

MONITORING RAPID URBAN EXPANSION: A CASE STUDY OF CALGARY, ALBERTA, CANADA

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ABSTRACT:

The city of Calgary, Alberta is the fastest growing major metropolitan area in Canada. Figures from the latest (2001) census indicate that the city has close to one million inhabitants. There are many challenges that face rapidly expanding urban areas including appropriate urban planning and the building and maintenance of critical infrastructure. Remotely sensed data have proven useful for monitoring urban development since the launch of the Landsat-1 satellite in 1972. From 1999 to 2003, the Landsat-7 satellite provided high-quality, low-cost data that can be enhanced through data fusion processes to provide 15 metre spatial resolution multispectral data. In this research, fused Landsat-7 image data for the years 1999, 2000, 2001, and 2002 were analyzed to determine the rate of urban expansion. Each image was acquired at approximately the same time of year (July-August) to minimize the effects of varying sun positions. Texture measures proved valuable in accounting for and distinguishing varying degrees of “greenness” in the imagery. They were also useful in separating agricultural fields from urban features. A combined unsupervised classification/image differencing change detection process with a combination of inputs including image texture, principal components, and the Normalized Difference Vegetation Index (NDVI) allowed for the monitoring urban development. The average expansion was estimated to be 4.62 square kilometres per year for the 1999-2002 period.

1. INTRODUCTION

The continuity of the Landsat program is one of the main reasons that data from this series of satellites have been utilized in widely varying application areas. In 1999, the Landsat-7 satellite was launched and for approximately four years it provided high-quality, low-cost data to the remote sensing user community. The failure of the Scan Line Corrector (SLC) at the end of May 2003 resulted in processing and data quality difficulties for which the USGS has now provided solutions (USGS, 2005).

Radiometric methods are very effective in the analysis of urban change (Forsythe, 2004; Hostert and Diermayer, 2003; Masek et al., 2000; Ridd and Liu, 1998). The use of fused or sharpened data for urban applications is also well-documented (Forsythe, 2004; Steinnocher, 1997; Zhang, 2002; Zhang, 2004). In this paper, a combined unsupervised classification/image differencing change detection process is utilized to examine urban expansion.

2. STUDY AREA

Calgary, Alberta is the fastest growing major metropolitan area in Canada (Statistics Canada, 2005). The Census Metropolitan Area (CMA) - (Figure 1) contains the smaller communities of Cochrane and Airdrie which are also developing rapidly. In addition, surrounding communities such as Okotoks and Strathmore are also growing in part due the economic prosperity that Calgary is currently experiencing.

Two distinct growth phases can be identified from census data for Calgary over the last 30 years. During the 1970's, the population grew by over 50% from 400000 in 1971 to 625000

in 1981. From the mid-1990's onward, large annual increases in population occurred, indicating, in part, a shift from a natural resource based economy to a more diversified financial system.

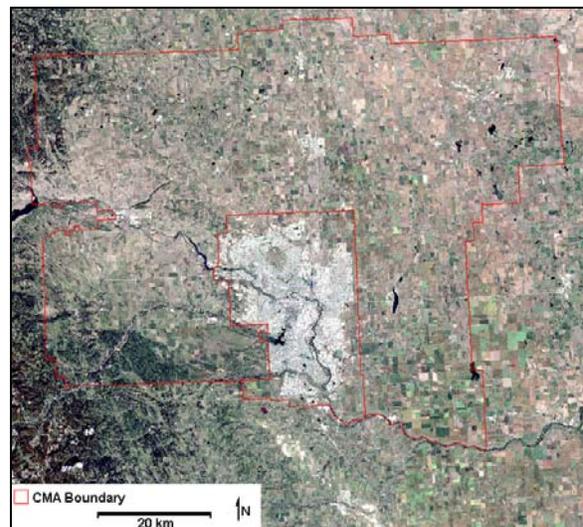


Figure 1: The Calgary Census Metropolitan Area (CMA) (Landsat 7 subset image - August 18, 2002)

3. DATA

Landsat 7 Enhanced Thematic Mapper (ETM+) imagery was acquired for the study area. The dates of image acquisition were: July 9, 1999 (Figure 2), August 28, 2000 (Figure 3), August 15, 2001 (Figure 4), and August 18, 2002 (Figure 5).

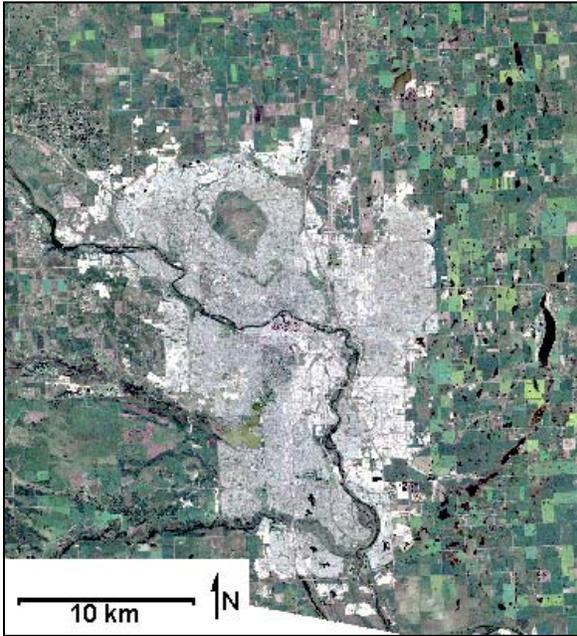


Figure 2: Landsat 7 subset image - July 9, 1999 (Path 42, Row 24)

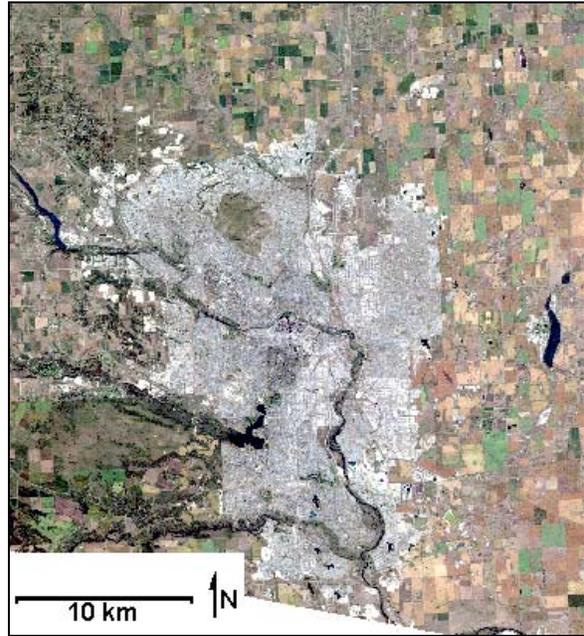


Figure 4: Landsat 7 subset image - August 15, 2001 (Path 42, Row 24)

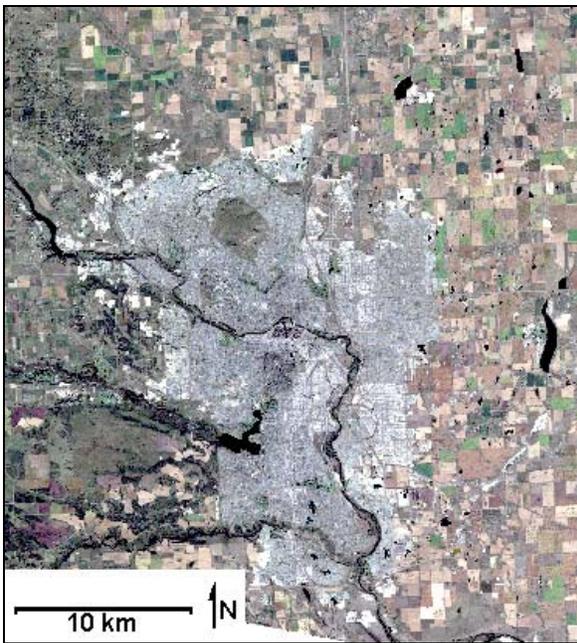


Figure 3: Landsat 7 subset image - August 28, 2000 (Path 42, Row 24)

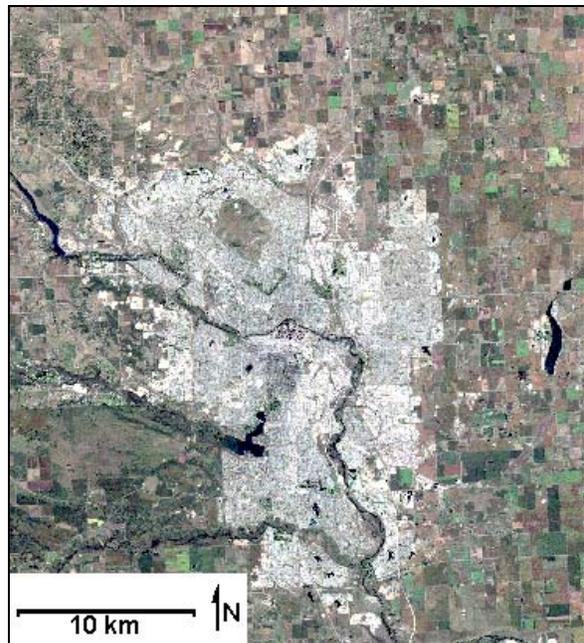


Figure 5: Landsat 7 subset image - August 18, 2002 (Path 42, Row 24, shifted 20% south)

4. METHODS AND ANALYSIS

The PANSHARP algorithm as implemented in the PCI Geomatica software eliminates problems (such as destruction of data spectral characteristics, colour distortion, and operator and data set dependence) that can occur during the data fusion or sharpening process (Zhang, 2002). All of the images were pansharpened to a 15m spatial resolution. The 2001 image was obtained in an orthorectified format NAD83 (GRS1980) UTM Zone 11 and then used as a base image to which the 1999, 2000 and 2002 images were registered. Root Mean Square (RMS) errors of under 0.25 pixels in both the X and Y directions were achieved which translates to a maximum error of 3 to 4 metres on the ground.

Unsupervised classification is used in this study to distinguish urban expansion from change that occurs due to other factors such as agricultural practices. Previous studies (Forsythe, 2004; Masek et al., 2000; Shaban and Dikshit, 2001; Yeh and Li, 2001) have shown that a number of features derived from the original satellite bands can be useful in distinguishing classes. De Kok et al. (2003), Forsythe (2004), and Shaban and Dikshit (2001) found that texture measures were a great asset for urban change detection. Figures 5-7 illustrate the texture measures that were derived. A 7x7 homogeneity option was determined to be the best selection for distinguishing urban and agricultural features having similar spectral characteristics. Additionally, Principal Components and Normalized Difference Vegetation Index (NDVI) were calculated.

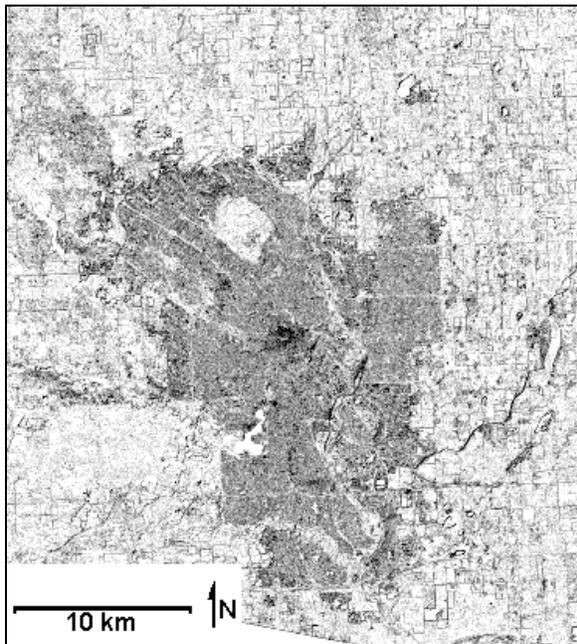


Figure 6: Image Texture - 2000

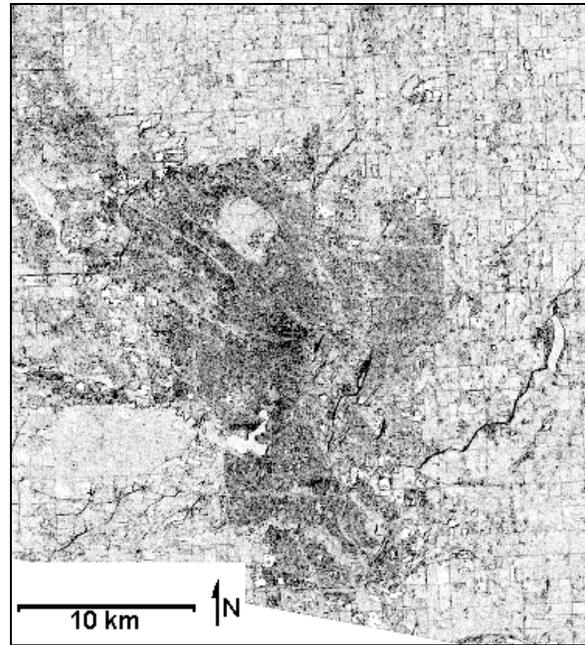


Figure 7: Image Texture - 2001

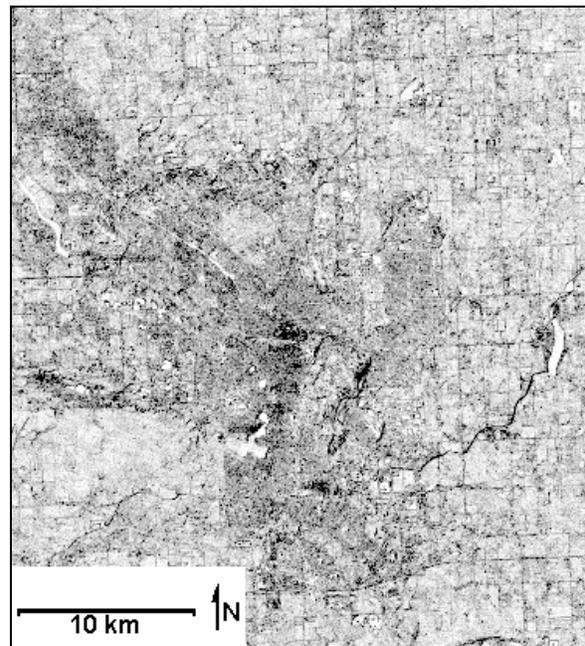


Figure 8: Image Texture - 2002

Figures 9-12 represent the results of image differencing operations using Band2 from the pansharpened images. Some interesting features include white areas generally representing disturbed areas where previous agricultural or forested land has been replaced by land being prepared for building and darker (blackier) areas mainly representing areas where housing developments have replaced disturbed land (Forsythe, 2003).

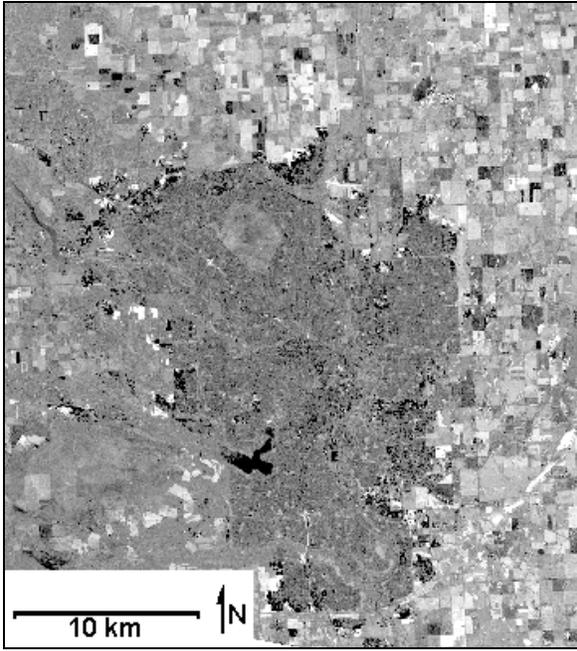


Figure 9: Band2 (2000) minus Band2 (1999)

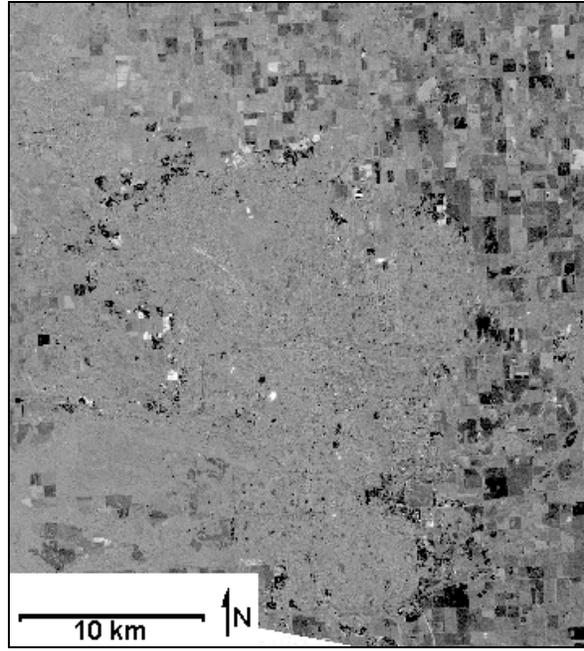


Figure 11: Band2 (2002) minus Band2 (2001)

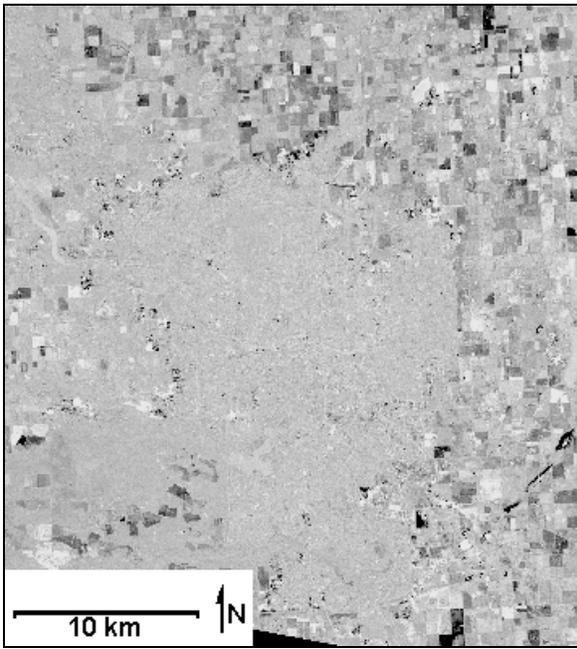


Figure 10: Band2 (2001) minus Band2 (2000)

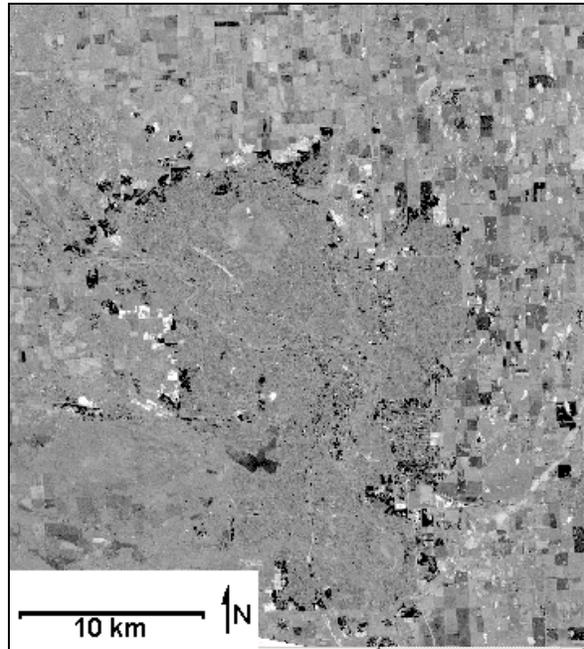


Figure 12: Band2 (2002) minus Band2 (1999)

The use of an unsupervised classification as an agricultural mask was necessary to complete the data requirements for these analyses. It can be clearly seen in Figures 9-12 that large agricultural areas have also changed (due to crop rotation or harvesting) in addition to the urban areas that were either newly developed or redeveloped. Image texture (as noted above) was very useful when included in the unsupervised classification procedures. It helped to discriminate between the urban and agricultural areas where spectral signatures were similar.

Aggregate classifications consisting of urban, greenspace, and water were developed from 255 original unsupervised K-means classes. This allowed for small features that may have caused classification problems to be clearly delineated and then assigned to the appropriate aggregate class.

ArcGIS was used to combine the difference images and the unsupervised classifications. Figure 13 illustrates the overall development that occurred during the 1999-2002 period.

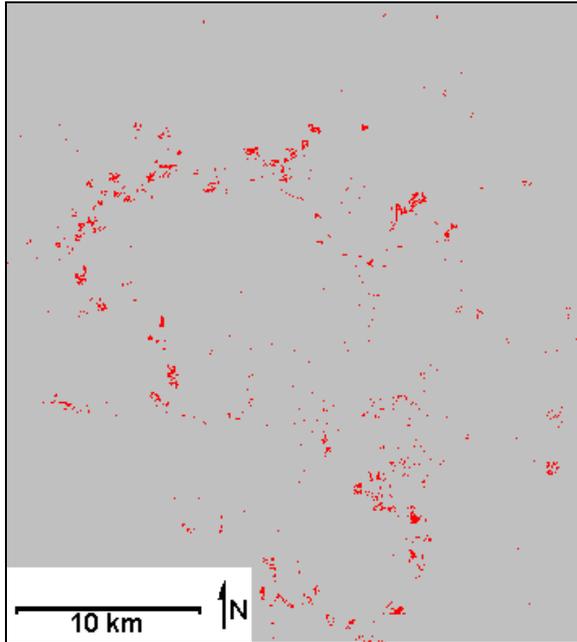


Figure 13: 2002 minus 1999 urban expansion areas (red)

A total of 13.86 square kilometres was identified as new urban development or redevelopment over the three year period. The average was 4.62 square kilometres per year.

5. CONCLUSION

Calgary is a rapidly expanding urban centre. The use of additional parameters (especially image texture) that can be generated from image data proved particularly effective in determining urban expansion. Although the images were acquired during the same season of the year, it was necessary to compensate for differences in greenness for satisfactory urban classification results.

A combined approach including image differencing and unsupervised classification allowed for the measurement of urban development and expansion. The fused or pansharpened images enabled finer detail to be distinguished than is possible with coarser resolution data. Continued work in applying image texture for urban area classification is anticipated.

REFERENCES

- De Kok, R., T. Wever, and R. Fockelmann. 2003. Automatic procedures for large-area mapping applied on urban environment. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (CD-ROM)*, Vol. XXXIV-7/W9. *Proceedings of the 4th International Symposium Remote Sensing of Urban Areas*. Regensburg, Germany, June 27-29, 2003. pp. 41-45. (CD-ROM). ISSN 1682-1777
- Forsythe, K.W. 2003. Monitoring "Megacity" Urban Development Pansharpened Landsat 7 Results for Toronto, Ontario, Canada. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (CD-ROM)*, Vol. XXXIV-7/W9. *Proceedings of the 4th International Symposium Remote Sensing of Urban Areas*. Regensburg, Germany, June 27-29, 2003. pp. 60-65. ISSN 1682-1777
- Forsythe, K.W. 2004. Pansharpened Landsat 7 Imagery for Improved Urban Area Classification. *Geomatica* Vol. 58, No. 1, March 2004, pp. 23-31.
- Hostert, P. and E. Diermayer. 2003. Employing Landsat MSS, TM and ETM+ for Mapping 3 Decades of Urban Change in Berlin, Germany. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (CD-ROM)*, Vol. XXXIV-7/W9. *Proceedings of the 4th International Symposium Remote Sensing of Urban Areas*. Regensburg, Germany, June 27-29, 2003. pp. 225-228. (CDROM). ISSN 1682-1777
- Masek, J.G., F.E. Lindsay, and S.N. Goward. 2000. Dynamics of Urban Growth in Washington D.C. Metropolitan Area 1973-1996 from Landsat Observations. *International Journal of Remote Sensing* Vol., 21, No. 18, pp. 3473-3486.
- Ridd, M.K., and J. Liu. 1998. A Comparison of Four Algorithms for Change Detection in an Urban Environment. *Remote Sensing of the Environment* Vol. 63. pp. 95-100.
- Shaban, M.A., and O. Dikshit. 2001. Improvement of classification in urban areas by the use of textural features: the case study of Lucknow City, Uttar Pradesh. *International Journal of Remote Sensing* Vol. 22, No. 4. pp. 565-593.
- Statistics Canada. 2005. <http://www.statcan.ca> (accessed 30 Jan. 2005)
- Steinnocher, K. 1997. Texturanalyse zur detektion von Siedlungsgebieten in hochauflösenden panchromatischen Satellitenbilddaten. *Proceedings of the 9th Symposium for Applied Geographic Information Processing (Angewandte Geographische Informationsverarbeitung IX), AGIT '97*. July 2 -4, 1997. Salzburg, Austria. pp. 143-152.
- United States Geological Survey (USGS). 2005. <http://landsat.usgs.gov/> (accessed 30 Jan. 2005)
- Yeh, A.G., and X. Li. 2001. Measurement and Monitoring of Urban Sprawl in Rapidly Growing Region Using Entropy. *Photogrammetric Engineering & Remote Sensing* Vol. 67, No. 1. pp.83-89.

Zhang, Y. 2002. A New Automatic Approach for Effectively Fusing Landsat 7 as well as IKONOS Images. *Proceedings of the IEEE/IGARSS'02*. Toronto, Canada. June 24-28, 2002. (CD-ROM).

Zhang, Y. 2004. Understanding Image Fusion. *Photogrammetric Engineering & Remote Sensing* June 2004; pp. 657-661.