SATELLITE IMAGE PROCESSING AND AIR POLLUTION DETECTION

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ABSTRACT

Environmental sensing is closely related to digital processing of observed signals and images. The paper is devoted to the analysis of mathematical methods allowing detection of concentration of dust particles observed by ground measuring stations and satellites. The first part of the contribution presents basic methods of two dimensional interpolation allowing the estimate of observed variables over the whole region of interest. The main part of the paper is then focused to satellite images and their processing. Owing to simultaneous observations on different frequencies it is possible to detect image differences and to compare them with surface measurements. The paper is devoted to the design and verification of algorithms of image denoising including wavelet use and their correlation. General methods studied in the paper allow further image segmentation, feature extraction, classification, detection of the most important sources of pollution, prediction and control of pollution sources.

1. INTRODUCTION

The paper discusses problems of image analysis and processing [1, 8, 3, 7] applied to satellite images allowing to obtain information on air pollution due to solid particles. The extracted information is then correlated with data on concentration of solid particles in the air obtained via surface measurements. Efficient use of correlation methods assumes in many cases proper signal preprocessing to remove specific signal components and to reduce substantial signal errors.

2. DATA ACQUISITION

2.1. Ground Observations

In order to validate results of satellite image processing, it has been possible to compare resulting values with those obtained at 103 observation points precisely defined by their longitude and latitude at the same time. Fig. 1 presents these surface observations interpolated to the whole Czech Republic. In this case, the linear two dimensional interpolation has been used allowing for evaluation of a given variable at the chosen grid points. Results of this interpolation are presented in Fig. 1 and Fig. 2. Further methods studied in this connection include cubic, spline and wavelet interpolation.

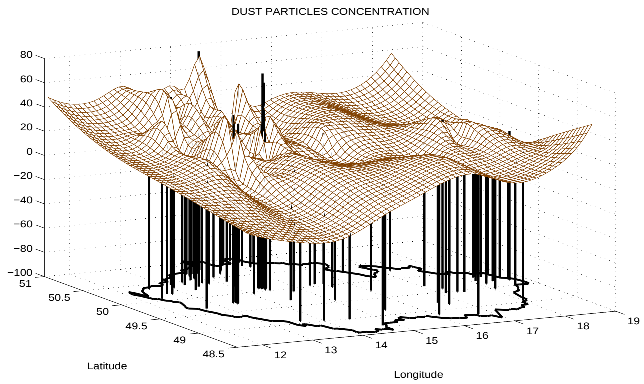

Figure 1: Surface observation of dust particles measured at 103 stations within the Czech Republic on July 20th 1998 at 13:30 and their interpolation

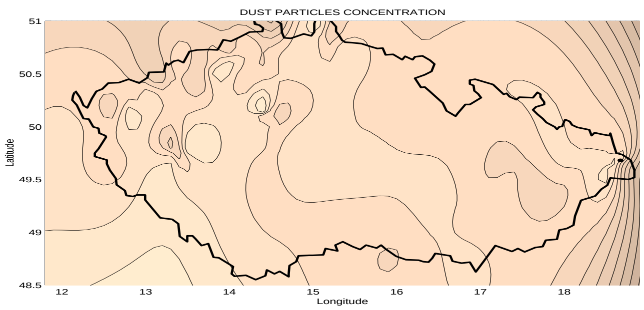

Figure 2: Contour plot of surface observation

2.2. Remote Satellite Sensing

Real data processed in this paper represent images taken by satellites operated by NOAA (The National Oceanic and Atmospheric Administration). All these satellites fly on elliptical or circular orbits around the planet earth, the earth's centre being the focal or central point and they belong to the so-called polar orbiting satellites which lay in rather low altitudes, typically at 850 km height. Each full orbit around the earth takes 100 minutes, 14 orbits are achieved per day. These orbits are usually sun-synchronous, i.e. the satellite crosses a certain point always at the same time of the day. Polar orbiters provide excellent pictures of all parts of the earth including the polar regions. Due to their orbital characteristics they cannot monitor short-term variations. The main apparatus of NOAA satellites is a scanning radiometer AVHRR (Advanced Very High Resolution Radiometer). This is a five-channel apparatus covering spectral ranges (1) 0.58-0.68μm, (2) 0.725-1.1μm, (3) 3.55-3.93μm, (4)10.3-11.3μm, (5) 11.5-12.5μm. The first two channels work with the reflected sun radiation only in red and close infrared region, the last two ones are fully heat radiation channels, and channel 3 is a mixed one.

Another type of satellites, represented by Meteosat satellites have a so called geostationary orbit, that means, that at the height of 36000 km above the equator the orbital period is exactly 24 hours and thus equals the orbital period of the earth itself, so that the satellite is always above the same point of the earth's surface. Satellites in geostationary orbits always view the same portion of the globe. Due to their position above the equator geostationary satellites only give a very distorted view of the polar regions where they are of practically no use. With the exception of these high latitudes the existing system of geostationary meteorological satellites give a global view of our planet.

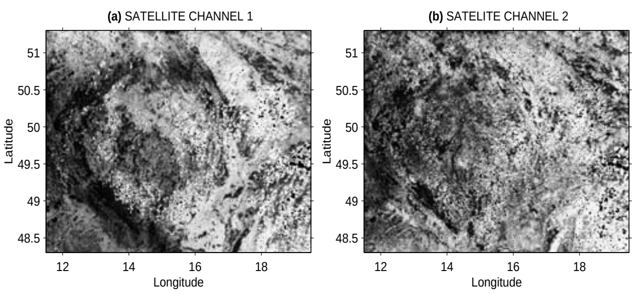

Figure 3: Satellite images of the Czech Republic from the NOAA satellite observed on July 20th 1998 at 13:30 presenting (a) channel 1 and (b) channel 2

An observation of the Czech Republic in a selected time is presented in Fig. 3 for the first two channels taken by the NOAA satellite, representing images obtained for different frequency lengths. It is assumed that these images contain the same information about surface objects, and they differ in reflection of presence of dust particles in the air. Correlation between these two images can thus be used for detection of dust particles, localization of sources of their immission and possible prediction of this type of air pollution.

3. IMAGE PROCESSING

3.1. Image Denoising

Digital filtering techniques allow both linear and nonlinear image processing. They can be used efficiently to remove various forms of noise from the processed data or some other specific parts of the data the presence of which is not desirable in further processing. In all these cases, the convolution kernel $\mathbf{H}_{K,J}$ of the filter applied moves along all rows and columns of the image data $\mathbf{A}_{M,N}$, modifying values of individual points of the image according to conditions specified by the two dimensional convolution

$$B(m+K/2, n+J/2) = \sum_{k=1}^{K} \sum_{j=1}^{J} H(k,j)\ A(m-k, n-j) \qquad (1)$$

In the most simple case, the mean value of a certain subimage matrix moving through the whole image is computed for every point of the image using the same values of the convolution kernel evaluated as a reciprocal value of the number of kernel values.

Application of more sophisticated FIR filters enable to evaluate values of a convolution kernel in a more precise way to reject selected image spectral components. Assuming the desired frequency response

$$|\mathrm{Dft}\{H(k,j)\}| = \begin{cases} e^{-j\ \omega_1 \alpha_1} e^{-j\ \omega_2 \alpha_2} & \text{for } -\omega_{1c} < \omega_1 < \omega_{1c} \\ & \quad -\omega_{2c} < \omega_2 < \omega_{2c} \\ 0 & \text{elsewhere} \end{cases}$$

we obtain the filter coefficients by applying the formula for the two-dimensional Fourier series, and we find the following solution for the coefficients

$$H(k,j) = \frac{\sin \omega_{1c}(k-\alpha_1)}{k-\alpha_1}\ \frac{\sin \omega_{2c}(j-\alpha_2)}{j-\alpha_2} \qquad (2)$$

where $\alpha_1 = \frac{K-1}{2}$ and $\alpha_2 = \frac{L-1}{2}$.

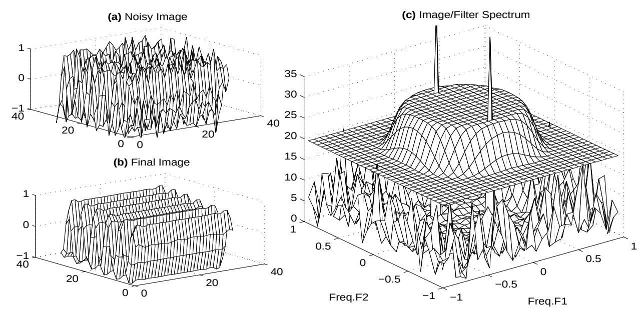

Figure 4: Image denosing presenting (a) a simulated image (b) its spectrum together with spectrum of the convolution kernel and (c) the final denoised image

Fig. 4 presents a simulated two dimensional signal is shown with added noise, its spectrum together with frequency characteristics of FIR filter and then the same image denoised using proposed FIR filter. Similar method has been used for satellite data processing for evaluation of the air pollution [4].

Median filtering [2, 6] standing for a non-linear method allows a very efficient removal of singularities in an observed sequence or image. This method is very often applied especially in image processing assuming application of overlapping matrices of size limited to 3 by 3 only. The central element of this matrix moves along all rows and columns of the original image. The median value of the given subimage belonging to this window is then used instead of its reference element in every case. This method has been applied to remove specific elements of satellite images, especially meridian which forms a part of the original data.

Image denoising has been studied also in connection with image decomposition and reconstruction by wavelet transforms [5]. This method provides a very efficient tool for image denoising as well.

3.2. Image Correlation

Correlation of two images stored in two matrices assumes evaluation of the correlation coefficient for corresponding subimage regions in matrices $\mathbf{A}$ and $\mathbf{B}$ which can be obtained using the relation

$$r = \frac{\sum_m \sum_n (A(m,n) - \bar{A})(B(m,n) - \bar{B})}{\sqrt{\sum_m \sum_n (A(m,n) - \bar{A})^2 \sum_m \sum_n (B(m,n) - \bar{B})^2}} \quad (3)$$

where $\bar{A}$ and $\bar{B}$ represent the mean values of the respective matrices $\mathbf{A}$ and $\mathbf{B}$.

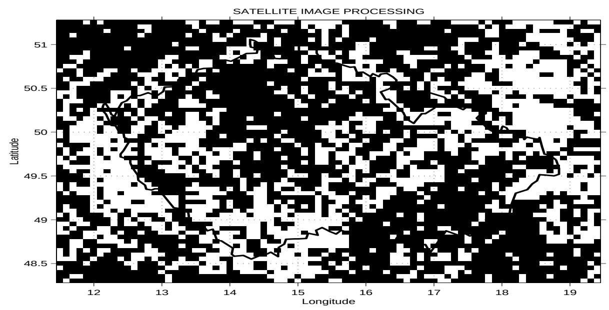

Figure 5: Thresholded correlation function of images of the Czech Republic from the NOAA satellite observed on July 20th 1998 at 13:30

Results of this correlation for images covering area of 10 by 10 pixels corresponding to the region of 0.1 by 0.05 degrees in longitude and latitude respectively are presented in Fig. 5. As the low coefficient can be used as a measure for dust particles, Fig. 5 presents the distribution of this variable bellow a certain threshold level only.

4. RESULTS

Values of solid particles concentration obtained from ground measurements were interpolated to the area of the whole Czech republic with the same resolution as that of satellite observations. This approach enabled comparison of both methods.

To eliminate the error given by the method of ground observation interpolation in the first stage the comparison has been studied at locations of 103 ground measuring stations presented in Fig. 6(b) only. Fig. 6(c) presents values evaluated from satellite observations at these locations using correlation area of size 15 pixels large at the same time. Correlation between these two series is given in Fig. 6(d) as one point for time of 13 hours. Owing to the principle of the measuring method used at ground measuring stations it is not possible to find precisely the time instant for the best correspondence between these two methods. That is the reason why Fig. 6(a) and Fig. 6(d) were evaluated to compare results of this correspondence for

- different time instants of ground observations
- different sizes of regions used for satellite channels correlation

The best correspondence has been found for the time 13:00 and region covering area of 15 by 15 pixels.

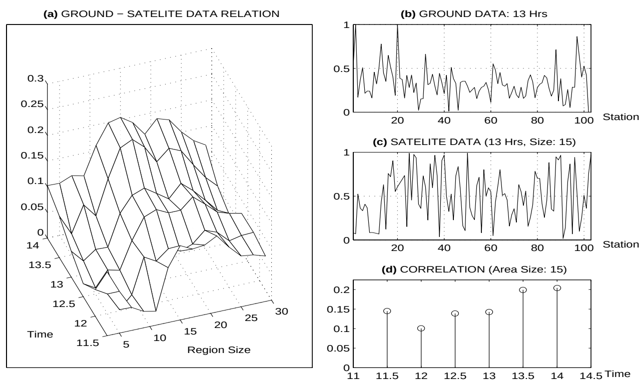

Figure 6: Correlation of satellite and surface data for all times on the day of July 20, 1998, for which the surface measurements are available

Comparison of two sets of observations is given in Table 1. It presents extreme values of dust particles concentration for both sets and it compares values obtained by ground measuring stations with that obtained from satellite measurements. The last column presents the correlation between corresponding series at 103 measuring stations confirming connection between these two methods.

Table 1: Comparison of observed values of dust particles concentration at selected locations with estimated values based upon satellite images and correlation of ground and estimated values at all measuring points

	Observed and Estimated Values				$C_{g,r}$
	Prague		*Mountains*		
	Ground	*Remote*	*Ground*	*Remote*	
Set 1					
Set 2					

5. CONCLUSION

Results presented in the paper justify correspondence between satellite and ground observations in case of appropriate weather conditions as correlation of the surface and satellite measurements gives very satisfactory results for some regions in which the concentration of dust particles in the air is measured. We can state that the satellite images do indeed contain information on air pollution. More detail statements on how this information can be used for evaluation of air pollution will be made after greater volumes of data are processed.

Studies of given data motivate subsequent research of general mathematical problems and they form a basis for further research in this area. Mathematical background used for these studies will include further methods of

- time series processing including two dimensional interpolation using non-linear methods and wavelet functions
- image preprocessing, filtering, image enhancement and channels correlation correlation

It is assumed that general methods of image processing will contribute both to environmental sensing and the following signal analysis.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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