NARROW-LINEAR AND SMALL-AREA FOREST DISTURBANCE DETECTION AND MAPPING FROM HIGH SPATIAL RESOLUTION IMAGERY: A FRAMEWORK

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ABSTRACT

Over the past decade, widespread disturbance has brought a large amount of narrow-linear and small-area disturbance features (e.g., ATV trails, seismic lines, pipelines/powerlines, well sites, forest roads and cut blocks) to forest areas in the Foothills Region of Alberta, Canada. This issue has prompted research into finding appropriate data and methods for mapping these narrow-linear and small-area disturbance features in order to examine their impacts on wildlife habitat. Recent released high-resolution remote sensing data and introduced image processing methods have the potential to update detail information on rapidly increased small forest disturbance. In this paper, we first described the characteristics of small forest disturbances and presented the nature of problems. Then we presented a framework for detecting and extracting narrow-linear and small-area forest disturbance features. Following the framework, we provided an overview of the types of imagery being used for small-feature extraction, discussed the methods that have potential in support of mapping small disturbance from high resolution imagery, and included experimental results in terms of mapping accuracy and completeness. The challenges and future directions for detection and mapping of small-scale disturbance are identified and synthesized at the end.

INTRODUCTION

Developments associated with oil and gas infrastructure, open-pit coal mining, forest management, and recreational use facilities have expanded rapidly in the natural forest area, such as the Foothills Region of Alberta, Canada (Schneider et al., 2003; Linke et al., 2005). As a consequence of increasing developments in the forest areas, the narrow-linear and small-area disturbance (e.g., ATV trails, seismic lines, pipelines/power lines, well sites, forest roads and cut blocks) increased dramatically in order to explore, access and haul resources (Linke et al., 2005). A study indicated that human activities were expected to keep increasing in the foothill region and one of major disturbance features - forest road – will be more than three times of current density over 100 years (Nielsen, 2008).

The narrow-linear and small-area disturbance features have been found to respond for the loss of original habitat, reduction in patch size, and increasing isolation of patches (Andren, 1994). Depending on the severity of the small-scale disturbance process and sensitivity of the ecosystems affected, native plants, animals, and many natural ecosystem processes are compromised or altered (Heilman et al., 2002). For many species, migration between suitable habitat patches becomes more difficult, leading to smaller population sizes (Vermeulen, 1993). The latest phase of Alberta's grizzly bear population census indicated that the grizzly bear population is less than half the size it was estimated to be in 2002. In comparison with other North American populations (Mowat et al., 2005), the low and declined density possibly resulted from high numbers of human-caused mortality (Nielsen et al., 2004).

Reliable and up-to-date disturbance maps that show all scales of forest disturbance are essential to fully understand up-to-date habitat quality and ensure adequate consideration of the effect of disturbance on native species. These maps are also required for a wide variety of forest planning, management, and modeling activities. Large-area forest disturbances, such as forest fire, larger cut blocks and road, have been mapped by coarse spatial resolution imagery (e.g. AVHRR or MODIS) at global scale and delineated by medium spatial resolution (20 - 30 m) satellite images (Landsat, Satellite Pour Observation De La Terre (SPOT) 4, or ASTER) at regional scale (e.g. Cohen et al., 1998; Collins and Woodcock, 1996; Franklin et al., 2002). However, the narrow-linear and small-area disturbance features (e.g., ATV trails, seismic cutlines, and well sites) are too small to be reliably detected and mapped with coarse and median spatial resolution imagery.

In recent years, the increasing availability of high spatial-resolution imagery from several satellite platforms with resolutions better than 10 m provides greater opportunities for visual recognition of small forest disturbance. In the same time, the image-processing capabilities on detection and extraction small forest disturbance have also improved. Given the significant impacts of the current human disturbance in Alberta forest areas it is urgent to assess what new remotely sensed data and processing methods may have potential for detecting and mapping narrow-linear and small-area forest disturbance features. Little paper has reviewed the use of remote sensing and image processing for mapping small forest disturbance features, such as trails in forest areas (Witztum and stow, 2004; Kaiser et al., 2004), while a substantive body of literature exists for mapping of larger features, both in linear (e.g. road) and polygonal (e.g. large cut blocks) shapes (e.g. Fischler, et al., 1981; Flanders et al., 2003; Gruen and Li, 1995). A successful study (Kaiser et al., 2004) dealing with the problem of retrieving smaller linear feature (i.e. transborder trails) demonstrated that it is possible to extract these features based on high resolution images; however, authors also indicated that it is necessary to test the existing image processing methods and to explore new techniques in order to extract accurate information from high resolution imagery efficiently.

Previous reviews have explored the application of remote sensing to feature extraction and have summarized the state of remote sensing technology up to the early 1970s (e.g. Baltsavias, et al., 2001; Gruen, et al., 1997; Gruen, et al., 1995; Quackenbush, 2004). In general, those studies covered a broad range of detection and mapping methods. This study provided a framework for the detection and mapping of narrow-linear and small-area forest disturbances. The differences between this work and other related studies are that the focus of this paper is small forest disturbance: narrow-linear features and small-area features. To meet this stated objective, background information and nature of problem pertinent to small forest features have been discussed first; then a framework for detection and mapping of narrow-linear and small-area features has been presented and the potential remote sensing data and methods have been gathered and examined; Third, the experiment results for the framework have been discussed; finally, conclusion and potential directions for future research priorities have been provided. The context of this paper deals with small forest disturbance occurred in Alberta, Canada.

APPROACHES FOR MAPPING FOREST DISTURBANCE FEATURES

Characteristics of Small Forest Disturbances

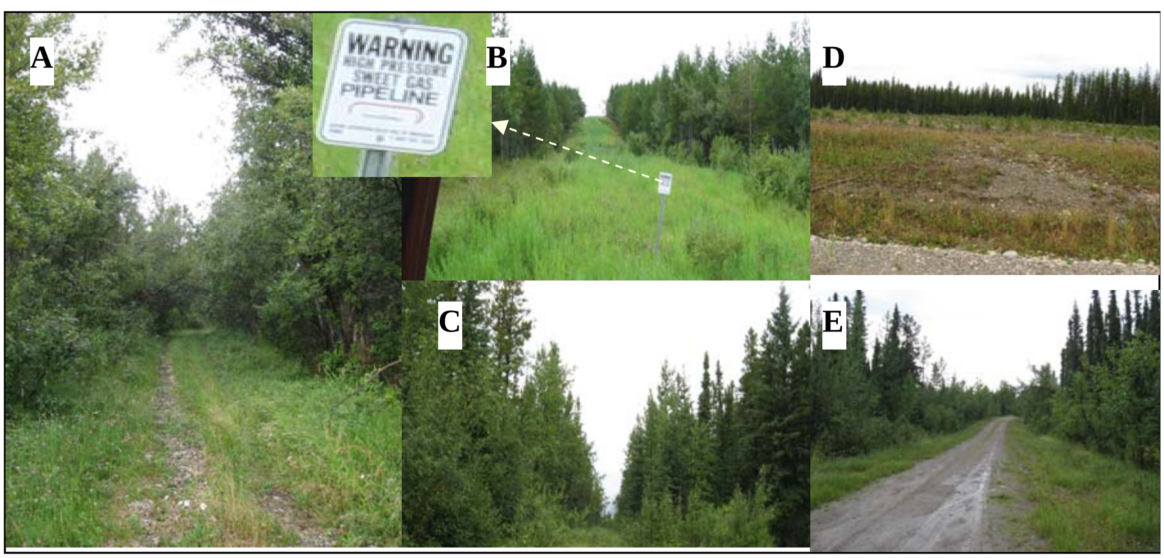

Figure 1. Pictures of some disturbance features (A. ATV trail, B. pipeline, C. Seismic cutline, D. Cut block, E. Forest road) taken in Foothill region of Alberta.

In order to appropriately detect and extract small-scale forest disturbance features from remote sensing data, we adopted several small forest disturbance features resulting from diverse human activities and discussed their characteristics. The selected small disturbance features were grouped into two types: narrow-linear disturbance (ATV trails, seismic lines, pipelines/power lines, and forest roads) and small-area disturbance (well sites and cut blocks). Our list of small forest disturbance features was not exhaustive, but covered the major features in our study area (Figure 1). The characteristics of selected disturbance features can be described from three aspects - spectral characteristics, geometric characteristics, and topological properties (Table 1). Of these characteristics, the features can be determined from remote sensing data and differentiated from each other theoretically. To differentiate the linear features from each other in the remote sensing imagery, the unique characteristic for each feature should be considered. For example, a forest road is relatively wide and has different spectral characteristics (gravel covered) from other linear features.

Table 1. Characteristics of Narrow-Linear and Small-Area Disturbance Features

<table>
<tr><th rowspan="2">Disturbance features</th><th colspan="2">Spectral characteristics</th><th colspan="3">Geometric characteristics</th><th rowspan="2">Topological property</th></tr>
<tr><th>Surface</th><th>Top</th><th>Length</th><th>Curvature</th><th>Width</th></tr>
<tr><td>Forest road</td><td>Firm and smooth surface, gravel covered</td><td>Open</td><td>Long</td><td>Straight with local curvature</td><td>Constant ~20-30m</td><td rowspan="2">Road networks</td></tr>
<tr><td>ATV trail</td><td>Heterogeneous surface, gravel and grass interlaced</td><td>Not always open</td><td>Short</td><td>Sinuous</td><td>Constant ~10-20m</td></tr>
<tr><td>Power/pipe line</td><td>Smooth surface, grass covered</td><td>open</td><td>Long</td><td>Very straight</td><td>Constant ~10-20m</td><td>Power/pipe line networks</td></tr>
<tr><td>Seismic cut line</td><td>Heterogeneous surface, gravel and grass interlaced</td><td>open</td><td>Long</td><td>Very straight</td><td>constant ~5-10 m</td><td>No</td></tr>
<tr><td>Cut block</td><td>Heterogeneous surface including mounding, exposed soil, and plough furrows</td><td>Open</td><td colspan="3">Unnatural polygonal shape</td><td>ATV road networks</td></tr>
<tr><td>Well sites</td><td>Smooth surface made from Concrete</td><td>Open</td><td colspan="3">Regular polygonal shape</td><td>Forest road networks</td></tr>
</table>

The Nature of the Problems

In the foothill region of Alberta, the increased narrow-linear and small-area disturbance rapidly modified specific landscape metrics. There are some existing GIS disturbance data for this region; however, existing GIS database always has certain deficiencies, such as not very accurate, not complete enough, or out of date. Considering the disturbance features have not been extensively documented and updated, using remote sensing to map these disturbance features would not only be helpful for wildlife habitat research, but also to large mapping projects that need current and accurate land cover from every area of Canadian forestry (Wunderle, 2006). The requirement at hand is therefore to detect and extract disturbance objects. We have stated in the previous section that the small forest disturbance features should be able to be identified from high resolution remote sensing imagery theoretically because of their specific characteristics. However, the extraction of disturbance features from remote sensing imagery could be considered more challenging than we thought for reasons that come from two aspects: 1) remote sensing data and 2) feature detection and extraction methods. Regarding remote sensing data, spatial resolution is just one of many variables that influence the extraction of disturbance features using remotely sensed imagery. Atmospheric and illumination conditions, geographical and temporal coverage, and cost of the image should all be considered when assessing the suitability of an image for a particular investigation. On the subject of feature extraction methods, there are a large variety of methods for linear or small-area feature extraction from high resolution imagery, but most of them are specific to roads, building, or other small features (e.g. Auclair, et al., 2001; Barzohar and Cooper, 1996; Katatzis, et al., 2001; Kaiser et al., 2002, Inglada, 2007). Their performance for detecting or extracting narrow-linear and small-area forest disturbance has to be examined. Therefore, there is a need to decide suitable remote sensing data and methods for forest disturbance feature extraction from the high resolution satellite data.

A Framework for Small Forest Feature Extraction

With the requirement of mapping narrow-linear and small-area forest disturbance features, a powerful, flexible, and extensible framework must be designed ahead of processing. After reviewing related literatures, the conceptual framework was created for mapping small forest disturbance features (Figure 2) which supposes to minimize human interaction up to final stage. The process framework include three stages: selecting input data, processing data, and producing output maps. The first stage involves selection and pre-processing of available imagery and checking available GIS layers and field data. The second stage involves selection of disturbance features, detection and extraction features, labelling attributes to each feature, and validation. The final stage involves producing disturbance database in raster or vector formats. A comprehensive view and comparison of data and methods involved in these stages is provided below.

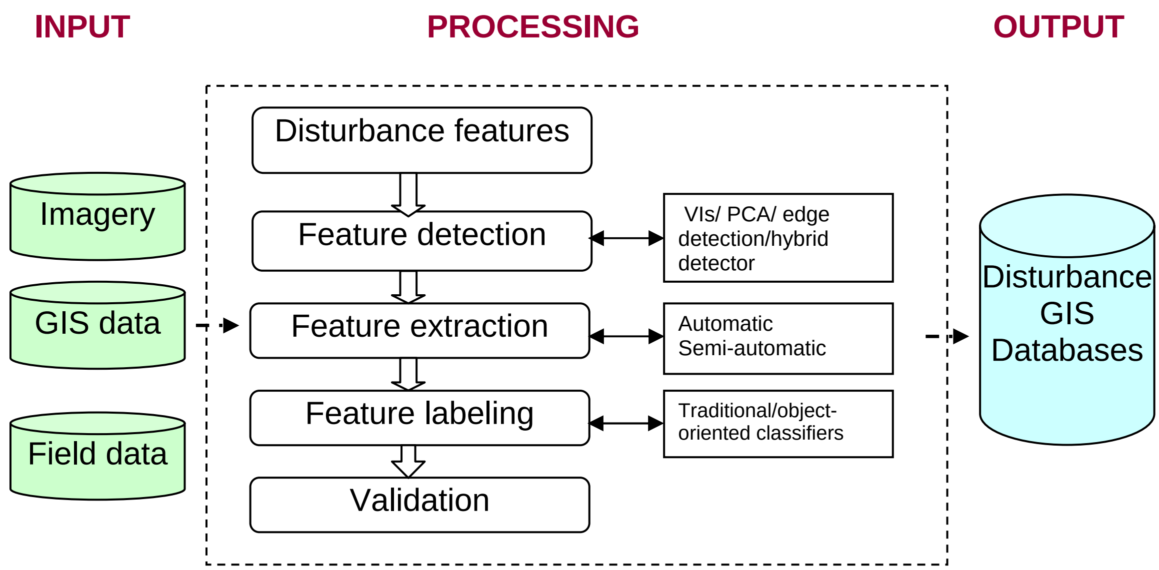

Figure 2. The process framework of detection and mapping narrow-linear and small-area forest disturbance features.

Possible input data. Although the input data include images, GIS data, and field data, availability of GIS data and field data are really project related. Therefore, we focused on the available optical imagery that could be considered in small-scale feature extraction. The body of literature for small feature extraction from high resolution images (e.g. SPOT 5) and even higher resolution images (Ikonos, Quickbird and Orbview-3) is substantial. Besides optical imagery, some authors have reported use of radar data for extracting small features, while others considered LiDAR data (e.g., Alharthy and Bethel; 2003; Hellwich, et al., 2002). However, radar and LiDAR data are not common because their images are quite different than the optical one and most of available extraction techniques are not suitable to be directly applied to radar and LiDAR data. Considering the sizes of selected disturbance features, remote sensing images with resolutions better than 10 m is of interest. The swath width of the image is also a concern when one studying a relatively large geographical area. The sensors such as SPOT 5 are the first of the high resolution satellites to balance large footprint with highly detailed imagery: providing multispectral imagery with a resolution of 10 m, combined panchromatic imagery with a resolution of 2.5 m, and a wide swath (60 km), therefore it increases the interest of the use in this application field.

Processing. The processing stage involved four steps (Figure 2): detection, extraction, labeling, and validation. Since there are some image processing systems conducting first three steps together, one might get confused with the definitions of first three steps. Feature detection is the first essential and important step of low level vision, defined as finding a small area in the image which may potentially be the object of interest (Inglada, 2007). Extraction is to extract each detected image patch by a description vector which will be used in a supervised classification scheme for labeling step. Labeling is to label the attribution of a class to the extracted object. Most articles combined feature extraction and labeling steps as one since a great deal of feature extraction studies only discussed one object (e.g. road system) and thus it is not necessary to label the feature after extraction. When studying several classes of features like forest narrow-linear and small-area disturbance discussed in previous section, feature labeling task should be performed separately. The existing methods and proposed methods for feature detection, extraction, labeling, and validation are reviewed and examined below.

Potential feature detection methods. Hundreds of feature detection techniques are present in the literature, but we focused on the techniques for detecting two major feature characteristics from high resolution imagery, that is, spectral and geometric. From spectral perspective, the primary challenge in detection features from satellite images is maximization of the feature-to-background ration. The vegetation index approach is one of solutions to this challenge since vegetation index is able to differentiate background information from some proposed features. For example, Wilson and Sader (2002) compared NDVI with Normalized Difference Moisture Index (NDMI) and found NDMI is more sensitive to cut block areas (both cleared and partial). Healey et al. (2005) found that the Tasselled Cap Wetness component is efficient in the detection of forest disturbance. The alternative popular approach for fast discrimination of spectral properties between proposed features and background information is principal component analysis (PCA), one assumes that the set of pixels of each example in the data base is a random vector and PCA is performed in order to obtain a set of eigenvectors which are used as a decomposition basis (Turk, 2001).

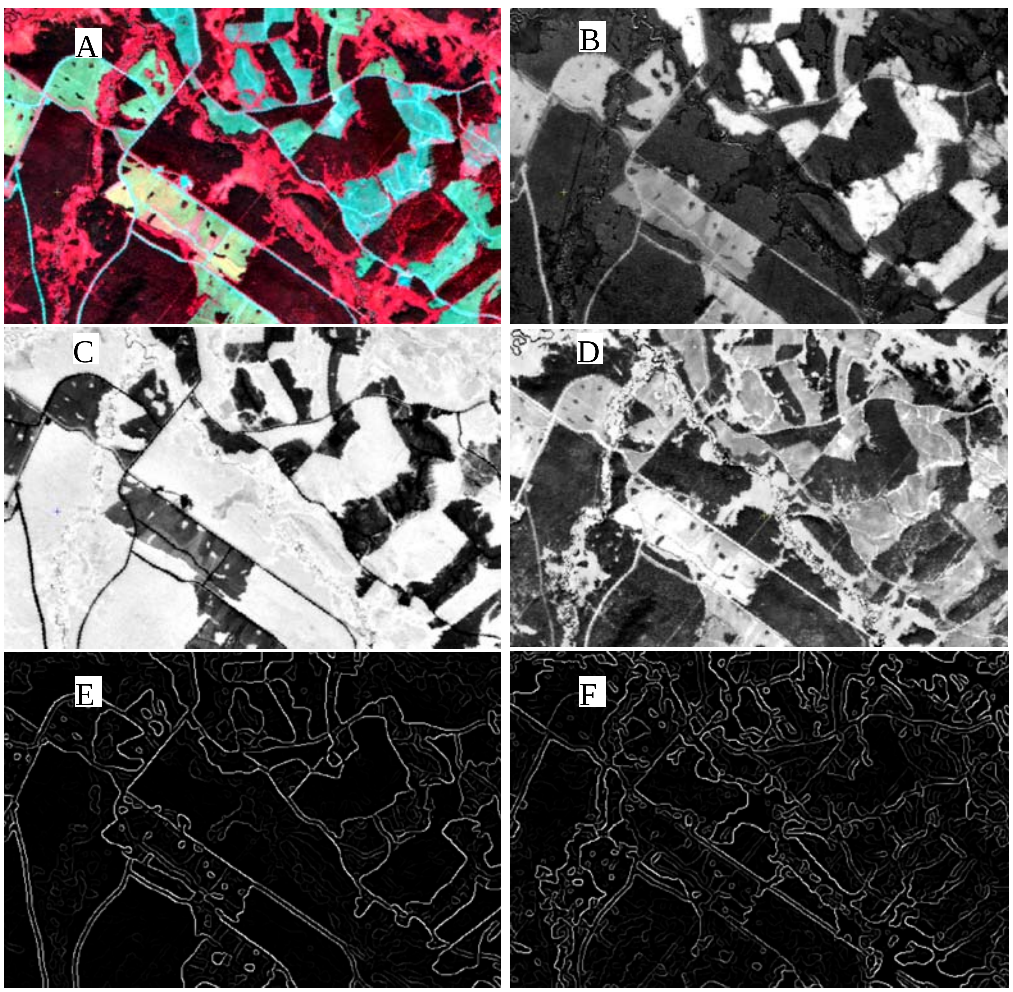

Figure 3. The portion of SPOT image acquired for the foothill region of Canada on July 21, 2005 with 10 m resolution (A, standard false color composite: RGB-321) and the detected disturbance features based on NDMI (B), NDVI (C), PCA (D – the first principle component), and Canny edge detection (E - Gradient magnitude 1 and F - Gradient magnitude 2) for the foothill region.

In order to detect feature fully, one should pay more attention to characterize the objects by using geometric information since the use of spectral pattern can introduce a source of variability - illumination and seasonal effects for example – that we should avoid (Inglada, 2007). Indeed, the objects of interest in our study area are well defined by the spatial attributes of their edges. Regarding the geometric properties, narrow-linear and small-area features can be identified through edge detection method. Edge detection normally tries to locate points of abrupt changes. A large variety of algorithms is available in the literature for edge finding and the essential edge detector can be viewed as two groups: differentiation and low-pass filtering (Zhu et al., 1999). The edge detection methods based on differentiation mainly used first and second order derivatives of the light intensity function. However, one of the greatest problems related with differentiation methods is their low capacity to reject high frequency noise. To solve this problem, some of the most recent researchers developed edge detectors using a combination of linear low-pass filtering followed by differentiation. For example, the steps for Canny edge detection (Canny, 1986) included: 1) apply a Gaussian filter to filter out noise; (2) compute X, Y gradients of the filtered image; and (3) suppress pixels whose gradient is non-maximum along the gradient direction.

The methods we presented here are mostly simply and commonly-used; however, lots of other feature detection approaches exist in the literature. What we should keep in mind is that no single method can be considered good for all disturbance features, nor are all methods equally good for a particular types of disturbance. Therefore, a great effort has to be made in order to find the best detecting method which is suited to the specific feature objects in forest areas and can be applied to high resolution images. Figure 3 shows a portion of a preprocessed SPOT image of the foothill region of Canada and the feature detection results developed from several commonly-used methods. The major features such as forest road and cut blocks can be identified from all the resultant maps, however, each method has its own advantage over other methods. For example, NDMI (Figure 3 B) had the advantage over other methods on identifying the differences between cut blocks and showing the ATV trials within some cut blocks. NDVI map (Figure 3 C) had the strongest contrast between major objects and background information. The first principle component (Figure 3 D) clearly showed the seismic lines while other methods could not identified them. The canny edge detection (Figure 3 E & F) could result in different degrees of edge details.

In this study, we proposed a hybrid detector which combined vegetation indices, PCA, and Canny edge detector together to identify the forest disturbance features. Ideally, the major disturbance features could be identified by using Canny edge detector to detect NDVI map. The ATV road could be detected by combining Canny edge detector with NDMI. The powerlines and seismic lines should be able to be identified by using some decision rules to remove the noise from the resultant map after performing Canny edge detector and PCA.

Potential feature extraction methods. After the feature detection step, feature extraction algorithms can be applied to every possible position of an analyzing window within the image. Several excellent survey papers on feature extraction algorithms techniques are available (Baltsavias, 200; Mena, 2003, Quackenbush, 2004; Trier et al., 1996). Feature extraction strategies are often categorized according to the degree of automation (i.e., automated or semi-automated). An automated extraction approach is intended to extract features from a scene without the need of sustained interactive operation from a human (Doucette et al., 2004). However, fully automated algorithms often produce incomplete results so that manual post processing is inevitable. Different from automated approach, the semi-automated method uses interactive user-provided information typically in the form of length, widths, and topological information, and allows manual editing of the extraction results (Kim et al., 2004). The examples of state-of-the-art techniques used for semi-automated linear feature extraction are energy minimization approaches such as “snakes” (Gruen and Li, 1995) and template matching (Vosselman and Knecht, 1995). Energy minimization is one of optimization techniques that seek for (local) energy minimum. However, this approach may not work well when it is difficult to define appropriate energy functions (Kim et al., 2004). For example, cut blocks may exhibit different geometric properties. In order to cope with this difficulty, template matching can eliminate the need of energy functions and hence offer wider applicability.

Regardless the advantage and disadvantage of automated and semi-automated algorithms, the performing time and energy savings should also be taken into account when performing the extraction techniques. Many authors state that their feature extraction methods provide significant benefits in terms of saving operator time and effort; however, the tools in the markets commonly require a substantial waiting time while training, especially when using high resolution images for a relative large area. Currently, a latest released tool (FeatureObjeX™, Geospace Inc.) minimizes this problem by using the fastest makeup tool in the market. In addition, this tool seamlessly blends automated feature extraction algorithms with interactive intelligent editing tools, to maximize the productivity of image analysts. In this study, we used this tool to extract the features automatically.

Potential feature labeling methods. A great diversity of image patches representing the different objects of interest can be obtained in feature extraction step, and we are thus facing a problem of correctly label the image patches. Remote sensing image classification is a commonly used method to label attributes to each patch of image (Chintan et al., 2004). The conventional classifiers are pixel-based (Dean and Smith, 2003), which assign a pixel to a class by considering the spectral similarities with the class or with other classes. Although the techniques are well developed and have sophisticated variations such as software classifiers, sub-pixel classifiers and spectral un-mixing techniques, it is argued that it does not make use of the spatial concept (Blaschke et al., 2000). For example, it was reported that per-pixel Maximum Likelihood classification (MLC) was limited by only utilizing spectral information without considering texture and contextual information (Dean and Smith, 2003). Zhou and Robson (2001) claimed that texture information was ultimately necessary if one is to obtain accurate image classifications. Therefore, this traditional type of classifiers might not be useful in our study since the selected disturbance features have some specific geometric or texture properties.

In recent years, many advanced classification approaches, such as artificial neural networks, fuzzy-sets, and expert systems, have been widely applied for image classification. After reviewing the discussed methods, we recommend to use the object oriented analysis combining with one of advanced classification algorithms (e.g. a fuzzy knowledge base) to label small-scale forest disturbance features since this approach classifies objects instead of single pixels and uses textural and contextual information as well as the spectral information, which enables it produce a disturbance map with a higher accuracy. A more detailed description about object-oriented image classification is presented in Yan et al. (2006). Consequently, the object-oriented classifier was used to classify those features based on their properties (e.g. shape, sinuosity, width, variation in width, dominant spectral value, and the variation in spectral value) with the disturbance map and original satellite imagery layers as inputs.

***Validation approaches*.** In order to validate the performances of different methods, lots of studies evaluated their map products based on visual assessment or other data sources (existing GIS data, field measurements, and other imagery). Visual assessment is subjective and limited by the accuracy of human interpretation. Consequently, a visual analysis is not sufficient to determine the limits and properties of the resulting maps (Péteri, 2004). For the evaluation based on other data sources, accuracy statistics (overall accuracy, errors of commission, and errors of omission) for mapping products was generally provided. However, considering registration error existed between image-derived features and those surveyed with GPS, defining some performance criteria is necessary ahead of evaluation. For example, an epsilon envelope (four-pixel wide) was created to each side of the pixel representing the GPS trail center line (Kaiser, 2004) to account for positional uncertainty. Six performance measures indicating different levels of accuracy were presented for a road extraction system (Heipke et al., 1995). Regarding small forest disturbance features, an extracted object lying within a tolerance zone of reference data should be considered a successful match during the accuracy assessment.

EXPERIMENT

The framework for extracting small forest disturbance described above has been successfully implemented in our study area and tested on a number of satellite images. In this section, some typical examples will be given. The proposed detection method has been used for distinguishing the major objects (forest road, well sites and cut blocks, Figure 4 B) and the minor objects (seismic lines and ATV trails, Figure 4 C). The good match between figure 4 A and B indicated satisfied detection accuracy for the major objects. However, the resulting minor objects map clearly showed seismic cut lines and ATV trials, but also include some background objects, such as river band patches. Therefore, the most errors in minor objects map were associated with commission rather than omission. This was acceptable as well since further extraction and labeling steps could also apply some advance methods to remove noise in the detection maps.

The disturbance features were identified using FeatureObjeX™ software tools by interactively selecting a small number of representative features (i.e., training features) from multiple layers composed of image bands and resultant maps from detecting step. As seen in figure 5 C, the semi-automated extraction technique produced a map included cut blocks and seismic lines. In general, the extracted disturbance map is acceptable when comparing it to SPOT multispectral and panchromatic images: major cut blocks and forest road were mapped and minor seismic cutlines were also delineated clearly. However, the well sites and ATV trials were not showed in the map since the most of trails were within cut blocks. The boundary of cut blocks and the holes in cut blocks were not precisely mapped.

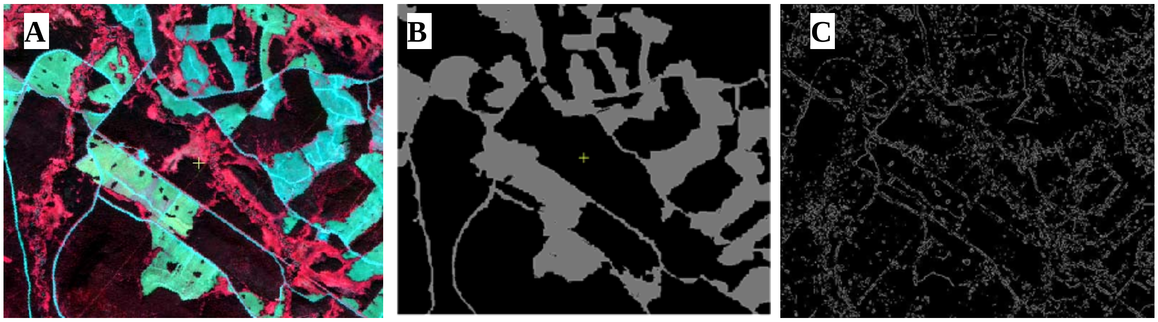

Figure 4. The portion of SPOT multispectral image acquired for the foothill region of Canada on July 21, 2005 with 10 m resolution (A, standard false color composite: RGB-321), the detected major disturbance features based on Canny edge detector and NDVI (B - in grey color), and the detected minor disturbance features based Canny edge detector, NDMI and PCA (C – in grey color).

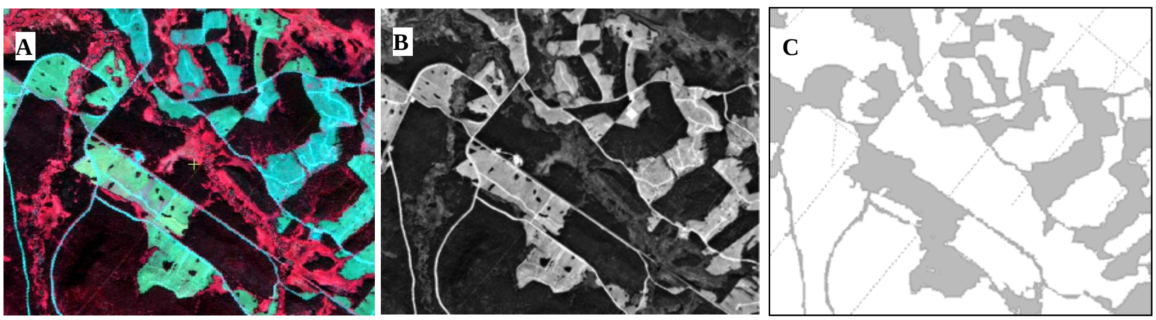

Figure 5. The portion of SPOT multispectral image acquired for the foothill region of Canada on July 21, 2005 with 10 m resolution (A, standard false color composite: RGB-321), the portion of SPOT panchromatic image acquired for the foothill region of Canada on July 21, 2005 with 2.5 m resolution (B), and the extracted disturbance features based the semi-automatic method (C – in grey color).

The characteristics of each disturbance features described in the previous section allowed us to build the decision rules to label each of the image patches based on the object-oriented classifications. The input layers for classification were the extracted disturbance features and raw image layers. Since the extracted map of disturbance features had an acceptable accuracy, we weighed this map higher during the classification. The rather small segmented objects were chosen for the classification since the some disturbance features (i.e. seismic lines) were very narrow. The labeling results indicated that the cut blocks and seismic lines could be labeled accurately in figure 6. However, it was a challenge to separate the forest road class from the ATV trail class although they have different characteristics – forest roads were wider and ATV trails were relative narrow. The ATV roads in the selected image were mostly within or around the cut blocks, so that it is very difficult to determine the width of the ATV road.

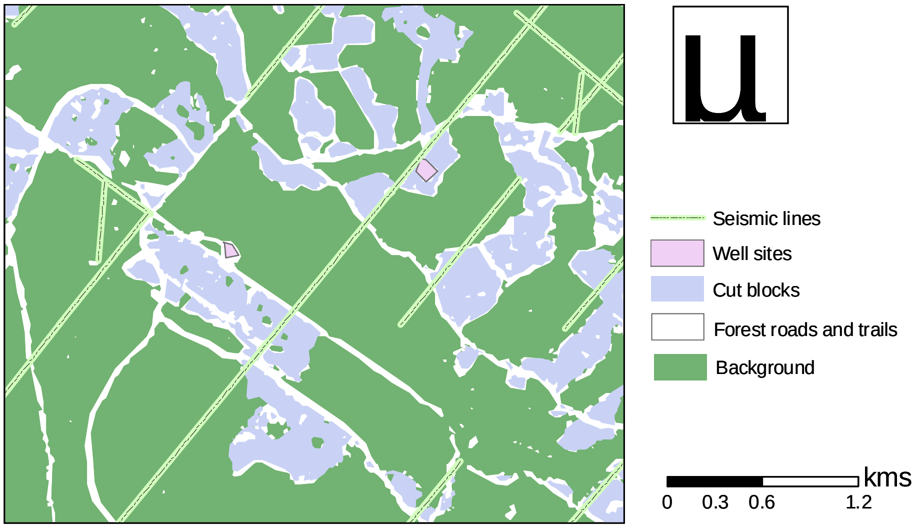

Figure 6. The classified disturbance features based the object-oriented method.

CONCLUSIONS AND ON-GOING RESEARCH

In this paper, we presented spectral, geometric, and topological characteristics of small forest disturbance features; outlined the nature of problem related to image data and methods; developed the framework for detection and mapping of narrow-linear and small-area features; and introduced and examined the potential remote sensing data and methods. In summary, remote sensing can assist in gathering data for studies of dynamic environments such as highly disturbed forest area in Foothill region of Alberta, but the data and methods must be fit for purpose.

Understanding the nature of problem, reviewing the literature, and examining the proposed framework provide ample evidence to support the conclusion that satellite imagery can be effectively used to map small forest disturbance features. At the same time we should also keep in mind that many other factors might influence the reliability and success of such mapping processes. Four issues are of particular significance and thus provide the directions for on-going research:

- Some disturbance features, such as ATV trails (<5 m) were not be able to be separated from forest roads in the selected image. This could be addressed by multi-resolution approaches. In relatively lower spatial resolution images (SPOT 5 10 m multispectral imagery), ATV trials tend to appear as lines. While in the higher resolution imagery (Quickbird 2.44 m multispectral images), ATV trails appear as elongated heterogeneous regions. Different from ATV trails, forest roads would always appear as elongated uniform regions. Eventually, we can fully extract the trail system, or separate trails from forest road.
- Regarding feature extraction methods, there are a large variety of methods for linear or polygonal feature extraction, but most of them are specific to roads or building. Their performance for detecting or extracting narrow-linear and small-area forest disturbance has to be examined. Some algorithms may have to be modified before applying to forest disturbance studies. For labeling extracted disturbance patches, on occasion, it may be unclear whether a linear feature represents an ATV trail or nearby, near-parallel linear features such as river boundaries. 'Rules' in the classification process can help to distinguish between these features. Accommodating such "rules" in the process flow is an area of much current research interest.
- It is important to decide which methods should be used for a specific study in order to saving time and efforts during data processing, but attention should also be paid to increasing understanding of the nature and magnitude of potential error and uncertainty, and how these can be propagated through derivatives from the source data. Without taking these uncertainties into account, it may be impossible to distinguish small-scale forest disturbances and their changes from imagery accurately. We will address such uncertainties in on-going analysis.

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