Royal Netherlands
Meteorological Institute
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Feasibility study of fog detection and visibility estimation using camera images

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Abstract

In this report two methods to assess the visibility from camera images during daytime are implemented and evaluated: landmark discrimination by using edge detection and visibility estimation from contrast attenuation between two targets. Two limited sets of images under varying visibility conditions were used. The first method recognized 26 cases out of a first set of 37 images correctly and 6 cases out of a second set of 7. The main cause of faulty recognitions was the threshold to determine strong edges. The second method yielded results which were in fair agreement with data from local present weather sensors on a clear day. For low visibility conditions (foggy day) the visibility was significantly overestimated due to lack of suitable (still visible and dark) objects. Bright targets resulted in a severe underestimation due to lower contrasts with respect to the background sky.

Introduction

Visibility is a meteorological variable which is important for road and air traffic amongst other things. Situations with low visibility affect the capacity of an airport or a road and can introduce delays. Low visibility can also lead to dangerous situations for traffic. Visibility is therefore a criterion for the issuance of a weather warning or alarm.

Visibility is a local phenomenon, which means that it can vary largely on a small spatial scale.[i] The Royal Netherlands Meteorological Institute (KNMI) uses sensors to determine the visibility. The visibility measurements are accurate, however, their sample volume is small and thus the measurements are representative for a small area only. The density of the meteorological observations network of KNMI is therefore insufficient to detect all occurrences of fog.

Nowadays cameras are widely used for various applications such as security, traffic, construction and tourism. There are many different types of camera's on today's market such as infrared, colour, black and white, autofocus etc. Image processing software is also readily available that allows interpretation of camera images. Image processing techniques can be used to separate objects from their background. This in turn suggests that they could be employed to estimate the visibility from camera images. The results could be used to alert users when the visibility is low (e.g. the presence of fog) and possibly even a quantitative measure of the visibility can be obtained from camera images. Visibility extracted from camera images has therefore the potential to provide useful information.

Using already existing camera images is an efficient means to obtain information on visibility or fog. It is a so-called big data application and is of mutual interest of KNMI as well as RWS (Dutch road authorities). Here a feasibility study is performed, investigating whether image processing software can be used to extract information on visibility from camera images. The study was performed during a 3 month traineeship at KNMI.

This investigation is an exploration of applying image processing techniques on a selection of camera images in order to study the feasibility of deriving visibility in different situations. In this investigation only day-time images are considered. First some background information about ways of determining visibility will be provided. Subsequently, an overview and assessment will be given about image processing techniques which can be used to derive visibility from camera images. Next, the results of the selected techniques will be provided and evaluated for a few selected cases. Finally, conclusions will be drawn based upon the outcome of this report and recommendations for future research are given.

Background

Visibility is defined as the greatest distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognized when observed against a background. Traditionally visibility was estimated manually by observers using visibility markers at known distances.[ii] In these situations the reported visibility is partly determined by the availability of suitable visibility markers, buildings and other objects during day-time and lamps at night. Physically, visibility can be described as the transparency of the atmosphere, which is reduced due to scattering and absorption by molecules and particles. The transparency or transmittance of the atmosphere is thus related to the atmospheric extinction. The transmittance can be measured using so-called transmissometers that measure the attenuation of a light source with known intensity over a fixed distance. KNMI uses a transmissometer with short base line of about 12m and long base line of about 75m as a reference for visibilities up to 2km at De Bilt. So-called forward scatter sensors are employed in the meteorological network to determine the atmospheric extinction by the amount of scattering, assuming extinction is mainly caused by scattering. The measurement volume of a forward scatter sensor is about 0.1 dm^3. Both instruments measure the visibility in a small area.

Visibility obtained by human observers is generally less accurate than when using instrumental means for visibility determination. This is due to the fact that the estimation is dependent on the observer's contrast threshold and (at night) the adaptiveness of the observer's eyes to darkness. These factors vary from one person to another, which causes a greater variation amongst visibility measurements than when using instruments. In addition, the observers estimation of visibility depends on the availability of suitable visibility markers, which restricts the resolution of the reported visibility. Observed and measured visibility have been compared extensively. Although there is a general agreement, systematic differences occur due to difference in position between the instrument and the observer (e.g. on the observation field versus on top of a building) and the reporting practices (e.g. instrument reports the 10-minute averaged visibility whereas an observer reported the minimum visibility or for aeronautical applications the so-called prevailing visibility that is considered representative for the aerodrome). The spatial representativeness of the observed visibility values (minimum or median) is much better than the visibility measured by transmissometers or forward scatter sensors.

Since visibility as defined above is an assessment and not a quantity, the quantity "Meteorological Optical Range" (MOR) was introduced, which is defined as: the length of the path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp at a colour temperature of 2700 K to 0.05 of its original value[iii]. The MOR can be measured objectively and is in fact the transparency of the atmosphere. Visibility and MOR are related through the criterion of recognition which states that objects can be recognized against the background when they have a contrast equal to the observer's contrast threshold. The latter is assumed to be 0.05 for an average human observer. MOR is related to the extinction by:

$$MOR = -\frac{\ln(0.05)}{\sigma} \approx \frac{3}{\sigma}$$

where σ is the extinction coefficient. For daytime observations, the MOR is approximately equal to the visibility. There are many other ways to define variables related to visibility depending for which application visibility needs to be known. For example the runway visual range (RVR) is used in aeronautical applications to indicate the distance up to which pilots can distinguish the runway lights. RVR can be derived from MOR once the intensity of the runway lights and the background luminance, against which the light should be distinguished, are known. In this report visibility is referred to as MOR.

The visibility range in meteorology is 10 m to 100 km. Critical visibility limits are 5000 m (haze), 1000 m (fog) , 200 m (dense fog) and 50 m (very dense fog). The visibility range for aviation is 10 m to 10 km , with 10 – 2000 m the crucial range for RVR .[iv]

Figure 1: Transmissometer setup, consisting of a transmitter (Xenon flash lamp) and two receivers.

Figure 2: Forward scatter sensor (present weather sensor), which emits an infrared beam of light that is scattered into the receiver.

Techniques

There are many techniques which can be considered for the estimation of visibility and detection of fog from camera images. In this chapter an overview will be given of these techniques with a short description explaining and evaluating each technique. The techniques can roughly be divided in two categories: (i) techniques that determine if objects are visible on an image or not and indicate whether the visibility exceeds their respective distance or not. This category is called landmark discrimination; (ii) techniques that make a quantitative estimation of the visibility from the image. All techniques assume that the distances of objects involved or the distances between them are known.

Landmark discrimination - Thresholding

One technique to measure visibility would be to threshold images. Thresholding is a method which determines a threshold value (or multiple) for the pixel brightness[v]. Above this threshold the pixel is set on 'true' and below on 'false'. By choosing the threshold in such a way that the (visible) objects are separated from the background (non-visible objects and clouds/horizon). The distance of the objects used for the threshold value are a measure for the visibility on the image.

While there exist many algorithms for thresholding images (histogram based, multiple thresholds, local/global etc.), they are all based on the distribution of grey values in images. Thresholding is a great image processing technique when there's a clear contrast of the objects against the background so that they can be separated using a grey-value threshold. However, the images which were available for the present investigation had a pixel distribution which was rather uniform and upon which no clear distinction between object and background could be made. Also, because of inhomogeneous illumination, caused by the varying position of the sun during the day, reflections cause some objects to have the same brightness as the background. This makes them indistinguishable from the background (sky/horizon) when using this thresholding. However, a big advantage of this technique is that it's fairly straightforward to implement. On the other hand using this technique yields mainly qualitative information about whether objects on the images are visible or not, since the thresholded image is a binary image.

Landmark discrimination -Edge detection

Another technique which can be used to distinguish objects from the background is edge detection. Most edge detection algorithms determine the local maxima in the image gradient, reflecting the discontinuous changes in image brightness at edges[vi]. By using this technique one can discern objects in the visible range. Provided the distances between the camera and the objects are known, the object at furthest distance from the camera, which is still recognizable in terms of its edges, gives a crude estimation of the visibility.

Edge detection is a well-known and widely used technique that can easily be used. The criterion to determine if an object is visible or not can be related to the number or fraction of edge pixels in the object area.

Landmark discrimination – High/Low pass filtering

High-pass filtering is used to suppress low frequencies in the image and enhance high frequencies (the details) in the image[vii]. This technique could also be used to separate a low frequency (smooth) background (such as the sky) from highly detailed objects and relate the visibility to the visible object at the greatest distance from the camera. One could also use a low-pass filter to enhance (relatively) uniform fog on images and suppress clear objects.

Filtering images with high-pass filters in the frequency domain is an easy and quick way to discern objects since the atmosphere acts as a low-pass filter when the visibility is low. However, the filter amplifies noise, can create artefacts (light halo's, dark lines), doesn't correct for lens contamination. Furthermore, the method requires the grey value function of the input image to be sufficiently smooth/convergent. Using a low-pass filter to detect fog also requires this last constraint on images and is still dependent on camera properties such as resolution and lens flare.

Landmark discrimination - Image ratio's

Fog can also be detected by computing the ratio between a foggy image to an image of the same scene on a clear day. The brightness of the resulting image (representing the value of this ratio) is related to the fogginess of the image. The higher the brightness of this image, the denser the fog on the foggy image.

Detecting fog by calculating the ratio in image brightness between a reference image of a clear day and foggy images has its limitations as well. One could think about for instance movement of the camera, autofocus, sun glare, camera resolution etc. An advantage of this method is that it's relatively easy to implement and it's verifiable by comparison of the input images.

Landmark discrimination – Uniformity segmentation

When observing fog on digital images, one would expect a relative uniform distribution of pixel values in the foggy areas. By checking the variability in the grey values of the image under consideration with for instance a discrete gradient estimation, the image can be divided into uniformity areas. By relating the degree of uniformity to the presence of fog a fog detector can be created.

Checking the uniformity in the grey values with for instance a gradient estimation does not only yield foggy areas, but also clear areas of the input images where the illumination is homogenous and the variability small. Other problems are the poorer fog detection capabilities near the edges (since there's a sharp transition), qualitative results, limitations by resolution and variability in fog values. In short this method is not very robust, but it does provide an indication of fog on images (of approximately the same time during the day) where fog can be segmented due to a clear uniform area relative to the areas of the image with detailed textures (such as visible objects).

Quantitative visibility estimation - Koschmieder's contrast ratio of 2 objects

From a physical point of view visibility can be calculated provided the extinction coefficient of the atmosphere is known. In 1924, Koschmieder established a relationship, which later became known as Koschmieder's law, between the apparent contrast $C(x)$ of an object at a distance x, seen against the horizon sky by a distant observer and its inherent contrast (C_0). The latter is the contrast that the object would have against the horizon when seen from very short range. Koschmieder's relationship can be written as[viii]:

$$C(x) = C_0 e^{-\sigma x}$$

with σ the extinction coefficient. $C_{0,}$ a constant dependent on scene illumination and the properties of the object itself, can be eliminated by comparing the contrasts of two objects with the same inherent contrast at different distances (x_1 and x_2). This results in:

$$\frac{C(x_2)}{C(x_1)} = e^{-\sigma(x_2 - x_1)}$$

From this ratio the extinction coefficient σ and thus the MOR can be estimated.

The most common way to calculate the visibility is to use contrast reduction to determine the extinction coefficient. This is the most direct and quantitative method of determining the visibility during daytime of all the techniques mentioned in this section. Koschmieder's law holds under the assumptions of a homogeneous atmosphere and using black objects. Since in practice these assumptions do not hold, this will cause errors. For example reflections of sunlight by the objects will cause the visibility to drop. Other inhibitions are resolution, autofocus, lens contamination, directional dependence of visibility etc.

Contrast

Contrast quantifies the degree to which objects are visible based upon difference in brightness or colour. In image processing there are several ways to define contrast. When the average brightness is nearly equal to the background brightness it is convenient to use the Weber contrast[ix]:

$$C_W = \frac{I - I_B}{I_B}$$

where *I* represents the intensity of the object under consideration and I_B the intensity of the background. Here it is assumed that the contrast of a nearby black object is high (C=-1) whereas in poor visibility conditions the object will fade in with the background (C=0). Note that the contrast can also be determined for individual RGB channels and that the contrast is a ratio so that changes in illumination are, in a first order approximation, taken into account.

There are many other definitions of contrasts in image processing . The Weber contrast is considered the most suitable for visibility estimation and is generally used for this purpose. Since images have a varying background (in this case mainly caused by inhomogeneous scene illumination) and since objects are no perfectly black, this formula will not be exact.

The contrast in an image depends on several digital camera properties such as gain/offset per pixel (shading), the fill factor (part of a pixel which is actually sensitive to light[x]), exposure, resolution, white balance, saturation, BLC (backlight compensation, adjust exposure of image to view objects in the foreground in more detail) etc. A larger fill factor for instance will improve the SNR (signal-to-noise ratio), but decrease the contrast due to smoothing from a finite sampling aperture. White balance corrects unnatural colours due to the prevailing colour temperature (temperature of a black body radiator which emits the same spectrum) in the image[xi]. Saturation indicates the purity of a colour[xii]. It's possible to define a colour contrast based upon a set of colours with different saturation.

Quantitative visibility estimation - Koschmieder's contrast of object observed from 2 distances

One can also estimate the visibility from contrast by using 2 images of the same object with the same background, obtained from 2 distances by 2 differently positioned camera's[xiii].

A disadvantage of using 2 cameras instead of 2 targets is that the cameras need to have the same settings (zoom, aperture size, exposure etc.) to give reliably estimate visibility. However, advantages of this method are that the black-body assumption is not necessary and no pre-knowledge of the intrinsic contrast of targets (calibration constant, C_0) is required.

Quantitative visibility estimation - Relative visibility

In order to obtain a lighting independent descriptor the relative visibility between a clear reference image and images with varying degrees of fog can be characterized by colour (RGB) ratio's. One could for instance study the clarity of the sky by examining the B/G ratio. On a clear day, when the visibility is high, one would expect the this ratio to be larger than on a grey hazy day. By using the ratio on a clear day as a reference, visibility on a set of images can be determined relative to this image.

Another way to define relative visibility would be to use multiple targets spread out over the images and calculate the ratio between each target's contrast to its contrast on a clear image. This is based upon the fact that objects with a higher contrast are better visible[xiv].

Relative visibility (RV) provides several advantages over the absolute visibility. The latter is spatially dependent and is not fully representable for a large inhomogeneous area by a single value. RV reduces this problem to a change in image features with respect to a reference image on a clear day. Determining RV from images is limited by camera movement, autofocus and scene illumination (when studying contrast). Another problem would be the lack of ground truth data for relative visibility.

Selected landmark discrimination and visibility estimation technique

For the present investigation two techniques have been chosen for implementation and further analysis based on the above evaluations: (i) Recognition of objects positioned at known distances from the camera using edge detection which is similar to an assessment of the visibility from human observers; and (ii) MOR estimation from contrast reduction between 2 objects with known separation of the objects.

Results

In this section results of applying the two implemented methods will be given. Explanations will be given in the next section.

Landmark discrimination - edge detection

The first method implemented was the landmark detection using edge detection. The camera images used were obtained from an AXIS 214 PTZ Network Camera using 1x zoom and a resolution of 768x576. The camera is computer controlled and fixed in a preset. A picture is taken every 10 minutes and stored in JPEG-format for further processing. The camera is located at the test field of KNMI behind the main building. Note that a transmissometer and a forward scatter sensor are located on the test field.

Firstly, a number of objects need to be selected on a clear image (no fog/clouds), which are clearly recognizable and whose visibility notably deviates on the other images of the same scenery. This selection was done by drawing a small rectangle around/inside the objects so that each rectangle contains edges of the object and its background. These landmarks are chosen such that they represent a wide variety of distances from the camera . Furthermore, with increasing distance the object size should increase, otherwise the camera can't detect the marker.

Next, the edges of the landmarks are computed in each of the rectangles by convolution of the input image with a Gaussian derivative with $\sigma=1$ (choosing a higher σ value notably decreases the number of edge pixels detected and a lower σ makes the image too noisy). Subsequently, a threshold is set to determine the number of strong edge pixels (belonging to objects). The threshold was determined manually to correspond to the value of edge pixels on an image where a targets is just visible according to the operator's perspective. Afterwards, the number of pixels in each of the object rectangles are counted and a second threshold is determined using a fixed percentage of the number of pixels inside each rectangle on a clear image. This second threshold sets the critical number of edges above which an object is deemed visible or not for each of the chosen objects. The thresholds were set to an intensity of 5 (corresponding to a 2% contrast threshold) and a critical number of edges of 10% of the pixels inside the rectangle's areas.

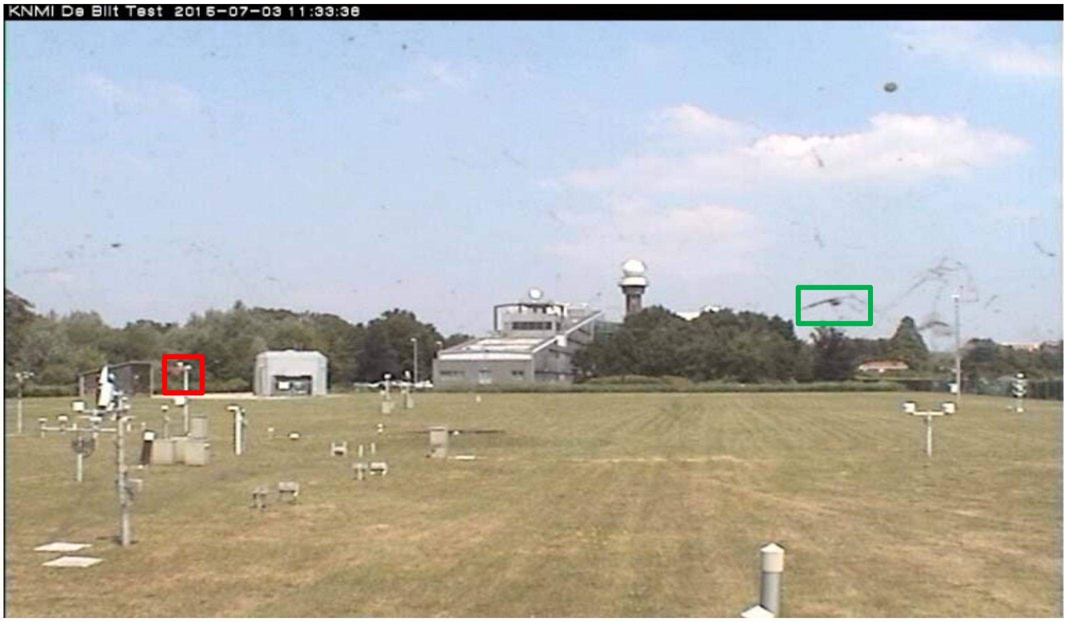
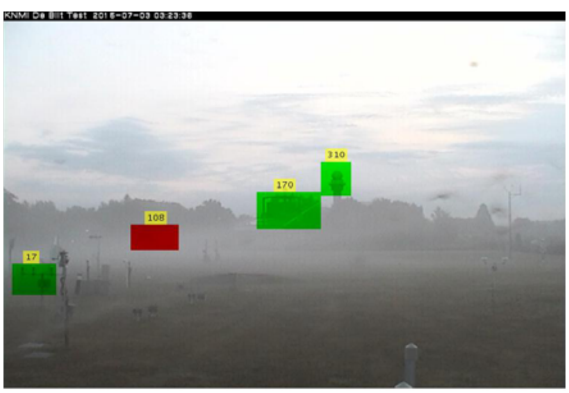


Figure 3: Example of an original image of the test field of KNMI on a clear day. Note the lens contamination (green) and the forward scatter visibility sensor (red).

Figure 3 is an example of a clear image, on which the landmarks need to be selected. The objects considered are a radiation sensor (distance 17 m); radiosonde shed (108 m); KNMI building (170 m) and radar tower (310 m). Below an example of an image on which the landmarks need to be discriminated is shown together with the result after the edge detection algorithm is applied. The radiosonde shed is not visible in this example although the objects farther away can be distinguished.



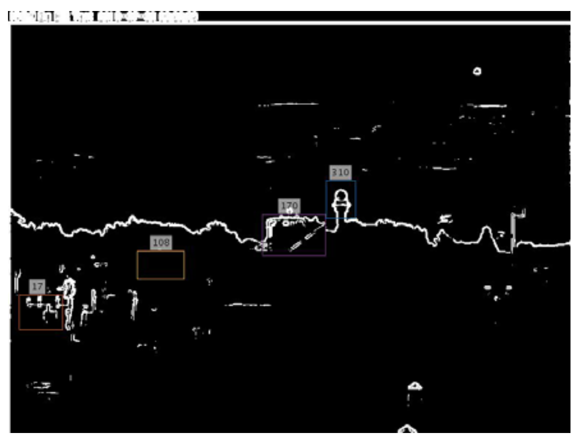


Figure 4 (left): Image obtained from the camera at the test field of KNMI. Figure 5 (right): Same image after edge detection is applied. The rectangles indicate the areas which were used for recognition of the object within them. The numbers above them indicate the distance in meters between the camera and the object in the rectangle.

In the figures 6-10 several fog cases are shown on July 3, 2015. The 4 landmarks chosen are indicated in the coloured rectangles with their respective distances. The results match reasonably well with how a human observer perceives the visibility of the objects on the images. For each figure the MOR measured by the forward scatter sensor (FS) located at the test field is indicated as a reference. The results shown in Figure 67 and Figure 10 don't agree with the FS data. The figures 6-10 show situations where the visibility reduction is not homogenous. For example Figure 8 and 9 where a fog bank seems to be present between the radiosonde shed and the KNMI building where a ditch is located.

The landmark discrimination method determines whether an object at a certain distance is visible. In inhomogeneous conditions the results are inconsistent. These conditions can be detected by the landmark discrimination method and the visibility that is reported in such conditions can be optimised to the users requirements, e.g. lowest visibility.

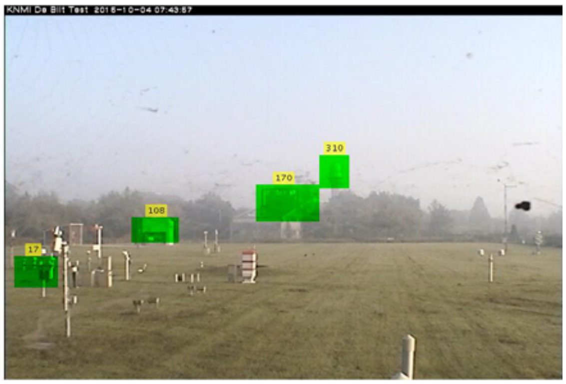


Figure 6: Image of a hazy day. All objects in the rectangles are visible (=green). FS visibility = 866 m.

Figure 7: Foggy image. Only the closest landmark is visible, others aren't(=red). FS visibility = 339 m.

Figure 8: Ground fog. Only the object at 108m isn't visible. FS visibility = 272 m.

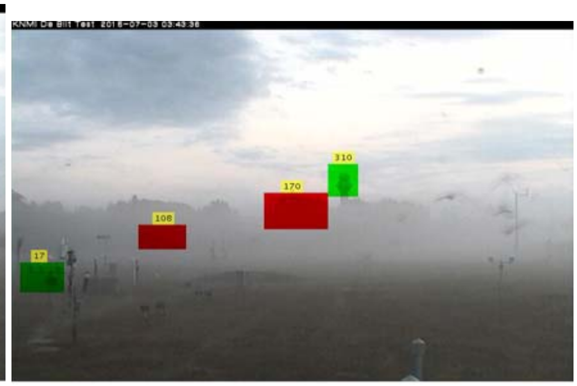


Figure 9: Fog covers objects at 108m and 170m. Closest and furthest object still visible. FS visibility = 122 m.

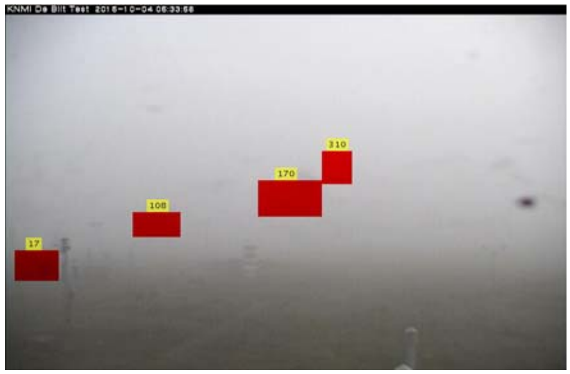


Figure 10: Fog covers almost the entire image. None of the landmarks are visible. PWS visibility = 61 m.

The FS MOR measurements are shown in figure 11 for July 3, 2015 with fog in the morning. Fog occurs when the visibility is lower than 1000 m. This upper limit is displayed in the same figure. At about 04:10 UT the fog has vanished and all of the landmarks should be visible according to the forward scatter sensor This corresponds to the results of the landmark discrimination, since all chosen objects became visible from 04:10 onward.

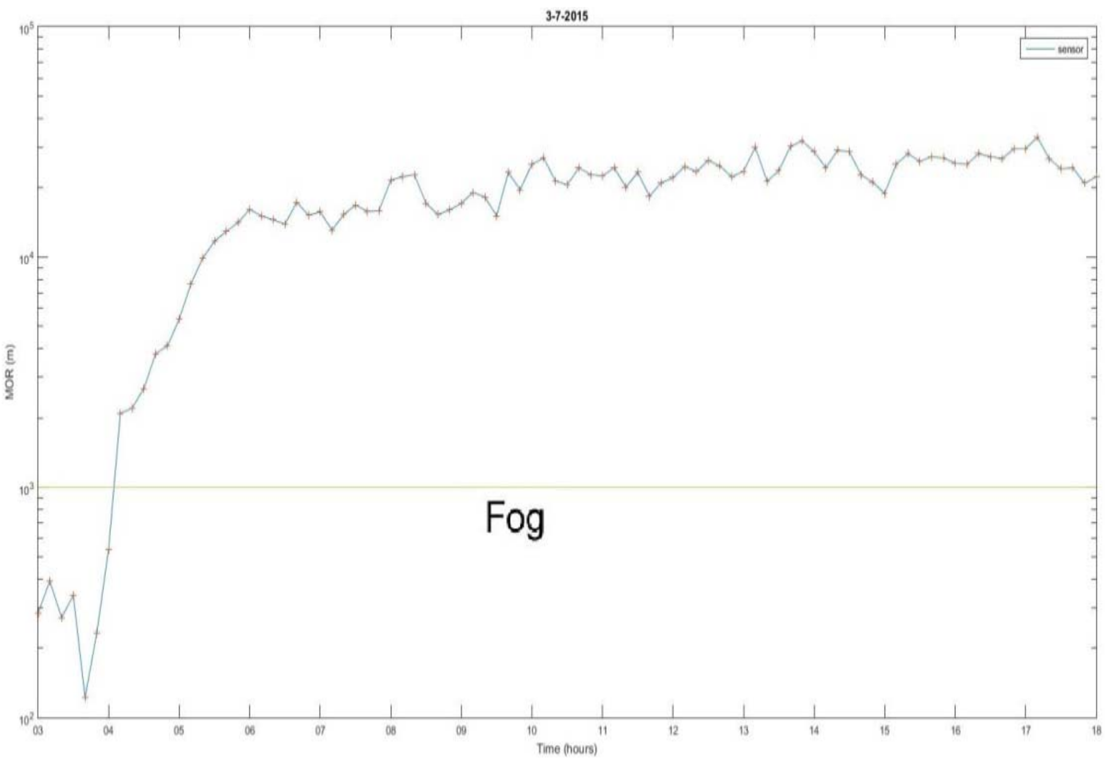


Figure 11: MOR of FS for July 3, 2015 a day with fog in the morning. The yellow line indicates the MOR upper limit for fog (1000 m).

To evaluate the sensitivity of the thresholds, which were chosen to distinguish 'real' edge pixels of objects and to determine when a landmark is visible, the landmark detection was applied to a set of 7 images at 18R touchdown of the Polderbaan at Schiphol on November 2, 2015. These images were obtained by another camera.

Figure 12: Example of an original image of 18R touchdown at Schiphol.

Figure 13: Clear image of Schiphol 18R touchdown. All landmarks (lamppost, viaduct both at 300 m, 2 tree groups at 1 km) are visible.

Figure 14: Hazy image of Schiphol 18R touchdown on the same day. The tree groups aren't detected anymore, while the left tree group is still visible to an observer.

The images in figures 13 and 14 were obtained by using the same thresholds as for the images of the test field at KNMI. As targets a lamppost, a viaduct (at 300 m) and two groups of trees (at 1 km) were chosen. On the left image the atmosphere is clear and all the landmarks are visible in agreement with the results of the algorithm. The FS at 18R touchdown reported a MOR of 9340 m. The right image shows a situation with haze (FS reported 3130 m). By visual inspection the left group of trees is still barely visible, while the method classifies this object as non-visible. On inspection of the change in intensity with position on the image, it turns out that in this region the change is too small in comparison with the threshold for edge strength. The object becomes visible again if the threshold is lowered to 2. The recognition of the landmarks on the other images of this set were in agreement with visual inspection of the images.

The threshold for critical edge strength is chosen based upon visual inspecting when an object is just visible. Choosing the threshold this way leads to an underestimation in this case, since this is a subjective matter. However, lowering this threshold means that the algorithm is more influenced by noise, which in turn brings about more falsely detected targets.

The landmark discrimination method, compared to visual inspection of the images, correctly identified the visibility/non-visibility of objects in 26 out of 37 (=70%) images for the test field set and 6 out of 7 (=86%) images for the Schiphol.

Visibility estimation from contrast attenuation between 2 targets

The second method that was considered estimated the visibility from the contrast reduction using Koschmieder’s law. The camera images used included the images obtained from the camera at the KNMI test field in De Bilt specified above. For August 1, 2015, a clear day, 31 images were used (from 12:00 till 17:00 UT) to check the method for homogenous conditions and high visibility situations. In these cases Koschmieder’s law should be nearly exact. Objects were chosen that have similar optical properties and which were sufficiently spaced. In the pictures below (Figure 15) two patches of trees were chosen and for the background a patch of the sky. On the same image also two other objects, namely the bright radar tower, a dark patch of trees and another patch of sky, were chosen. The pixel values were averaged over the selected areas to reduce spatial variations.

From these pictures the visibility is obtained from the contrast attenuation for each of the 3 colour channels (RGB) and for each of the 2 choices of targets and is plotted in figure 16. The choice of 2 patches of trees for the objects is indicated by the ‘trees’ curves in the legend and the choice to use the radar tower and a patch of trees as targets is indicated by the ‘tower’ curves. For comparison the values of a forward scatter sensor, located at the same scene, are shown in the same figures. From the graphs it can be seen that there is a significant underestimation of the visibility obtained from the ‘tower’.

Also, notice that for the ‘trees’ plots the visibility is worst for the blue channel, while this colour has the highest estimated visibility for the ‘tower’ curves. Another point worthy of mentioning is that the green and red channels fluctuate more than the blue channel. Other objects that have been considered are buildings and grass. The results of the first are often affected by reflections, the latter by shadows and the position of the sun. When objects are not black or sufficiently dark, the derived visibility is frequently significantly underestimated.

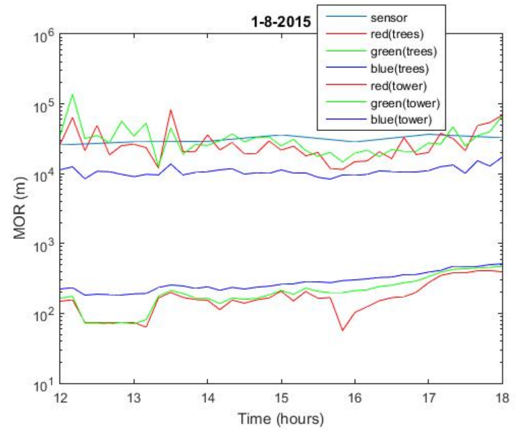
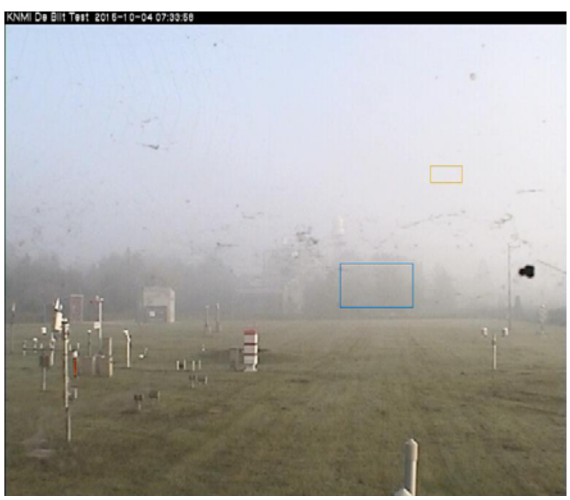


Figure 15: Input image of a clear day. Red, blue(front) and yellow rectangles indicate 'trees' set of targets used, while green, purple and blue(back) rectangles indicate the 'tower' set.

Figure 16: Graph of the estimated MOR(m) vs time(hours) for a clear day. Plots of present weather sensor data, MOR estimation from the 'trees' targets and from the 'tower' set of targets for the colour channels (RGB) are shown.

This method was also used to estimate the visibility on a day with fog in the morning. The chosen objects now include a patch of trees and part of a black pole. The visibility graph clearly shows a large overestimation of about a factor 6 in the early morning (05:00 – 07:00). Also notice the dip at around 10:00.



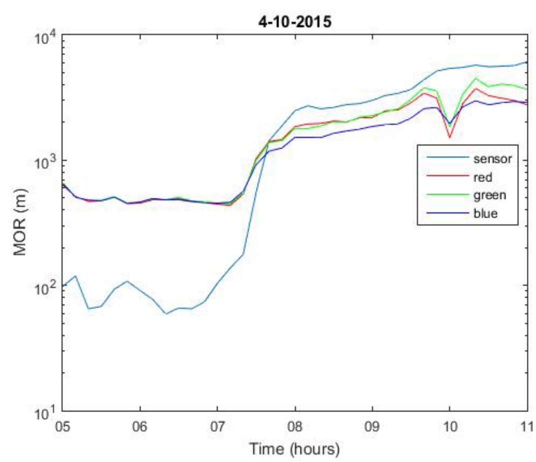


Figure 17: Input image of a foggy day(morning). Red, blue and yellow rectangles indicate targets used.

Figure 18: Graph of the estimated MOR(m) vs time (hours) for a foggy day. Plots of present weather

Figures 19 and 20 illustrate the visibility estimation from images of 18R touchdown at Schiphol. These images were obtained from screen dumps of images obtained from a LTC 0630 Series Dinion2X Day/Night camera. Once again choosing trees as targets which are sufficiently spaced, yields the best results for visibility when compared to the data of the forward scatter sensor near touchdown. The red channel shows a discrepancy at 10:00.

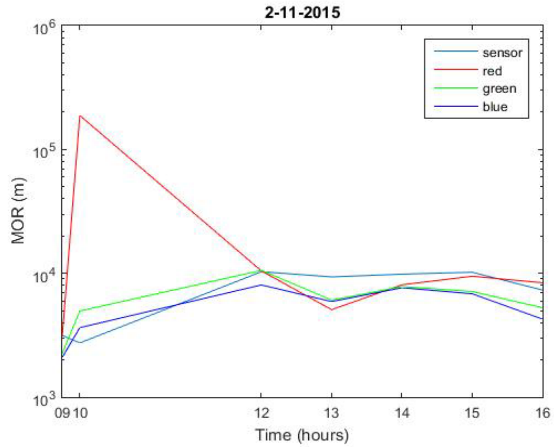


Figure 19: 18R touchdown of Schiphol (Amsterdam). Red, blue and yellow rectangles indicate chosen targets and background.

Figure 20: Estimated visibility and MOR of forward scatter data on November 2, 2015.

In order to study the dependence of the targets on their location throughout the image, two other patches of trees were chosen. From figure 22 it can be seen that the visibility is underestimated for all 3 colour channels.

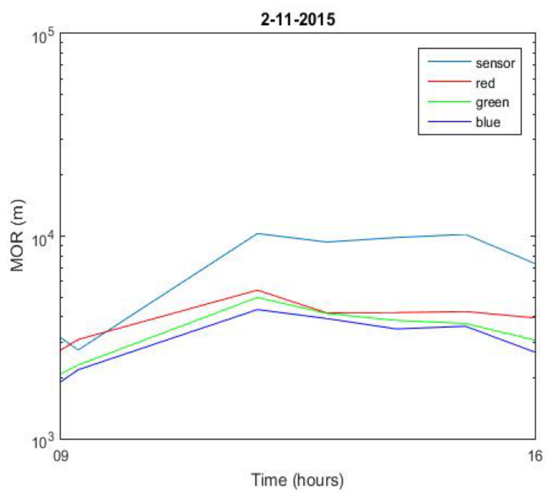


Figure 21: 18R touchdown of Schiphol (Amsterdam). Same day but different objects/background chosen as indicated by the red, blue and yellow rectangles.

Figure 22: Estimated visibility and forward scatter data for the choice of targets from the previous figure.

Discussion

The landmark discrimination method using edge detection yields an indication of a visibility regime instead of a single value. By comparison with the FS values a few cases were off. One could argue that the radar tower is still visible in Figure 7, since it's silhouette is still distinguishable. Studying the intensity of the pixels of this object after convolution with a Gaussian derivative, the values proved to be lower than the threshold which determines the strong edges. This can be corrected by lowering this threshold without affecting the results for the other images of the test field. In Figure 8 the FS is covered in shallow fog, while the tower and the main building rise above the fog. This explains why the FS measures a MOR which is lower than the furthest recognizable target on the image. On Figure 10 the landmark discrimination suggests a visibility < 17 m since not even the object (radiation sensor) closest to the camera is visible. However, the FS indicates a visibility of 61 m, so the latter should be visible. In fact, by looking visually at the input image this object is still visible. The threshold which determines the number of strong edges an object needs to have in order to be visible was chosen empirically to be 10% of the maximum number of edges of each target for a clear image. The landmark discrimination results obtained at 18R touchdown at Schiphol indicate that the threshold are quite good although there is room for improvement.

Unfortunately no landmarks at large distances were available in the camera images to extend and test the discrimination method to larger visibility values.

The landmark discrimination method also works when the visibility situation is inhomogeneous. The results of the method can then be inconsistent. The requirements of the user should be considered on what visibility should be reported in such conditions, e.g. lowest visibility.

The dual target approach, which calculates visibility from contrast reduction has proved to require certain conditions from digital images which have to be met.

First of all, suitable objects need to be available. A target is suitable if it's sufficiently dark (less reflected light, dark objects are better visible than brighter ones) and large enough to be detectable by the camera. Choosing a bright far target such as the radar tower in Figure 15 results in a significant underestimation of the visibility, since the added reflected light from the tower surface causes a lower contrast and thus a lower estimated MOR. It is advantageous to choose the targets along a straight line. This reduces the influence of background stray lights and atmospheric inhomogeneity's along the image. Furthermore, the distance to the near target and the distance between the targets should be large enough for sufficient attenuation of the target contrast. These two distances determine the visibility regime which can be detected within reasonable error. The error in the visibility increases when the visibility is much larger or much smaller than the distance between targets. In the first case the contrast reduction is too small and for the latter the object(s) fade into the background making it(them) not suitable for visibility derivation.

Besides the availability of suitable objects, images should have objects which are similarly illuminated by the sun. Inhomogeneous lighting is mostly caused by the change in position of the sun during the day and clouds. In order to achieve this requirement a good approximation is to use images on which the sun is behind the camera on a relatively clear day. Overexposure also causes errors and should either be corrected for (adjust camera aperture or shutter speed) or these images should be left out of consideration as was done in this report.

The estimated visibility is further limited by the resolution of the images and the camera response function (CRF). A lower resolution will actually decrease the contrast and consequently decrease the object visibility. The camera response function determines the relationship between the scene radiance and the image intensity and therefore the contrasts of the targets from which the visibility is estimated.

For a clear day the estimated visibility (from the trees) compares well with the sensor data in Figure 15. The green channel yields the best result. Blue yields the lowest visibility, while for the 'tower' choice of targets, blue yields the highest visibility. The latter can be explained by the difference in intrinsic contrasts between the targets (wavelength dependent). When using similar dark objects, (trees) the visibility on this clear day is lowest for blue due to Rayleigh scattering, since shorter wavelengths are scattered more. For a foggy day the visibility is significantly overestimated in the morning when fog occurred (visibility <= 200 m) in Figure 18. The main cause (aside from the general ones listed above) is non-suitability of objects. The trees in Figure 18 were in the morning not visible, which makes them not suitable as target. However, there were no sufficiently dark objects available, which were still distinguishable at these low visibilities. The dip in the curves at around 10:00 can be explained by the position of the sun at the time which casts shadows on the closest target.

For Schiphol images, the discrepancy at 10:00 in the red channel was caused by bright illumination of the sun, which caused a reddening (Figure 1. The results of individual colours can point out problems for specific situations. The visibility estimation seemed very target dependent. It's hypothesized that the attenuation between the trees (about 700 m) in Figure 21 is too small to accurately estimate visibility for these images.

For all images of the test field the red and green channels fluctuated the most. This is mainly caused by the large fluctuations in the background sky in these channels (see figure below). Throughout the day the clarity of the sky changes (clouds), which is coupled to changes in red/green, while the amount of blue stays the roughly the same. Though, there was a clear dominance of red over the whole of each image of the test field at De Bilt. This is possibly due to the automatic white balance setting of the camera.

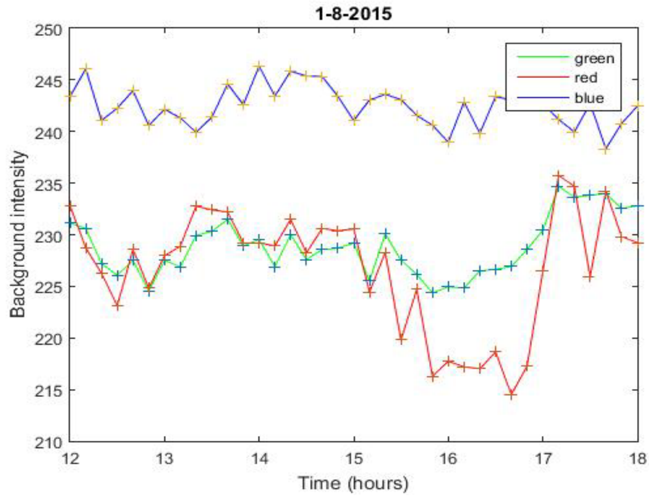


Figure 23: Change in background (sky) RGB values throughout a clear day.

Conclusion and recommendations

In this report two methods to detect the visibility using camera images were implemented and evaluated: landmark discrimination using edge detection and visibility estimation from contrast attenuation between two targets. Both methods were tested on 2 sets of images of different scenes. The landmark discrimination recognized all targets correctly compared to visual inspection of the images on 26 out of 37 (=70%) cases for the test field De Bilt set and 6 out of 7 (=86%) images for the 18R touchdown Schiphol set using the same thresholds. The main cause for recognition errors is the difference in the nature between targets (edge-based, uniform etc.). When the landmark discrimination method fails to identify an object it is generally barely visible. The second method yielded reasonable visibility values in a clear afternoon for both the test field in De Bilt and at Schiphol in comparison with local forward scatter data. The targets chosen have to be sufficiently dark and spaced (depending on the visibility) in order to obtain reliable results. Considering the results of individual colours can be useful to identify problems in specific situations. When the visibility was low (fog), a significant and consistent overestimation of the visibility was obtained for the test field images. It is suggested that this is due to the lack of dark objects nearby the camera, which could still be distinguished.

For future research it is recommended to evaluate both techniques using larger sets of images on which the horizon is visible. In addition, sufficiently dark markers such as dark hills, meadows, trees need to be available at a wide range of distances. One could also place black-white targets manually, but this is a rather expensive and most probably unpractical task. The threshold to determine the strong edges can possibly be related to the contrast threshold of 0.05 by estimating the barely discernible contrast from the dynamic range of the image. Furthermore, a camera with a higher resolution can be employed to study the dependence of the performance of both methods on resolution. Both methods can be supplemented with image registration algorithms (normalized cross-correlation, template matching) to correct for a moving camera.

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