A locally adaptive technique for forest regeneration assessments from high resolution aerial images

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ABSTRACT

The success of forest regeneration is an essential component in sustainable forest management. Its accurate and timely assessment, usually done by field surveys, constitute an integral part of forest vegetation management. Interpretation of aerial photographs can possibly alleviate this process, but the use of digital aerial images offers the potential for more quantitative semi-automatic computerized assessments. With this in mind, a locally adaptive technique to regeneration assessment from high resolution aerial images (30-60 cm/pixel) was developed. It detects the young trees and produces information such as stem density, average tree spacing and stocking of given stands. It can also pin-point areas of under or overstocking. This technique is based on previous work directed at tree detection in mature forest with medium resolution images (1-3 m/pixel) which detects local maxima and considers them to represent the "tree tops" of conifers. Whether used with mature forest stands in medium resolution images or for regeneration assessments in high resolution images, it is generally only appropriate for dense stands where every tree is surrounded by shade. Its use on sparse stands generates numerous false positives on the ground between the trees. For such cases, a modification of the algorithm to take into consideration the presence of a specific shadow for every tree alleviates the problem. The hybrid approach described here is capable of switching from one mode of operation to the other (open or dense stand) based on a pre-computed local directionality factor. Preliminary results on regeneration stands of various ages and densities demonstrate its capabilities.

RÉSUMÉ

La réussite de la régénération forestière est un composante essentielle d'une gestion forestière durable. Son estimation opportune et précise, typiquement faite par des inspections sur le terrain, constitue une partie intégrale de la gestion de la végétation forestière. L'interprétation de photos aériennes peut possiblement alléger ce processus, mais l'utilisation d'images aériennes numériques offre le potentiel d'une évaluation quantitative semi-automatique faite par ordinateur. Pour cette raison, une technique d'évaluation de la régénération à partir d'images aériennes de haute résolution (30-60 cm/pixel) et qui s'adapte au contexte local fut développée. Elle détecte les jeunes arbres et produit pour un peuplement

• Presented at the 19th Canadian Remote Sensing Symposium, May 24-30, 1997, Ottawa, Canada.

donné de l'information telle la densité des tiges, l'espacement moyen et la densité relative. Elle peut aussi nous indiquer les endroits d'une densité relative excessive ou insuffisante. Cette technique est basée sur des travaux antérieurs dirigés vers la détection d'arbres en forêt mature à partir d'images d'une résolution moyenne (1-3 m/pixel) qui détecte des maxima locaux considérés représentatifs des cimes de conifères. Qu'elle soit utilisée pour la forêt mature à partir d'images d'une résolution moyenne ou pour la régénération à partir d'images de haute résolution, elle est généralement seulement appropriée pour les peuplements denses où chaque arbre est entouré d'ombre. Son utilisation sur des peuplements plus ouverts génère de nombreuses détections peux appropriées sur le sol visible entre les arbres. Pour ces situations, une modification de l'algorithme pour prendre en considération la présence d'une ombre spécifique à chaque arbre diminue le problème. L'approche hybride décrite ici est capable de passer d'un mode d'opération à l'autre (peuplement ouvert ou dense) à partir d'un facteur de directionnalité évalué à l'avance. Des résultats préliminaires sur des peuplements en régénération d'âge et de densité variés démontrent ses capacités.

INTRODUCTION

Assessing the success of forest regeneration is of prime importance in sustainable forest management. In particular, forest managers require accurate, timely and preferably inexpensive information about the vegetation development in recently cut areas in order to prescribe corrective actions if necessary. "Forest vegetation management (FVM) is that part of silviculture directed at manipulating the rate and course of early plant succession to achieve a forest stand of a particular composition, structure, and form, within a specified period of time" (Wagner, 1994). Practicing good forest vegetation management is vital to Canadian forest companies, specially as areas demonstrated sufficiently restocked can typically be used towards allowable cut quotas.

In order to assess the extent to which remote sensing could contribute in forest vegetation management, a workshop was held in Sault Ste-Marie, Ontario, in December 1995. The "workshop participants were most confident in recommending the traditional aerial camera and film [approach]" at this point in time, but recognized that "research is needed in preparation for the imminent digital era" (Pitt *et al.*, 1996). This paper describes a first response to such needs. It is generally understood that even if the upcoming high resolution satellites (0.8-5 m/pixel) (Fritz, 1996) are unlikely to be very useful in detailed regeneration assessments, the existence of various digital airborne sensors (CASI, MEIS, digital frame cameras) and the possible digitization of aerial photographs make the use digital approaches conceivable. Moreover, the potential gains in efficiency make them desirable.

FOREST VEGETATION MANAGEMENT REQUIREMENTS

During the early development of forest stands, whether undergoing natural or man-made regeneration, vegetation surveys are conducted to assess the stand's progress toward specific management objectives and to decide if corrective actions are needed. Typically, information is gathered on density, stocking, distribution, survival, health, species composition, brush competition and regeneration performance. Density is "a measure of the number of trees per unit area", while stocking "is the number of well-spaced trees relative to some reference density" (Brand, 1988). The spatial distribution (i.e., uniformity) exhibited by these two parameters is also of major importance. It leads to the delineation of areas judged under or over stocked, where corrective measures may be applicable.

Generally, only pre-defined acceptable species are considered in these assessments, although nowadays, the gathering of detailed species information is getting more prevalent to quantify species diversity. Still, in a lot of cases, brush competition is only assessed as "acceptable" or "unacceptable" and the regenerating species as "free to grow" or not. But, increasingly, more sophisticated assessments of forest productivity are needed in terms of height/growth targets. Only density, stocking, and distribution are addressed in this paper.

IMAGE AND GROUND DATA

Our developmental work in automating forest regeneration assessment was carried out with a MEIS-II image of the Sturgeon plantation from the Petawawa Research Forest, near Chalk River, Ontario (approximately 46^o of latitude and 78^o of longitude). The image (Fig. 1) was acquired in November 1982 at a spatial resolution of 30 cm/pixel. It contains (Fig. 2) man-made stands of Jack Pines and Scots Pines of different ages (3-11 years old) and planted with different spacing (1.5 - 4 m). Some of the stands are dense enough for the individual tree crowns to be completely surrounded by shade, while for the more open stands, the mostly grass covered ground is quite visible and so are individual tree shadows. It is a simple situation with coniferous trees of uniform size and spacing, and low lying ground vegetation that has senesced, turned brown or lost its leaves. The only complications are dune-like rolls in the terrain that make some of this mostly grass covered ground bright in some areas and dark in others. In general, the autumn acquisition probably facilitates the separation of the coniferous trees from the other ground vegetation.

TECHNIQUES AND METHODS

A technique originally developed to detect and count mature trees in medium resolution MEIS images (1-3 m/pixel), and then, to identify their species using only the conventional pixel-based classification programs of the time (Gougeon and Moore, 1989) was first applied to the image. It consists in detecting local maxima in the most appropriate spectral band (typically the near-infrared). In dense coniferous stands where individual tree crowns appear separated by areas of shade, the algorithm generally isolates a single pixel per tree, usually corresponding to its well illuminated tree top. However, in sparser stands where sun illuminated ground is also visible, the algorithm picks up numerous false positives on the ground. To remedy this situation, a new version of the algorithm was created that looks for an area of shade at a specific distance and direction (based on sun angle) from the potential tree top.

This newer algorithm eliminates most of the false positive tree tops from the more open areas, independently of the local illumination conditions. Indeed, for the well lit backgrounds, sizeable trees have definite shadows, and for the darker backgrounds, shade is omnipresent. The necessary condition is met in both cases. In fact, the new version of the algorithm also deals well with dense stands since the trees are surrounded by shade. Thus, the original algorithm may only be necessary to deal with trees too small to project a noticeable shadow in a sparse stand situation. Since the detection of 2-5 year old trees is needed for FVM (Pitt et al., 1996), an hybrid approach was created. It consist of switching between the two modes as needed by the situation at hand. The resulting algorithm can be construed as locally adaptable.

Our criteria for switching between the two situations is based on local directionality. Indeed, older open stands with their distinct tree shadows on bright backgrounds exhibit much more directionality than the dense stands where trees are completely surrounded by uniform shade or the very young stands with small trees that do not project any noticeable shadows. So, using gradient analysis, an image is created that highlights areas with a strong directional component in a direction commensurable with that of the sun's direction. That image is later thresholded and the resulting mask used as guide to switch between the two modes.

After individual trees are properly detected, information such as stem density, average tree spacing and stocking can be easily obtained for any given forest stand. Since the prescribed stocking is usually known, areas of under and over stocking can be highlighted. If for some reason, the prescribed stocking was unknown to the image analyst, areas that diverge from the average tree density could be highlighted. Similarly, if stands were not known *a priori*, it is possible to get reasonable automatic stand boundaries based on factors such as stem densities (Gougeon, 1997). Stand outline polygons and the information about their content could then be transferred to a forest inventory residing on a geographic information system.

RESULTS AND DISCUSSION

The individual trees identified by applying the original technique to the 30 cm/pixel Sturgeon Plantation image (Fig.1) are showed in Figure 3. This technique is known to work reasonably well with medium resolution (1-3 m/pixel) images of mature coniferous stands (Gougeon and Moore, 1989). Here, it performs well on the dense stands where trees are surrounded by shade, but a lot of false positives are visible on the grassy background in the more open stands. The roads and other completely open areas also produce numerous false positives.

Figure 4 shows the individual trees identified by applying the above technique modified to look for an area of shade at a specific distance and direction (based on sun angle) from any potential tree top. The improvement for open stands is dramatic, leaving very few false positives. Although lacking specific shadows, the dense stands are also relatively well assessed. Indeed, because of the simple way in which shadows are detected, the shade found all around these trees registers in a similar way as a specific shadow. However, good assessments of very young stands (< 3 years old), where trees are not tall enough to create a sizeable specific shadow, is lost. For our specific image acquisition (spatial resolution, sun elevation, plantation type, etc.), the critical detection age appears to be four years old. For these trees, individual shadows are generally detected, except when on very bright background material. Stands of younger trees could benefit more from using the original technique.

The directionality-related mask used to switch between the two modes in the hybrid approach is shown in Figure 5. It was obtained by running a 3x3 gradient operator on the near infra-red image and producing an intermediate image that highlights areas with a strong directional component in a direction commensurable with that of the sun's direction. That image was later thresholded and the resulting mask used as a guide to switch between the two modes. The mask corresponds well with the open stands that have trees with distinctive shadows. It is even sensitive to the shadows of the leafless larch trees that have low visibility in the pseudo-colour infrared MEIS-II image shown in Figure 1.

Figure 6 shows the individual trees identified with the new hybrid approach. It permits a reasonable assessment of all the stands, whether very young, or more mature, in dense or open arrangements. Due to the mask's imperfections, a few false positives were reintroduced in the open stands. Areas devoid of trees also generate considerable false positives. However, it is often possible to mask out these areas *a priori* with a little preprocessing or based on auxiliary information, as was done here by manually delineating a mask for the roads.

ON-GOING WORK

These visually encouraging results need to be verified in a more quantitative manner and for repeatability. The area under scrutiny and several other areas have been the subject of a comparison between ground counts and photointerpretation counts done on aerial photographs and on MEIS-II images at different spatial resolutions (Brand *et al*., 1991). A quantitative comparison with this new locally adaptive approach is in the works. Also, since one MEIS-II image was acquired in August (*vs.* November here), it may be possible to assess the significance of image acquisition in late autumn.

Use of individual tree crown techniques developed for mature forests (Gougeon 1995a, b, c) to assess the crown areas of the older regeneration is also the subject of on-going work. Detection difficulties are expected with the open stands with well illuminated background material (as seen in Gougeon 1996, Fig. 4b). If tree crown pixels can be identified adequately, species differentiation or tree health assessment should be explored.

CONCLUSION

Regeneration assessments are a crucial part of managing forests for sustainability. Potential gains in efficiency could be made if reliable assessments can be obtained from the automatic analysis of digital images. This work represents a first attempt at detecting individual trees in order to automatically evaluate regeneration density, spacing and stocking. The locally adaptive technique presented here permits the detection of young and older trees, in dense as well as open stands, with little false positives. The approach's apparent success needs to be quantified and tested for repeatability. This is the subject of ongoing work.

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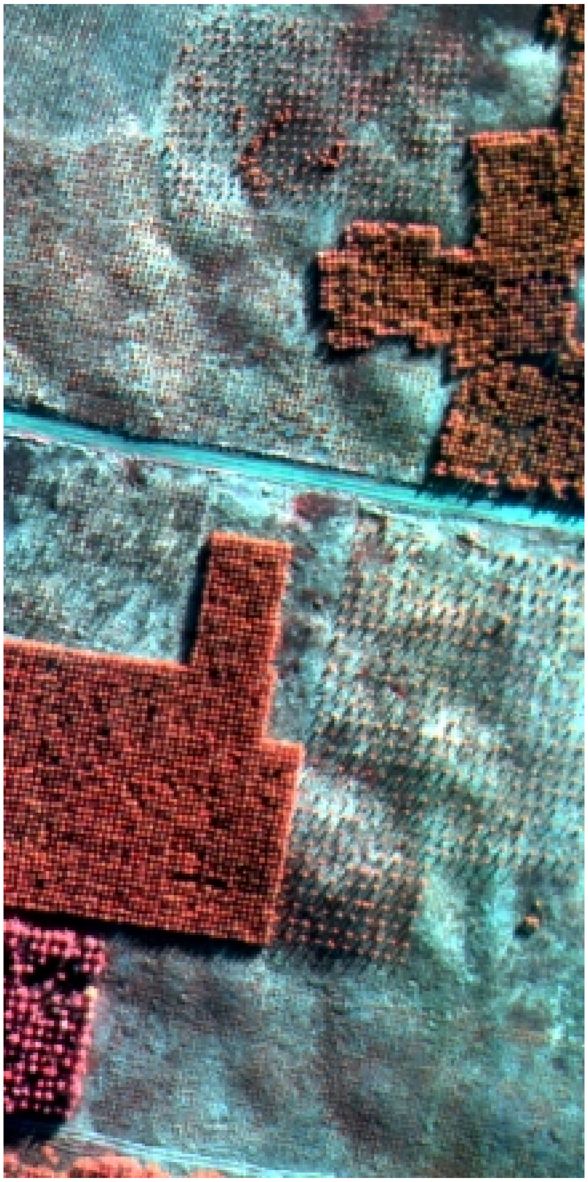


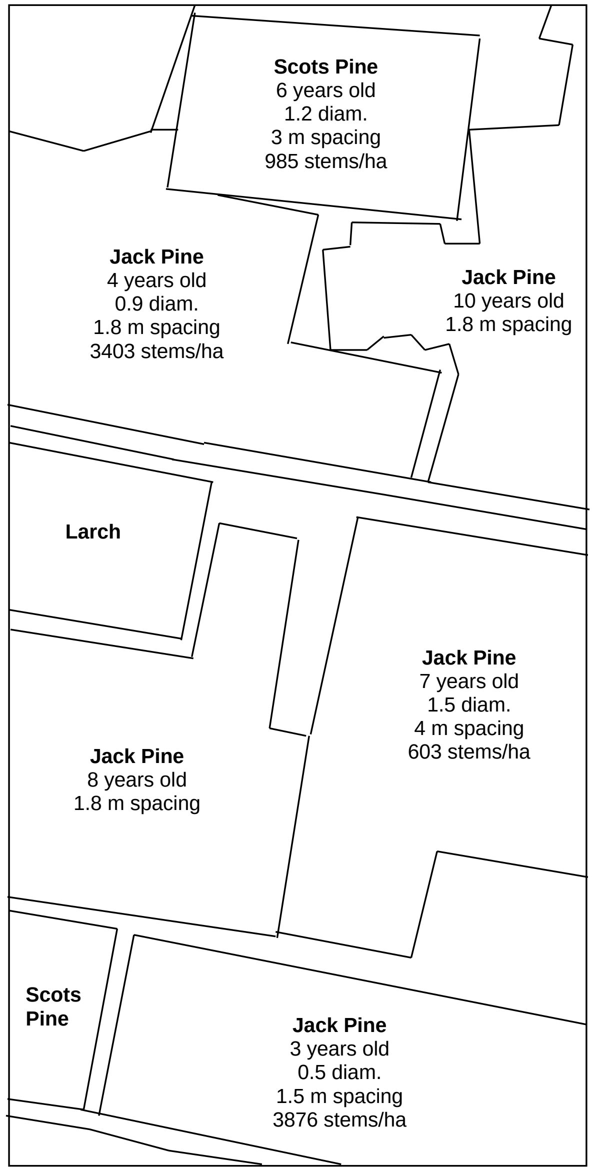
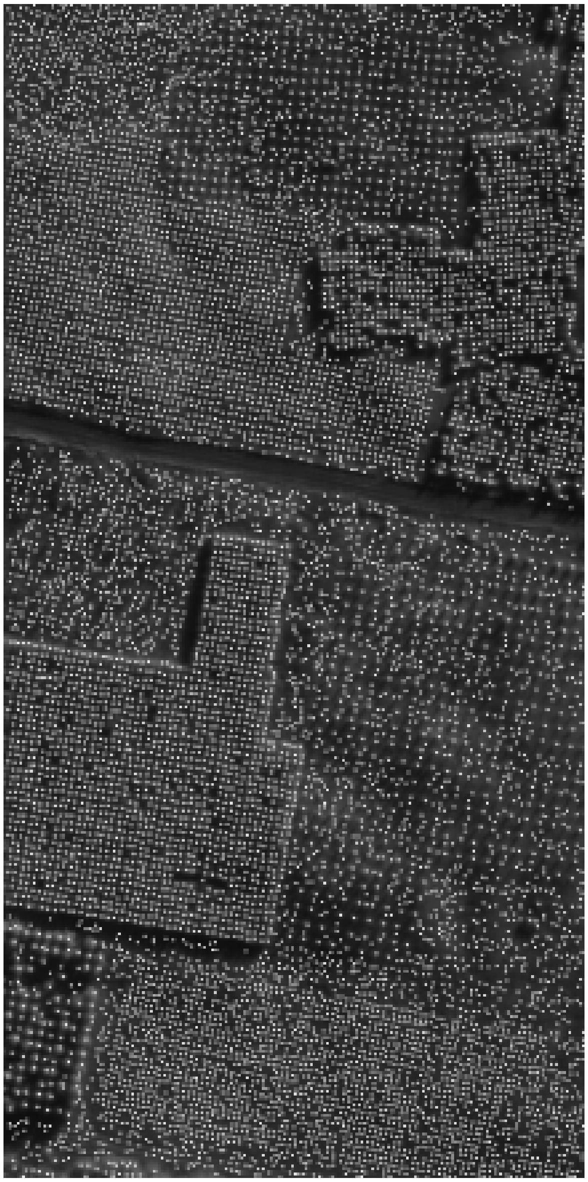


Fig. 1 (left) - Pseudo-colour infrared view of a MEIS-II image (30 cm/pixel) of the Sturgeon Plantation in the Petawawa Research Forest near Chalk River, Ontario.

Fig. 2 (right) - Characteristics of the regeneration stands in Figure 1.



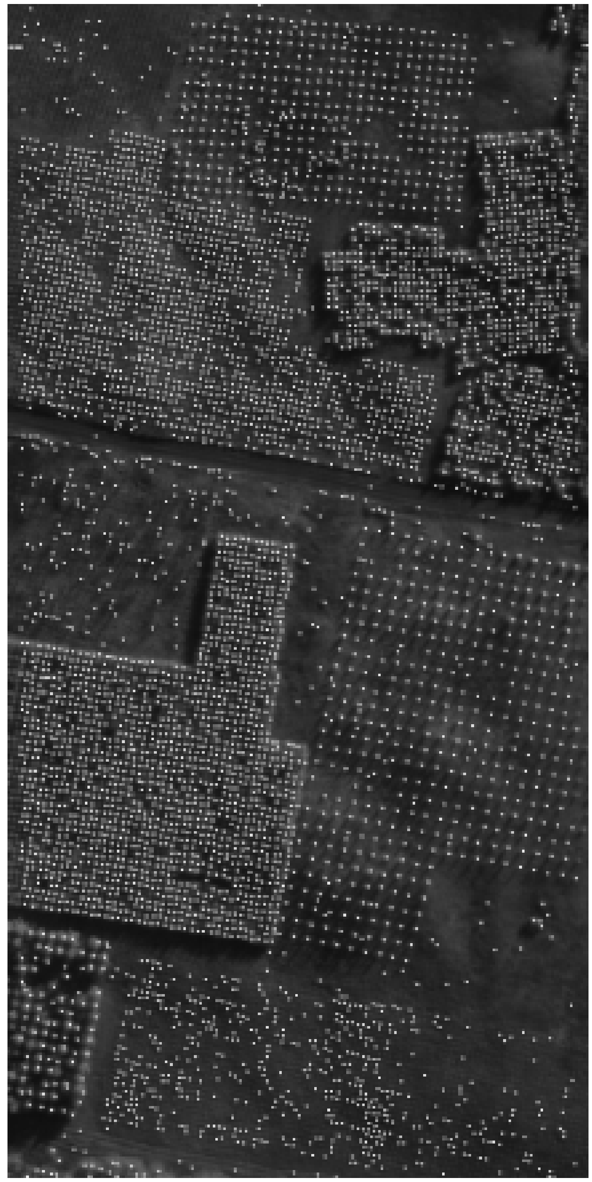


Fig. 3 (left) - Results from the original technique developed for dense mature stands in medium resolution images (1-3 m/pixel) and based on simply finding local maxima (Gougeon and Moore, 1989). As expected, it works well for dense stands, but produces numerous false positive in open stands.

Fig. 4 (right) - Results from the modified technique for which a shadow in a specific direction (commensurable with that of the sun's direction) has to be detected before the local maxima is considered to represent a tree. It is more appropriate for open stands, but still works well with most dense stands. It has difficulties with trees too small to produce any detectable shadow.

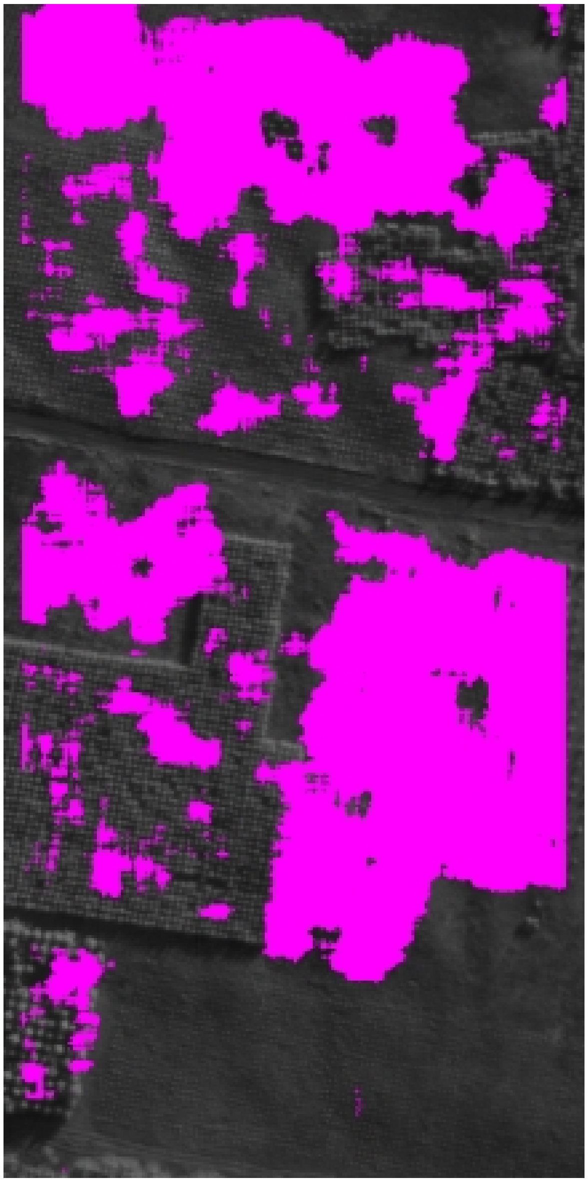
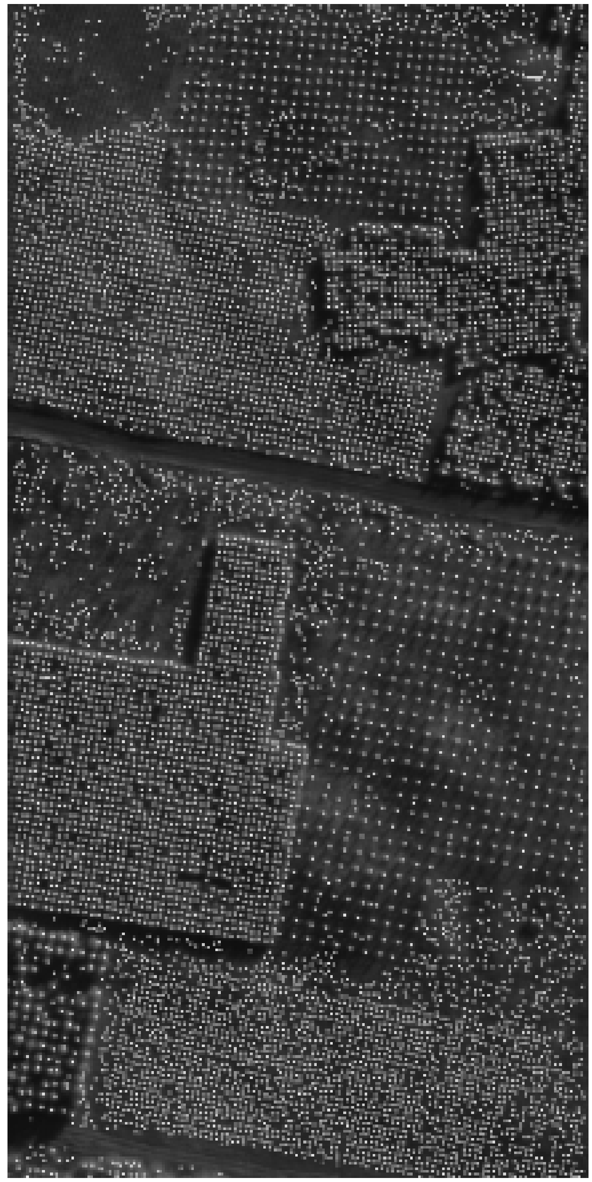
 

Fig. 5 (left) - The high directionality mask used in the hybrid approach to switch between the two (open and dense stands) techniques. It is based on gradient analysis and mask regions that have a high directional component in a direction commensurable with that of the sun's direction.

Fig. 6 (right) - Results from the hybrid locally adaptive approach which can deal with most open and dense stands. Non-forested areas could have been masked out. It should permit good assessments of stand densities, stocking, and spacing.