# BUILDING DETECTION IN OFF-NADIR VERY HIGH RESOLUTION SATELLITE IMAGES BASED ON STEREO 3D INFORMATION

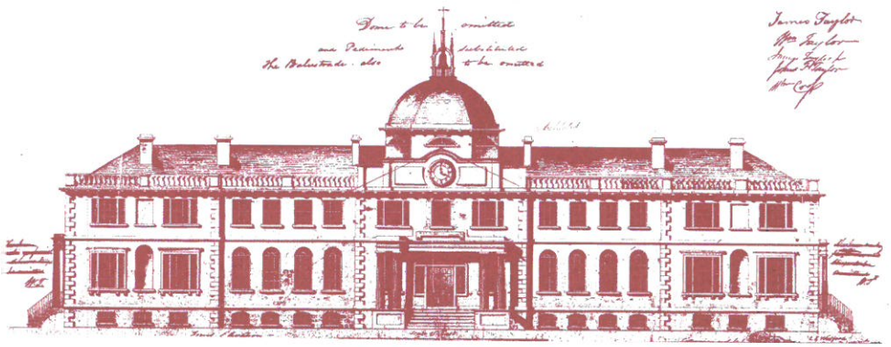

## Abstract

Mapping or updating maps of urban areas is crucial for urban planning and management. Since buildings are the main objects in urban environments, building roof detection is an important task in urban mapping. The ideal geo-spatial data source for mapping building information is very high resolution (VHR) satellite images. On the other hand, because buildings are elevated objects, incorporating their heights in building detection can significantly improve the accuracy of the mapping. The most cost-effective source for extracting the height information is stereo VHR satellite images that can provide two types of stereo 3D information: elevation and disparity. However, most VHR images are acquired off-nadir. This acquisition type causes building leaning in the images and creates major challenges for the incorporation of building height information into roof detection. Thus, this PhD research focuses on finding solutions to mitigate the problems associated with 3D-supported building detection in off-nadir VHR satellite images. It also exploits the potential of extracting disparity information from off-nadir image pairs to support building detection.

In the research, several problems associated with building leaning need to be solved, such as building roof offsetting from its footprint, object occlusion, and building façades. Moreover, the variation of the roofs offsets based on the building heights. While building roof offsets create difficulties in the co-registration between image and elevation data, the building façades and occlusions create challenges in automatically finding matching points in off-nadir image pairs. Furthermore, due to the variation in building roof offsets, the mapped roofs extracted from off-nadir images cannot be directly geo-referenced to existing maps for effective information integration.

In this PhD dissertation, all of the above identified problems are addressed in a progressively improving manner (i.e., solving the problems one after another while improving the efficiency) within the context of 3D-supported building detection in off-nadir VHR satellite images. Firstly, an image-elevation co-registration technique is developed that is more efficient than the currently available techniques. Secondly, the computation cost is then reduced by generating disparity information instead of the traditional elevation data. This allows bypassing a few time-consuming steps of the traditional method. Thirdly, the disparity generation is then extended from using one pair of off-nadir images to using multiple pairs for achieving an enriched disparity map. Finally, the enriched disparity maps achieved are then used to efficiently derive elevations that are directly co-registered with pixel-level accuracy to the selected reference image. Based on these disparity-based co-registered elevations, building roofs are successfully detected and accurately geo-referenced to existing maps.

The outcome of this PhD research proved the possibility of using off-nadir VHR satellite images for accurate urban building detection. It significantly increases the data source scope for building detection since most (> 95%) of VHR satellite images are off-nadir and traditional methods cannot effectively handle off-nadir images.

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UNIVERSITY OF NEW BRUNSWICK

# SCHOOL OF GRADUATE STUDIES

ORAL EXAMINATION


**Alaeldin Suliman**


IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

Ph.D. Candidate

**Alaeldin Suliman**

Graduate Academic Unit

**Geodesy & Geomatics Engineering**

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**December 13, 2016**

**1:30**

**Head Hall, GGE**
**Room E11**

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**Examining Board**:

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|---|---|
| Dr. Yun Zhang (Geodesy & Geomatics Eng.) | Supervisor |
| Dr. David Coleman (Geodesy & Geomatics Eng.) | |
| Dr. Emmanuel Stefanakis (Geodesy & Geomatics Eng.) | |
| Dr. Julian Meng (Electrical & Computer Eng.) | Chairperson |

**External Examiner**:
Dr. Gunho Sohn
Program Director, Geomatics Engineering Program
Dept. of Earth & Space Science & Engineering (ESSSE)
York University

**The Oral Examination will be chaired by**:
Dr. John Kershaw, Associate Dean of Graduate Studies

## BIOGRAPHY

**Universities attended (with dates & degrees obtained)**
2014: Diploma in University Teaching, University of New Brunswick, Canada
2007: M.Sc., Civil-Surveying Engineering, University of Benghazi, Libya
2001: B.Sc., Civil Engineering, University of Garyounis, Benghazi, Libya

**Publications**:
**Peer-Reviewed Journal Papers**

1. **Suliman, A.**, & Zhang, Y. (2015). Back-propagation neural networks in remote sensing image classification – A review on the design and implementation of the networks. *Journal of Earth Science and Engineering*, 5(1), 52-65.
2. **Suliman, A.**, & Zhang, Y. (2015). Development of line-of-sight digital surface model for co-registering off-nadir VHR satellite imagery with elevation data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 8(5), 1913-1923.
3. **Suliman, A.**, Zhang, Y., & Al-Tahir, R. (2016). Registration-based mapping of aboveground disparities (RMAD) for building detection in off-nadir VHR stereo satellite imagery. *Photogrammetric Engineering & Remote Sensing*, 82(7), 535-546.
4. **Suliman, A.**, & Zhang, Y. (2016). Segment-based terrain filtering technique for elevation-based building detection in VHR remote sensing images. *Advances in Remote Sensing*, 5(3), 2016.
5. Sharaf-El-Din, E., Zhang, Y., & **Suliman, A**. (2016). Mapping the concentrations of surface water quality parameters using a remote sensing and artificial intelligence framework. *International Journal of Remote Sensing*. In Press.
6. **Suliman, A.**, & Zhang, Y. (2016). Double projection planes method for generating enriched disparity maps from multi-view stereo satellite images. *The photogrammetric Record*, (Accepted with major revision).
7. **Suliman, A.**, & Zhang, Y. (2016). Disparity-based generation of line-of-sight DSM for image-elevation co-registration to support building detection in off-nadir VHR satellite imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*, (Under Review).
8. **Suliman, A.**, & Zhang, Y. (2016). Optical-elevation data co-registration and classification-based height normalization for building detection in stereo VHR images. *International Journal of Remote Sensing*, (Under Review).

**Conference Papers**

1. **Suliman, A.**, & Zhang, Y. (2014). Integration of off-nadir VHR imagery with elevation data for advanced information extraction. *Proceedings of the 2014 IEEE Geoscience and Remote Sensing Symposium (IGARSS)*, 13-18 July, Quebec, Canada.
2. Jabari, S., Zhang, Y., & **Suliman, A**. (2014). Stereo-based building detection in very high resolution satellite imagery using IHS color system. *Proceedings of the 2014 IEEE Geoscience and Remote Sensing Symposium (IGARSS)*, 13-18 July, Quebec, Canada.
3. **Suliman, A.**, Zhang, Y., & Al-Tahir, R. (2016). A novel technique for mapping the disparity of off-terrain objects. *IOP Conference Series: Earth and Environmental Science, 34*(1), 012035.
4. **Suliman, A.**, Zhang, Y., & Al-Tahir, R. (2016). Co-registering and normalizing stereo-based elevation data to support building detection in VHR images. *Proceedings of the Imaging & Geospatial Technology Forum (IGTF). The ASPRS annual conference 2016*. April 11-15, Fort Worth, US.
5. **Suliman, A.**, Zhang, Y., & Al-Tahir, R. (2016). Slope-based terrain filtering for building detection in remotely sensed VHR images. *Proceedings of the Imaging & Geospatial Technology Forum (IGTF). The ASPRS annual conference 2016*. April 11-15, Fort Worth, US.
6. **Suliman, A.**, Zhang, Y., & Al-Tahir, R. (2016). Enhanced disparity maps from multi-view satellite images. *Proceedings of the 2016 IEEE Geoscience and Remote Sensing Symposium (IGARSS)*. July 10-15, Beijing, China.
7. **Suliman, A.**, Zhang, Y., & Al-Tahir, R. (2016). Extracting accurate building information from off-nadir VHR images. *Proceedings of the Ninth International Conference on Geographic Information Science (GIScience)*. September 27-30, Montreal, Canada.
8. **Suliman, A.**, & Zhang, Y. (2017). An efficient approach for image-DSM co-registration for urban building extraction. *Proceedings of the Biennial International Joint Urban Remote Sensing Event (JURSE)*, 5-7 March, Dubai, United Arab Emirates. (Accepted on Nov. 15/ 2016).

**Conference Presentations**

1. **Suliman, A.**, & Zhang, Y. "*A novel disparity-based building detection*", The 2015 Graduate Research conference (GRC), UNB, April 23, Fredericton, Canada. (***Award winning presentation***)
2. **Suliman, A.**, & Zhang, Y. "*Object-space disparity concept for enriched disparity maps from multi-view satellite images*", The 2016 Graduate Research conference (GRC), UNB, April 22, Fredericton, Canada. (***Award winning presentation***)