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Detection of The Pine Trees Damaged by Pine Wilt Disease using High Resolution Satellite and Airborne Optical Imagery

Seung-Ho Lee*†, Hyun-Kook Cho*, and Woo-Kyun Lee**

*Remote Sensing Laboratory, Korea Forest Research Institute

**Division of Environmental Science and Ecological Engineering, Korea University

Abstract : Since 1988, pine wilt disease has spread over rapidly in Korea. It is not easy to detect the damaged pine trees by pine wilt disease from conventional remote sensing skills. Thus, many possibilities were investigated to detect the damaged pines using various kinds of remote sensing data including high spatial resolution satellite image of 2000/2003 IKONOS and 2005 QuickBird, aerial photos, and digital airborne data, too. Time series of B&W aerial photos at the scale of 1:6,000 were used to validate the results. A local maximum filtering was adapted to determine whether the damaged pines could be detected or not at the tree level from high resolution satellite images, and to locate the damaged trees. Several enhancement methods such as NDVI and image transformations were examined to find out the optimal detection method. Considering the mean crown radius of pine trees, local maximum filter with 3 pixels in radius was adapted to detect the damaged trees on IKONOS image. CIR images of 50 cm resolution were taken by PKNU-3 (REDLAKE MS4000) sensor. The simulated CIR images with resolutions of 1 m, 2 m, and 4 m were generated to test the possibility of tree detection both in a stereo and a single mode. In conclusion, in order to detect the pine tree damaged by pine wilt disease at a tree level from satellite image, a spatial resolution might be less than 1 m in a single mode and/or 1 m in a stereo mode.

Key Words : Pine Wilt Disease, Detection, Local Maximum Filter, High Spatial Resolution Satellite Image, PKNU Digital Airborne Data.

1. Introduction

Both red pine (*Pinus densiflora*) and black pine (*Pinus thunbergii*) are dominant tree species, and cover ca. 30% of whole forest area in Korea. But nowadays area of pine forest has been getting reduced due to the disease and insect attack.

In 1905 pine wilt disease had occurred at first and destroyed nearly all of the pine forest in Japan. In Korea pine wilt disease was observed at first in Busan City in 1988 (Enda, 1989). We presumed the pine wilt disease was migrated from Japan, because Busan is quite near to Japan and also the climate conditions are similar with Japan. In recent years pine wilt disease has spread over rapidly and the total infected area reached at 668,000 hectares in Korea (Korea Forest Service, 2005).

All the affected trees will be blighted to death

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† Corresponding Author: Seung-Ho Lee (frishlee@foa.go.kr)

within few months, and it is a serious threat to pine forest nowadays. Thus, to prevent the spreading of pine wilt disease in time it is very important to find out the damage front as early as possible. But conventional filed surveys for data collection are labour cost and time consuming works in a huge and rugged mountain area. And these field data are often inconsistent and unreliable due to surveyor's bias and the subjectivity of visual discrimination of damage status (Reich and Price, 1998).

Remote sensing data is often regarded as an useful information source for such purposes. However, the use of space-borne remote sensing data has been limited due to the relatively coarse spatial resolution. In fact, it is not easy to detect the damaged trees by pine wilt disease in low or medium resolution imagery, because in most cases the symptoms occurred in a tree level, not in a stand level instead. Recently, the new generation of high spatial resolution satellite image like IKONOS and QuickBird is expected to solve this kind of matter.

Therefore, the purposes of this study were 1) to determine whether the damaged pine trees could be detected at the tree level from the high spatial resolution satellite image, and 2) to find out the possibilities how to detect the pine trees damaged by pine wilt disease using multi-platform and multi-temporal remote sensing data including high spatial resolution satellite images, aerial photos, and digital airborne data. A further objective is aimed to build the simulated image to determine the optimal spatial resolution for detection of damaged pine tree, and to look into the feasibility of the planned KOMPSAT-2 MSC image with a spatial resolution of 1 m.

2. Materials and Methods

1) Pine Wilt Disease

The cause of pine wilt disease is infestation of pinewood nematode (*Bursaphelenchus xylopilus*). The nematodes are blocking the tracheid of pine tree and dropping the efficiency of plant metabolism, which leads the pine tree blight to death. The pinewood nematode is not able to migrate from tree to tree by itself. The main vector insect is a sawyer beetle (*Monochamus alternatus*). The sawyer beetle is infected with the pinewood nematode while it transforms from pupa to adult in the wood of the damaged pine tree. Once a beetle emerges and it flies to the healthy crown of pine tree for sufficient feeding. When the beetles are gnawing the new shoots, the nematodes invade into the wounds of the shoots. A beetle can holds about 270,000 worms of nematodes. They rapidly propagate to infest in the vascular tissues and in the sapwood. This disease attacks the individual tree, not the whole stand instead. Thus, once a pine tree is damaged, tree cutting follows as soon as possible to prevent the disease from spreading to neighbouring trees.

2) Study Site

The study site is located at Daebyun-ri, Gijang-gun, Busan, Korea (Fig. 1). Daebyun-ri is one of the

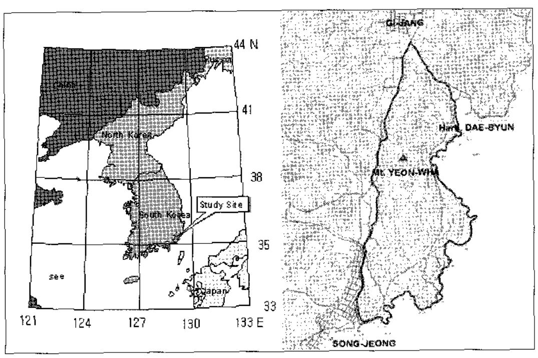

Fig. 1. Location map of study area.

infected areas by pine wilt disease since 1998. The areal extent of study area is approximately 805 hectares with a 6 km long and 2.5 km wide.

3) Satellite Images and Aerial Photographs

Considering the life cycle of sawyer beetle and control activities, date of imaging is very important to detect the damaged trees using satellite image. Thus the best time was assumed between November and January to obtain an image for this purpose. A pan-sharpened IKONOS Geo image obtained on January 13, 2000 and January 19, 2003, and QuickBird obtained on February 2, 2005 were used as high spatial resolution images (Fig. 2). Both IKONOS and QuickBird images have 4 spectral bands with 1 m and 0.6 m spatial resolution, respectively.

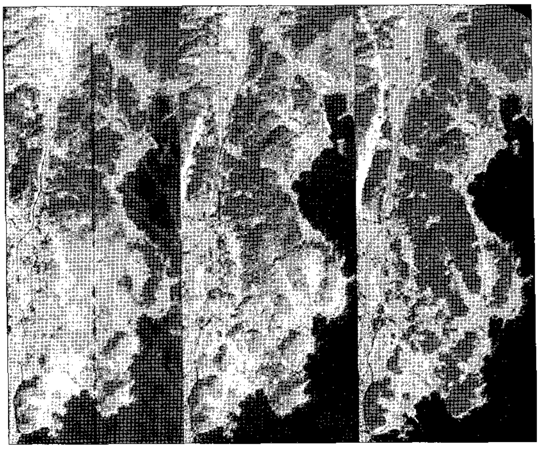

Fig. 2. IKONOS (2000, 2003), and QuickBird (2005) images (from left to right).

Table 1. Time series of aerial photographs.

Date of Imaging		Camera		Film	Qt.
		Model	Focal Length		
2001	May	Jena LMK 15/2323	152.23 mm	B&W	34
	Nov.	Wild 15/4 Nr. 13084	153.67	B&W	35
2002	May	ZEISS RMK A 15/23	152.59	B&W	30
	Nov.	WILD 15/4 UAGA-F	153.59	B&W	30
2003	June	ZEISS RMK A 15/23	152.77	B&W	29
	Nov.	WILD 15/4 UAGA-F	153.59	B&W	33
2004	May	ZEISS RMK A 15/23	152.63	Color	35
	Nov.	WILD 15/4 UAG-S	152.85	B&W	50

Time series of black & white aerial photos at the scale of 1:6,000 taken from 2001 to 2004 (Table 1) were used to develop the methodology to detect the damaged pines on high spatial resolution satellite image, and also to validate the results. The aerial photos were scanned by Ultrascan5000 with a resolution of 20 μm which corresponds to 12 cm at ground. Scanned aerial photos were oriented with aerial triangulation of bundle block adjustments, and were analysed through the digital photogrammetric system of Socet Set Version 5.2. (Fig. 3).

4) Algorithms for Individual Tree Detection

Not yet any research had been tried to locate the individual tree and to reveal the characteristics of it

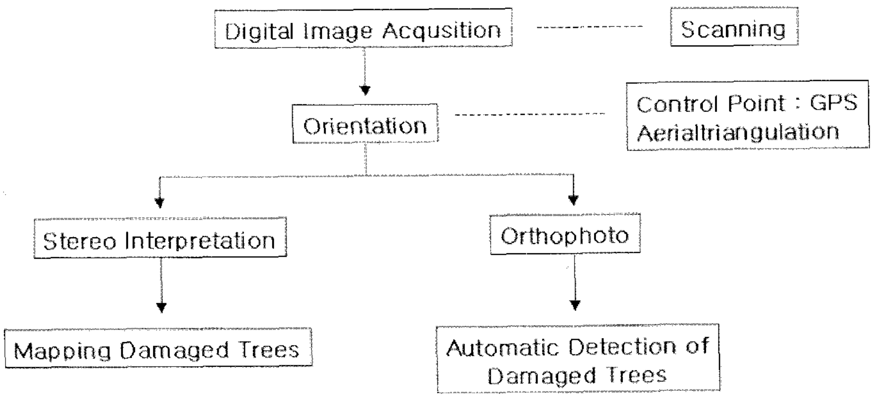

Fig. 3. Flowchart of aerial photo interpretation.

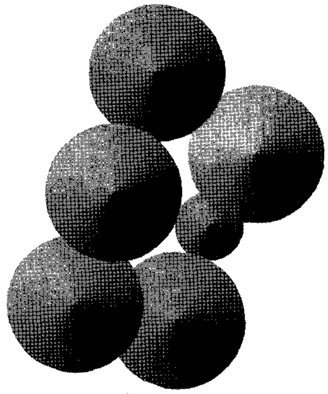

Fig. 4. Simulated crown model.

using high spatial resolution satellite image except aerial photo and airborne data. Thus, the methodologies developed from the previous studies using aerial photo and airborne imagery were reviewed whether they could be applied to high spatial resolution satellite image or not. To detect the individual damaged tree, the principles and characteristics how to take image of the individual tree crown must be understood as well as the classification properties as mentioned above. As the tree crown on sunny face appeared brighter compared with it on shadow part in common, crowns can be distinguished clearly from the others on high spatial resolution image. When drawing the crown profile based on the pixel values of the image, as the tree crown often has a highest value and looks bright, it looks like a conical shape or mountain terrain. On the other hand it becomes darker near the margin of tree crown and seems to be a valley. In most cases, shadow part includes the ground surface, undergrowing vegetation and a portion of crown and so on. Moreover, crown apex appears much brighter than the other part of the crown. Fig. 4 shows the simulated crown model visualized at a relief-shaded map. Individual trees may be detected on high spatial resolution imagery as regions of high reflectance. At present, detection and delineation algorithms are based on two distinct spectral properties of tree crown: 1) the association of a tree apex with a local maximum brightness value, and 2) delineation of the crown boundary by local minimum brightness value.

(1) Local Minimum Filtering

Gougeon (1998) developed the local minimum filtering to detect the darkest pixel with a low value between two neighboring crowns, and utilized the forest area only after discriminating the forest and non-forest using automated or semi-automated classification techniques in a pre-processing step. Generally image has various types of noises and in most cases they degraded the quality of both image and outputs. Therefore, these noises were removed by low pass filtering and the large shadow existed in the forest was eliminated by introducing the appropriate threshold value. But even though the local minimum filtering used for preprocessing or entire step may not separate every crown or crown clusters. In this case it would be preferable to use various kinds of rule-based algorithms to isolate the tree crown.

(2) Local Maximum Filtering

Wulder *et al.* (2000) investigated the use of local maximum filtering to locate the trees on MEIS-II high spatial resolution imagery. As mentioned above, the pixel with the local maximum value was considered as a crown apex, because the brightest one located on the crown apex and/or near the crown center. The local maximum filtering was introduced to find out the brightest pixel within the window with variable size of pixels. The resultant image enhanced by filtering depends on the image spatial resolution and a window size, too. Basically the pixel size of the image must be smaller than the average crown diameter. If the selected window was too large and crown clusters existed in a window, missing trees occurred. On the contrary if the window size was too small, too many crowns appeared in a window due to multiple radiance peaks for an individual tree crown (Wulder *et al*, 2000). Thus, local maximum value detected in the small window does not always represent the actual crown apex.

3. Results and Discussion

1) Detection of Damaged Trees from Scanned Aerial Photos

Visually, the spectral crown structure is analogous to that of an upward pointing cone or mountainous shape when viewed in three dimensions (Fig. 5). To detect the tree apex the local maximum filter with 10 pixels in radius corresponding to ca. 2.5 m in diameter was adopted, because the mean crown diameter of the pine trees growing in the study site was 3 m approximately. The difference of 0.5 m is regarded as shadow among tree crowns.

In local maximum filtering, a moving window was passed over all pixels in an image to determine the tree location, if a given pixel had a higher reflectance than all the others within the window. Pixels identified as the highest digital number within the window were assigned as tree locations. As the damaged trees appeared brighter than healthy trees in black & white aerial photographs, threshold value was used to separate the damaged trees from healthy ones.

2) Detection of Damaged Trees from IKONOS Image

Considering the spatial resolution of IKONOS and the mean crown radius of pines, local maximum filter with a window size of 3×3 pixels was used to eliminate the unusual pixel values in the image.

From Fig. 6, the spectral profile indicates that only the band 4 can separate the damaged (red) and healthy (green) trees. Therefore, band 4 was used for threshold operation. But it was still difficult to separate the damaged trees from healthy ones. The main reason perhaps relied largely on mixed pixels among the tree crowns. In addition, 1 m spatial resolution is perhaps too coarse to separate the tree crown in a dense forest composed with small tree crowns.

To predict the spreading pattern of pine wilt disease over time multitemporal satellite images were orthorectified and coregistered. The 2000 IKONOS image was rectified using RPC and DEM data, whereas 2003 image without own RPC data was rectified using the RPC derived from GCPs, which were selected from orthorectified 2000 image. The total RMSE of these coregistered images was 1.8 m.

QuickBird image had a RPC metadata, too. To compare the accuracy of ortho-rectification between 2003 IKONOS and 2005 QuickBird image, 20 ground control points were selected independently from both images. The RMSE of horizontal (X) direction was 2.99 m, 5.07 m in vertical (Y) direction, and total RMSE was 4.16 m. However, over mountain region RMSE was 7 m in X and 15 m in Y direction. This RMSE were too high due to image displacement caused by the difference of viewing angles and altitudes of satellites. The RMSE were too high to detect the damaged pine trees from the multitemporal high resolution images.

Even though, all the images were geometrically corrected well, considering the spectral properties of single date image, detection of pine trees affected by pine wilt disease from IKONOS image was still behind of expectation yet. Each IKONOS image had a different viewing angle and moreover 2000 image had a radiometric noise caused by cloud and haze. 1 m spatial resolution may not be enough to detect the individual trees with small crowns in a dense forest.

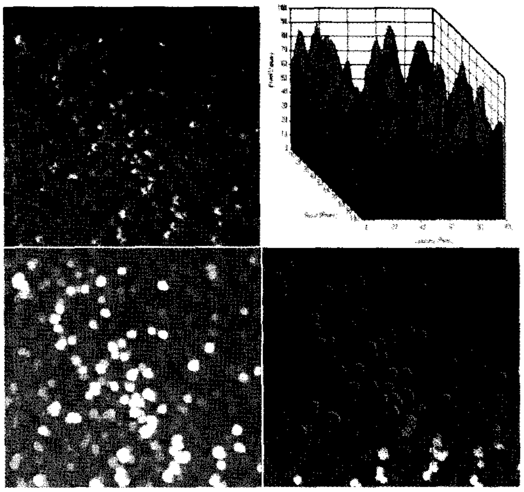

Fig. 5. The original photo (upper left), crown profile of pine stand (upper right), the result of local maximum filtering (lower left) and damaged trees detected by threshold (lower right).

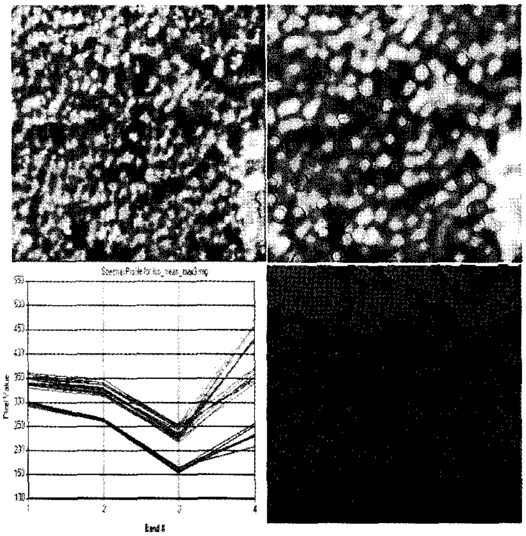

Fig. 6. Original image (upper left), Local Maximum (upper right), the spectral profile (lower left), separation of damaged trees (lower right).

Thus, as post-classification comparison method could not be applied to change detection, several image transformations such as NDVI, Tasseled Cap Transformation, RGB Clustering, Principal Component Analysis were introduced to enhance the image interpretation effects (Fig. 7). Nevertheless, there were no any advantages for detection of

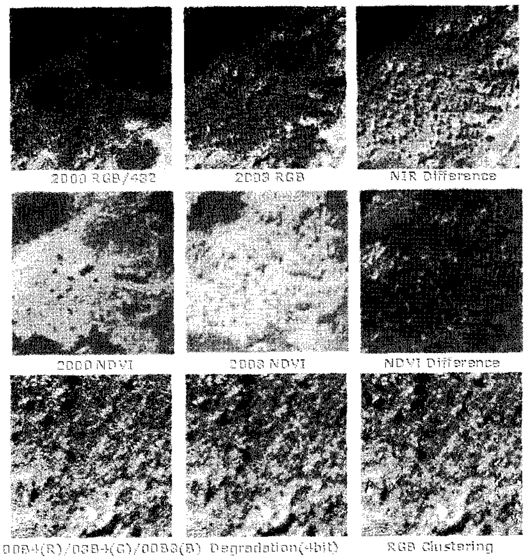

Fig. 7. Image enhancements applied to IKONOS images.

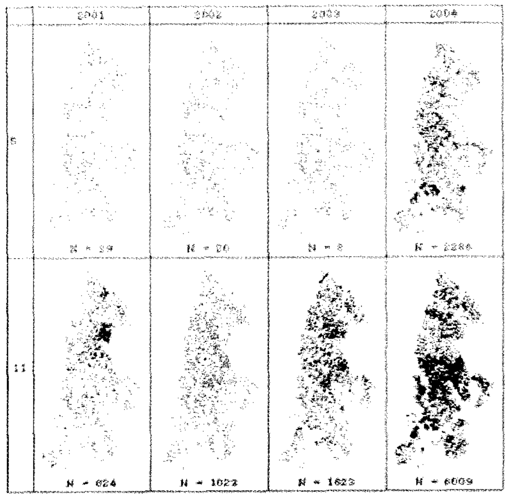

Fig. 8. Damaged pine trees interpreted from aerial photos.

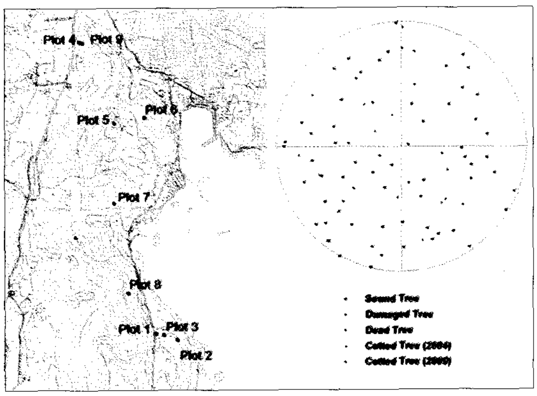

Fig. 9. Field plots layout.

damaged pine trees in Pan Sharpened IKONOS Geo Image.

3) Damaged Pine Trees from Time Series Aerial Photographs

Through photo-interpretation in a stereo mode, the distribution map of damaged pine trees were produced using time series of aerial photos (Fig. 8). As damaged trees by pine wilt disease generally appear much lighter in tone than do healthy ones, dead trees can be clearly discriminated from aerial photographs (Fig. 10).

Less than 30 dead pine trees were detected in May from 2001 to 2003, on the other hand in November these were rapidly increased. In most cases, in order to prevent the infection to neighbouring trees nearly all of the dead and/or infected trees were removed from November to middle of coming May. Thus, number of damaged trees were much lower in May rather than in November. However, damaged trees were detected as much as 2,286 in May 2004 due to the insufficient control efforts, which might lead to 6,009 dead trees in November 2004. Despite of such efforts, without proper and complete control activities the damaged pine trees were tremendously increased year by year.

4) Field Measurements and Accuracy Evaluation

In order to get a reference data for accuracy evaluation, tree positions were measured precisely using Total Station, Range Finder and DGPS equipments. The measurements were carried out on 0.1 ha size circular plot (Fig. 9).

The 9 plots were selected randomly in natural pine forest regarding stand density. All trees with larger than 6 cm in diameter at breast height were measured and recorded with its status such as healthy, infected, dead and cut tree and so on. Table 2 shows the measurements from field survey. Stand density of all plots was ranged from 400 to 1,210 trees per hectare. 27.3% of pine trees were revealed as damaged trees.

As shown in Table 3, from 9 plots 365 trees were identified through aerial photo interpretation, whereas the total number of standing trees was 598 in the field. Generally interpretation results give an underestimation in aerial photos rather than in field measurements. There are many reasons to cause such an underestimation. This largely depends on both the characteristics of forest stand structure and aerial photo, either. Comparing with field measurements, ca. 61% of standing trees were identified in aerial photos. Many difficulties occurred in a dense natural pine forest. Pine stands growing in the study area

Table 2. Field measurements from Total Station equipment.

Plot	Healthy Trees	Infected Trees	Dead Trees	Cut ('04)	Cut ('05)	Others	Trees /ha	Ratio (%)
1	54	7	43	2			1,060	49.1
2	59		2	11	13		850	30.6
3	54		7				610	11.5
4	45	1	1	3	9		590	23.7
5	30		1	3	5	1	400	23.1
6	39		2	8	10	1	600	33.9
7	44		2	8	5		590	25.4
8	33			11	15	2	610	44.1
9	110	2	5			4	1,210	6.0
Sum	468	10	63	46	57	8	724	27.3

Table 3. Accuracy comparison of photo-interpretation with field measurements.

plot	Photo Interpretation						Filed Survey		
	Healthy Trees		Damaged Trees		Total		Healthy Trees	Damaged Trees	Total
	No.	%	N	%	Nr.	%	Nr.	Nr.	Nr.
1	53	86.9	20	46.5	73	70.2	61	43	104
2	56	94.9	10	66.7	66	89.2	59	15	74
3	35	64.8	12	171.4	47	77.0	54	7	61
4	26	56.5	10	100.0	36	64.3	46	10	56
5	28	93.3	3	50.0	31	86.1	30	6	36
6	26	66.7	5	41.7	31	60.8	39	12	51
7	14	31.8	5	71.4	19	37.3	44	7	51
8	14	42.4	7	46.7	21	43.8	33	15	48
9	40	35.7	1	20.0	41	35.0	112	5	117
Sum	292	61.1	73	60.8	365	61.0	478	120	598

were so dense, and composed with small and big trees. Thus a small tree located among and/or under the big trees may not be found in aerial photos.

In a case, pine trees are growing so close, neighbouring 2 or 3 trees clump into one tree to form a big crown (Fig. 10). This is one of the well-known problems in aerial photographs. In addition to them, most of the pine trees have bending stems with irregular crown shapes, and they were leaning away from the upright positions. Therefore, it is very difficult to locate the exact tree position on the aerial photos due to the skewing of the top and bottom of the tree. Moreover, time span between date of imaging and field survey may bring about such a difference, too.

5) Detection of Damaged Pine Trees from QuickBird Image

In Fig. 11 considering the resolving power of multiplatform images having different spatial resolutions each other, the damaged pine trees can be detected well visually from QuickBird, digital CIR of PKNU3, and B&W aerial photo.

In order to evaluate the detection accuracy from QuickBird image 3 sample plots which were previously used to test the photo interpretation results were visually analyzed (Fig. 12). Comparing with field measurements more than 90% of healthy trees and 65% of damaged trees were detected from 3 sample plots.

6) PKNU3 Multispectral Airborne Data

The PKNU3 is a small size of airborne photographing system developed by the Pukyong National University. The PKNU3 consists of a multi-spectral camera (REDLAKE MS4000 Duncantech) and a thermal infrared camera (Raytheon IRPro). The REDLAKE MS4000 can produce RGB and CIR images of 1600 × 1200 pixels with a resolution of 7.4 μm. Images were taken at January 12, 2005 by PKNU3 onboard KA32T helicopter. The average flying altitude was 1,000 m above sea level, and the image has a GSD of 50 cm. Image has a 60% end-lap and 30% side-lap for stereo analysis. The images were oriented with Leica Photogrammetry Suite (LPS). As being different from frame camera digital image has no fiducial marks, all the parameters for the inner orientation were fixed. Parameters used in orientation were taken from the result of Lee and Choi (2004), the developer of PKNU systems.

After image orientation an orthophoto with a spatial resolution of 50 cm was produced. With cubic

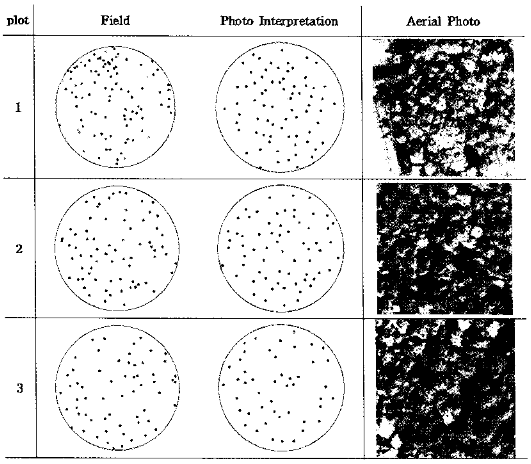

Fig. 10. Evaluation of photo-interpretation of damaged pine trees.

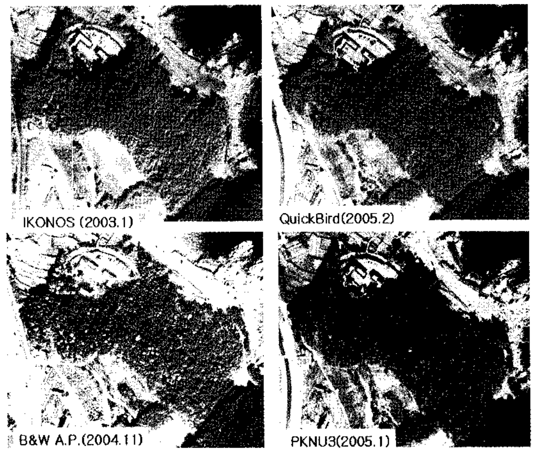

Fig. 11. Comparison of detection efficiency by spatial resolution of multiplatform imagery.

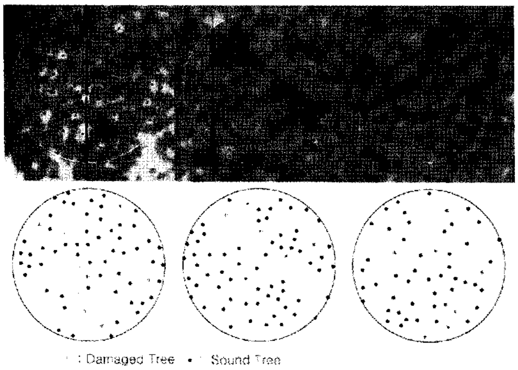

Fig. 12. Visual interpretation of damaged trees from QuickBird image.

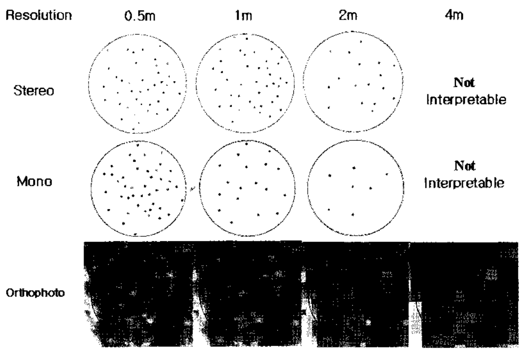

Fig. 13. Trees identification in stereo and orhtophoto with varying spatial resolution (Plot 2).

convolution method the original images were resampled at a spatial resolution of 1 m, 2 m, and 4 m, respectively, and also oriented for stereo interpretation. The visual interpretation was carried out in stereo and mono mode (Fig. 13). All trees within the plot were recorded with the attributes of damage status. Damaged trees appeared more or less in lighter tone, whereas the healthy trees appeared in bright reddish color on a CIR image. Generally the damaged trees were identified clearly on CIR image with 50 cm resolution.

Table 4 shows the interpretation results. In case of 50 cm spatial resolution, it showed a similar result of identification in both stereo and mono mode. However, comparing with field measurement ca. 50% of trees were identified. This result largely depends on the stand characteristics as mentioned above. With a spatial resolution of 1 m, they showed quite different result between stereo and orthophoto interpretation. The stereo interpretation showed similar results in both 0.5 m (total 104 trees) and 1 m (total 99 trees) spatial resolution image. However, the number of identified trees was reduced from 105 to 52 in orthophoto interpretation. This indicates that interpretation with stereoscopic view has a great advantage in 1 m resolution image.

The image with a 2 m spatial resolution makes it

Table 4. Identification of individual trees in stereo and single mode by various spatial resolution images (Unit: Number of Trees).

Plot	Status	Field Survey	Stereo			Ortho		
			0.5m	1m	2m	0.5m	1m	2m
1	Dead	50	15	14	5	11	5	3
	Healthy	54	26	27	12	32	13	4
2	Dead	15	7	5	3	4	3	2
	Healthy	59	32	28	8	34	12	7
3	Dead	7	1	1	1	1	1	1
	Healthy	54	23	24	9	23	18	7
Sum	Dead	72	23	20	9	16	9	6
	Healthy	167	81	79	29	89	43	18

difficult to recognize the individual tree crowns. Thus the capability to identify the individual tree becomes lower. This effect occurred in both stereo and mono mode. With the stereo mode only 36.5% of the entire trees interpreted in 0.5 m image were identified, and in orthophoto only 22.9% of the trees were detected compared with that of 0.5 m image. However, it was impossible to recognize the individual trees without any prior information in a 4 m spatial resolution image. Only the outline of crown shape could be vaguely recognised in the stereo modus. Thus visual interpretation was not performed to identify the individual trees in a 4 m image.

4. Conclusions

The local maximum filtering as the detection algorithm of pine trees damaged by pine wilt disease was applied to high spatial resolution satellite image. Considering the mean crown radius of pine trees local maximum filter with 3 pixels were adapted to detect the damaged pine trees on IKONOS image. But it was difficult to separate the damaged trees from healthy ones from IKONOS image. The main reason of such a result perhaps relied largely on mixed pixels among the tree crowns. In addition, 1 m spatial resolution of IKONOS image was too coarse to separate the tree crown in a dense forest composed with relatively small tree crowns. Moreover, the pan-sharpened DRA (dynamic range adjusted) applied image could also played a certain extent of role for this result, too.

From the point of view a single date of IKONOS image was not sufficient to detect the damaged pine trees. Thus several enhancement methods including NDVI, PCA, RGB Clustering were introduced to find out the optimal detection method and to enhance the visual interpretation. However, these efforts could not provide any merits for detection of damaged pine trees in Pan-Sharpened IKONOS Geo Image.

When dealing the multi-temporal high resolution satellite images it is very important to coregister the images each other with a high precision. But sometimes the IKONOS orbiting the same track shoot the images at different viewing angles, and images often have some radiometric noises caused by cloud and haze. Moreover, when registering IKONOS and QuickBird images, they showed a high RMSE mainly in mountainous terrain due to image displacement caused by different viewing angles of sensors and different altitudes of satellites. In this case it was no use of making the registration of these images, even though one image was orthorectified precisely.

Generally damaged trees by pine wilt disease appear much lighter in tone than do healthy ones. In fact, in a sense of qualitative interpretation standing trees whatever they may be damaged or healthy were identified clearly in large scale B&W aerial photos, digital airborne CIR image and QuickBird image. However, in a quantitative sense many difficulties occurred to detect the individual trees and to locate the exact tree positions. This led to underestimation for detection of damaged trees compared with field measurements. The comparisons with field measurements indicated that approximately 61% of standing trees were identified from 9 sample plots in aerial photos, and more than 90% of healthy trees and 65% of damaged trees were detected from 3 sample plots in QuickBird image.

There were many factors to influence the efficiency and accuracy of detection capability from high resolution images. These largely depend on both the characteristics of forest stand structure and aerial photo, either. Most of pine stands are so dense and the pine trees have bending stems with irregular crown shapes. For such reasons, it is very difficult to locate the exact tree position on the aerial photos due to the skewing of the top and bottom of the tree. In addition, both the accuracy of aerial photo orientation and transferring the sample plots onto the photos may bring about the errors, too. More often by removal of damaged trees missing trees occurred due to the discrepancy in date of imaging.

Finally, CIR images with a spatial resolution of 50 cm taken by PKNU-3 system were used to simulate the images with spatial resolutions of 1 m/2 m/4 m, and to find out the optimal size of spatial resolution. In order to evaluate the possibility of tree detection visual interpretation was performed both in a stereo and mono mode, and compared with field surveying data. With a spatial resolution of 1 m, they showed a quite different result between stereo and orthophoto interpretation. The lower the spatial resolution was, the lower the detection accuracy was. Therefore, in order to detect the pine trees damaged by pine wilt disease at a tree level, satellite image should have a spatial resolution of below 1 m in a single mode or 1 m in a stereo mode. Even though stereo images can improve the detection capacity, it is not easy to obtain the stereo images with a cheap price.

Still for better detection of pine wilt disease lots of problems remains unsolved as further researches. They may follow to detect the front area for effective control of the infected pine trees, and to develop the prediction model of spreading pattern, eventually. It needs also the feasibility test of the planned KOMPSAT-2 MSC image with a spatial resolution of 1 m for this purpose in the near future.

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