visIvis

Evaluation of Vision based Visibility Measurement

Dr. Harald Ganster, DI Jean-Philippe Andreu, DI Jochen Steiner

JOANNEUM RESERACH Forschungsgesellschaft mbH, Graz

Dipl.-Met. Jürgen Lang

MeteoSolutions GmbH, Darmstadt

Reliable and exact assessment of visibility is essential for safe air traffic or other critical infrastructure. In order to overcome the drawbacks of the currently subjective reports from human observers, we present “visIvis”, an innovative solution to automatically derive visibility measures from standard cameras by a vision-based approach.

<u>Related Work</u>

To their best knowledge, the authors do not know of currently commercially available systems for determining the visibility based on camera images. The certified state of the art for automated visibility measurement is represented by visibility sensors (e.g. forward scatter meters as used in RVR measurements [1]). Those sensors allow only for very local measurement, whereas camera-based methods achieve a representative measurement of the visibility in the complete surroundings of the camera location.

Several research aims already target camera-based visibility estimation. E.g. the weather services of the Netherlands (KNMI [2]) exploit camera images by similar means as the detectors in the visIvis system (feature detectors, global dehazing), but they still rely on a few manually selected landmarks with known distances to derive the prevailing visibility.

A variety of approaches uses physics-based models to derive a visibility measure (e.g. Koschmieder model in [3] or other measures of contrast [4] as well as models of light extinction [5]). Besides focusing only on one specific method to estimate visibility, they also have some pre-requisites (e.g. in [4] the measurement target has to be on a straight line with two cameras) that hinders getting a representative measurement of the complete scenery.

In contrast to the presented approaches, within visIvis the most suitable image areas are automatically detected by the system and their detection method is parameterized fully automatically as well. Furthermore, by fusion of a variety of visibility detectors the complete image can be used for deriving reliable representative measurements.

visIvis-System

Based on a small set of training images with very good and bad visibility conditions (cf. Figure 1), the system visIvis detects fully automatic the best suited image regions for visibility derivation (e.g. buildings or orographic structures). At the same time the optimal parameters (e.g. image features and quality criteria) for the visibility recognition are derived. The system exploits a variety of visibility detectors in order to achieve the optimum performance for each individual image region. Among others, the system incorporates feature based methods like edge detectors as well as dehazing approaches (e.g. [6])

Figure 1: Sample training images for good and bad visibility conditions from the airport in Graz.

Visibility Assessment

Assessment of visibility is done separately for each image region and displayed according to customer preferences. A very intuitive way is the display in a color image, where the result is marked "visible" as a green area and the result "not visible" as a red area. Thus, a meteorological observer or user of the system can very quickly capture the current prevailing visual situation, where, for example, existing ground fog is clearly recognized as a visual obstruction and displayed accordingly in a red-green mask (cf. Figure 2). "Gray" areas of Figure 2 are not evaluated because they were detected to have too low qualities for the automated visibility measurement during the automatic configuration of visIvis.

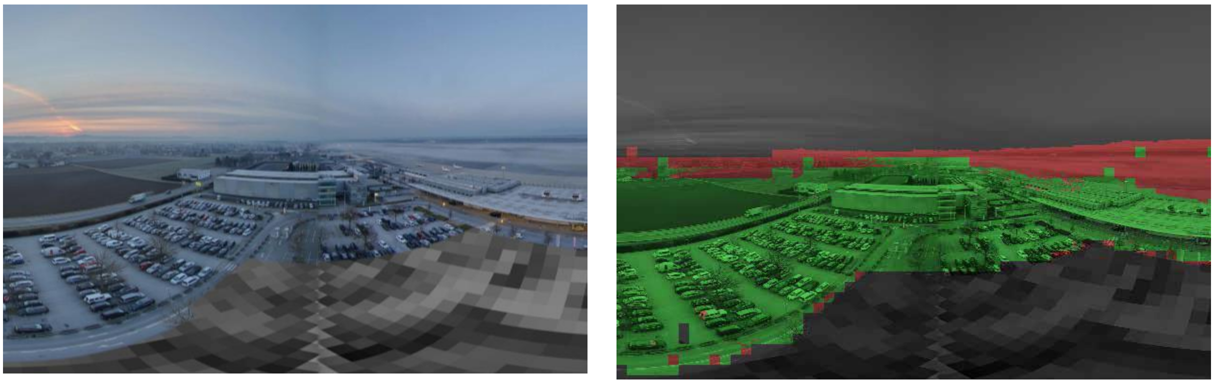

Figure 2: Raw image of a high-resolution airport tower camera (left) and result of vision based visibility measurement (right) correctly detecting the fog bank along the runway.

Visible Distance Determination

The system further integrates distance measures by georeferencing the calibrated camera image and exploiting high-resolution elevation data derived from digital surface and terrain models (DSM, DTM). By using this established distance map, where each image pixel is registered to its corresponding distance, and statistical analysis of visible and non-visible image regions, a representative estimate of the prevailing visibility is given for the complete camera-covered area.

Obviously, due to the perspective image acquisition the different visibility ranges cannot be covered in an equally balanced way in the camera images (e.g. closer ranges will account for higher pixel numbers). Thus, a reasonable range combination was set up with so-called distance classes that were chosen to allow determination of representative prevailing visibility by still covering meteorological relevant thresholds as well as observer regulations (e.g. “Visual meteorological conditions” [7] and “WMO Measurement of Visibility” [8]). Table 1 gives an overview on the distance classes derived from observer regulations and the finally used set-up in a specific visIvis-application (color-coded). Relevant thresholds (e.g. 300m, 1500m, 5000m) are well represented and each derived class contains a representative number of image pixels to allow for robust visibility derivation.

Distance Class	Threshold	Distance Class	Threshold	Distance Class	Threshold
0-49	50	800-999	1000	10000-11999	12.000
50-99	100	1000-1499	1500	12000-14999	15.000
100-149	150	1500-1999	2000	15000-19999	20.000
150-199	200	2000-2999	3000	20000-24999	25.000
200-299	300	3000-3999	4000	25000-29999	30.000
300-399	400	4000-4999	5000	30000-49999	50.000
400-499	500	5000-5999	6000	50000-69999	70.000
500-599	600	6000-7999	8000	70000-100000	100.000
600-799	800	8000-9999	10.000		

Table 1: Distance classes set-up for the visIvis application at location Munich.

Based on the derived distance classes and with the help of the visibility detection (red and green image regions) the basic representation of the prevailing visibility is given in a histogram (Figure 3). The classes with high visibility percentage rates allow the observers to directly assess prevailing visibility conditions.

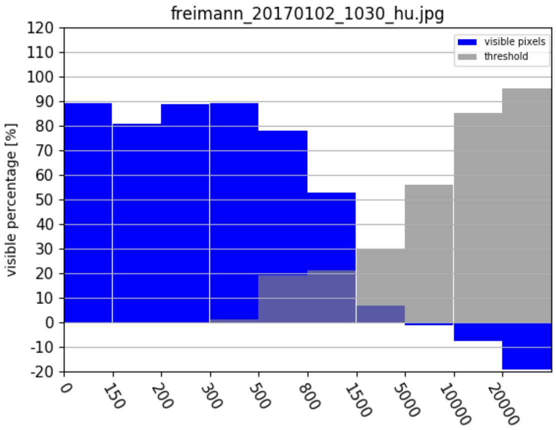

Figure 3: Exemplar illustration of histogram-based visibility determination.

With the help of the histogram analysis, visIvis reports at least two deterministic visibility values: the so-called minimum (conservative) visibility (all sight classes consistently rated positive starting at the closest range) and a maximum visibility (corresponds to the ranges detected as visible that are furthest away). Experience from pilot systems and evaluations have shown that the maximum class is best suited as deterministically derived measure for prevailing visibility.

Practical examples and demonstrator results

In the following, some results of visIvis implementations are illustrated and discussed, that show the capabilities and benefits of the automated visibility measurement for a variety of scenarios, including both ATM scenarios and synoptic applications. It also gives examples how the measurements are best presented for individual users in the respective scenarios.

Figure 4 shows detections of visible regions at two time instances within an ATM scenario. The images captured by a ground-based camera show the performance of dissolving fog.

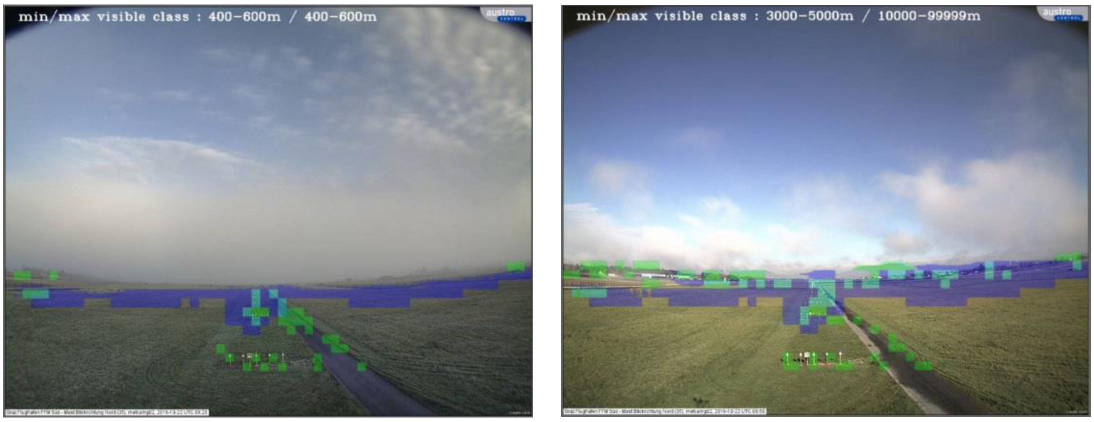

Figure 4: Comparison of visIvis results in an ATM scenario at a ground based camera with dissolving fog (courtesy of AustroControl).

On the left side there is perfect correspondence between observer (500m) and automated visIvis system (Class: 400-599m), whereas on the right side image the observer already gave 12.000m of prevailing visibility and the automated system derived sight class 3000-4999m as it still detected correctly the remaining fog banks. Nevertheless, the system also gives a second value the maximum visibility which in this case was Class 10.000m+ showing again good correspondence to the observer.

Figure 5 illustrates a span of 2 hour comparison between runway visual range sensors (black line), the visIvis result (green) and the officially stated observer report (black dots). It clearly indicates the value of the automated measurements that were used as a tool to check the plausibility of the RVR measurements.

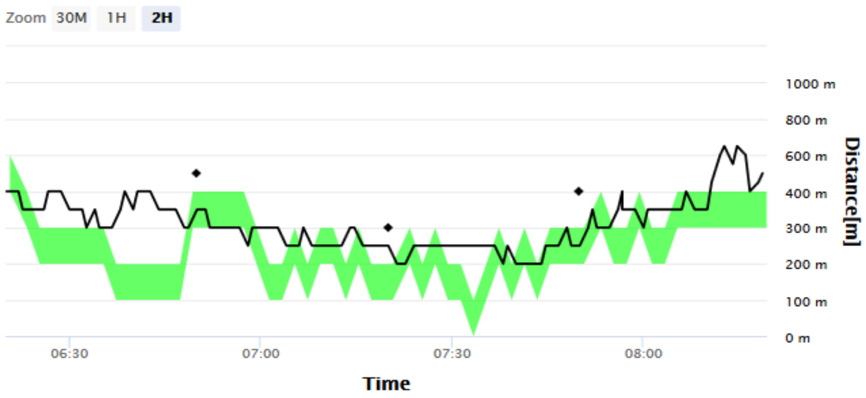

Figure 5: Comparison of visIvis measurements with observer reports and RVR-sensors (courtesy of AustroControl).

Figure 6 and Figure 7 illustrate visIvis results within synoptic applications at the locations Hamburg and Munich. Although the second example for the Hamburg application (Figure 6) is disturbed by raindrops visIvis can reliable detect the correct prevailing visibility of >10.000m. The raindrops cause some misclassifications of individual image regions, but due to the assessment of the complete image via distance classes visIvis is very robust against such artefacts.

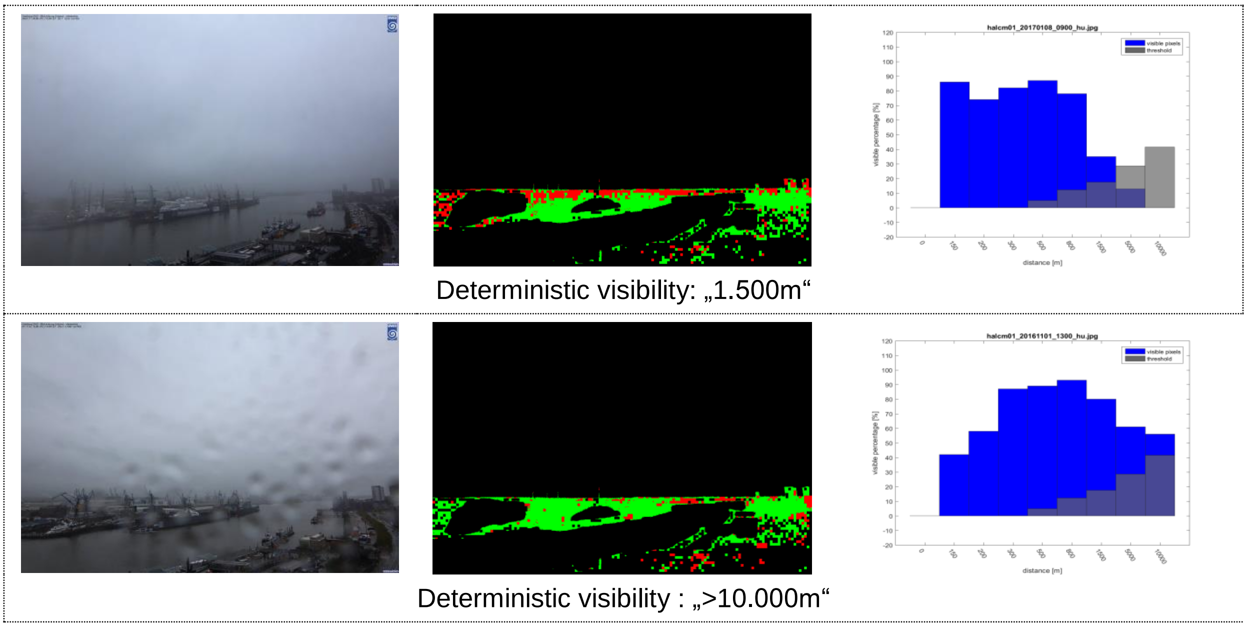

Figure 6: visIvis results for the location Hamburg: raw image (left), visibility detection (red/green, middle), and corresponding visibility histogram (rights), (courtesy of Deutscher Wetterdienst).

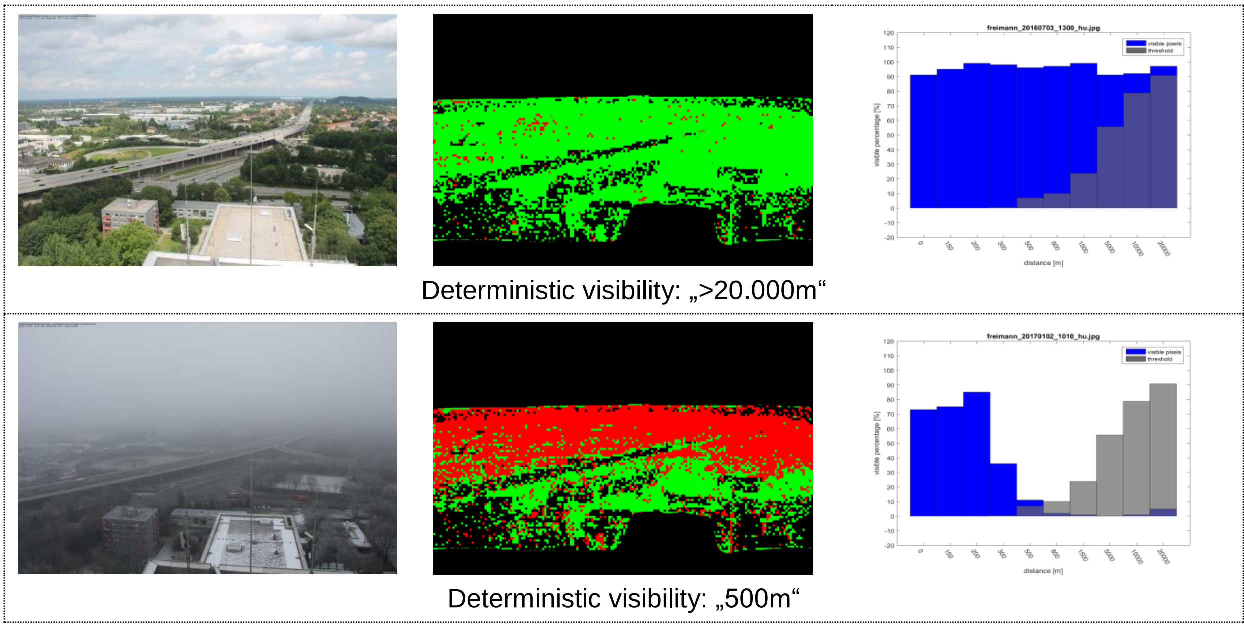

Figure 7: vislvis results for the location Munich: raw image (left), visibility detection (red/green, middle), and corresponding visibility histogram (rights), (courtesy of Deutscher Wetterdienst / foto-webcam.eu).

Summary and Discussion

In air traffic management (ATM) and monitoring of critical infrastructure, the exact description of the atmospheric state - and thus the visibility - is an indispensable basis for any further weather forecast. Vislvis automatically captures the visibility of a large-scale area and thus supplements the current weather observation in the sense of a reliable objective plausibility check.

First installations of vislvis are already in use, respectively in use within a set-up process, by ANSPs and weather services (e.g. AustroControl and Deutscher Wetterdienst) that proof the system's ability to support automated assessment of the weather situation by standard cameras. Although, the ground-based camera (cf. Figure 1, Figure 4) used in this specific evaluation is not perfectly suited for an automated measurement as mid-range distances are heavily under-represented due to occlusions, the achieved performances according to QUAM [9] for different distance classes are in the range from 5-20%, which is in-line with the required performance for observation reports (Table 2).

Measurement / Groundtruth	0-1499m	1500-2999m	3000-4999m	5000-9999m	>= 10000m	Measurement Uncertainty (QUAM)
0-1499m	10	0	0	0	0	0,00%
1500-2999m	7	8	4	0	0	17,93%
3000-4999m	1	12	5	4	0	20,81%
5000-9999m	0	3	4	15	0	18,61%
>= 10000m	0	0	0	6	27	7,54%

Table 2: Confusion matrix for the evaluation of vislvis for the camera at Graz airport (cf. also Figure 1, Figure 4, Figure 5).

In the future, we aim to certify visIvis for automated weather monitoring, so that visIvis can complement the current state of the art and, if necessary, replace it.

Acknowledgements

The authors would like to thank AustroControl and Deutscher Wetterdienst for providing image material and reference data as well as for valuable contributions during the evaluation.

References

[1] Runway Visual Range: https://en.wikipedia.org/wiki/Runway_visual_range

[2] Wiel Wauben and Martin Roth, EXPLORATION OF FOG DETECTION AND VISIBILITY ESTIMATION FROM CAMERA IMAGES, WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation, CIMO TECO 2016, Session 2, O2 (8)

[3] Thomas Sutter, Fabian Nater and Christian Sigg, Camera Based Visibility Estimation, WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation, CIMO TECO 2016, Session 2, P2 (64)

[4] Du, Ke & Wang, Kai & Shi, Peng & Wang, Yang. Quantification of Atmospheric Visibility with Dual Digital Cameras during Daytime and Nighttime. Atmospheric Measurement Techniques. 6. Pages 2121-2130, 2013.

[5] Nathan Graves, Shawn Newsam, Camera-based visibility estimation: Incorporating multiple regions and unlabeled observations, Ecological Informatics, Volume 23, Pages 62-68, 2014

[6] K. He, J. Sun, and X. Tang. Single Image Haze Removal Using Dark Channel Prior. IEEE Transactions on Pattern Analysis and Machine Intelligence, 33(12):2341–2353, Dec 2011.

[7] ICAO: Annex 2 to the Convention on International Civil Aviation – Rules of the Air, 10. Edition, July 2005, Chapter 3.9 VMC visibility and distance from cloud minima

[8] WMO Guide to Meteorological Instruments and Methods of Observation, Chapter 9: http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html

[9] Quantifying Uncertainty in Analytical Measurement: https://www.eurachem.org/index.php/publications/guides/quam