused by sticking snow. The system was operated at two sites with significantly different sets of visibility targets. One site included distant mountains as targets. The other was limited to nearby targets; plywood targets. The other was limited to nearby targets; plywood targets (painted black) were constructed at this site to assess sensor performance with ideal targets. In contrast to the point visibility sensors used in most automated weather observing systems, the prevailing visibility sensor can, in principle, detect sector variations in visibility. In order for this capability to be effective in practice, many targets must be located at different ranges and in different directions. A concept was developed for greatly increasing the number of available targets and for estimating their range using data collected under different visibility conditions. Some work has also been done to extend the operation of this prevailing visibility sensor to night-time by using lights as targets.

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Evaluation of a Prevailing Visibility Sensor Based on a Scanning Solid State Video Camera

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1. INTRODUCTION

Over the last several years, the Phillips Laboratory has conducted a research effort developing weather sensors and techniques that will satisfy the requirements of the Air Force for an automated surface weather observation system. Where requirements were similar to those of other Federal agencies, cooperative efforts were activated. However, where the requirements differed, independent efforts have been pursued. For example, initial Air Force requirements for an aviation weather observation included the specification of prevailing and sector visibility. This paper will discuss the evaluation of an instrument developed to meet this need.

1.1 Background

The increasing consideration given to automating weather observing over the last 10 to 15 years has been driven by several factors. Principal among these are the ever increasing demands for more timely, accurate and objective specifications of critical aviation-related weather elements and the realization, in the face of decreasing budgets, of the intensive use of manpower to achieve these observations.

The substitution of automated sensors for the human observer has, however, not been without penalty. Automated devices, particularly airfield visibility sensors, have the capability of sampling the atmosphere only in a limited volume. To the extent that the atmosphere is experiencing a restriction in visibility that is homogeneous in space, the visibility sensor will give a representative measure of the restriction. To the extent that the atmosphere is experiencing rapidly changing, or inhomogeneous conditions, the visibility sensor will not give a representative measure of the restriction.

A study (Chisholm et al, 1974) of the variability of visibility in the vicinity of an air field runway found that measurements varied the most in radiation fogs and to a lesser extent in advection fog, rain and snow. They found that the assumption of time persistence led, after 15 minutes, to a 67 percent error in radiation fog, 43 percent in advection fog, and 38 percent in rain. A single sensor used to predict a 3-sensor mean along the entire runway yielded standard errors ranging from 11 to 26 percent in advective fogs and 33 to 51 percent in radiation fog. The correlation of two sensors 1200 meters apart resulted in standard errors of 25 to 30 percent in advective fogs and 100 percent in radiation fog.

In contrast to the limitations of localized, or point-measuring sensors, a scanning television system can more nearly emulate the human observer by selectively viewing targets of opportunity, both near and far, around the full horizon.

1.2 Sensor Description

The imaging system discussed in this paper was developed by the Marine Physical Laboratory (MPL) of the Scripps Institute of Oceanography of the University of California San Diego (Johnson, 1989). It consists of a television camera with a telephoto lens (5° horizontal field of view) mounted on a computer-controlled precision rotary table that permits images of the horizon to be recorded at selected azimuth angles. A Charge Injection Device (CID) camera was chosen for its linear response and hence accuracy in making contrast measurements. Selected camera images are processed in real time to determine the visibility.

The sensor is configured for a site by identifying suitable rectangular target areas (as black as possible) at known ranges in a number of scenes at different azimuth angles. Originally up to five targets could be defined per scene, but this number was increased to 16 in recent software versions. An area of the sky is also selected in each scene to determine the horizon sky luminance L_s. The average sky and target brightnesses are combined to determine the "apparent" contrast of the target. The apparent contrast C_r is measured by:

$$C_r = (L_t - L_s)/L_s \qquad (1)$$

where L_t is the target luminance. The inherent contrast C_o of the target is the apparent contrast when the visibility is perfect. The inherent contrast of a perfect black target ($L_t = 0$) is -1. Normally each target is measured every minute. The option of measuring only the 20% darkest pixels of the target was used to minimize the problem of a small offset that could occur with camera positioning by the precision rotating table.

The apparent contrast C_r and range r are combined with an assumed inherent contrast value C_o and a contrast detection threshold ε (normally 0.05) to compute a visibility V:

$$V/r = [\ln(\varepsilon/C_o)]/[\ln(C_r/C_o)] \quad (2)$$

V is defined as a visibility limit if the calculated visibility is less than r or more than four times r. The target visibilities are combined to estimate sector and then prevailing visibilities using complex MPL algorithms.

The results of the one-minute real-time data analysis are stored in disk files containing the prevailing visibility and the raw data on target contrast and sky brightness. In addition, selected scenes are stored as full 512x480 8-bit pixel images on Exabyte tapes. Most of the data analysis presented in this paper is based on the disk files. The stored images are used to identify targets and examine target anomalies.

2. TEST SITES

2.1 Hanscom AFB Site

At the Hanscom AFB site, 24 targets in nine scenes were selected for the first data collection period. In Table 1 these targets are numbered according to increasing range; ranges were determined from local maps. The imaging system was installed with the zero azimuth pointing approximately east, with increasing azimuth toward the north. Because Phillips Laboratory is located just to the northwest of a nearby ridge, all scenes were selected in the northwesterly half of the full horizon (azimuth 42° to 194°).

As might be expected, the most distant targets in Table 1 are mountains and the intermediate range targets are ridges. The difficulty in identifying distant ridges on local maps led to a gap (more than a factor of four) between the nearest mountain and the most distant ridge. This gap had a profound influence on the prevailing visibility calculations and inspired some ideas for increasing the number of usable targets (see Section 4.1).

2.2 Otis ANGB Site

The PL/GP Weather Test Facility on Cape Cod is located on level land with a view, unlike Hanscom AFB, of the full horizon. Otis has many nearby targets (cedar trees) but few distant targets (range above three miles). At Otis black rectangular plywood targets were installed in two directions (northerly and southerly) at 1/16-mile increments out to 3/8 mile. The Otis site is thus well equipped to study the performance of the imaging system under fog conditions, which are frequent at the site.

Table 1. Hanscom AFB Targets

Target	Azimuth (deg)	Range (miles)	Description
1	42	0.20	Light Pole
2	57	0.25	Evergreen Tree
3	194	0.30	Evergreen Tree
4	121	0.40	Doorway
5	121	0.60	Window
6	130	1.0	Tree
7	146	1.0	Ridge
8	194	1.5	Ridge
9	86	1.8	Evergreen Tree
10	121	1.8	Evergreen Tree
11	86	1.9	Window
12	130	2.5	Ridge
13	121	2.7	Ridge
14	130	3.8	Ridge
15	130	4.2	Ridge
16	42	4.5	Ridge
17	57	4.5	Ridge
18	86	4.5	Ridge
19	42	6.0	Ridge
20	86	6.0	Ridge
21	146	27.6	Mountain
22	121	31.3	Mountain
23	112	40	Mountain
24	107	42	Mountain

3. DATA ANALYSIS

3.1 Prevailing Visibility

Figure 1 shows a prevailing visibility plot for a day where the visibility is very good. Note that the scale of the plot changes at 10 miles. Early in the day the data show digital jumps around 20 to 30 miles visibility. These jumps are caused by the apparent contrasts of close-in (i.e., 4-6 miles) targets drifting back and forth over the contrast limits allowed in the prevailing visibility calculation. After 1700 hours the contrasts of these targets are consistently outside the algorithm limits and the prevailing visibility gradually (with some high frequency noise) drifts up from 60 to 110 miles.

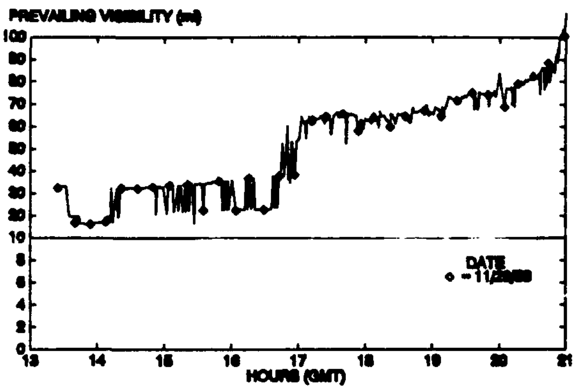

Fig. 1. Prevailing Visibility for 11/29/89

The MPL prevailing visibility algorithm follows the definition of prevailing visibility as being the maximum distance that can be seen over half the horizon. This definition translates into taking the median of all valid visibility measurements. Since the number of targets is typically small, the algorithm also makes use of the upper and lower visibility bounds set by targets with measured contrasts that are too close to the assumed inherent contrast or are below the detection threshold. In principal, the use of the median visibility can effectively reject outlying data points. However, the small number of targets (e.g., the gap in PL/GP targets between 6 and 27 miles) may not always permit successful outlier rejection.

Some targets, (11 and 24), that were stable in the summertime, were found to be unstable in the fall and winter seasons. The instability was due to exhaust vents on the tops of intervening buildings that produced visible clouds that intermittently obscured the target or the sky background. These targets were excluded from subsequent calculations.

3.2 Calculated Black Target Visibility

The problems noted in the MPL prevailing visibility algorithm suggested that a different approach might be worthwhile. First, the different accuracy for each target is taken into account by weighting each measurement according to its expected accuracy. Second, the visibility V_o is calculated for an ideal black target (C_o =-1) rather than the real targets. Equation 2 becomes simplified in this case:

$$\ln(C_r) = r\,\ln(\varepsilon)/V_o = -\sigma\, r, \qquad (3)$$

where the black target visibility V_o is related to the extinction coefficient σ:

$$\sigma = -\ln(\varepsilon)/V_o. \qquad (4)$$

The visibility algorithm carries out the following steps:

1) Rejects targets with apparent contrasts above 0.5 or below 0.07.

2) Calculates the visibility of a black target from the apparent contrast and range of each target, assuming that the inherent contrast of target is 0.80 (also used in the MPL algorithm for most targets).

3) Calculates mean black target visibility as a weighted average of the individual calculated black target visibilities. The weighting used reflects the error caused by errors in the assumed inherent target contrast. Thus, the targets with the lowest apparent contrast (while still above the 0.07 cutoff) have the highest weights.

Figure 2 shows the calculated black target visibility for the same day for which the prevailing visibility is plotted in Figure 1. Two differences are noted between the two plots. The calculated visibility for 1300 to 1700 hours is much more steady and greater than the prevailing visibility. Apparently the close-in targets were effectively eliminated from the calculated visibility. The calculated black target visibility is also smoother than the prevailing visibility after 1700 because Target 24 has been eliminated.

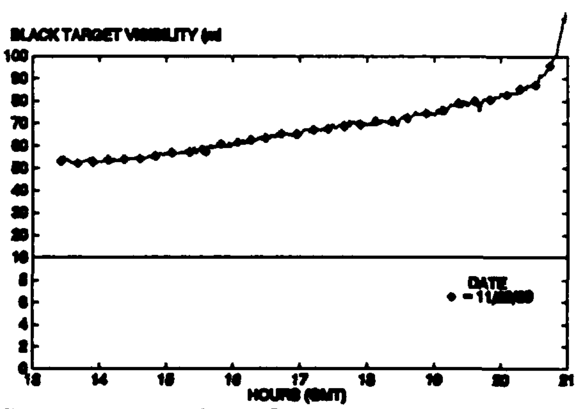
Fig. 2. Calculated Black Target Visibility for 11/29/89

The use of "black target" visibility has two advantages:

a) It can be used to correct the measured target contrast to estimate the inherent target contrast. Equation 2 can be rearranged to give:

$$C_o = C_r/\exp[-\sigma r], \quad (5)$$

b) It is consistent with the definition of visibility used to interpret the data from point visibility sensors.

The black target visibility is slightly larger the actual target visibility because it assumes a higher inherent target contrast (1.0 rather than 0.8).

3.3 Inherent Target Contrast

Figure 3 shows the apparent contrast for targets 15 and 16 (both ridges) on 11/29/89. Figure 4 shows the results of using Equations 4 and 5 (V_o from Figure 2) to correct the apparent contrast C_r in Figure 3 to yield an estimate of the inherent target contrast C_o. Since the V_o is estimated using much more distant targets than those in Figures 3 and 4, the correction is not very sensitive to the assumed inherent contrast of the distant targets.

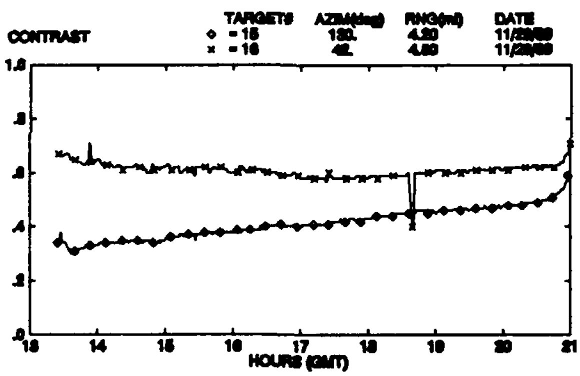

Fig. 3. Targets 12, 13: Apparent Contrast on 11/29/89

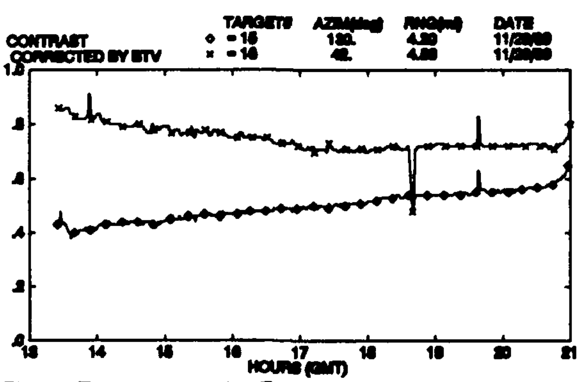

Fig. 4. Targets 12, 13: Estimate of Inherent Contrast on 11/29/89

The two ridge targets in Figure 4 have similar ranges but different azimuth angles. The estimated inherent contrast of the two targets in Figure 4 is quite different. The variation with time of day also varies in the opposite direction because of sun angle effects.

3.4 Fitted Visibility, Inherent Contrast

An alternative method of processing target contrast data is to fit the measured values to one or more parameters. The natural least-square fit method is to minimize the sum of the squares of the difference between the calculated and measured target contrast for a selected group of targets. One of the parameters of the fit must be the black target visibility which is independent of the target characteristics. Figure 5 shows the fitted (black target) visibility for 11/29/89, assuming an inherent contrast of 0.8 for all targets. Measured contrast ratios below 0.1 were excluded from the fit. The resulting visibility is significantly lower than the calculated black target visibility in Figure 2, which heavily weights the most distant targets and is probably more accurate. The anomaly at 1840 hours in Figure 5 is caused by contrast anomalies for the azimuth 42 targets (numbers 16 and 19); this irregularity ilustrates the dependence of the least-square-fit visibility on close targets.

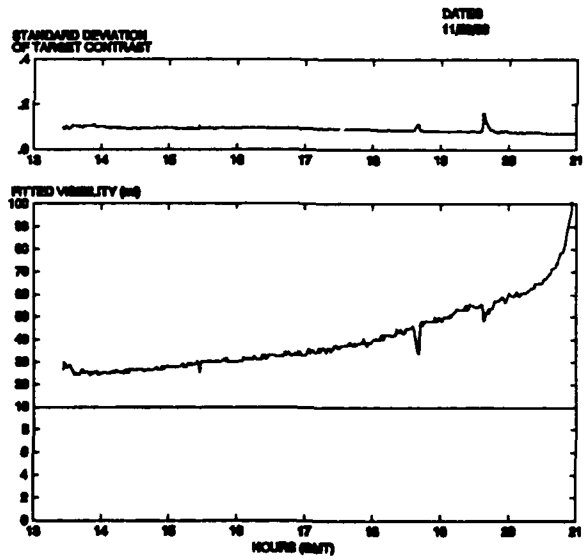

Fig. 5. Fitted Visibility for 11/29/89

The least-square-fit method gives an additional parameter: the variance of the fit. The top plot of Figure 5 shows the estimated standard deviation of the fit (square root of the sum of the squares of the differences divided by the number of targets minus the number of fitted parameters). The target contrast standard deviation on 11/29/89 was steady at about 0.1 except for the times of the anomalies where somewhat larger values were noted.

The least-square-fit method can be used to detect variations in the inherent target contrast if all the selected targets are assumed to have the same inherent contrast. Figure 6 shows the results of such a two-parameter fit on the 11/29/89 data where all ridge and good mountain targets are used. The fitted inherent contrast (upper curve in top plot of Figure 6) varies from 0.6 to 0.7 through the day and the standard deviation (lower curve in top plot) is somewhat smaller than that obtained in Figure 5 for all good targets assuming an inherent contrast of 0.8. A lower assumed value would appear to be more accurate as an overall value for the ridges and mountains.

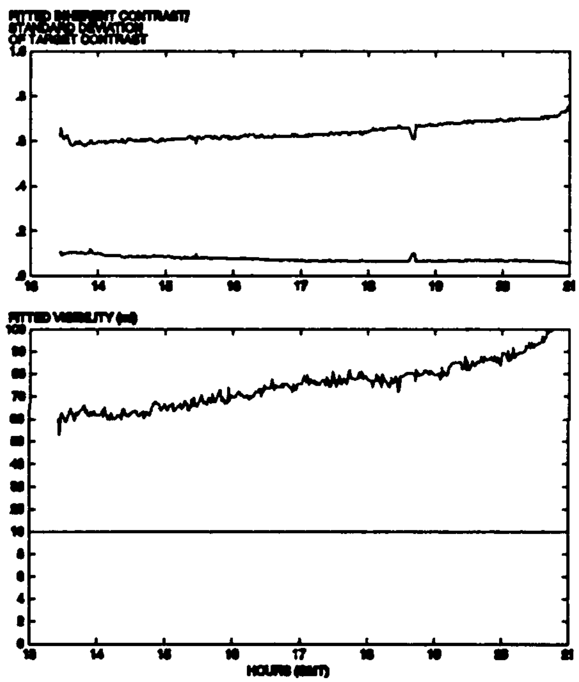

Fig. 6. Fitted Visibility and Inherent Target Contrast on 11/29/89 using Targets 12 to 23 (Ridges and Mountains)

3.5 Snow Effects on Target Contrast

A snow storm in January 1990 produced significant effects on target contrast. On the morning of 1/21/90 all trees were snow covered, but most snow had fallen off by the middle of the day. Figure 7 shows the prevailing visibility for that day. The reported low visibilities early in the morning were perhaps a factor of two low because of the changes in inherent contrast.

The change in inherent contrast was studied using the analysis method presented in Figure 6. Figure 8 shows the fit to a number of near natural targets including Target 2, an evergreen tree. Since the fitted contrast is dominated by the nearest target,

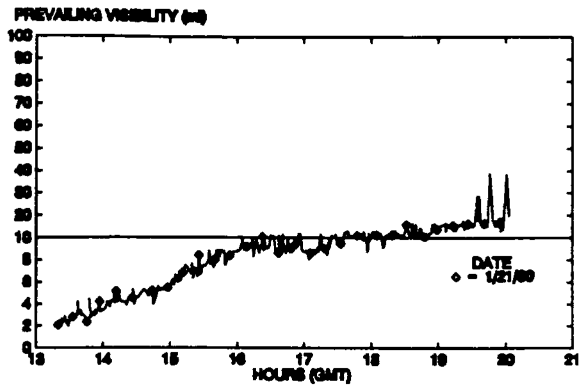

Fig. 7. Nominal Prevailing Visibility for 1/21/90

all fits that included Target 2 (but not Target 3 which had a different behavior) had a similar shape. The stored images of Target 2 were studied through the event and found to be snow covered until about 1700 hours, as would be expected from the contrast fit data of Figure 8.

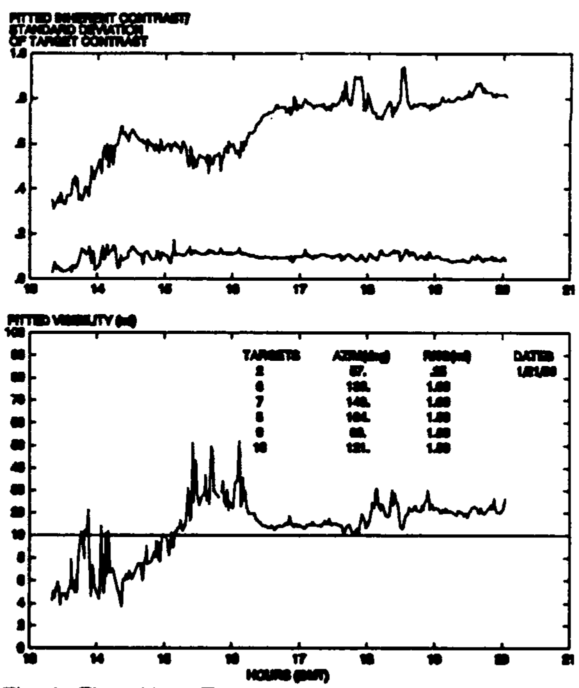

Fig. 8. Fit to Near Targets on 1/21/90

4. FUTURE DEVELOPMENT

4.1 More Targets

Just as for human observers, the measurement of prevailing visibility with an imaging system is highly dependent upon the number and quality of visibility targets. The best visibility estimates are obtained when a taget is just visible. Thus, targets are needed at all ranges. If directional variations in visibility are to be detected, targets are also needed in all directions.

In principle every pixel in an image can be treated as a target if the range and inherent contrast can be identified. The inherent contrast can be identified on a clear day, but the range is more difficult. One approach is to measure the apparent contrast for many targets under a variety of visibility conditions. The target range can then be determined by a least-square fit to the target range, inherent target contrast and a black-taregt visibility that is assumed to be the same for all targets at a given time. One method of defining ridge targets for this purpose is to scan a selected vertical band through many ridges, looking for contrast discontinuities. Large grassy areas could be treated similarly; the inherent contrast could be assumed to be the same for all pixels, leaving range and visibility as the only variable affecting the apparent contrast.

4.2 Night Operation

MPL has developed a method of increasing the averaging time of the CID camera for night operations. Even with the increased sensitivity, night visibility measurements will require the use of lights as targets. In principle every light in an area could be used as a target and treated as the projector of a transmissometer. Software can be readily developed for indentifying and testing the stability of available lights. Some testing has already been done with artificial lights. Variable intensity lights were installed on six targets (the North leg) at the Otis site. Several tests were conducted under clear and fog conditions to determine optimum light settings. Early results have been very promising.

5. REFERENCES

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