An Empirical Evaluation of Perceptually Shaded Slope Maps for LIDAR Visualization of Urban Areas

Thomas J. Pingel, Northern Illinois University
Keith C. Clarke, University of California, Santa Barbara

The Annual Meeting of the Association of American Geographers
April 9 – 13, 2013
Los Angeles, CA
This project focuses on supporting visualizations of LIDAR-derived Digital Elevation and Surface Models (DEMs and DSMs) of urban areas.

It is in support of a larger project to create immersive geographic virtual environments.
A perceptually shaded slope map (PSSM) represents cognitive slope as a graytone value.

It differs from traditional shaded relief (hillshade) visualizations in that it does not consider aspect, and it exaggerates the vertical component of slope.
Relief Shading

• Hans Gyger’s 17th century shaded relief maps of areas of Switzerland
• Eduard Imhof (1895 – 1986) led the development of the modern method
• Digital DEMs and hillshade algorithms (Horn, 1981) led to widespread use
• reliefShading.com
• shadedRelief.com
Jenny and Hurni (2006) recently described a method to computationally recreate Imhoff’s color shaded relief maps.
Kennelly (2008) discusses many techniques to augment the traditional shaded relief, including multiple sources of illumination and the use of curvature.
While traditional hillshading is “naturalistic” there are significant differences between novice and experienced users of these maps, and shaded relief maps do not necessarily perform best, despite their more “realistic” appearance (Wilkening and Fabrikant, 2011).

They also do not translate to urban areas very well, where relief is typically low, and aspect is highly regular.
Kennelly (2006) offers some methods that bring out immense detail in a DEM-derived LIDAR visualization.
But we know that realism is not always best for visualizations.

We also need a straightforward way for GIS users to create visualizations with this data that are useful for a variety of purposes, not just more aesthetically pleasing.
This is a LIDAR-derived Digital Surface Model of UC Santa Barbara, represented in shaded relief.
This is a PSSM of the same data.
PSSMs are based on the idea of “cognitive slope.”

People exaggerate the vertical component of slope by a factor of 2.3x.

(Pingel 2010, following Proffitt et al. 1995)
Perceptually Shaded Slope Maps (PSSMs)

- Slope (dx/dy) is multiplied by a vertical exaggeration factor (~2.3x), then transformed to degrees and mapped [0 90] to [0 1] graytone.
- Resulting appearance looks hand-drawn, which speaks to its efficacy as a visualization.
- No spatial displacement errors common with orthophotos.
- Offers a higher contrast image than hillshade, with better affordance for color overlay.
- Most appropriate for mixed / urban environments.
Last year, we successfully used PSSMs in combination with our LIDAR filter *SMRF* to visually explore the forest floor of the ancient Maya site, El Pilar.
Empirically Measuring Performance

If perceptually shaded slope maps are better than comparable visualizations for the communication of a scene, then they will tend to perform better with respect to accuracy and response time.
Methodology

• Participants
  • n = 45; Mean age, 20.2 years
  • Recruited from introductory geography classes

• Tasks
  • Mental rotation
  • Profile estimation

• Sites
  • Urban - DeKalb, IL (1 m; 6 x 6 km)
  • Rural – Santa Barbara, CA (30 m; 60 x 150 km)

• Dependent variables
  • Accuracy rate
  • Response time

• Independent variables
  • Presentation Type: PSSM, hillshade, elevation (hypsometric)
  • Geography Experience
  • Sex
  • Environmental Spatial Ability (SBSOD of Hegarty et al., 2002)
Profile Assessment Task

Given an image and a supplied transect, select the correct profile from three alternatives.

251px transects on a circular image

Presentation type, center pixel, and degree of rotation were randomly varied

50 recorded responses per participant, aggregated by presentation

response time: M = 9.6 sec., SD = 4.3

accuracy rate: M = 58%, SD = 17%
Rotation Assessment Task (Urban)

Determine whether two images depicting an urban area are the same or mirror images of each other.

n = 30; response time: M = 6.3 sec. (SD = 3.2); accuracy rate: M = 75% (SD = 18%)
Rotation Assessment Task (Mountain)

Determine whether two images depicting mountainous terrain are the same or mirror images of each other.

n = 30; response time: M = 5.9 sec. (SD = 2.5); accuracy rate: M = 75% (SD = 16.5%)
In each task, there was strong evidence for the commonly observed speed / accuracy trade-off.

Individual differences were also notably large.
Results: Profile Assessment

Ellipse plots place text at the mean, and the axes are scaled to the standard deviation.

RMANOVA was marginally significant for accuracy ($p = 0.059$) but not for response time.
RMANOVA was marginally significant for response time ($p = .11$) but not for accuracy.
RMANOVA was not significant for response time but was significant for accuracy ($p = .019$).
RMANOVA was not significant for response time but was significant for accuracy ($p = .019$).
Aggregate Performance by Geography Experience

- Low
  - Hillshade
  - Elevation
  - Bonemap

- High
  - Hillshade
  - Elevation
  - Bonemap
Aggregate Performance by Sex

[Graph showing performance by sex, with two separate plots for female and male, illustrating the relationship between reaction time below mean and accuracy rates for bonemap, hillshade, and elevation.]
Aggregate Performance by ESA
Conclusions

• PSSMs are competitive alternatives to traditional visualizations of elevation-based data.
• Just as fast; typically more accurate
• Easily generated with existing GIS software
Future Work

• Perception of graytone is itself perceptually biased (Monmonier, 1980). How does this interact with bias in slope perception for the PSSM?

• How much vertical exaggeration is ideal from a performance perspective?

• How do PSSMs compare against more advanced DEM visualization techniques?

• What explains why natural scenes show stronger differences in performance?

• What kinds of scenes most affect performance?

• What explains the fact that PSSMs seem to be processed differently according to sex and ESA?

• Given the high contrast and white background, would this visualization enhance overlay operations?
Acknowledgments

I wish to thank the IC Postdoc Program for funding early portions of this project and Anabel Ford for sharing the El Pilar LIDAR data.