Toward an automatic real-time mapping system for radiation hazards

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Abstract. Detection and monitoring of nuclear accidents is of great importance. Many European countries have installed gamma dose rate monitoring networks to perform this task. Interpretation of the data would greatly benefit from real-time automatically generated maps with interpolated values based on the monitoring network. In this paper we present a first step toward a real-time automatic mapping system for radiation hazards in the Netherlands. This prototype is designed to be used in non-emergency cases. It extracts the data from the network, automatically interpolates it, and serves maps in an interoperable way through a Web Map Service. Future developments include improvements in the interpolation algorithms to be able to deal with extreme values and a more complex WMS client.

1 INTRODUCTION

When a nuclear accident occurs, it is important to detect and monitor the development of the contamination. In the Netherlands the National Radioactivity Monitoring (NRM) network was established to perform this task. The network consists of 153 monitoring stations scattered across the country. Real-time automatically interpolated maps based on the point data from the NRM would benefit the decision making process. In this project, we developed a first step toward such a system. It is intended to be used for non-emergency data, without extreme outliers. In this stage it is not yet in operational use. The system collects the data from the NRM, interpolates it and serves resulting maps through a Web Map Service [2]. The NRM produces point data sets every 10 minutes. Over the next 10 minutes the automatic interpolation is performed. The emphasis of the project is both on geostatistics and on the implementation of the WMS. This paper first discusses the geostatistical model used for the interpolation, next
it describes the system in which this was implemented. Finally we discuss some of the challenges we still face toward the goal of an emergency real-time automatic mapping system.

2 Automatic Spatial Interpolation

Maps of the ambient dose rate are made using universal kriging [1]. We assume that the $n$ measurements from the NRM network $z(x_i)$ are a realization of the random field $Z(x)$ with the following properties:

$$Z(x_i) = \beta_j + e(x_i), \quad i = 1, \ldots, n$$

(1)

with $x_i$ a measurement location within soil type $j$, $\beta_j$ the mean ambient dose rate for soil type $j$ and $e(x_i)$ a zero-mean residual. In this case soil type is used as a systematic trend. We assume that semivariance ($\gamma$) depends on distance only, i.e. that $e(x_i)$ is intrinsically stationary [1]:

$$\frac{1}{2}E[(e(x_1) - e(x_2))^2] = \gamma(\|x_1 - x_2\|), \forall x_1, x_2 \in \mathbb{R}$$

(2)

A variogram model is fitted to a sample variogram to determine the function of semivariance versus distance. Assuming that the kriging standard error is distributed normally, the 95% prediction interval is approximated by:

$$[\hat{z}(x_0) - 2\sigma_k(x_0), \hat{z}(x_0) + 2\sigma_k(x_0)]$$

(3)

where $\hat{z}(x_0)$ is the kriging prediction and $\sigma_k(x_0)$ is the kriging standard error, both at target location $x_0$. The prediction interval makes it possible to estimate if and where a certain level is exceeded. This is an improvement over interpolation techniques such as inverse distance weighted interpolation. The procedure used is universal kriging but bears similarity to ordinary kriging within soil classes.

A common way to fit a variogram model is by visual comparison between the variogram model and the sample variogram. In this study we automated this process. An initial guess of the variogram model is used as a starting point for fitting a variogram model to the sample variogram through weighted least squares. The weights are equal to $N_k/h_k^2$, where $N_k$ is the number of point pairs and $h_k$ is the average distance, both associated with bin $k$. The two panels in figure 1 show the output from the automatic fitting procedure. The numbers next to the blue dots are the amount of point pairs associated with that particular bin in the sample variogram.
Figure 1: An example of the output from the automatic fitting procedure. The numbers are the amount of point pairs associated with that particular bin in the sample variogram.

Note that the nugget variance is fixed to a known value based on additional short range data collected in a separate monitoring survey.

3 MAPPING SYSTEM

Figure 2 shows a flowchart of the automatic mapping system. It has two distinct parts: the data and the user processing part. The data processing part extracts data, interpolates it and serves the results through a Web Map Service (WMS). It produces three kinds of interpolated maps: 1) kriging prediction, 2) kriging standard error and 3) position of the prediction interval classified relative to a threshold. Figure 3 shows examples of the output. The data collection program is written using a combination of Python [6] and R [5]. The WMS server was implemented using MapServer [7]. The user processing part handles the requests from the user. A test CGI-based client, written in Python, extracts the interpolated maps from the WMS server, see figure 4.

4 FUTURE DEVELOPMENTS

This prototype system was not designed to deal with emergency situations. The extreme values would make the assumption of intrinsic stationarity highly doubtful. Despite that, our kriging interpolation may still be of
some value in the case of extremes. The system needs to be expanded using interpolation techniques that can deal with data containing extreme outliers. Methods such as Bayesian kriging, normal score kriging and indicator kriging could be candidate methods to consider. This expansion would make the system suitable for real-time automatic interpolation system in emergency cases.

The results from the automatic mapping system are presented through a WMS. A WMS serves an image of the data, rather than the data itself. This limits the interactivity that the user can have with the system. One solution is to use a Web Coverage Service (WCS) [3]. The WCS serves the actual data, not just a visual representation. The dynamic interaction is situated at the side of the client, resulting in a fat client. Another solution is to use a Web Processing Service [4] (WPS). A WPS can implement any GIS operation. The user can change parameters in the WPS and obtain the resulting maps. The dynamic interaction would be limited to the server-side. This could keep the client lightweight.

**REFERENCES**

Figure 3: Examples of the three types of output from the automatic mapping system. (a) Kriging prediction (nSv/h), (b) kriging standard error (nSv/h) and (c) approximate 95% Prediction interval classified relative to 95 nSv/h. Crosses represent the locations of the monitoring stations.


Figure 4: Client application running inside a web browser.
