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<th>Title</th>
<th>BUILDING EXTRACTION IN HAZARDOUS AREAS USING EXTENDED MORPHOLOGICAL OPERATORS WITH HIGH RESOLUTION OPTICAL IMAGERY</th>
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In this thesis, a method based on mathematical morphology is proposed for accurate building extraction in hazardous areas. The thesis is composed of five chapters.

Chapter 1 is an introduction explaining the research background, problem statement, and research objectives.

Remote sensing techniques have been extensively exploited in hazard mapping, rescue, excavation emergency response, and disaster mitigation and rebuilding processes. Remote sensing is the leading technique to quickly map the damage at different scales, coordinating the relief effort and to assess the vulnerability of the areas. Rescue and evacuation of occupants from the hazardous regions are the main tasks of emergency management. In other words, damaged building detection is the key element in the disaster crisis management and response procedures. Generally both airborne and space-borne optical sensors can cover large areas, and they can hence be used for damage detection in large-scale disasters.

The objectives of this study is to develop a method based on mathematical morphology to extract buildings in hazardous areas with high accuracy using space borne and airborne optical imagery.

Chapter 2 makes a brief survey of existing studies for building extraction using airborne or space-borne imagery. The surveyed methods can be classified into two categories: edge-driven and region-driven methods. The edge-driven methods are mainly focused on the delineation of building boundary and segmentation of building roof polygons or faces. Many of these works showed shortcomings in their applications to hazardous areas, because of the influence of the errors occurred by debris. In contrast to the edge-driven methods, region-driven methods have significant advantages, because it can incorporate prior high level knowledge such as texture, intensity, and shape models. The main drawback of these techniques is that it needs complex combinations of image processing approaches to distinguish proper building shapes. Mathematical morphology is a promising approach for image segmentation based on analysis of spatial structures of imagery. This approach is used in this thesis for building extraction in hazardous areas.

Chapter 3 explains the proposed method for building extraction. The method is composed of the following three steps to extract buildings before and after a hazardous event. 1) Image structural information is extracted by multiscale applications of two kinds of the morphological operators, i.e., opening by
reconstruction and closing by reconstruction. In this step, multiscale transformed images are generated by applying the two kinds of morphological operators to an original grey-scale image using different sizes of structural elements. 2) A set of differential images, i.e., differential morphological profiles (DMP), are created by taking the difference between the multiscale transformed images in two different directions, i.e. opening and closing. The pixels of the DMP contain feature vectors showing the spatial information on the shape and size of quasi-homogeneous regions in the image. 3) Finally by applying an appropriate classification rule to the DMP, buildings of different shapes and sizes can be identified. Random forest classification method was selected here after trying three types of classification rules, i.e., the hit-or-miss transform using different shapes and sizes of templates, the support vector machine, and the random forest classification method.

In addition to the mathematical morphology, spatial Fourier transform was also applied to small gridded square areas to obtain auxiliary information on overall areal damages.

Chapter 4 shows experimental results in Ishinomaki City in Miyagi Prefecture at the time of the 2011 Tohoku Earthquake. High resolution optical images on board IKONOS and QuickBird satellites and aerial photos were used to extracts buildings before and after the earthquake. Different shapes of structural elements (square, disk, and rectangular) were tried to create the DMP and the square structural element proved to show the best performance for building extraction. The results of building extractions were compared with manually extracted buildings from the same optical images. The ratings of the overall accuracy of building extraction were 81.2%, 76.9%, and 84.2% respectively for three types of classifiers, i.e., the hit-or-miss transform, the support vector machine, and the random forest classifier. Finally combining the results of the morphological analysis and the spatial Fourier transform contributed to improving the accuracy of building extraction.

Chapter 5 gives conclusions of this research and suggests some future works. This research proposed a method based on mathematical morphology for building extraction in hazardous areas using aerial photos or satellite optical sensors. The method will contribute to quick identification of damaged buildings and infrastructures, and help planning measures for rescue and recovery after enormous disasters.
（論文審査の結果の要旨）

本論文は、空間フィルターの一種である拡張モルフォロジー演算子を用いて、高分解能（解像度1m以下）の光学衛星リモートセンシング画像から災害時の建物被害を把握する手法を提案し、実際に2011年の東日本大震災時の被災地域に適用してその有効性を検証したものである。得られた主な成果は次のとおりである。

1. 高分解能の光学衛星リモートセンシング画像に拡張モルフォロジー演算を施すことによって、様々なサイズの建物や地物に対応する差分モルフォロジー画像を生成し、それらにパターン分類手法を適用することにより被災地域の建物被害を把握する手法を開発した。本手法を、東日本大震災前後に取得された石巻市のIKONOS衛星画像、QuickBird衛星画像および航空写真に適用し、建物被害の把握に有効であることを確かめた。

2. 差分モルフォロジー画像を計算する際に用いる構造要素（structure element）として、種々の形状のものを適用して建物の抽出精度を比較し、建物被害を抽出する上で有効な形状を決定した。

3. 差分モルフォロジー画像に適用するパターン分類手法として、SVM（Support Vector Machine）とRF（Random Forest）を比較し、後者の方が高い精度で建物被害を把握できることを示した。

4. 対象とする衛星画像を格子状の小領域に分割して、その各々にフーリエ変換を施すことにより空間周波数を計算し、そのパターンから小領域の建物や道路の並び及びランダムさを推定し、街区ごとの被害を把握する方法を考案した。この方法を拡張モルフォロジー演算による建物被害の推定方法と組み合わせることにより、被害把握の精度が向上した。

以上をまとめると、本論文は、高分解能の光学衛星リモートセンシング画像に拡張モルフォロジー演算を施すことによって大規模災害時の建物被害を把握する手法を開発したものであり、学術上、実際上寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。また、平成26年10月23日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。