On Use of Fuzzy Surfaces to Detect Possible Elevation Change

Peter Fisher\textsuperscript{1}, Jan Caha\textsuperscript{2}

\textsuperscript{1}Department of Geography, University of Leicester
\textsuperscript{2}Department of Geoinformatics, Palacký University in Olomouc,
\texttt{jan.caha@klikni.cz}

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Introduction

- the main research question – **the difference of two surfaces with uncertainty and its use in decision making**
- fuzzy surface is a model that captures both the **surface elevation** itself and **its uncertainty**
- crisp surface stores for each coordinate $x, y$ a value $z$ that represents the height
- **fuzzy surfaces** stores a **fuzzy number** $\tilde{Z}$ representing the possible **range of values** ($z$)
- a fuzzy number is a special case of a fuzzy set that represents vague, imprecise or ill-know values
- **fuzzy numbers** are compared to **probability distributions** – there are **similarities**, but they are **not interchangeable**
Aims

- examination of elevation change over a British coastal dune field which is essential for coastal flood defence providing environmental security
- aim to detect elevation change between fuzzy surfaces constructed from multi-temporal LiDAR data
- change is calculated by means of fuzzy arithmetic
- the resulting differential surface is classified into categories by the amount of change with use of possibility theory
- the main focus is on methods – the case study being used as an illustrative example
Fuzzy surface

- grid cell records a **single number** which is usually intended to record the elevation at the **center of the cell**
- could be representative of elevations within the cell in some **other way**
- in fuzzy surface crisp value is replaced by a fuzzy number
- **triangular fuzzy number** (TNF) – specified by minimum, median (peak value) and maximum
- fuzzy surfaces for the study were inferred from LiDAR data with a 2m grid size applying simple filters – minimum, median and maximum over a 5x5 moving window
- the process does not have to be used only for raster data, the same procedure can be used for points
Fuzzy surface - creation

Use of filter to determine fuzzy surface from crisp surface.
Fuzzy surface - creation

Use of filter to determine fuzzy surface from points.
Fuzzy surface - case study - 1998

Minimum, median and maximum values describing TFNs for every grid cell in the DEM for the dunefield in 1998.
Fuzzy surface - case study - 2000

Minimum, median and maximum values describing TFNs for every grid cell in the DEM for the dunefield in 2000.
Change detection

- each pixel of fuzzy surface can be indicated by the **triplets** – \([\text{min}, \text{median}, \text{max}]\)
- \([a, b, c]\) – surface from year 2000
- \([d, e, f]\) – surface from year 1998
- the **difference**: \([a, b, c] - [d, e, f] = [a - f, b - e, c - d]\)
Point values of elevations represented as crisp values and TFNs for 1998 and 2000.
Change detection – example

TFN representing the change in elevations between 2000 and 1998.
Change detection – case study

The TFN representing the difference in elevations between 1998 and 2000.
Evaluation of the Fuzzy surface

- identify those areas where the surface is greater than and less than a specified threshold $t$
- the process is more complex working with a fuzzy surface
- the threshold can be contained in a fuzzy number, making it hard to determine if the fuzzy number is actually bigger or smaller than the threshold
- utilization of possibility theory – two measures, possibility and necessity
- for each pixel possibility and necessity of the pixel value being higher or lower than $t$ can be calculated (4 values)
Comparison of fuzzy value to a threshold

Graphs of the possibility and necessity that the TFN is greater than zero.
Comparison of fuzzy value to a threshold

Graphs of the possibility and necessity that the TFN is less than zero.
Possibility and necessity of each pixel being less than zero.
Evaluation of the Fuzzy surface – case study

Possibility and necessity of each pixel being greater than zero.
Conclusion

- proposed approach shows how the difference between surfaces can be calculated for two fuzzy surfaces
- how the results can be identified as the change being greater than and less than some specific threshold
- the approach emphasizes uncertainty of the surface, not only in the calculation of difference but also in evaluation of the change which is achieved using two measures (possibility and necessity)
- capturing of contradictory information
- contradictory information may easily occur when dealing with uncertainty, because the values are no longer crisp and thus they cannot easily be categorized
Thank you for your attention.