Detection of the pine trees damaged by pin wilt disease using multiplantform and multitemporal remote sensing data

DETECTION OF THE PINE TREES DAMAGED BY PINE WILT DISEASE USING MULTIPLATFORM AND MULTITEMPORAL REMOTE SENSING DATA

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ABSTRACT

The purpose of this study was to find out the possibilities how to detect well the pine trees damaged by pine wilt disease using multi-platform and multi-temporal remote sensing data including high spatial resolution satellite image of IKONOS and QuickBird, 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.

Time series of B&W aerial photos at the scale of 1:6,000 were used to develop the methodology to detect the damaged pine trees on high spatial resolution satellite image, and also to validate the results. A local maximum filtering was adapted to determine whether the damaged pine trees could be detected or not at the tree level using the high spatial resolution satellite image, and to locate the damaged pine trees. The L-Max filter with 10 pixels in radius was adapted to detect the tree apex.

Considering the life cycle of sawyer beetle and control activities, date of imaging is very important to detect the damaged trees using satellite image. A pan-sharpened IKONOS Geo image obtained at 2000 and 2003, and QuickBird obtained at 2005 were used as high spatial resolution images. Several enhancement methods, including vegetation index and digital image transformations, were examined to find out the optimal detection method. Considering the mean crown radius of pine trees L-Max filter with 3 pixels in radius was adapted to detect the damaged trees on IKONOS image. Color infrared images with a spatial resolution of 50cm were taken by PKNU-3 (RED-LAKE MS4000) camera system. From PKNU-3 image the simulated images with spatial resolutions of 1m, 2m, and 4m were generated to test the possibility of tree detection both in a stereo and a single mode. The test was performed with visual interpretation and compared with field surveying data. In conclusion, in order to detect the pine tree damaged by pine wilt disease at a tree level, satellite image should have a spatial resolution of less than 1m in a single mode or 1m in a stereo mode, either.

Key words: pine wilt disease, detection, high spatial satellite image, local maximum filter, PKNU digital airborne data, simulated image

INTRODUCTION

Both red pine (*Pinus densiflora)* and black pine (*Pinus thunbergii*) are the most favorite and dominant tree species in Korea (Bae, 2003). Pine forest covers ca. 30% of whole forest area in this country, but nowadays its area becomes smaller and smaller. One of the main causes influencing the decrease of pine forest is the disease and insect attack.

In 1905 pine wilt disease had occurred in Japan for the first time and destroyed nearly all of the pine forest in Japan. In Korea pine wilt disease was observed at first in Busan Metropolitan City in 1988, the second biggest city and the largest harbor for trading (Enda, 1989). We presumed that the pine wilt disease was migrated from Japan, because Busan city is quite near from Japan, and also the climate and site conditions were similar with them of the infected places in Japan. In recent years pine wilt disease spread rapidly over in Korean peninsula and the total infected area reached at 668,000 hectares (KFS, Oct. 2005). It is called as "AIDS of Pine", because all of the affected trees will be blighted to death within few months. Nowadays it is a serious threat to pine forest.

Thus, to prevent the spreading of pine wilt disease in time it is very important to find out the damage front as possible as in early stage. But conventional ground surveys for data collection are labor cost and time consuming in a relatively huge and rugged mountain area. And the results of these surveys 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 a useful information source for such purposes. However, the use of space-borne remote sensing data has been limited by the relatively coarse spatial resolution. Up to now, forest managers have paid a little attention to the satellite data and still they have used aerial photographs solely and field survey in case of necessity. In fact, it is not easy to detect the damaged area by pine wilt disease in low and/or medium resolution imagery, because in most cases the symptoms occurred in a tree level, not in a stand level instead.

The new generation of high spatial resolution satellite images like IKONOS and QuickBird is expected to overcome this matter, since the spatial resolutions are comparable with those of aerial photographs. Moreover it is also expected that the KOMPSAT-2 (Korean multipurpose satellite) MSC (Multispectral Camera) image data will contribute to enhance the application of high spatial resolution satellite image.

Therefore, the purposes of this study were 1) to determine whether the pine trees damaged by pine wilt disease could be detected at the tree level using the high spatial resolution satellite image, and 2) to find out the possibilities how to well detect the pine trees damaged by pine wilt disease using multi-platform and multi-temporal remote sensing data including high spatial resolution satellite image of IKONOS and QuickBird, 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 1m.

MATERIALS AND METHODS

Pine Wilt Disease

The cause of pine wilt disease is infestation of pinewood nematode (*Bursaphelenchus xylopilus*).

The nematode is 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 on its own without any help. The main vector insect is sawyer beetle (*Monochamus alternatus*). The sawyer beetle is infected with the pinewood nematode while it transforms from the pupa to the adult in the wood of the damaged pine tree. Young pinewood nematodes enter into the spiracles of the adult. Once a beetle emerges and it flies to the healthy crown of pine tree for sufficient feeding from the new shoots of young branches. 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 pinewood nematodes. They rapidly propagate to infest in the vascular tissues and in the sapwood.

This disease attacks individual trees, 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 neighboring trees. Therefore date of imaging is very important to detect the damaged trees using satellite image.

Study Site

The study site is located at Daebyun-ri, Gijang-gun, Busan Metropolitan City, Korea (Figure 2). Daebyun-ri is one of the infected areas by the pine wilt disease since 1998. The areal extent of study area is approximately 805ha with a 6km long and 2.5km wide.

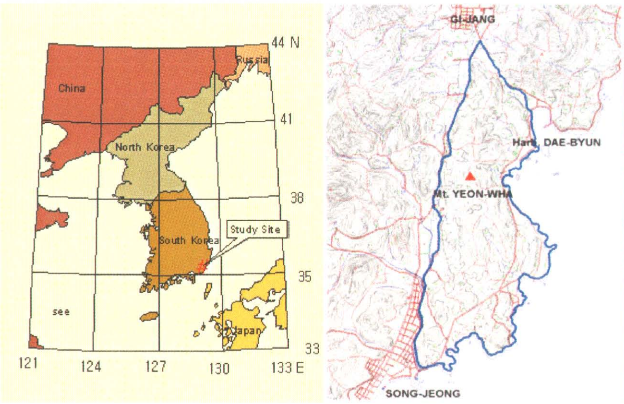

Figure 1. Location map of study area

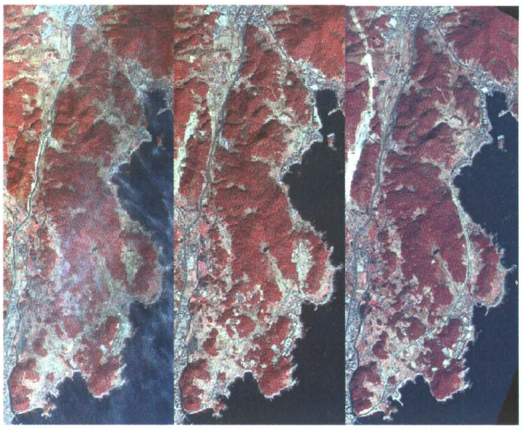

Figure 2. 2000(left) and 2003(center) IKONOS, 2005QuickBird (right)

Satellite Image and Aerial Photographs

Considering the life cycle of sawyer beetle and control activities, between November and January was assumed to be the best time 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 (Figure 2). Both IKONOS and QuickBird images have 4 spectral bands with 1m and 0.6m spatial resolution, respectively.

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

Table 1. Time series of aerial photographs

Date of Imaging		Camera		Film	Qt.
		Model	Focal Length		
2001	May	Jena LMK 15/2323	152.23mm	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

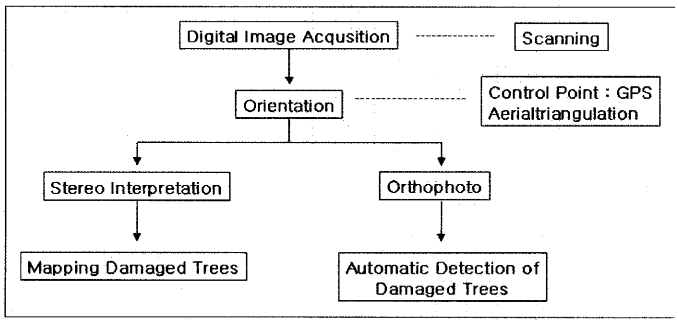

Figure 3. Flowchart of aerial photo interpretation

Algorithms for Individual Tree Detection

Not yet any research had been tried to locate the individual tree and to reveal the characteristics of it 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, under-growing vegetation and a portion of crown and so on. Moreover, crown apex appears much brighter than the other part of the crown. Figure 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.

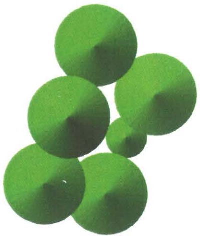

Figure 4. Simulated crown model

- Local Minimum Filtering

Gougeon (1998) developed the local minimum (L-Min) 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 preprocessing 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 L-Min 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.

- Local Maximum Filtering

Wulder *et al.* (2000) investigated the use of local maximum (L-Max) filtering to locate trees on high spatial resolution imagery (1m) obtained from Multi-Detector Electro-Optical Imaging Sensor (MEIS-II). 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. In this study L-Max filtering method was introduced to find out the brightest pixel within the window with variable size of pixels.

Walsworth and King (1998) tried to delineate the tree crowns using high-pass filter. For this the properties of the original image was enhanced to isolate the crown apex, and to locate the crown boundary an inverted image was generated by substituting the pixel with lowest value by 255 and the pixel with highest value by 0. 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, L-Max detected in the small window does not always represent the actual crown apex.

RESULTS AND DISCUSSION

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 (Figure 5). To detect the tree apex the L-Max filter with 10 pixels in radius corresponding to ca. 2.5m in diameter was adopted, because the mean crown diameter of the pine trees growing in the study site was 3m approximately. The difference of 0.5 m is regarded as shadow among tree crowns.

In L-Max 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.

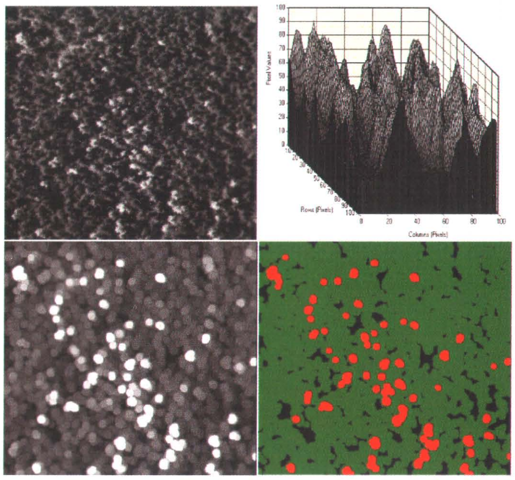

Figure 5. The original photo (upper left), crown profile of pine stand (upper right), the result of local maximum filtering (lower left) and damaged trees detected by threshold (lower right).

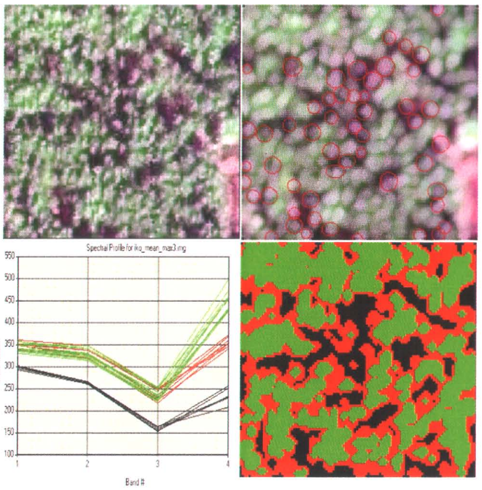

Figure 6. Original image (upper left), L_max (upper right), the spectral profile (lower left), separation of damaged trees(lower right)

Detection of Damaged Trees from IKONOS Image

In general as the spatial resolution is increasing, the internal radiometric variability within meaningful objects will be increased (Aplin *et al.*, 1999). Moreover, the high spatial resolution image needs a high accuracy of geometric correction based on rigorous sensor model and rational polynomial model, but actually it is very difficult to achieve the low RMSE of less than sub-pixel (Toutin and Cheng, 2000). The same methodology was applied to high spatial resolution satellite image of IKONOS. As the IKONOS image has 1m spatial resolution and considering the mean crown radius of pine trees, the window size was changed into 3×3 pixels. Also a focal mean filter was put into operation to eliminate the unusual pixel values in the image.

From Figure 6, the spectral profile indicates that only the band 4 can separate the damaged (red) and undamaged (green) healthy trees. The other bands may not distinguish the differences. Therefore, band 4 was used for threshold operation. But it was difficult to separate the damaged trees from healthy ones. 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 is perhaps too coarse to separate the tree crown in a dense forest composed with relatively small tree crowns. In addition, the pan-sharpened DRA (dynamic range adjusted) applied image by Space-Imaging was used, and it could also play a certain extent of role for this result, too.

Image Enhancement for Multitemporal and Multiplatform Imagery

To predict the spreading pattern of pine wilt disease over times multitemporal satellite images obtained from IKONOS and QuickBird were orthorectified and coregistered. The 2000 IKONOS image was rectified using RPC (Rational Polynomial Coefficient) and DEM (Dgital Elevation Model) data, whereas 2003 image that had no own RPC information was rectified with RPC derived from GCPs, which were selected from orthorectified 2000 image. The total RMSE of these coregistered images was 1.8m.

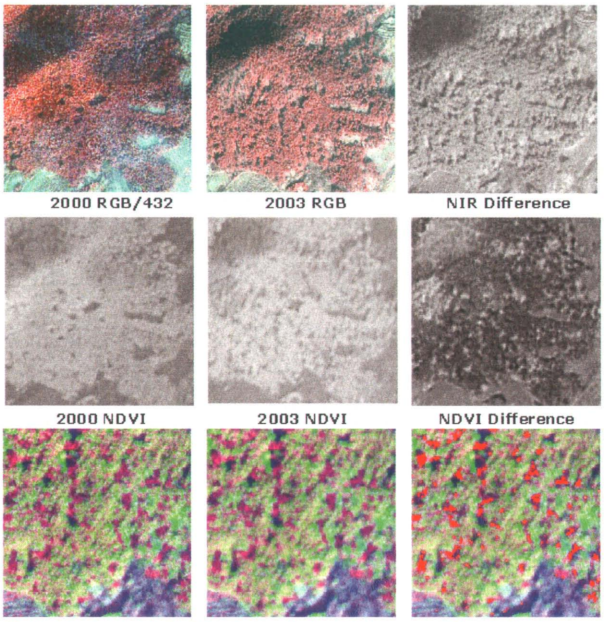
2000 RGB/432
2003 RGB
NIR Difference
2000 NDVI
2003 NDVI
NDVI Difference
00B4(R)/03B4(G)/00B3(B) Degradation(4bit)
RGB Clustering

Figure 7. Image enhancements applied to IKONOS images

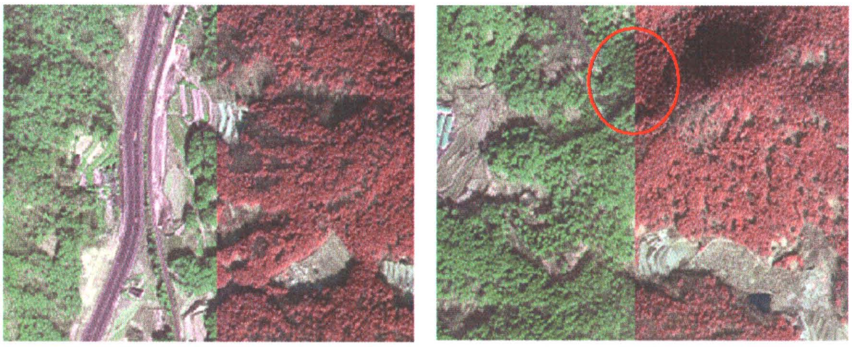
(a) plain terrain (b) mountainous terrain

Figure 8. Comparison of coregistration between QuickBird(left) and IKONOS(right) image

Even though, all the images were geometrically corrected well, considering the spectral properties of single date image, as mentioned above, 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. 1m spatial resolution may not be enough to detect the individual trees with small crowns in a dense forest. 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 (Figure 7). Nevertheless, there were no any merits for detection of damaged pine trees in PanSharpened IKONOS Geo Image.

QuickBird image has a RPC metadata, too. Comparing the accuracy of orthorectification between 2003 IKONOS and 2005 QuickBird image, in a flat terrain two images were matched well, whereas in hilly and mountainous terrains they showed a big mismatch due to image displacement caused by the difference of viewing angles and altitudes of satellites (Figure 8). To calculate the RMSE 20 ground control points were selected independently from both images. The RMSE of horizontal (X) direction was 2.99m, 5.07m in vertical (Y) direction, and total RMSE was 4.16m. However, over mountain region RMSE was 7m in X and 15m in Y direction. These RMSE were too big to detect the damaged pine trees from multitemporal high resolution images.

Damaged Pine Trees from Time Series Aerial Photographs

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 (Figure 5 and 11). Through photointerpretation in a stereo mode, the distribution map of damaged pine trees were produced using time series aerial photos (Figure 9). Roughly 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 next year. 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 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 trees were tremendously increased year by year.

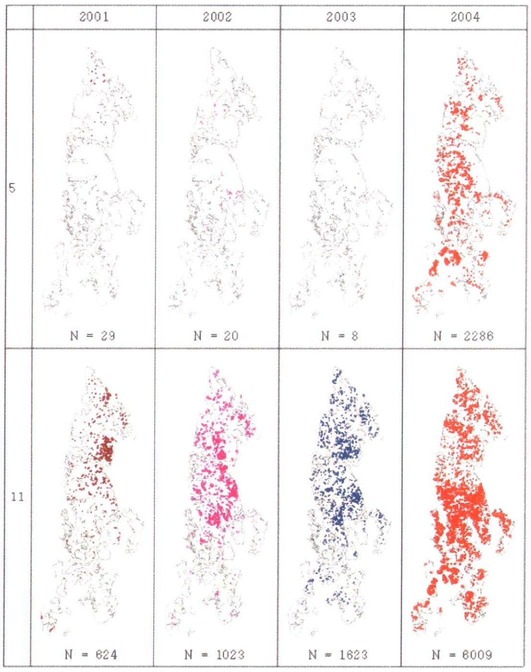

Figure 9. Damaged pine trees interpreted from time series aerial photos

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 0.1ha size circular plot (Figure 10). The 9 plots were selected randomly in natural pine forest regarding stand density. All trees with larger than 6cm at DBH 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. 28.3% of pine trees were revealed as damaged trees.

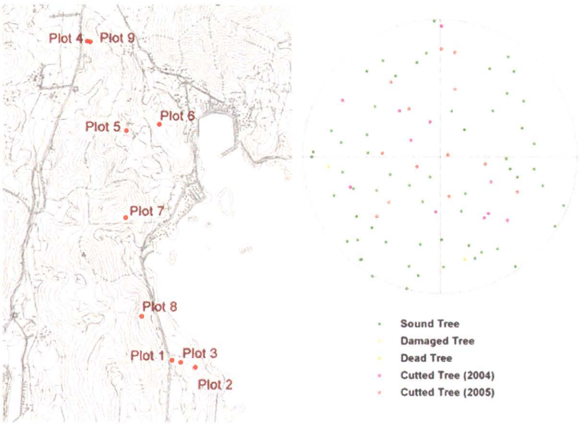

Figure 10. Field plots layout

Table 2. Field measurements from Total Station equipment

Plot	Heathy	Infected	Dead	Cut('04)	Cut('05)	Others	Trees/ha	Ratio(%)
1	54	7	43	2			1060	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	1210	6.0
Sum	468	10	63	50	62	8	734	28.3

Table 3. Accuracy comparison of photointerpretation with field measurements

	Photo Interpretation						Filed Survey		
	Healthy Trees		Damaged Trees		Total		Healthy Trees	Damaged Trees	Total
	Nr.	%	Nr.	%	Nr.	%			
1	53	86.9	20	46.5	73	70.2	61	43	104
2	56	96.6	10	66.7	66	90.4	58	15	73
3	35	59.3	12	120.0	47	68.1	59	10	69
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	335	65.4	79	63.7	414	65.1	512	124	636

As shown in Table 3, from 9 plots 414 trees were identified through aerial photo interpretation, whereas the total number of standing trees was 616 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 measurement, ca. 65.1% of standing trees were identified in aerial photos. Many difficulties occurred in a dense natural pine forest. Pine stands growing in the study area were so dense and composed with relatively small 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 (Figure 11). 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.

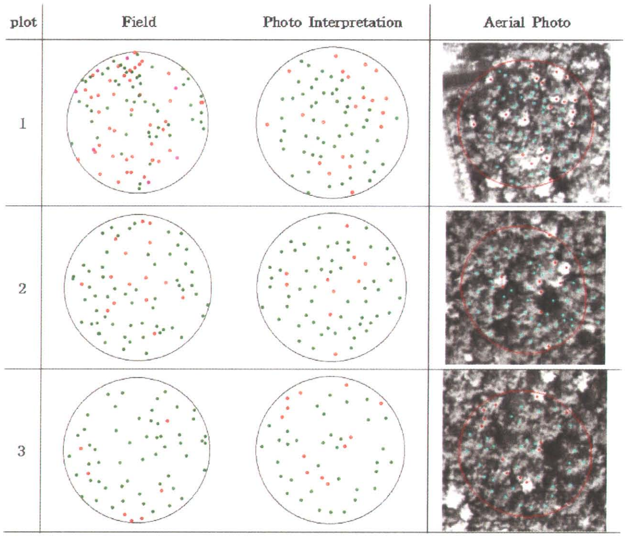

Figure 11. Evaluation of photo interpretation of damaged pine trees

- Detection of Damaged Pine Trees from QuickBird Image

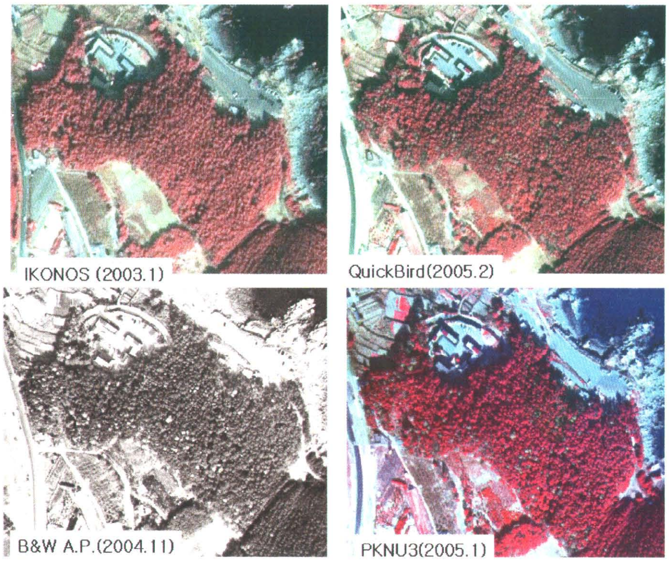

Figure 12. Comparison of detection efficiency by spatial resolution of multiplatform imagery

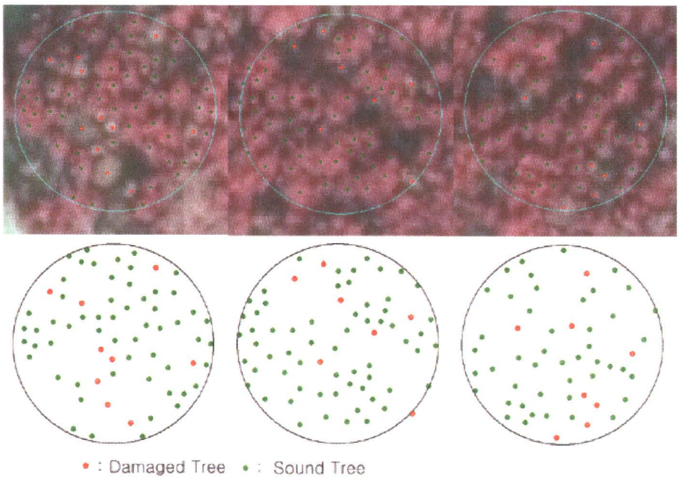

Figure 13. Visual interpretation of damaged trees from QuickBird image

In Figure 12 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 (Figure 13). Comparing with field measurements more than 90% of healthy trees and 65% of damaged trees were detected from 3 sample plots.

PKNU3 Multispectral Airborne Data

The PKNU3 is a small size 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 7.4μm. Images were taken at January 12, 2005 by PKNU3 onboard KA32T helicopter. The average flying altitude was 1,000m above sea level, and the image has a GSD of 50cm. 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 50cm was produced. With cubic convolution method the original images were resampled at a spatial resolution of 1m, 2m, and 4m, respectively, and also oriented for stereo interpretation. The visual interpretation was carried out in stereo and mono mode (Figure 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 red color on a CIR image. Generally the damaged trees were identified clearly on PKNU CIR image with 50cm resolution.

Table 2 shows the interpretation results. In case of 50cm 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 1m, they showed quite different result between stereo and orthophoto interpretation. The stereo interpretation showed similar results in both 0.5m (total 104 trees) and 1m (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 1m resolution image.

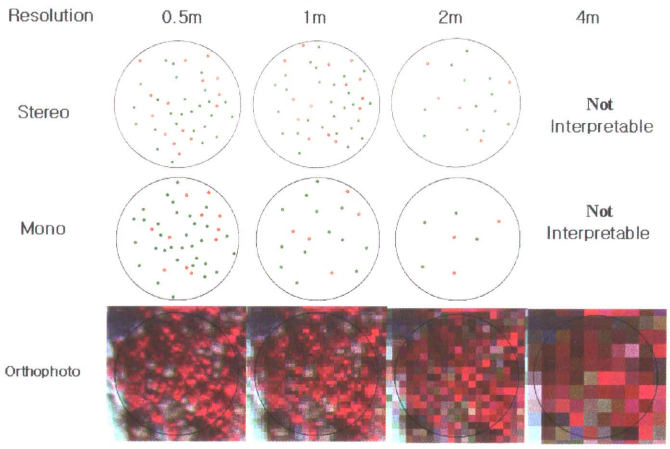

Figure 13. Trees identification in stereo and orhtophoto with varying spatial resolution (Plot 2)

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

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

The image with a 2m spatial resolution makes it difficult to recognize the individual tree crowns. Thus the capability to identify the individual tree becomes lower. This effect occurred in both stereo and orthophoto modus. With the stereo mode only 36.5% of the entire trees interpreted in 0.5m image were identified, and in orthophotos only 22.9% of the trees were detected compared with that of 0.5m image.

However, it was impossible to recognize the individual trees without any prior information in a 4m 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 4m image.

CONCLUSIONS

Multiplatform and multitemporal images with different spatial resolution were tested and evaluated to find out the possibilities of detection of pine trees damaged by pine wilt disease. We applied the local maximum filtering as the detection algorithm to high spatial resolution satellite image. Considering the mean crown radius of pine trees L-Max filter with 10 pixels in radius on aerial photos and 3 pixels were adapted to detect the damaged pine trees on IKONOS image.

Considering the spectral properties of IKONOS image, only the NIR band 4 could separate the damaged and healthy trees. But it was difficult to separate the damaged trees from healthy ones. 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 by Space-Imaging 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 multitemporal 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 big mismatch 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 Color IR 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 65% of standing trees were identified from 9 sample plots in aerial photos, and morethan 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. Pine stands are so dense and composed with relatively small trees. Thus neighbouring 2 or 3 trees clumped into one tree as if to form a big crown, and a small tree growing under the big trees may not be found in aerial photos. In addition, most of the pine trees have bending stems with irregular crown shapes, and they were leaning away from the upright positions. For this reason, 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, color infrared images with a spatial resolution of 50cm taken by PKNU-3 (REDLAKE MS4000) system were used to simulate the images with spatial resolutions of 1m/2m/4m, 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 a single mode, and compared with field surveying data. With a spatial resolution of 1m, 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 1m in a single mode or 1m in a stereo mode. Even though stereo images can improve the detection capacity, it is not easy to obtain the stereo images and they are so expensive, too.

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 1m for that purpose in the near future.

REFERENCES

Aplin, P., P. Atkinson, P. Curran (1999). Fine Spatial Resolution Simulated Satellite Sensor Imagery for Land Cover Mapping in the United Kingdom. Remote Sensing of Environment 68: 206-216.

Bae, J. S. (2003). A review of historical, cultural and economical values of pine tree, Proc. Symposium on Korean forum on forests for sustainable society. pp. 15-38.

Cho, N.C., C.U. Choi, S.W. Jeon and H.C. Jung (2004). Research for verification and calibration of Multi-spectral aerial photographing system (PKNU 3). Proceeding of ACRS 2004. CD-ROM.

Enda, N. (1989). The Status of Pine Wilting Disease Caused by Bursaphelenchus xylophilus (Steiner et. Buhrer) Nickle and Its Control in Korea. Jour. of Korean Forest Society 78(2): 248-253.

Gougeon, F. (1998). Automatic individual tree crown delineation using a valley-following algorithm and a rule-based system. Proceedings of the International forum on Automated interpretation of high spatial resolution digital imagery for forestry. Victoria, BC, Canada. pp. 11-23.

Korea Forest Service (2005). http//www.foa.go.kr

Lee E.K. and C.U. Choi (2004). Research for Calibration and Correction of Multi-Spectral Aerial Photographing System (PKNU 3). J. Korean Association of Geographic Information Studies. 7(4): 142-154.

Pouliot, D.A., D.J. King, F.W. Bell and D.G. Pitt (2002). Automated tree crown detection and delineation in high-resolution digital camera imagery of coniferous forest regeneration. Remote Sensing of Environment 82(2-3): 322-334.

Reich, R.W. and R. Price (1998). Detection and classification of forest damage caused by Tomentosus Root Rot using an airborne multispectral imager (CASI). Proceedings of the International forum on Automated interpretation of high spatial resolution digital imagery for forestry. Victoria, BC, Canada. pp. 179-185.

Toutin T. and P. Cheng (2000). Demystification of IKONOS! EOM 9(7): 17-21.

Wulder, M.A., K.O. Niemann and D.G. Goodenough (2000). Local Maximum Filtering for the Extraction of Tree Locations and basal Area from High Spatial Resolution Imagery. Remote Sensing of Environment 73: 103-114.