Temporal interpolation in Meteosat images

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Abstract

The geostationary weather satellite Meteosat supplies us with a visual and an infrared image of the earth every 30 minutes. However, due to transmission errors some images may be missing. European TV weather reports are often supported by such infrared image sequences. The cloud movements in such animated films are perceived as being jerky due to the low temporal sampling rate in general and missing images in particular. In order to perform a satisfactory temporal interpolation we estimate and use the optical flow corresponding to every image in the sequence. The estimation of the optical flow is based on images sequences where the clouds are segmented from the land/water that might also be visible in the images. Because the pixel values measured correspond directly to temperature and because clouds (normally) are colder than land/water we use an estimated land temperature map to perform a threshold between clouds and land/water. The temperature maps are estimated using observations from the image sequence itself at cloud free pixels and ground temperature measurements from a series of meteorological observation stations in Europe. The temporal interpolation of the images is based on a path of each pixel determined by the estimated optical flow. The performance of the algorithm is illustrated by the interpolation of a sequence of Meteosat infrared images.

Keywords: Optical flow, temporal interpolation, Meteosat.

I Introduction

For presentation of weather reports it is of interest to be able to perform temporal interpolation in sequences of images supplied by the geostationary Meteosat satellite. The Meteosat satellite covers Europe, the North Atlantic and the African continent. We will restrict ourselves to the georectified images of Europe from the infrared channel of the satellite that the Danish Meteorological Institute (DMI) use in the daily TV weather report. The visual channel of the satellite is not used because of the uselessness of nighttime images.

Ideally one image is received from the satellite every half hour, however at least twice a day, at 11.30 am and 11.30 pm, the images are missing due to transmission of other types of data (and low bandwidth). Also, missing images may and do occur frequently due to transmission errors. This coarse temporal sampling in general and the missing images in particular make the cloud movements in animation of such images seem jerky.

For the presentation DMI also wants to segment the clouds from land/water, so as to be able to insert a texture map (i.e. blue water and green land) at cloud free pixels. To avoid clouds disappearing and/or (re)appearing it is evident that such a segmentation should have temporal smoothness properties.

The infrared channel of the satellite corresponds directly to temperature, and because clouds are colder than the surface of the earth the segmentation may be performed by a threshold operation. At DMI the standard approach for the TV weatherreport has been to use a global threshold for all pixels and all images in the daily sequence. This is of course an un-optimal approach, and it results in obvious errors, particular in winter when ground temperatures in the northern part of Europe are comparable or lower that cloud temperatures over other parts of Europe. On Danish television it was always cloudy over the Bay of Botnia in wintertime.

We propose to use an estimated ground level temperature map to differentiate between cloud pixels and land/water pixels. This temperature map is generated using two sources of information, namely partly the observed temperature at cloud free pixels in the image sequence, partly ground measurements of temperature at a series of meteorological stations. The identification of cloud free points in the image sequence is based on the observability of known terrain features, e.g if a coast line is visible at a pixel, this pixel is cloud free. All these point measurements are then interpolated to temperature maps corresponding to each of the original images, and a segmentation is performed.

With respect to the temporal interpolation a naïve approach would be to fade from one image to the next. This, however, results in an unwanted pulsating effect between blurred and sharp images. We find that a satisfactory temporal interpolation should be based on the (cloud) flow field. In order to estimate the flow field we will employ an algorithm based on local estimates of the distribution of spatio-temporal energy and a smoothness constraint that punishes high spatial derivatives implemented in a Markovian random field setting[1].

Finally, in order to estimate the value of a pixel at an intermediate (interpolated) time, the spatio-temporal path of that pixel is estimated by fitting a polynomial to the estimates of the flow vectors at two time instances before and two time instances after that point in time. Having estimated the path, the pixel is assigned a weigthed mean of the observed pixel values on its path in the previous and the next image.

II Data

The algorithms described in this article will be applied to a sequence of images recorded by the Meteosat 5 satellite. The images are from the infrared channel (10.5 - 12.5 μm). Preliminary processing performed by the Danish Meteorological Institute consist of mapping to a polar stereographic projection, interpolation to a equirectangular 7 km grid, and subsection to 576×768 images. The center of the grid is at $48.4°$ N latitude and $8.2°$ E longitude. The images are recorded with a time interval of 30 minutes.

III Methods

Given the estimated flow fields corresponding to each image in the image sequence[1] this application holds two tasks. Namely estimation of a ground level temperature map to be used then segmenting the clouds, and the generation og intermediate images by temporal interpolation.

A Estimation of Temperature Maps

Given timeseries of temperature measurements at a series of meteorological ground stations a temperature map is generated. The ground stations are shown in Fig. 1. Each station provides a temperature every 3 hours.

In addition to these points a number of cloud free (coastal) points are extracted from the image sequence. The cloud free coastal points are identified by use of the histograms of land pixel and sea pixel values within a 5×5 neighbourhood of each coastal point. Note that coastal points are known in advance because the image sequence is georectified.

The conversion between temperature measured in degrees Celsius and measured intensity in the thermal Meteosat images is made by use of a table supplied by the Danish Meteorological Institute.

In order to satisfy the time constraints an operational scheme requires, we choose a simple iterative method for the estimation of smooth temparature maps. Based on all points a temperature map is

Fig. 1: Each cross represents a ground temperature gathering station. Data is supplied by the Danish Meteorological Institute.

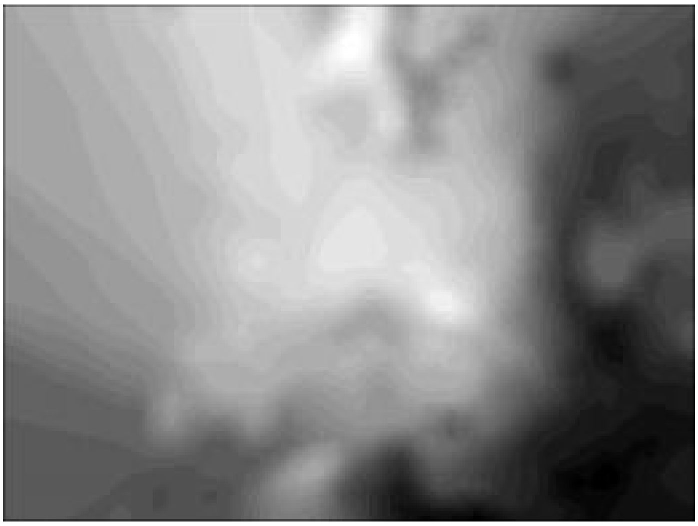

Fig. 2: This is the interpolated temperature map for the June, 24th 04:30 GMT image.

generated using a linear interpolation scheme. The estimated temperature at a point is found as the average of the values at the nearest known ground control points weighted by the inverse of their distance to the actual point. Because the extraction of coastal ground control points may have errors, we compare the measured temperature at the ground control point with the estimate that we arrive at by excluding that particular ground control point. Using the difference between the measured and the estimated value, we can calculate an empirical estimation variance. This variance estimate is used to exclude unreliable measured ground control points. We exclude those points that deviate more than 3 standard deviations. This is done iteratively until no change occur.

Finally the estimated temperature maps are smoothed over time using a local temporal mean filter, and a linear temporal interpolation is performed in order to produce temperature maps corresponding to each of the Meteosat images. An example of an interpolated map is shown in Fig. 2 The threshold is set so as normal cumulus clouds should be detected. The top of cumulus clouds is found at a height of 2 km, and because temperature decrease upwards at a rate of $6 - 8^\circ/km$ the threshold is set at the equivalent of 14° Celsius.

B Estimation of Intermediate Images

For each image in the sequence a dense flow field is estimated. This flow field is estimated in a two step procedure described in [1]. First, local estimates of (normal) flow are found based on the local distribution of spatio-temporal energy. This local distribution is sampled using a set of Gabor filters. Second, the local estimates of (normal)

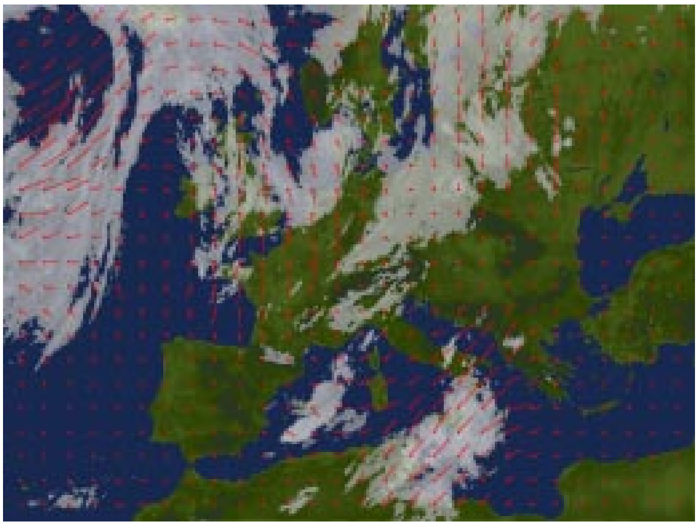

Fig. 3: The clouds have been segmented using the technique described in Section A and the corresponding estimated flow field is overlaid as red vectors. The starting point is marked with a dot and the length is proportional to the speed.

flow acquired at cloud pixels are then interpolated to a dense flow field using a Markov random field that punishes large spatial first order derivatives. An example of an image that has been segmented and overlaid with the estimated velocity field is shown in Fig. 3.

In [1] a simple interpolation scheme is described. This scheme consists of extrapolating each image linearly according to the estimated flow field at that image. We propose a more elaborated technique. At a given pixel at a given time instance we find the path of that pixel by fitting a third order vector polynomial to the flow vectors estimated at the times of the two previous and the two next Meteosat images. An example of an interpolated image is shown in Fig. 4. Note that we have obtained temporal as well as spatial smoothness in the interpolation.

IV Conclusion

A technique for temporal interpolation in sequences of thermal weather satellite imagery has been described. In particular an algorithm

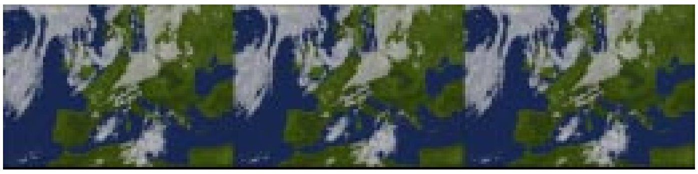

Fig. 4: The left and right images are the segmented original June 24th 0600 and 0630 GMT Meteosat images. The middle images is the interpolated images using the algorithm describde in this article.

for segmenting the clouds from land/sea pixels using an estimated ground level temperature map has been developed. This temperature map is based on timeseries of temperature measurements obtained at a series of meteorological ground stations as well as ground temperatures extracted directly from the imagery. An iterative algorithm for extraction of cloud free (coastal) points for this purpose has been described as well. Furthermore a technique for performing temporal interpolation based on estimated flow fields is developed. For a given pixel at a given time the path of that pixel is estimated using a third order vector polynomial, which allows interpolation of pixel intensities along this path. All in all this results in a highly visually satisfying temporal and spatial interpolation of the coarsely sampled satellite data.

V Acknowledgements

The authors wish to thank Senior Scientist Hans H. Valeur and Poul Nielsen, the Danish Meteorological Institute, for providing image data.

References

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