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Detecting and controlling forest damage area caused by insects and diseases with Remote Sensing, GIS and GPS 2001

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(Research Report of the APEC Project)

2001

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General Center for Forest Pest Control of Guangdong Province
General Center for Forest Pest Control of Zhejiang Province
General Center for Forest Pest Control of Liaoning Province

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Preface

There is currently much concern regarding recent anthropogenic effects on regional and global environments. Fossil fuel burning and tropical defoliation are largely responsible for dramatic year to year increases in atmospheric CO_2 and other greenhouse gas concentrations, and it is predicted that these increases will result in major global warming. Such a warming would differentially affect the vegetation in the various biomass but the types and magnitudes of these vegetation changes are currently open to speculation. Meanwhile, many of the forests in the world are undergoing serious decline. The damage or decline caused by forest diseases and insects is among the most serious forest hazards.

Remote sensing provides a means for obtaining regional and global perspectives on the status of the Earth's vegetation. It is generally assumed that remote sensing will play an important role in ascertaining the severity of forest change by forest diseases and insects on various forest communities, and will be important in monitoring any regional and global forest changes that might occur in response to global changes.

Geographic Information System (GIS) is a technical system which provides the functions supported by computer software and hardware to enter, store, update, inquire, manipulate, analyze, synthetically apply, display, map and output the data describing the real world. Therefore many users have taken GIS as important tools in forest management which can not only accomplish general data management, but also establish the professional model for growth, forecast, management and decision based on spatial attribute table and select the best management scheme through simulation, evaluation and comparison for all kinds of management process. If combined with GPS and RS technology, GIS can survey the forest resource dynamic change.

The more recent use of global positioning systems (GPS) offers the possibility of collecting, directly in the field and at reasonable cost, the exact coordinates of geographic positions. GPS now permits the establishment of a link between a map and a real, physical location on the Earth's surface, whether the location refers to an area, a moving object such as a plane, or a forest protection manager. The GPS + GIS + remote sensing combination thus permits flexible, effective, real-time management of forest resources at the landscape level.

Chinese government has been paying continuing attention to controlling the forest pest damages and spending much money in protecting our limited forest resources. Especially with the advanced development of remote sensing, GIS and GPS technology, many projects have been conducted to probe into effective monitoring method of forest pest damage. Our study has gained sound achievements, and we are sponsored by APEC to share results with other countries. The final objective is to protect our limited forest resources and earth environment, and to realize forest sustainable development.

Wu Honggan

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Chapter 1

Satellite Remote Sensing Monitoring Technology of Forest Damages Caused by Pine Caterpillars

On July 23, 1972, Landsat-1, originally named ERTS-1, was launched from Vandenburg Air Force Base in California. The launch of Landsat-1 was the beginning of a new era in monitoring the Earth's natural resources. Today, acquisition of resource data from Earth-orbiting satellites is commonplace. This chapter discusses the progress and feasibility of satellite imagery for monitoring and assessment of forest conditions, the characteristics of two satellites used for detecting forest health presently in orbit, and applications in forest health protection in China.

1. Spectral properties of vegetation and principle of monitoring forest damage with remote sensing

There is a typical reflectance curve for healthy vegetation. The absorption features centered at approximately 0.48 and 0.68 μm represent strong chlorophyll absorption. The reflectance at 0.52-0.60 μm indicates the green portion of visible light, which is not absorbed. The strong reflectance feature extending from approximately 0.75 to 1.3 μm, referred to as the near-infrared (NIR) plateau, characterizes healthy leaf tissue. The sharp rise in the curve between 0.68 μm and the NIR plateau is referred to as the red edge. The slope and position of this red edge have been directly correlated with leaf chlorophyll concentrations.

Chlorophyll and carotenoid concentrations may vary, and additional pigments may build up within leaves in response to stress. Such variations can appear as subtle spectral changes in the visible and red-edge portions of reflectance curves from vegetation in decline. The position and slope of the red edge also change as healthy leaves progress from active photosynthesis through senescence. Such phenological and health information is an important aspect of the remote detection and recognition of stress response (damage) in vegetation.

High reflectance values in the NIR plateau characterize healthy leaf tissue. Reflectance in this region is due to multiple refractions occurring along cell wall-water-air interfaces as a result of differing refraction indices for these leaf components. The studies suggest that changes in cellular health within leaves are associated with reduced reflectance along the NIR plateau. Such spectral properties, which can be remotely detected, may provide information regarding cellular health in vegetation over large areas.

The reflectance values in the 1.65 μm and 2.20 μm region can provide an accurate indication of leaf water content. Study results suggest that spectral data from the reflective short-wave infrared (SWIR) may be very useful in detecting various levels of water-related stress in vegetation.

Therefore the near-infrared (NIR) and short-wave infrared (SWIR) are the important spectral regions for forest resources change. If we want to detect the forest conditions effectively, we had better choose satellite sensors that have NIR and SWIR channels.

2. Strengths and weaknesses of remote sensing techniques in monitoring forest damage

Earth-orbiting satellites have the capacity to view and capture large areas of land in a single image, making them an excellent tool for monitoring and assessment of land cover and land use. Another strength of satellites is that they return to the same point over the Earth's surface at regular intervals (e.g., Landsat satellite's return time or temporal resolution was 16 days). Provided that cloud-free or near-cloud-free weather conditions exist, satellites can obtain data at predictable intervals for monitoring change. The satellite data is received in digital form, ready for computer-assisted analysis, and many Earth-orbiting satellites have spectral sensitivities in the visible, near-IR, and thermal-IR regions of the electromagnetic spectrum(EMS). And the regions of EMS can make it easier for us to identify different kinds of vegetation and vegetation condition.

The major weakness of the Earth-orbiting satellites in operation today, especially with regard to forest health protection, is their relatively low spatial resolution and low temporal resolution. While present day spatial resolutions such as Landsat TM satellite are adequate for many natural resources applications£-such as analysis of land form, land use, crop forecasting, and land cover mapping, they are still unable to resolve the fine to moderate levels of forest damage of vital interest to forest health specialists. Generally the biowindows of forest diseases and insects damage is less than 15 days. Consequently, use of data from Earth-orbiting satellites in forest health protection has, to date, been limited to test and demonstration projects. Fortunately some high spatial resolution satellite will be launched in succession in the coming years. And they can obtain data in the shorter intervals. Therefore we can be full of hope for satellite application in forest protection.

3. Landsat and its data properties

The Landsat satellites have been acquiring Earth resource data since 1972 and all have been in a polar orbit. Landsats 1, 2, and 3 returned over the same point on the Earth's surface every 18 days, and Landsats 4, 5, and 7 returned over the same point on the Earth's surface every 16 days. (Landsat 6 was lost in space.)

The early Landsat satellites (Landsate 1-3) were equipped with a four-band multispectral scanner. Spectral resolution consisted of two visible bands and two near-IR bands (Tables 1.1). Spatial resolution was 80 m, temporal resolution was 16 or 18 days, and image swath width was 185 kilometers.

Table 1.1. Spectral resolution of Landsat MSS

Band	Spectral Resolution (μm)	Spectral Location
4	0.5 - 0.6	Green
5	0.6 - 0.7	Red
6	0.7 - 0.8	Near - IR
7	0.8 - 1.1	Near - IR
8*	10.4 - 12.6	Thermal - IR

*Band 8 was first made available on Landsat 3

MSS data have been used for land cover classification, change detection, geological investigations, geomorphological mapping, hydrological studies, forest inventory, soil studies, oceanography, and crop yield estimations. In forest health protection, MSS imagery has been used for mapping areas of extensive forest defoliation and tree mortality.

The Landsat Thematic Mapper (TM), first carried aboard Landsats 4, 5, and 7 in addition to the MSS, is a more sophisticated instrument with increased spectral and spatial resolution. The TM has a spatial resolution of seven bands selected specifically for forest vegetation analysis (Table 1.2). Spatial resolution for all bands except band 6 is 30 meters, while band 6 has a 120-meter resolution. Area covered by a single TM scene is 31,450 square kilometers (185 kilometers by 172 kilometers).

Table 1.2. Spectral resolution of Landsat TM

Band	Spectral Resolution (μm)	Spectral Location
1	0.45 - 0.52	Blue
2	0.52 - 0.60	Green
3	0.63 - 0.69	Red
4	0.76 - 0.90	Near - IR
5	1.55 - 1.75	Mid - IR
6	10.4 - 12.5	Thermal - IR
7	2.08 - 2.35	Mid - IR

TM data have been widely used in many disciplines including agriculture, cartography, civil engineering, forestry, geology, geography and land and water resources analysis. Applications in forest health protection include mapping of heavy, widespread damage and change detection.

Landsat 7, which was launched April 1999, has on board an enhanced TM capable of producing panchromatic data with a spatial resolution of 15 meters and a multi spectral resolution of 30 meters. Ground receive stations are around the world. And more pleasantly we can obtain the data with low cost in time.

Now Landsat 5 and 7 are in the orbit. Therefore we can obtain the data in shorter intervals.

4. IKONOS and its data properties

IKONOS is a high resolution commercial Earth imaging satellite launched September 1999. The satellite is owned and operated by SpaceImaging headquartered near Denver, Colorado, and is considered to be the world's highest-resolution commercial satellite. IKONOS is in a sun-synchronous polar orbit at an altitude of 681 kilometers (423 miles). A single image captures an area of 11 by 11 kilometers. Spatial resolution is 1 meter in panchromatic mode and 4 meters in multi spectral mode. Spectral resolution of the multi spectral band is 4 meters, with band sensitivities in the blue, green, red, and near-IR regions of the EMS (Table 1.3). Temporal resolution is given at three days at 1-meter resolution and 1.5 days at 4-meter resolution.

Table 1.3. Spectral resolution of IKONOS

Sensor Mode/Band	Spectral Resolution (μm)	Spectral Location
Multispectral		
1	0.45 - 0.52	Blue
2	0.52 - 0.60	Green
3	0.63 - 0.69	Red
4	0.76 - 0.90	Near - IR
Panchromatic 1	0.45 - 0.90	Blue-near - IR

It is anticipated that IKONOS imagery will find applications in precision farming and agriculture, mapping, natural resources management, urban planning and zoning, oil and gas exploration, travel and tourism etc. Although it is difficult to obtain the data now, we are confident to its application in forest health protection.

More high resolution commercial Earth imaging satellites will be in orbit in the coming years. They can promote the application of satellite imagery in forest healthy protection.

5. Applications (pine caterpillar defoliation mapping) in China

In the past ten years, forest damage caused by diseases and insects has become more and more serious and resulted in tremendous loss in APEC members. One of the main reasons is that people can not make timely and precisely monitoring and make long-term forecasting about forest diseases and insects so that we can not control it at the beginning. Although people can not precisely predict the occurrence and development of the diseases and insects on current science and technology level, we can detect the early calamity location and do our best to minimize the loss. The following introduces a method to detect the early damage areas with TM data and make a rudimental understanding about the process of occurrence and development of forest diseases and insects through comparing and analyzing the recent year's data. It is admitted that satellite imagery data can make effective monitoring for pest origin. This opinion provides the possibility of making macroscopic monitoring about the important forest diseases and insects with the satellite remote sensing technology and provides a new technology for prevention of damage. At the same time, through analyzing the dynamic change of forest pest damage and the biologic property of forest diseases and insects, people can make long-term forecast of forest diseases and insects to realize the sustainable development of forestry.

In China, forest diseases and insects occurred vast area in recent years, 80,000 square kilometer per year, have resulted in 5 billion yuan direct economic loss. Frequent forest diseases and insects have maintained high level and has strong tendency to rise. Among the top ten types of forest diseases and insects, pine caterpillar disaster ranks first. So effective monitoring and controlling of forest diseases and insects has special value in reducing the loss of forest pest damage of our country.

In the past half century, the science of forest protection has made rapid progress. But it is a passive procedure. Forest biological disaster control at the turn of the century is confronted with great crisis.

For the artificial forest, there are four problems to be resolved in China.

- Some serious biological disasters in history have not been controlled, for example, the continuous harm of pine-moth *Dendrolimous pinidiatrea*, the continuous menace to£¢Three North Shelter Forest£¢system caused by poplar borer *Saperda calcarata*, *Valsa sordida* and *Dothiorella gregaria*.
- Some secondary forest biological disasters are turning to main menace. For instance, Pine Diprionidae's occurrence in large scale is menacing the shelter forest of Three Gorges in Chongqing Municipality, and paper pulp industry in south China is being threatened by the extension of *pseudomnas solanacearum*.
- Quarantining pests are becoming menace. Pine's withering caused by *Bursaphelenchus xylophilus* through the medium of *Monochamus alternatus* still continues to spread and ruin pine woods.
- With the deterioration of whole ecological environment, ecological diseases break out into disasters, as an example, recently, plenty of city green trees have died of *Valsa* in northeast and north China.

For the natural forest, there are two problems to be resolved in China.

•Natural forest not exploitation and no direct disturbing and distroyed by human being. Stable forest ecosystem has occured disaster because of the change of the global climate. Such as the *Lophodermium* **sp.** causes the *Abies* death in large belt area in Xizang Autonomous Region.

•Natural forest disturbed and destroyed by human being. The biological disasters are very serious because of the over-exploitation in this kind of forest.

5.1 Introduction

Masson pine (*Pinus massoniana* Lamb) is one of the principal timber species in south China and has a wide distribution. Its amount of volume is more than half of the whole timber amount in south China. However, its distribution area is often invaded by masson pine caterpillar, one of the most serious forest insects in China. Pine tree growth is influenced and the harvest of turpentine is reduced in the low damaged forest, and trees are killed in the heavy damaged forest. The masson pine caterpillar also has impact on human being and ecological environment. The governments and administrative departments of these areas have utilized a great number of labor forces, materials and financial resources to measure, protect and harness the damage caused by pine caterpillar, this has restrained the damage from rapid infestation. As the pine caterpillar is characterized by its quick development, it is very difficult to effectively control and predict the damage by traditional ways.

Although the damage symptoms caused by different agents may vary, analysis of the damage caused by pine caterpillar can provide insight into other types of damage that result in needle loss. The pine caterpillar feeds on the buds and needles of old shoots of massion pine. In severe outbreaks, it may feed on previous year's needles. Most feedings occur in late spring, early summer or early autumn. The partially consumed needles and other feeding debris become caught in a web-like feeding tunnel produced by the pine caterpillar and adhere to the tree for a short time. The feeding debris is eventually knocked off by wind and rain, and bare branches become exposed.

Remote sensing systems provide a means of discriminating, mapping and monitoring vegetation efficiently. The overall objective of this study was to correlate various levels of forest defoliation in South China with remote sensing data, some specific goals are as follows: (1) to determine the feasibility of using satellite-borne sensors such as Landsat Thematic Mapper(TM) data to map, measure and monitor coniferous forest defoliation caused by the pine caterpillar through time, (2) to describe the relationships between spectral data and defoliation (percentage of needle loss), and (3) to determine what levels of coniferous forest defoliation can be detected.

Assessments of defoliation caused by the pine caterpillar permit monitoring of an outbreak and estimation of the distribution and quantity of damage. Such assessments can also be used in some forest jurisdictions as a measure of stand condition. This, in turn, is used to determine where to implement pine caterpillar control programs, to assist harvest scheduling and to plan other silvicultural measures. Leckie D.G. et al (1987) had predicted that approximately 20% differences in defoliation can be discriminated with the best spectral bands and that there were significant differences between four classes of defoliation for most spectral bands.

In all, satellite-borne remote sensing could acquire forest condition information over large areas periodically and provide technical possibilities for timely monitoring of forest diseases and insects.

We have made further research in many regions of China, such as Qianshan county in Anhui Province, Jiangshan city in Zhejiang Province, Chaoyang region in Liaoning Province, and so on. The biological property of pine caterpillar hazard can be remarkably distinguished in these test area. These study areas are typical regions with frequent pine caterpillar hazard.

5.2 Universal management of remote sensing data

5.2.l Data collection

Landsat's TM5 and TM7 data can be obtained from Remote Sensing Satellite Ground Station of Chinese Academy of Sciences. In order to reduce the difference caused by phenology, data with close phonological period is often of first choice.

5.2.2 Data pre-process

At first, we make precise geographic calibration and registration to the yearly data. To keep the precision in one pixel, ground control points from the newest 1:10,000 topographic map were chosen. Meanwhile, DGPS can also be used to achieve ideal result.

5.2.3 Data normalization

To facilitate the comparison and analysis, normalization has been done to the yearly TM data.

5.2.4 Disaster information extraction

According to previous experience, during the slow growing season of plant, because of the withering of herbs and defoliation of forest, the green biomass will reduce, and this make the detection of forest disaster more convenient. The stress index is an ideal parameter to identify the green biomass difference.

5.3. Data analysis and results in Anhui Province

5.3.1 Data analysis

TM image data of November 15, 1993, December 7,1995 and October 22, 1996 are selected respectively.

To understand the methodology of extracting forest damage information from TM data, we selected the data set of 700 hectare sample areas in disaster forest, in terms of sight analysis for three years image. Figure 1.1 shows the DN values of the three years TM data, which have a decreasing tendency (except TM6). In figure 1.2, standard deviation increases yearly. So these data comprise abundant information. Figure 1.3 shows that the maximal difference of four ratios between 1996 and 1995 or 1993 sample data is situated on the ratio TM5/4. And the maximal standard deviation of those ratios between 1996 and 1995 or 1993 sample data is also situated on the ratio TM5/4. From the analysis of several kinds of ratio, we can find that TM5/4 is the best vegetation index to extract forest change information in the winter, which coincides with previous research result very well.

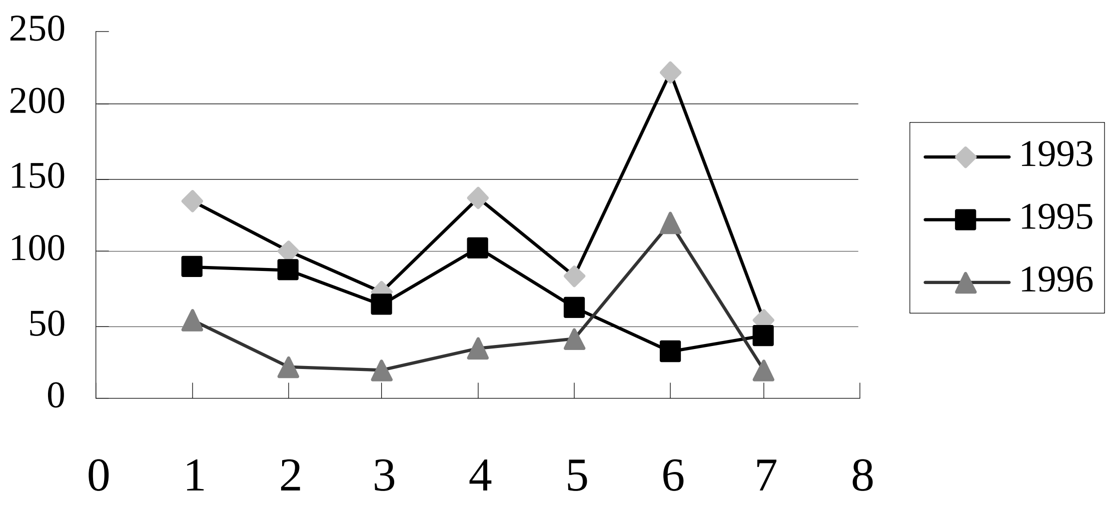


Fig.1.1 DN values of seven TM bands

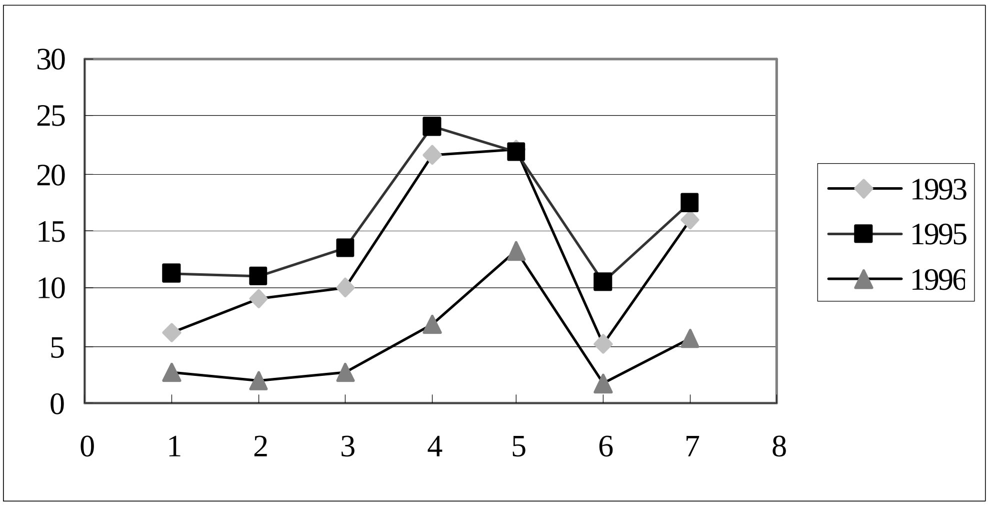


Fig.1.2 Standard deviation of seven TM bands

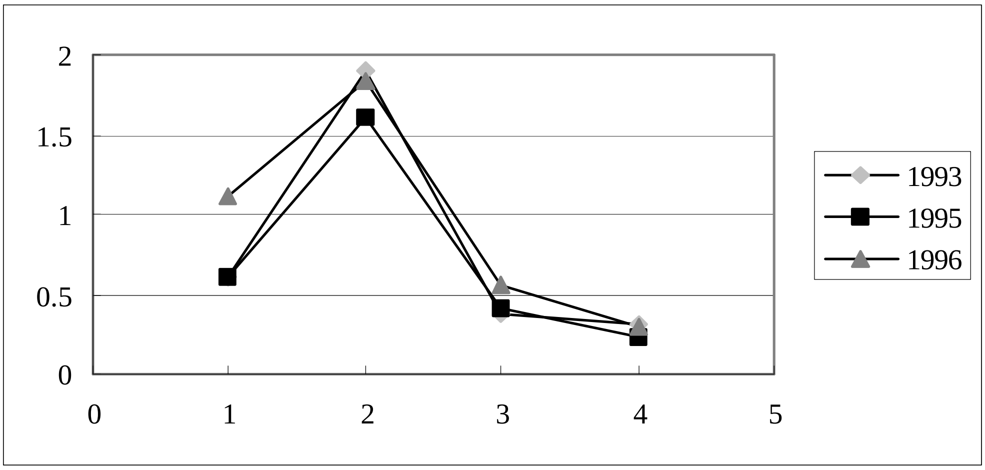


Fig.1.3 Comparison of four ratios vegetation index.(1-TM5/4, 2-TM4/3, 3-TM7/4, 4-TM(4-3)/(4+3))

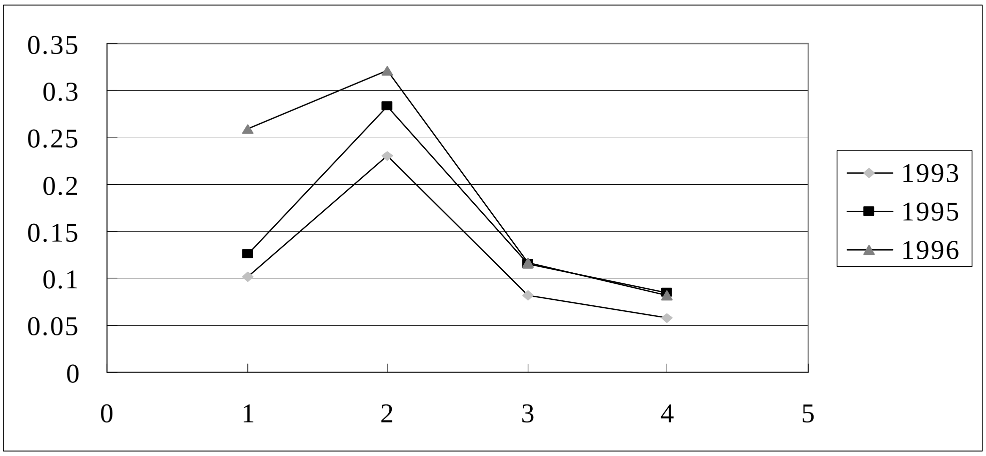


Fig.1.4 Standard deviation of four ratios vegetation index

5.3.2 Early damaged area

To make a clear illustration of the feasibility and validity of satellite remote sensing techniques in monitoring forest insects and diseases, we have chosen TM images of three regions and made automatic classification to them, this has formed an actual description of the spectrum change of the hazard regions during four years. (see Fig. 1.5, Fig. 1.6, Fig. 1.7)

From forenamed three groups of images, we can find that the occurrence and development of forest diseases and insects is a process from point to surface. Satellite remote sensing data can actually record this gradual change process. The areas of three hazard regions in the 1995 image are very small. But after three generations of the pine caterpillar, the hazard rapidly diffused in vast region in 1996. Therefore, if the start points of pests can be detected timely and precisely, the disaster in vast areas will not occur and the damage loss will be reduced.

5.3.3 Post-classification process

To improve classification precision and get rid of the non-forest change information, we took the filtering process to the analysis results based on the pixel and removed the non-forest change information with GIS data, finally, we got the change image map of forest health change of the whole county. (see Fig. 1.7 and Fig. 1.8)

5.3.4 Results

Through a comprehensive view of last decades' research results and experience of the world, we select American Landsat TM data as the main information source to study the quick extraction of forest damage caused by pine caterpillar with remote sensing. After precise geometric calibration of three years' data, all data were normalized with the 1993 data as the base data, and this can be used for getting rid of the changes of non-forest region. After filtration and vectorization, the forest health change vector image map for the two years were obtained. There are three levels: The better growing - excellent (the leaves are well or the needle loss is under 40%), the worse growing - medium (the defoliation are between 40% and 70%), and the worst growing - serious (the defoliation are beyond 70% or the forest is deforested or fired). The change ratio of each level is shown in table 1.4.

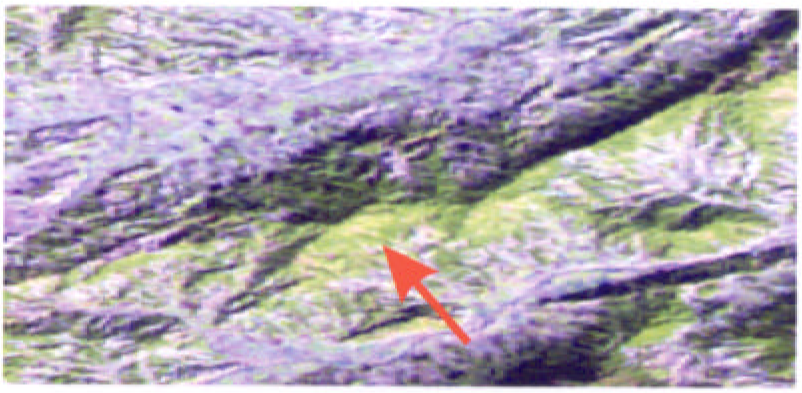
Table 1.4 Degree of forest healthy change

	Good	Medium	Severe	Sum of polygons
1995	2218	456	21	2695
1996	1921	1174	470	3565

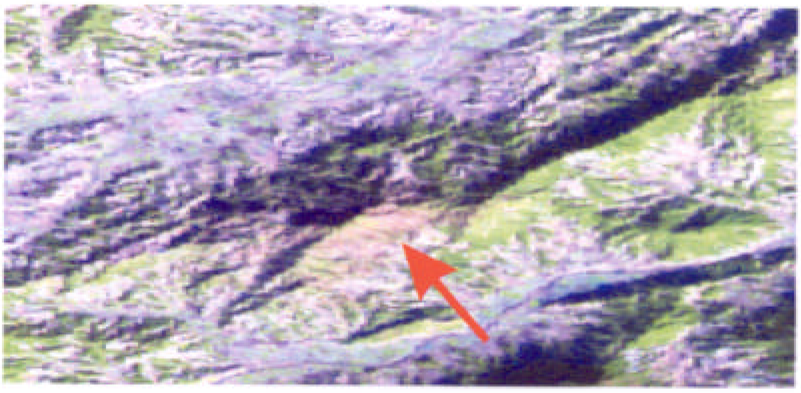
We can output the inner points of all disaster areas of different levels and transform them into the coordinate value under WGS-84 coordinate system. Then we go to the field to begin our validation and investigation. Considering many factors, we just make the ground validation with medium or serious changes. These changes were caused by forest diseases and insects, deforestation, fire and so on. Table 1.5 shows the validation results, and it satisfies the need of practical production. Of course, this is just the beginning, we will continue improving our monitoring model in order to make integrated detection and assessment for current year's forest healthy change through annual periodic detection. According to the biologic property, the distribution range of pest can be reconstructed to guide the investigation of forest diseases and insects of the following year, including determining the temporal investigation routine, and temporal standard areas. Through these works, we hope the origin of pests can be found as early as possible so as to take prevention and protection measure, control its diffusion, and minimize the loss. For provincial level management department, they will not only analyze the data provided by local region, but also supervise and manage the disaster information to obtain real time information, to guide macroscopic adjustment and controlling of the disaster.

Table .5 Polygon validation of field investigation

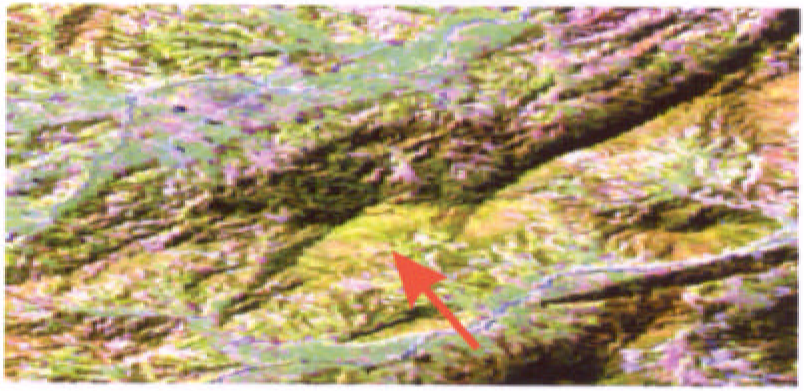
		Medium	Heavy
1995	Sum	138	20
	Polygons caused by forest diseases and insects	97	7
	Polygons caused by deforestation and fire		13
1996	Sum	179	119
	Polygons caused by forest diseases and insects	171	109
	Polygons caused by deforestation and fire		10



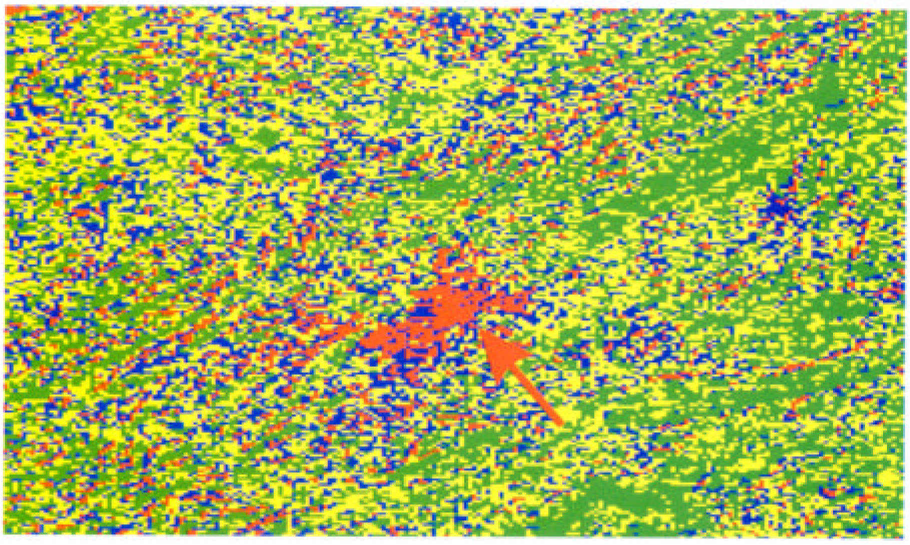
a) TM composite image in 1993



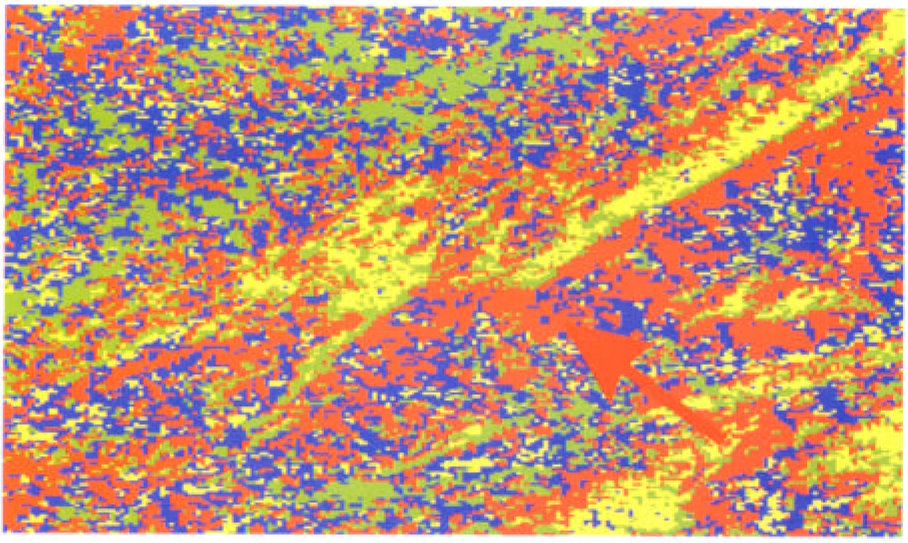
b) TM composite image in 1995



c) TM composite image in 1996



d) Green biomass change map based on single pixel(1995)



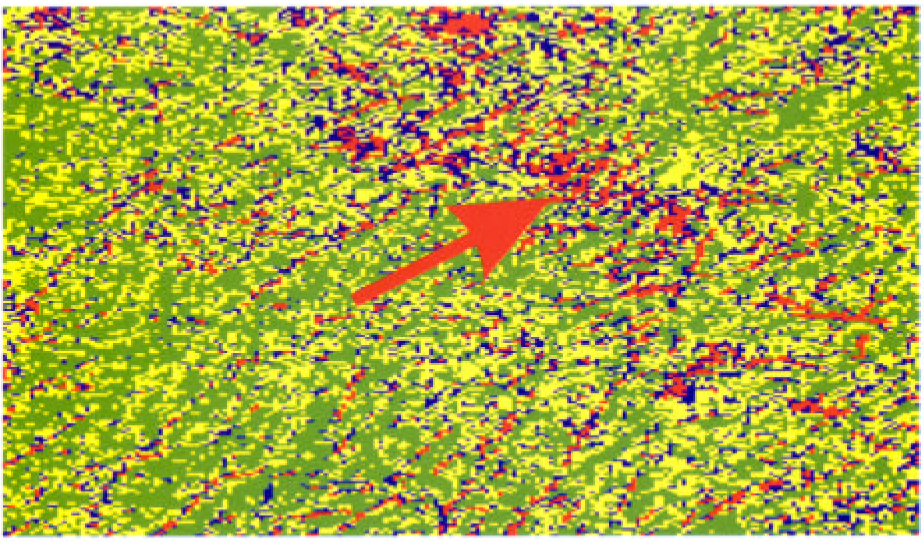
e)Green biomass change map based on single pixel(1996)

Fig.1.5 Evolving process of yearly green biomass change based on TM images in site A

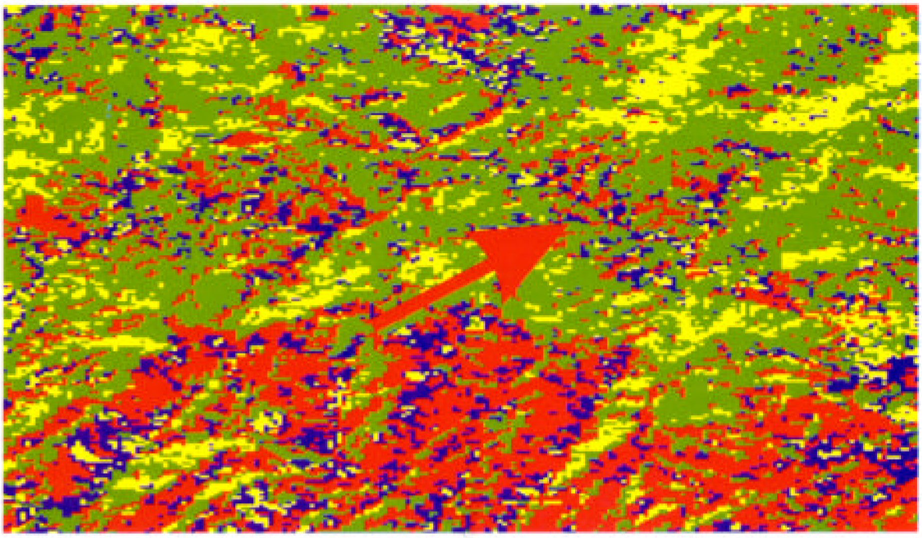
a) TM composite image in 1993

b) TM composite image in 1995

c) TM composite image in 1996

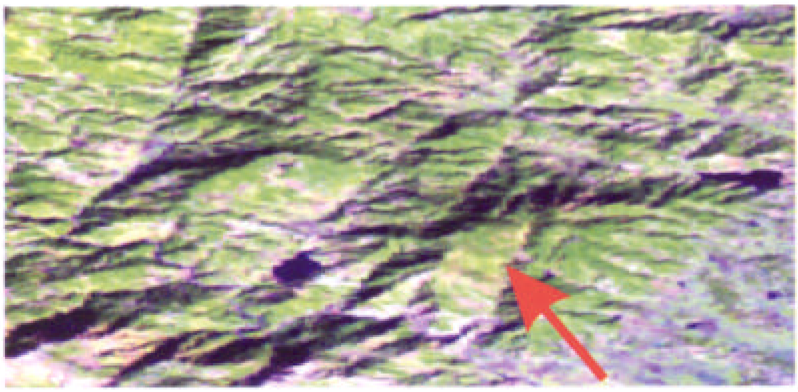


d) Green biomass change map based on single pixel(1995)

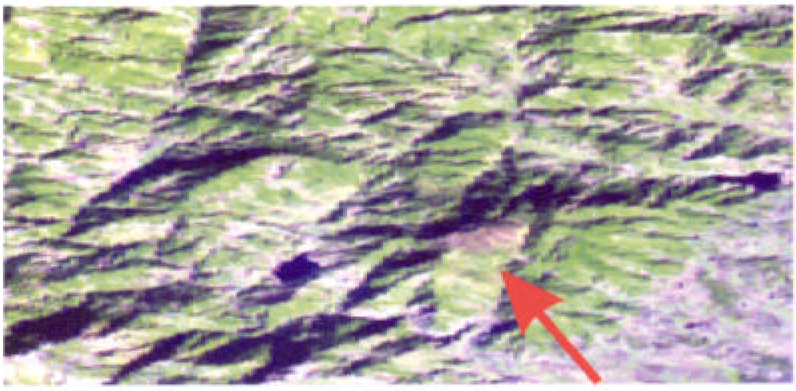


e) Green biomass change map based on single pixel(1996)

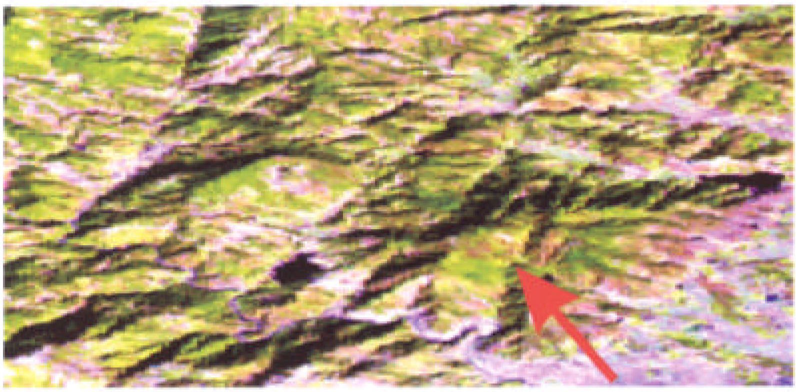
Fig.1.6 Evolving process of yearly green biomass change based on TM images in site B



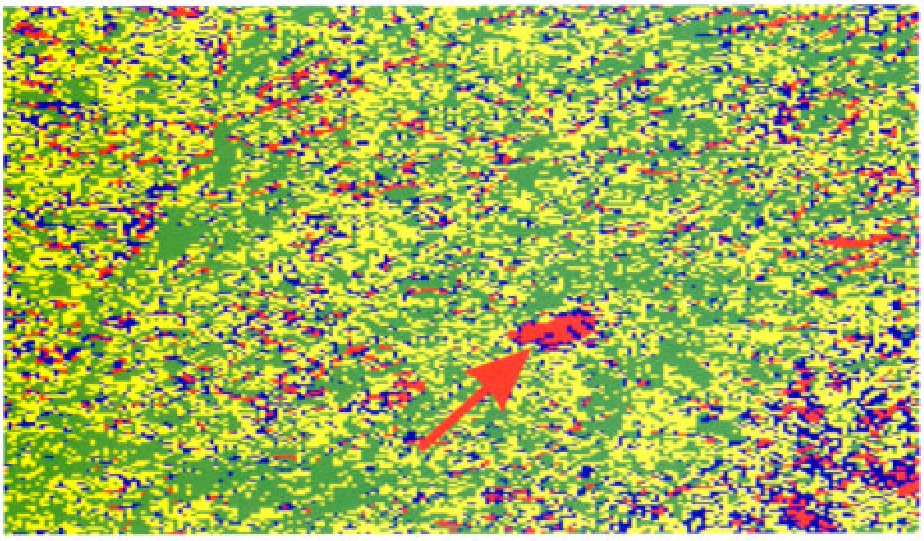
a) TM composite image in 1993



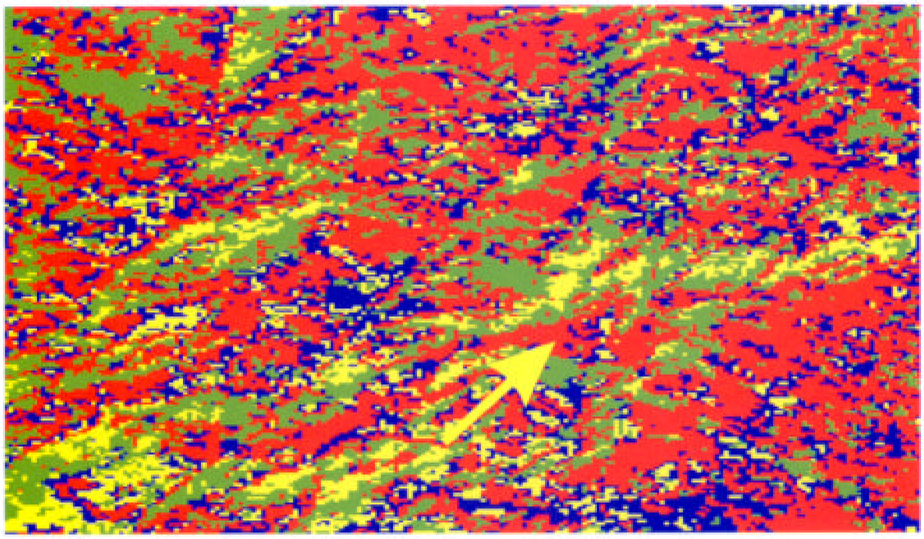
b) TM composite image in 1995



c) TM composite image in 1996



d) Green biomass change map based on single pixel(1995)



e) Green biomass change map based on single pixel(1996)

Fig.1.7 Evolving process of yearly green biomass change based on TM images in site C

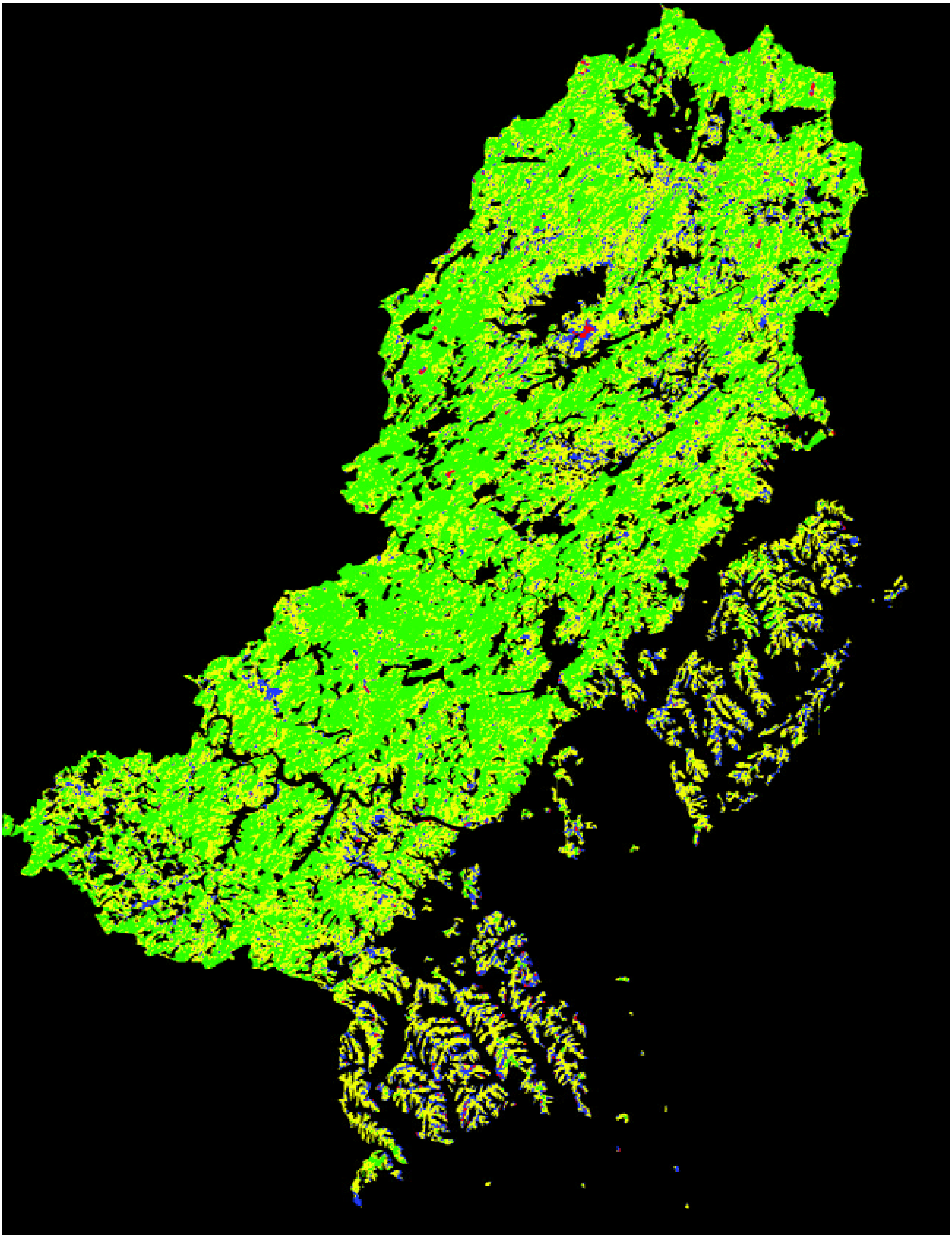


Fig.1.8 Forest health change map of Qianshan County of Anhui Province in 1995£¨Green¡ªealthy forest, Yellow¡ªaround 30 of needle loss percentage, Blue¡ªaround 50 of needle loss percentage, Red¡ªLarger than 70 of needle loss percentage)

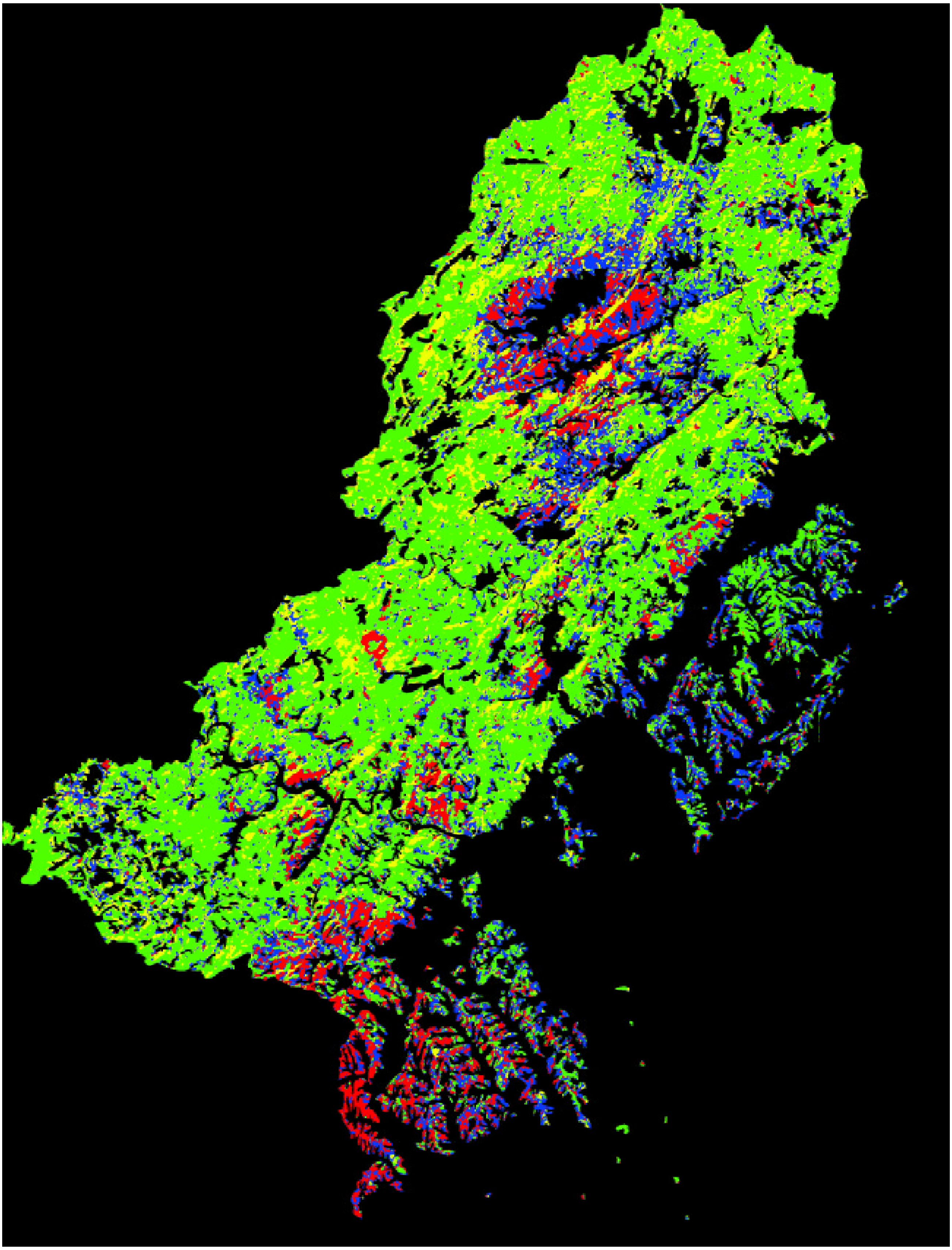


Fig.1.9 Forest health change map of Qianshan county of Anhui Province in 1996(Green¡ªhealthy forest,Yellw¡ªaround 30 of needle loss percentage, Blue¡ªaround 50 of needle loss percentage, Red¡ªLarger than 70 of needle loss percentage)

5.4 Data analysis and results in Zhejiang study areas in southeast China

The research was conducted at the pine forest located in Jiangshan City, Zhejiang Province in southeast China. Half of the city is covered by masson pine distributed in hillsides.

The city is mainly covered by immature stands of different densities and suffered varying levels of defoliation by pine caterpillar from August to September in 1992.

5.4.1 Remote sensing data acquisition

Four Landsat-5 TM half scenes covering the region described above were obtained and they were acquired on November 29, 1989, November 21, 1992, October 20, 1992, and October 26, 1994 respectively. The 1994 and 1989 data sets represent conditions that the forest was not damaged by the insects, whereas the 1992 data sets were acquired during major defoliation caused by pine caterpillar. Although the 1992 data were acquired one to two months after what is considered to be the peak of the infestation, it is not long enough for vegetation to recover yet and the defoliation were still quite evident.

The above data sets can also be divided into two groups of which the October data sets stand for conditions in growing season and the November data sets stand for conditions in non-growing season. For every group of data sets, solar azimuth and elevation were similar. And it is assumed that vegetation was at phenologically comparable states for both groups of data sets. Ancillary data, such as 1:10,000 topographic map (partly) and 1:25000 forest maps made in 1989 were used to exclude the disturbances.

5.4.2 Ground survey

A total of 702 field plots were sampled in March 1993. The plots were stratified by high versus low elevation£¬ high versus low canopy closures and high versus low damage levels. Selected plots were required to support individual pine stands with minimum stand size of one hectare. It was later determined that 321 plots did not meet the design criteria of overstory homogeneity and were thus withheld from further analysis.

The stand ages of the above plots typically ranged from 5 to 22 years, the tree heights from 2 to 8 meter, the diameter at breast height from 5 to 12 centimeters, and the crown class from 1 to 4. There were about 5 to 10 whorls in each plot. Ground cover under canopy varied greatly with herbs or shrubs being predominant.

Table 1.6 Stand types of constant damage region in study area

Stand types	Canopy closure	Understory coverage(%)
1	£¾0.45	¡Ý50
2	£¾0.45	£¼50
3	£¼0.45	¡Ý50
4	£¼0.45	£¼50

A total of four types of pine stands located in the regions with constant damage were selected(see Table 1.6) and they were chosen to represent a gradient from low to high levels of forest damage. A ground survey was conducted from March to April, 1993. Three hundred and eighty one quadrates(100m¡Á100m) were selected in building the monitoring model, and they are the training areas for carrying out inventory of pine forest stand and damage. The quadrates locations were marked on a configuration map (1:10,000 scale topographic maps). Since losing needles is one of the major symptoms of the forest infested by the pine caterpillar, the percentage of needle loss was estimated by visual interpretation with an accuracy of about 10% in each quadrate. Meanwhile the plot's other information such as crown closure, diameter at breast height, average tree height, crown class and understory compositions are all investigated and recorded. All the plots were positioned in field by measurement with the positioning error less than 20 meters.

5.4.3 Image pre-processing

Four subsets of images representing the study area were extracted from TM scenes acquired. In order to alleviate the confusion of multi-temporal spectral radiance differences, the 1992 data sets were normalized against the October 1994 and the November 1989 data sets respectively using a series of bright or dark ground targets. To normalize data, the digital number(DN) values of all bands were extracted from all targets for four data sets. The 1992 values were regressed against the 1994 and the 1989 values and a linear relationship were obtained. The regression equation was used to convert the 1992 DNs into values comparable to 1994 and 1989 values. All ground targets for normalization were presumed to have undergone minimal amounts of reflectance change between the acquisition of the two group of data sets. The TM data were rectified to Transverse Mercartor grid using a nearest neighbor resampling method. A 3¡Á3 kernel of pixels surrounding the center of each plot was extracted from the TM data sets. Digital numbers for these nine pixels were used to derive an average for each plot.

5.4.4 Data analysis

There are in TM sensor seven bands of which band 2, band 3 and band 4 are respectively green reflectance region, red strongly absorbed region and near-infrared strongly reflectance region of healthy vegetation. In particular, band 3 and band 4 form a sharp contrast between absorption and reflection and both of them are important bands for detecting chlorophyll concentration, estimating leaf area index and biomass. Moreover, Band 5 and band 7 in the mid-infrared spectrum can sensitively discriminate differences of temperature and water content in vegetation. When pine forest is invaded by pine caterpillar, the needles will be reduced and there will be exposed barks, branches and twigs. Under these circumstances, the digital numbers of band 2 and band 4 will decrease and the values of band 1, band 3, band 5 and band 7 will increase correspondingly. All of the above facts constitute the theoretical basis for detecting forest damage with TM data sets.

According to statistical analysis of the November data sets, spectral signatures of field plots damaged correspond to the previous research results. Table 1.7 shows the difference between 1989 and 1992 November data sets. It indicates that the defoliation or reduction of green biomass caused by pine caterpillar has evident reflection in the TM imagery in 1992. How to enhance and extract these damage information is one of our major study objective.

Table 1.7 Comparison between 1989 and 1992 data sets in November

Items	Years	TM1	TM2	TM3	TM4	TM5	TM7
Mean	1989	50.74	19.43	18.66	34.68	42.33	15.30
Mean	1992	58.20	26.22	26.04	34.43	51.33	21.79
Standard variance	1989	2.267	1.733	2.802	6.573	10.424	4.680
Standard variance	1992	2.993	2.347	3.989	6.158	11.697	5.216
Minimum	1989	45.00	15.22	11.44	14.00	9.78	3.00
Minimum	1992	51.88	20.47	17.76	13.14	14.21	7.87
Maximum	1989	59.00	26.67	30.22	50.56	69.67	30.67
Maximum	1992	67.19	31.31	35.73	48.91	79.49	34.28

5.4.5 EXTRACTION OF DAMAGE INFORMATION

William *et al*.(1985) used ratio vegetation indices of Landsat MSS band 5 over band 7 to discriminate heavy forest defoliation from a category of moderate defoliation and healthy forest with accuracies of 75 to 80 percent. Williams and Nelson(1986) developed techniques to delineate and assess forest damage due to defoliating insects with a reported

90 percent classification accuracy for delineating insect-damaged and healthy forest. Vogelmann and Rock(1988) evaluated Landsat TM data for its ability to detect and measure damage to spruce-fir stands and their study indicated that TM band 5/4 and 7/4 ratios correlated well with ground observation of forest damage defined as percentage of foliage loss.

Change detection using multi-temporal data had previously been employed primarily for the evaluation of land cover changes associated with urbanization(Christenson and Lachowski, 1976; Wickware and Howarth, 1981; Estas *et al*., 1982), desertification(Coiner, 1980; Robinove *et al*., 1981) and coastal zone monitoring(Weismiller *et al*., 1977; Hong and Iisaka, 1982). Specific applications of change detection to monitor defoliation include Nelson(1983), who evaluated image differencing, rationing, and vegetative index differencing of Landsat MSS data for detecting defoliation due to gypsy moth. That study concluded that the vegetative index differencing and an MSS 5 ratio gave the best indication of forest canopy change, with accuracies of about 78 percent. Vogelmann and Rock(1989) used multi-temporal Landsat TM band 4 image differencing with single-date band 3 and 5 data to distinguish between high and low levels of defoliation of hardwood forests caused by the Pear Thrips.

5.4.5.1 Extraction of defoliation in non-rowing season with single-date TM data

In south China, deciduous forest usually drop foliage in early to middle November and herbage vegetation has also faded at this moment. Because the understory vegetation is mainly deciduous broadleaf trees and herbage, the effects of understory vegetation on spectral contribution can be neglected. Analysis of the plots data showed that when canopy closure of the stand(dense pine forest) is greater than 0.45, TM ratios 5/4, 7/4 and (4-5)/(4+5) were found to be strongly correlated with defoliation at the 0.05 level of confidence. Especially, ratio TM 5/4 is the best vegetation index to distinguish four damage levels: healthy pine stand, light damaged stand, moderate damaged stand and heavily damaged stand(0%-30%-50%-70%-100%). As for sparse canopy(canopy closure<0.45), it is difficult to distinguish defoliation differences with single-date TM data sets.

5.4.5.2 Extraction of defoliation in growing season with single-date TM data

In order to probe into effects on spectral reflectance of understory vegetation, we used TM data sets in October during whcich all vegetation are green to find the way for differentiating defoliation. Firstly, we divided dense pine forest into two categories in terms of the presence or absence of understory vegetation, here £¢presence£¢ was defined as greater than 50 percent shrub vegetated cover. While ratio TM 5/4 is still an effective vegetation index to detect damage changes for the latter, only ratio TM 4/3 can be used to measure differences of defoliation for the former case. As for sparse canopy, it is still a difficult problem with single-date TM data.

5.4.5.3 Extraction of damage with multi-temporal TM data

Image differencing or delta detecting (ID) is a technique whereby changes in brightness values between two or more data sets are determined by cell-by-cell subtraction of co-registered image data sets. The subtraction (differencing) produces an image data set where positive and negative values represent areas of change.

(1) Monitoring damage during vegetation’s non-growing period Because the understory vegetation such as the broadleaf trees and the herbs have dropped leaves or become yellow and faded in late November in the study area£¬it can be considered that spectral contribution of understory vegetation is very little and can be neglected. By analyzing various transformations £¨K-T, K-L, IHS£©and their combinations, it can be concluded that ratio TM5/4 is an effective parameter to reflect the level of forest damage when the closure of understory vegetation is small. Analysis of the difference of TM5/4 between the two years showed that ¦¤TM5/4 (difference of TM5/4 between the two years) can be used to assess four levels of needle loss damage. Result of variance analysis showed that the difference is obvious.

(2) Monitoring damage during vegetation’s growth period As the understory vegetation is still vigorous in October, spectral contributions from understorey vegetation will gradually increase with the decrease of crown leaves

of the top layer and the ability to monitor damage caused by forest disease and insects using remote sensing method will decrease. As some plots were covered with cloud on Oct. 26, 1994, only 367 of plots are used for analysis. It can be shown that only three levels of needle loss can be assessed by ¦¤TM4/3(the difference of TM4/3 between the two years). Result of variance analysis showed that the difference is obvious.

It is still an urgent important problem how to get rid of or lessen the disturbance of the understory vegetation and to build effective models for monitoring damages.

5.4.5.4 Building remote sensing monitoring model of pine caterpillars

Because visual method were used in the surveying of the damage, there will be errors. So it is reasonable to consider that the value of TM5/4(x) of a plot whose damage percentage is y% is the powered average of TM5/4 values of the known plots whose damage values and TM5/4 values are y_i% and X_i respectively. Non-parametric regression method can be applied to study the relation between y and x.

(1) Non-parametric regression method to build the relation between y and x. Suppose that the regression relation in which we are interested is f(y)=E(x|y),¬ where y¡ÊR^1 and f(y) is usually estimated by non-parametric kernel regression method whose form can be described as following:

where K(x) is called the kernel function and is usually a probability density function; hn>0 is called the width

$$f(y)=\frac{\sum_{i=1}^{n} X_i K\left(\frac{Y_i-y}{h_n}\right)}{\sum_{i=1}^{n} K\left(\frac{Y_i-y}{h_n}\right)} \quad (1)$$

function and a good selection is hn=2.345¡Ád¡Án-1/5, where d is the stand error. Formula (1) is called the non- parametric regression estimation of f(y). K(x) can have many forms and in this paper it takes the following form:

$$K(x)=\frac{3}{4\sqrt{5}}\left(1-\frac{1}{5}x^2\right)I\{|x|\le\sqrt{5}\} \quad (2)$$

(2) Emulating the above non-parametric regression curve using parameter model. Usually twenty one values of needle loss (y%) are taken respectively as 0%, 5%,¬... 100%. And the corresponding values of f(y) can be obtained through formula (1) as $f_n(0)$, $f_n(5)$, ...$f_n(100)$. The Logist curve :

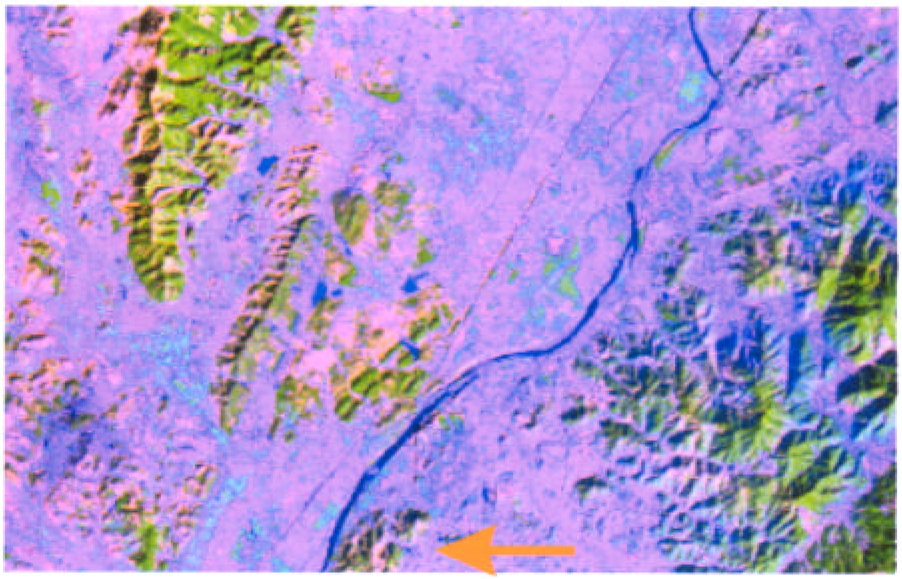
$$x = x_0+\frac{M}{1+m\times \exp(-R\times y)} \quad (3)$$

can be used to emulate the above twenty one points.

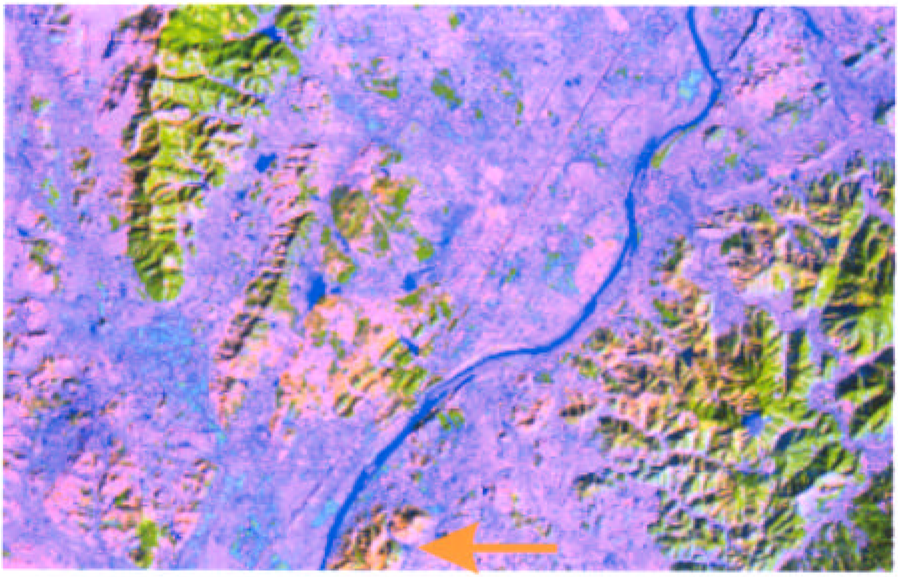
Relation between needle loss (y) and TM5/4 (x) can be obtained from (3) as following:

$$y=-\frac{1}{R}\mathrm{Log}\left[\frac{M}{m\times(x-x_0)}-\frac{1}{m}\right] \quad (4)$$

and this formula can be used to calculate the damage.



a) TM composite image in 1989



b) TM composite image in 1992

Fig. 1.10 Evolving process of yearly green biomass change based on TM images in Zhejiang Province study area

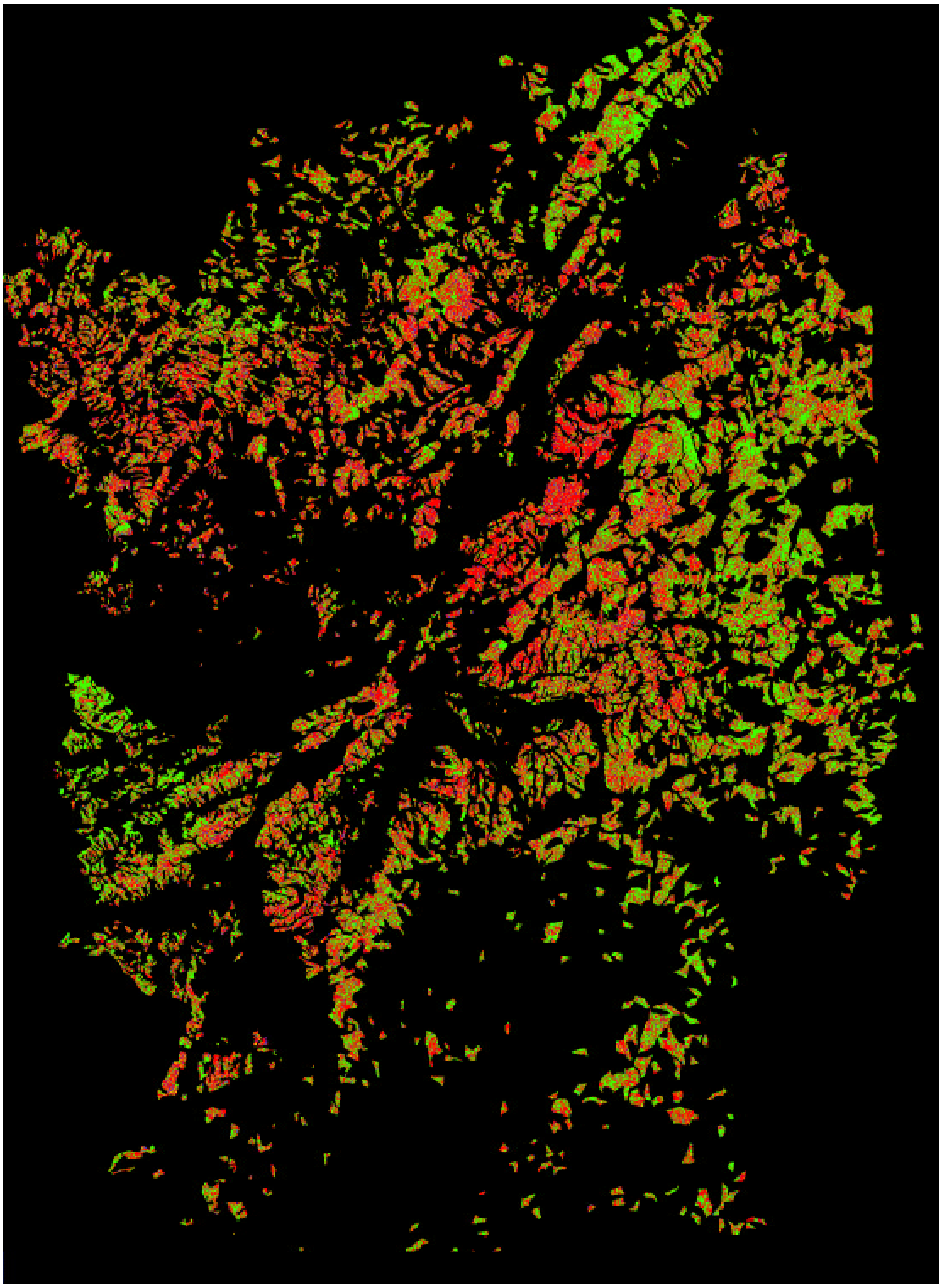


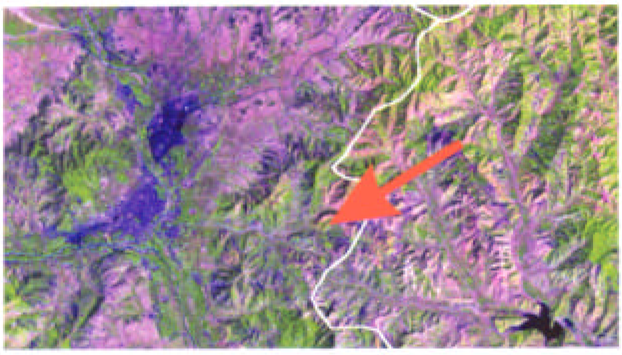
Fig.1.11 Forest health change map of Jiangshan County of Zhejiang Province in 1992(Green¡ªhealthy forest, Yellow¡ªaround 30 of needle loss percentage, Blue¡ªaround 50 of needle loss percentage, Red¡ªLarger than 70 of needle loss percentage)

We can obtain the change map of forest health situation by post-classification progressing.(See Fig.1.11 and Fig.1.12)

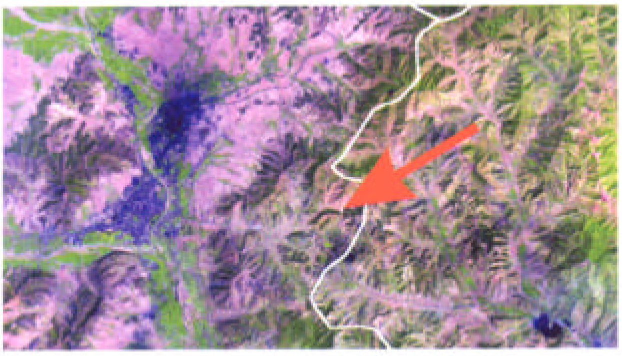
5.6 Detection of forest healthy situation of Liaoning Province in Northeast China

In June, 1987, forest damage caused by pine caterpillar occurred in vast areas of Chaoyang region. In 2000, continual droughts also heavily influenced the growing of forest. From the comparison and analysis of two images, we can clearly see the change of forest quality.

We obtained two scene TM data on 24, June 1987 and on 27, June 2000. After processing and classification, vegetation change information can also be extracted.(see Fig. 1.12 and Fig. 1.13)



a) TM composite image in 1987



b) TM composite image in 2000

Fig. 12 TM imagery in site A of Liaoning Province

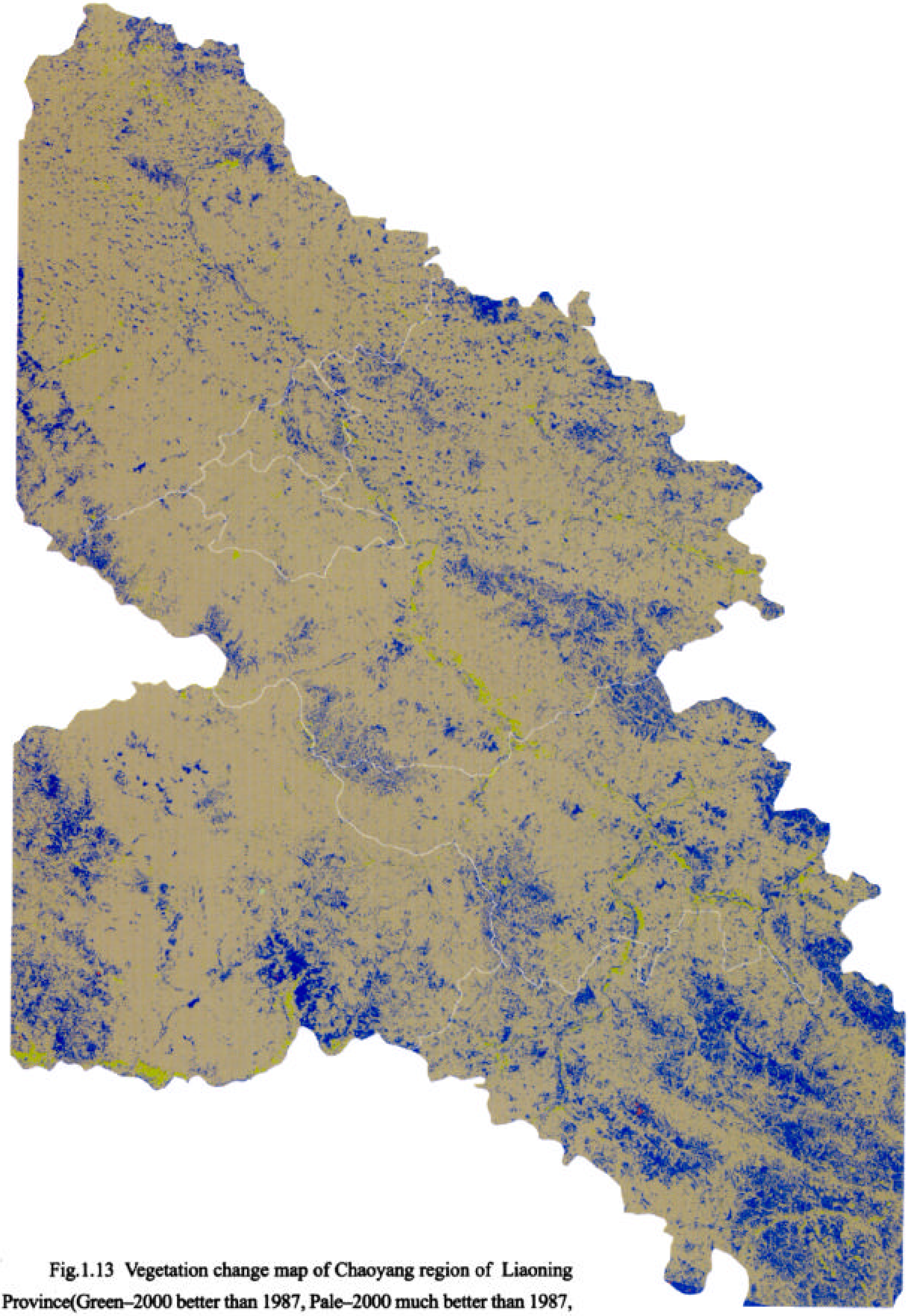


Fig.1.13 Vegetation change map of Chaoyang region of Liaoning Province(Green–2000 better than 1987, Pale–2000 much better than 1987, Blue–1987 better than 2000, Red–1987 much better than 2000)

5.7 Technical methodology

In order to have large scale monitoring, the Landsat TM data is chosen as main data resource. Through nearly ten years of study and probation in Heilongjiang, Zhejiang, Anhui and Liaoning provinces in China, a series of methodology has been obtained to rapidly analyze and process the remote sensing data, preliminary models assessing forest damage have been established. The main flow of the technology is demonstrated by figure 1.14.

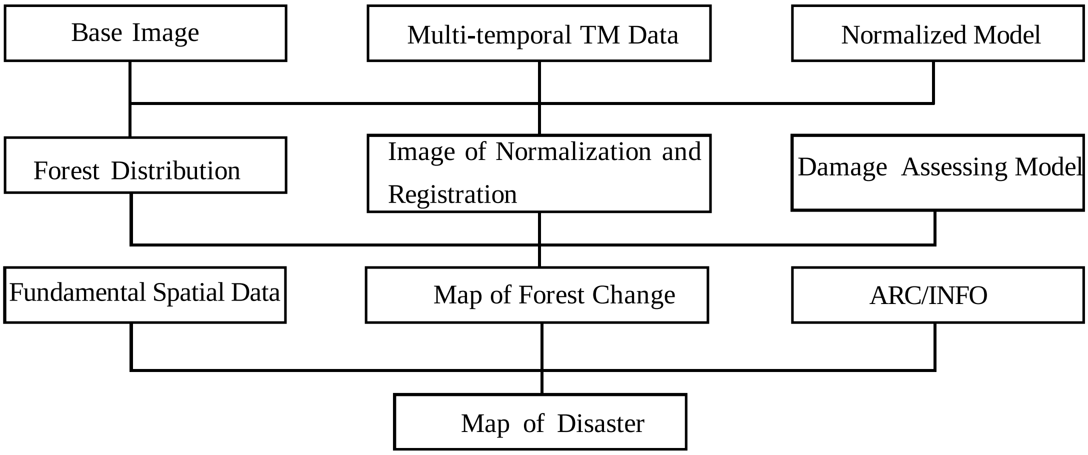


Fig.1.14 Flow chart of the technology

5.8 IKONOS image and its potential

Fig.1.15 shows a Spaceimaging's 1- meter panchromatic image. It can distinctly differentiate the single tree. But the color changes of tree foliage and crown cannot be reflected. Fig.1.16 shows a Spaceimaging's 4- meter multispectral image. We can also discriminate between different tree crowns but the characteristics of single tree cannot be distinguished, and we can use its NIR information to detect the early and subtle changes of foliage. Fig.1.17 is a Spaceimaging's 1-meter orthorectified products obtained in October 1999. It provides map-accurate metric data and combines the spatial content of the 1-meter black-and-white data, with the color content of the 4-meter multispectral data. We can distinctly identify the single tree crown. It is possible to detect the single tree changes quantificationally and positionally. It is out of question that high resolution satellite data can be used to detect the forest pest damage while there are not any reports. It is successfully used to monitor the agricultural damage. Therefore its application will be very extensive in forest health protection.

Fig.1.15 1-meter panchromatic image of IKONOS

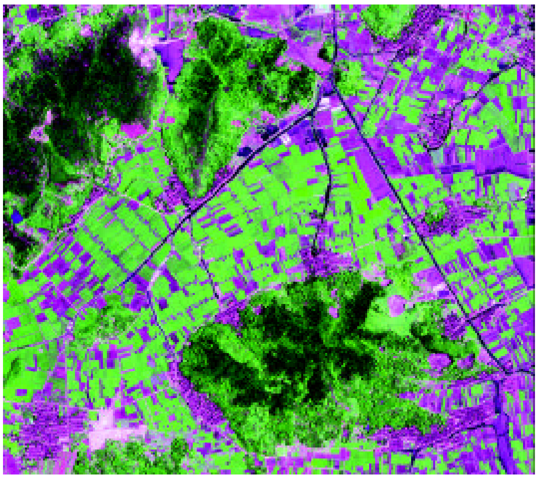


Fig.1.16 4-meter color image of IKONOS

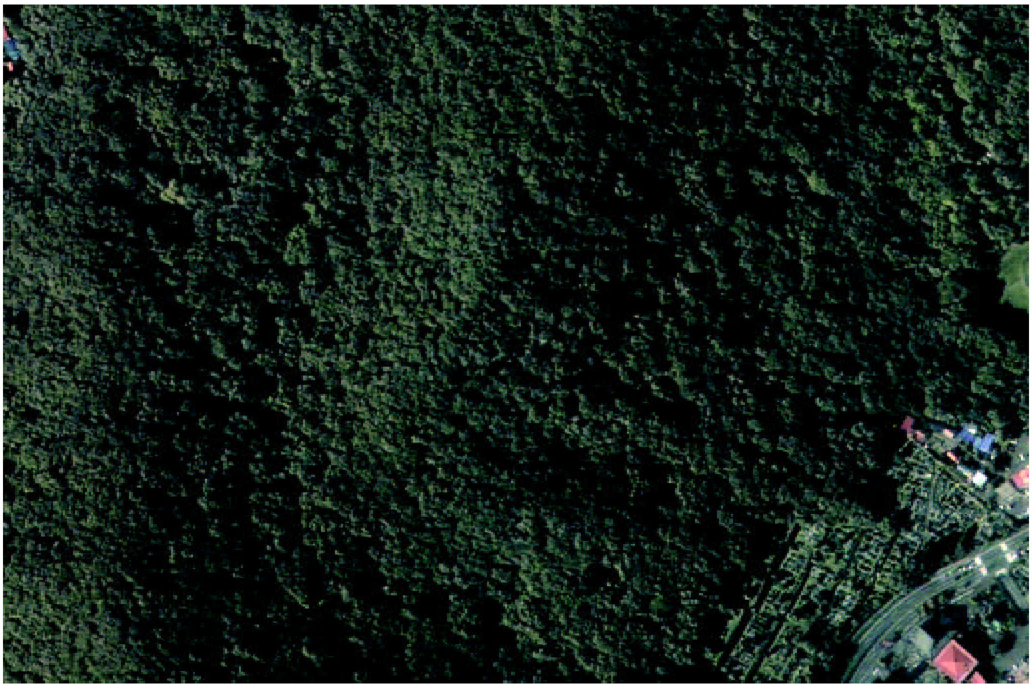


Fig.1.17 1-meter color image of IKONOS

6. Conclusions

Advancement in space and computer technology has greatly facilitated the wide applications of remote sensing, geographic information system and global positioning system. They have become important tools in the production and management of forest resources in developed countries. However, in developing countries like China, the economy and technology are not so advanced and the management works are mainly done by backward investigation method. We hope that these techniques can be improved through our research works, so that they can be widely used in forest resource management and contribute to the social economic sustainable development.

7. Acknowledgments

The research described in this chapter was sponsored by National Forestry Administration, the Ministry of Science and Technology, Anhui Province, Zhejiang Province and Liaoning Province of the people's Republic of China. The work was carried out in the Qianshan County of Anhui Province, Jiangshan County of Zhejiang Province, Chaoyang region of Liaoning Province. We wish to acknowledge the contribution of Wu Jian, Shi Jin, Cui Hengjian, Tang Jian, Tu Jinbo, Wang Run, Chen Linhong, Yan Xiaojun, Sun Yongping, Feng Zhiqiang, Huang Jianwen and many others who worked during the course of satellite remote sensing.

Chapter 2

Monitoring Techniques of Forest Diseases and Insects with Airborne Digital Videography

1. Introduction

US forest service has been working with airborne videography as a tool for the detection of forest pest infestations since 1986. During the past fifteen years US forest service has standardized an off the shelf videography system. And now they have been developing more advanced systems. Based on the last videography system they replace the S-VHS video camera with high resolution digital camera and develop the electronic sketch-mapping system. Therefore the technique has been more perfect. Because of technical problems, it is difficult to use digital camera and electronic sketch-mapping in developing countries. Whereas the airborne digital videography can play important roles in forest healthy protection.

Airborne digital videography has proved to be an effective remote sensing tool for resource managers. Some of its major benefits can be described as following:

1) video data provides a permanent record conditions at the time of the detection, and hence eliminate the subjectivity of the observers,

2) cost of video imagery is far less than conventional frame photography,

3) video operator can view £¢Live £¢ imagery in the aircraft as the imagery is being collected, thereby vastly improving the quality of the data according to different terrain,

4) video operator can record real-time GPS position data input as the video data is being collected, and

5) the convenience for computer progressing

The practical application has found digital video to be useful but there are some technical barriers to overcome. The primary barrier is the high cost to mosaic and geometrically correct the digital video data due to the long time needed. Therefore we can only process the single frame with ERDAS image processing system now to extract the position information of damage areas or points.

Aerial sketch-mapping is the main method to detect forest diseases and insects all along in those countries with vast forests, such as USA and Canada. Limited by national power and other factors, the developing countries have been adopting the ground investigation method. Facing the invasion of fatal disaster, such as pine wood nematode disease (*Bursaphelenchus xylophilus* Nickle), pine needle hemiber lesian soale (*Hemiberlesia pitysophila* Takagui), Loblolly pine mealy bug (*Oracella acuta* Lobdell) and American white moth (*Hyphantria cunea* Drury), our current method is so helpless. With the diffusion of disaster region and the lack of precise detection, the loss is so heavy in China that it has endangered the ecological security in many world-level heritage protection regions, such as Huangshan Mountain, Jiuhua Mountain. Therefore, currently the most crucial task is to solve the problem of precise detection and dead tree cleaning. In order to conquer the defect of aerial visual sketch-mapping and aerial photography, USFS has begun the research in the field of aerial videography and aerial infrared digital camera since mid-1980s and has achieved satisfactory progress. China introduced this technology at mid-1990s and gradually solved many technological problems in practice. Aerial video technology has the advantage of mobile flexibility and real-time detection. Therefore, it has been one of the approaches to detection of forest diseases and insects in many countries.

2. Equipment needed by video acquisition system

2.1 The flight acquisition system

•Video Camera

Sony DCR VX-1000E (or another DV enable video camera system) with IEEE 1394 (Fireware, Ilink) interface

•Camera Mount

The mount provides a stabilized, vibration-free, rigid, vertical camera port. It allows the camera to be mounted vertically inside the aircraft within the camera port, providing an unobstructed field of view to the ground below.

The mount provides the ability to rotate¡À45 degrees around the vertical axis of the camera lens centerline, thereby allowing for correction due to aircraft drift from cross-winds. Furthermore it allows the ability to rotate¡À10 degrees about the lateral axis of the field of view to correct for tip. Finally, it allows the ability to rotate¡À5 degrees about the longitudinal axis of the field of view to correct for roll.

•Video Monitor Panasonic BT-S1000N AC/DC color monitor

The on-board color monitor is Panasonic BT-S1000N AC/DC. It is used in place of an electronic viewfinder that would have had to be mounted on the camera and would have been difficult and uncomfortable to use, give the camera's vertical mounting. The aerial videographer used the monitor to verify what imagery was being acquired.

•GPS Equipment

Any GPS receiver capable of output data with one time per second. It should be noted that navigation equipment and positioning receivers must be equipped.

We use GARMIN GPS 195 portable receiver to navigation and positioning in the flight and the field. Trimble GPS 132 receiver is used to precisely position for airborne video data.

•Attitude Sensor

The Watson Industries attitude sensor (ADS-C232-1A/18) is used to measure the tip and roll angle of the aircraft during video acquisition. The data can be used to improve the imagery geometrical characteristics.

•Horitor Time Code Generator

The Horitor Time Code Generator (GPS_3_USFS) ties the GPS and attitude data together and encode the information onto the digital video tape using SMPTE time codes. It generates its own caption that can be display on screen.

2.2 The ground image processing system

•PC computer

PC Pentium III 550, with a minimum of 128MB of RAM for Windows 98 or Windows NT server 4.0, a minimum of 128MB of RAM for Windows 2000, a minimum of 20GB of hard disk, and 24-bit color graphics card.

•IEEE 1394 Interface Card DV 500 IEEE 1394 interface card

The DV 500 processes analog (S-Video, Composite video) and digital (DV, IEEE1394) signals via corresponding inputs and outputs.

•Software ERDAS, ARC/INFO, GPStran and so on.

2.3 Airplane type

All kinds of airplane are suitable. But for lowering cost, we prefer light plane or small plane.(seeFig.2.1)

a) Yun-5 airplane of China

b) Haiyan light plane of China

Fig. 2.1 Small planes in monitoring and protection of forest insects

3. Technical process of aerial digital videography

3.1 Aviation preparation and airline design

It is required to mark precisely the detection region on large-scale topographic map; provide the aviation parameters, including aviation height, coverage area and aviation intervals, and so on; finally, with special software, calculate all waypoints and preliminary points that can be directly uploaded to the GARMIN navigation receiver after compilation.(see Fig.2.2)

In general, to assure the airplane to correctly enter predetermined course, according to the velocity difference

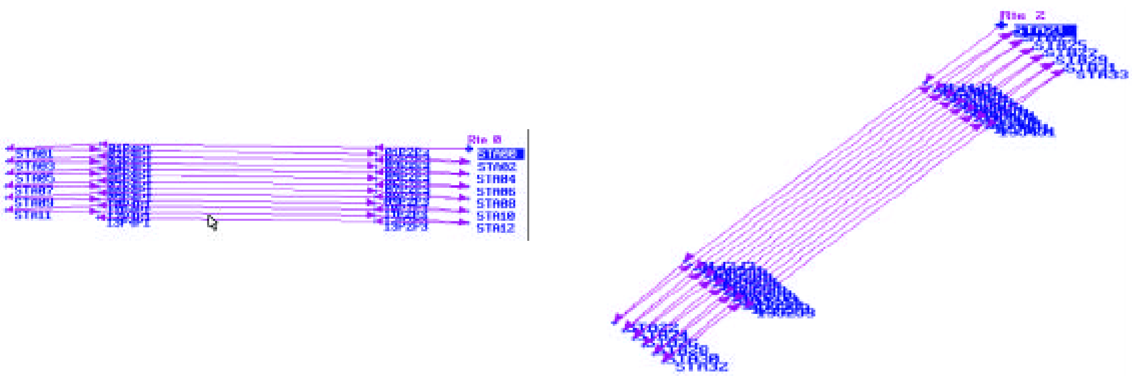


Fig. 2.2 Flight line and waypoint designed by thematic software

of airplane, the adjustment region with some lengths are necessary. The length of adjustment region of Yun-5 airplane is 3 kilometers .

If the data can not be uploaded into computers, all waypoints must be printed and passed to the pilot.
3.2 Installation and test of aerial video data acquisition system

Data collection part of airborne video detection equipment mainly includes digital camera, GPS receiver, attitude sensor, coding/decoding instrument, monitor, power adapter etc. These equipments should be installed stationary position of airplane in terms of work need. Most of the equipments apply the DC provided by airplane. Of course, the storage cell is also of better choice.

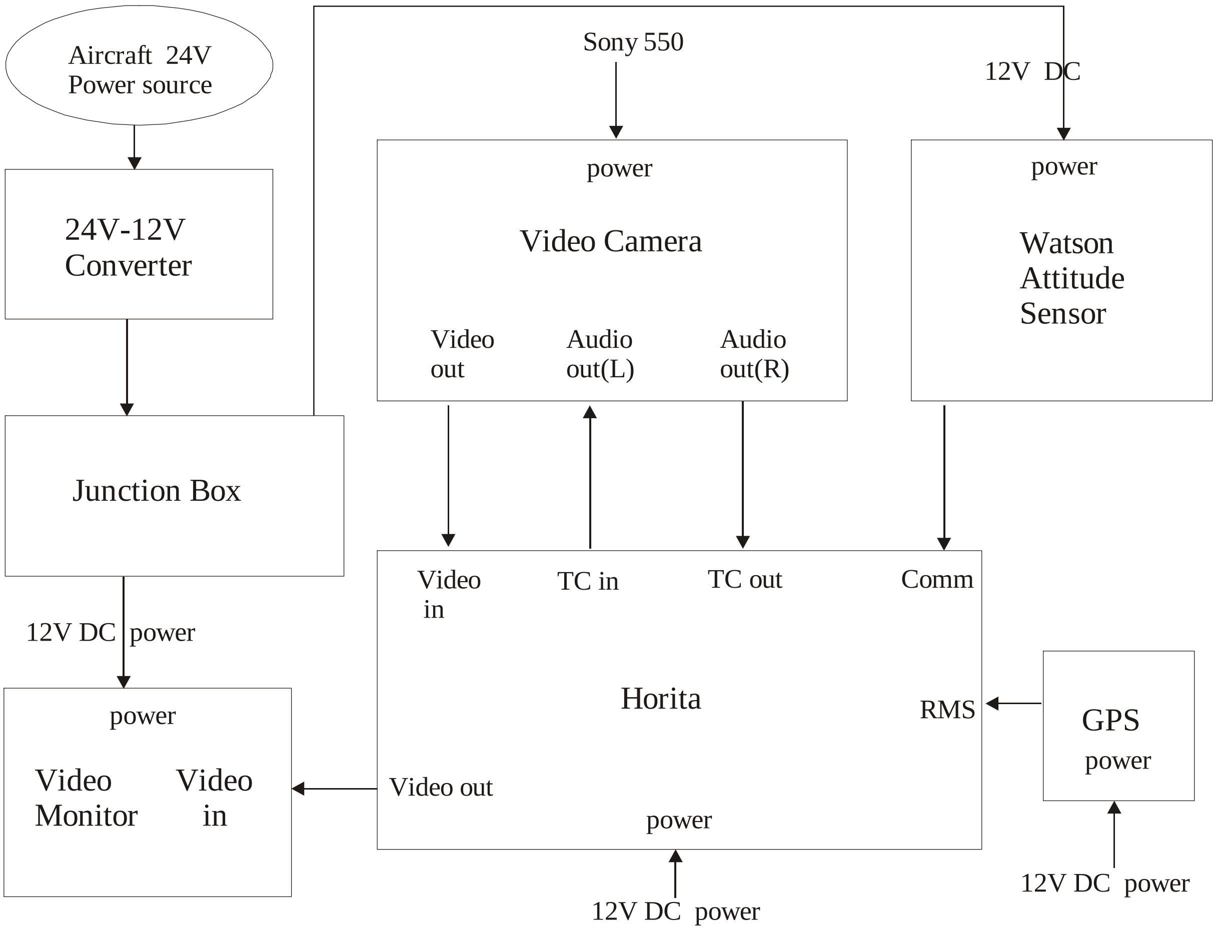


Fig. 2.3 Airborne video camera acquiring system

Most of the aerial video detection equipments apply 12V DC, ASTRON 2412-20 power convertor is used to convert 245-28V DC to 12V DC. Electrical trunks line box mainly distributes the 12V DC provided by the power convertor to each image collection unit. Fig.2.3 is Technological process of data acquiring.

3.3 Collection of video data

According to the navigation information or the notification information of the pilot entering or exiting work areas, open and close camera in time. When the plane fly stably and before the data of each flight is recorded, the attitude should be reset.

Because of no high resolution DEM, the attitude's low sensibility and lack of stable application software, we can not automatically mosaic the image data at present. Considering obvious terrain in forest region and the difficulty of maintaining the aviation height, the focus should be adjusted momentarily to ensure a stable range of ground coverage.

4. Indoor processing of video data

4.1 Extraction of GPS data of flight line

In the design of this system, the data of flight track and attitude is recorded on audio channel at stable rate. For the precise positioning of image, GPS data must be outputted by special software. Fig.2.4 is technological process of data reading.

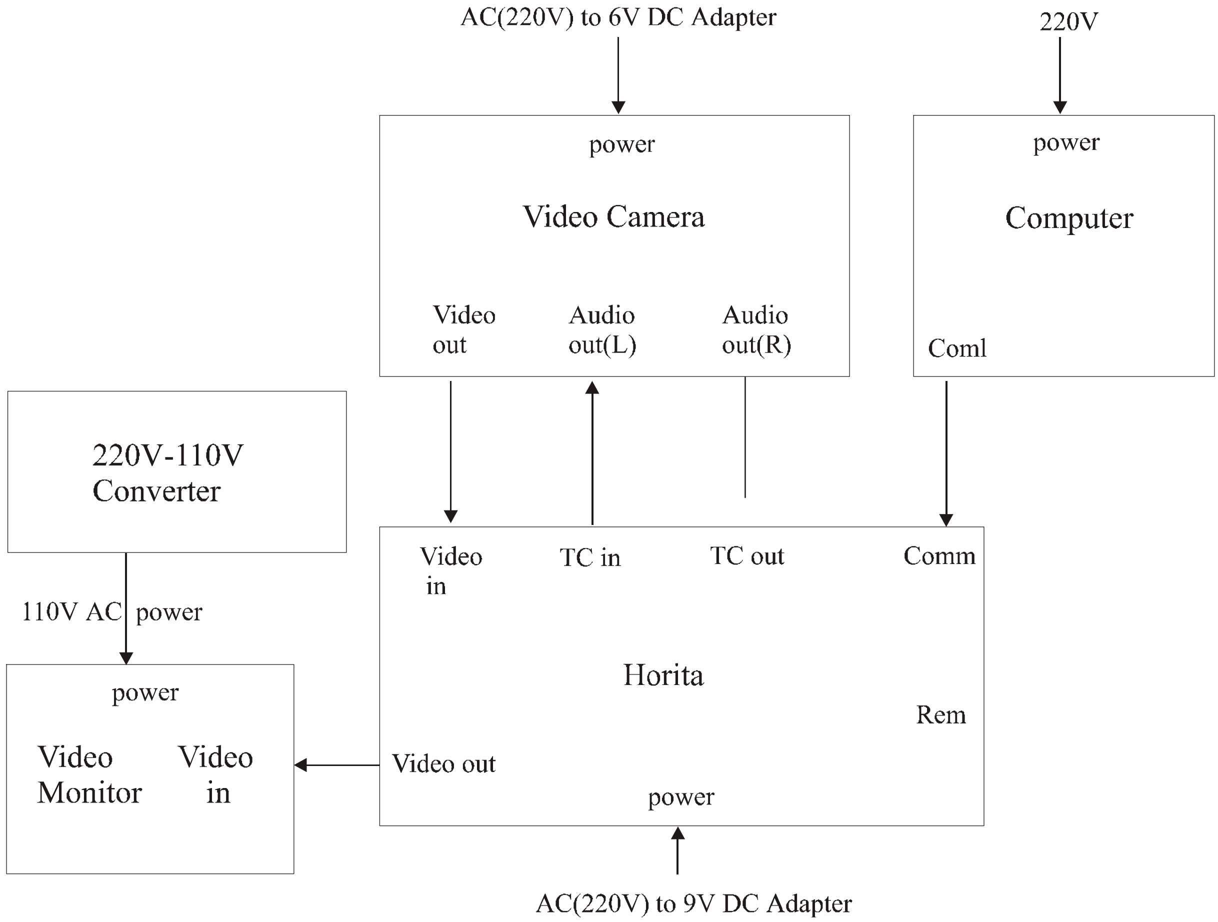


Fig. 2.4 Reading of GPS data

4.2 Projection transformation of flight line data

The transformation was done between WGS-84 coordinate system and 1954 Beijing coordinate system in China with special software so that users can analyze the disaster data by integrating with other GIS data.

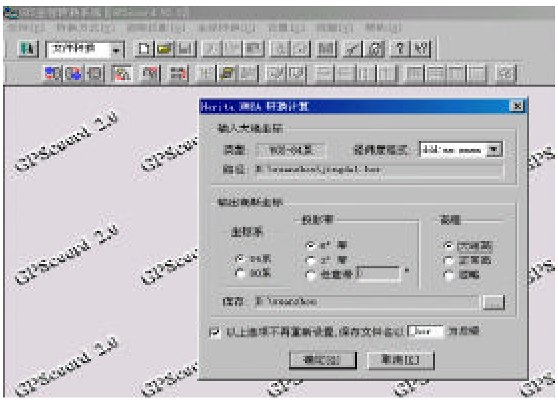


Fig. 2.5 Interface of data transformation

4.3 Extraction and positioning of disaster data

From a theoretical view, images can be mosaicked with highly precise DEM data. But for many reasons, the application prospect is not so evident. The only thing we can do is to provide real-time, precise disaster information to satisfy the need of forest production. Now we extract the forest change region mainly by viewing first, then make special process and analysis to these regions. Then we can calculate image size by home-made software. And ERDAS image process system can be used to extract damage information. Fig.2.6 is the process of data processing.

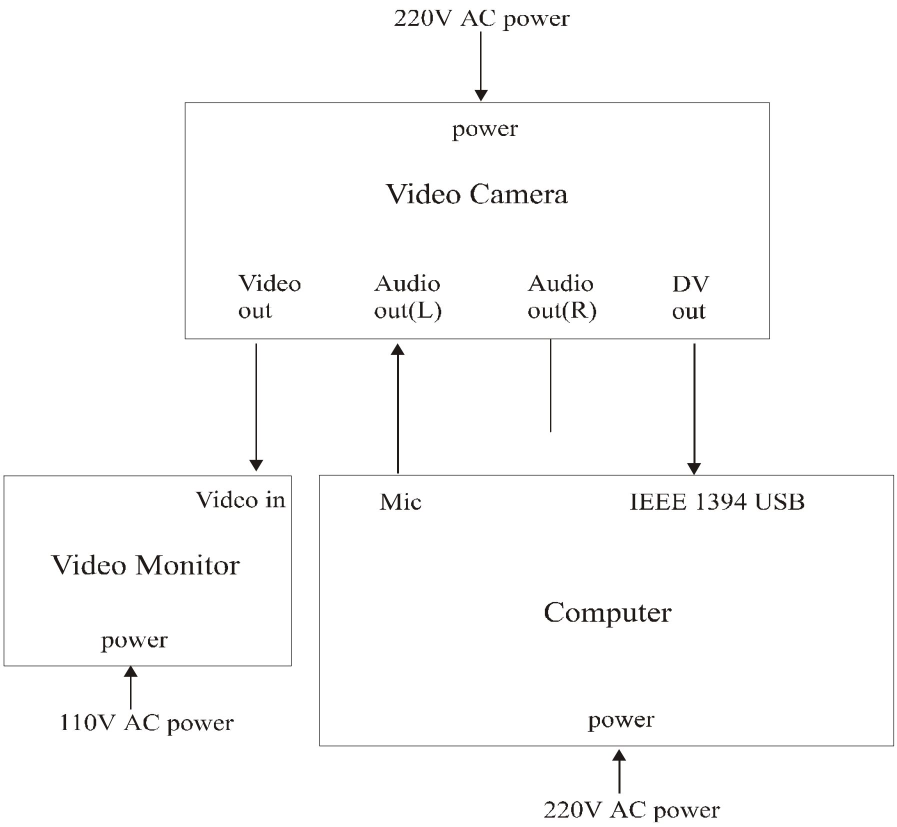


Fig. 2.6 Reading of damage data

4.4 Output of disaster point and disaster areas

Because the information extraction of disaster point and disaster region mainly depends on the vector model in ERDAS, coverage file can be easily converted to the data format file.

5. Key technology of airborne digital videography

In the practical application, we should commendably resolve the following problem to accurately, timely, and effectively detect the forest pest damage.

5.1 Automatic design of flight line

The quick calculating and uploading of flight line is an important factor to improve work efficiency and reduce the cost.

5.2 Conversion of GPS data

Airborne digital videographic system is actually a integrated system of GIS, GPS and remote sensing techniques. The accurate data transformation between GPS and GIS is also very important.

5.3 GPS and video data's synchronous search technology

To ensure the synchronization between GPS data and video frame is the key technique in the image processing.

5.4 Rapid repositioning of disaster areas

Base on GIS, we can output the location information of damage areas and damaged single tree. And we can find them in the field with GPS receiver.

5.5 Damage classification technology

We can quickly extract the damage infomation with monitoring models.

6. Application of airborne digital videography

In 2000 and 2001, we respectively took four detection tests of pine wood nematode disease (*Bursaphelenchus xylophilus Nickle*) and pine caterpillars in Huizhou City of Guangdong Province, Xuancheng region of Anhui Province, Nanning region of Guangxi Zhuang Autonomous Region and Huangshan City of Anhui Province. During these tests, we got much precious experience and data that are valuable for the improvement of system function.

6.1 Detection test of individual dead trees

Pine wood nematode, known as pine cancer, has cost tremendous loss in the world. Because of its infectivity and truculency, it is difficult for current ground investigation method to find the early affected individual trees and control them timely. As a result, the disaster diffuses and the loss aggravates. So it is significant for the protection of environment to find and clean wilted stumpage as soon as possible. The aerial detection method becomes the best way to implement real-time forest health detection. Though it is impossible for modern remote sensing technique to precisely distinguish the harm of different diseases and pests, the technology has active sense in reducing investigation range and grasping development status. Therefore, all levels of production departments have high ardor and expectation for developing effective and applied aerial remote sensing detection technology.

Several images beneath show the wilted stumpages under different terrain and plant composition condition. They illustrate that airborne digital videography technique can precisely assess the current status and quality of single tree.

Limited by technology, local units can not utilize image processing system and GIS to analyze and visualize vector and raster data. However, in order to facilitate the field detecting, trace and hazard point data can be overlaid with topographic maps and the result can be in TIF format so that more direct information can be achieved.

Fig.2.7, Fig.2.8, Fig.2.9, Fig.2.10 are the frame images of airborne video system. Fig.2.11, Fig.2.12, Fig.2.13 are the monitory results map in Anhui Province.

Fig.2.7 Individual dead trees

Fig.2.8 Dead trees on top of cliff

Fig.2.9 Dead trees on barren grass slope

Fig.2.10 Standing tree that is just dead

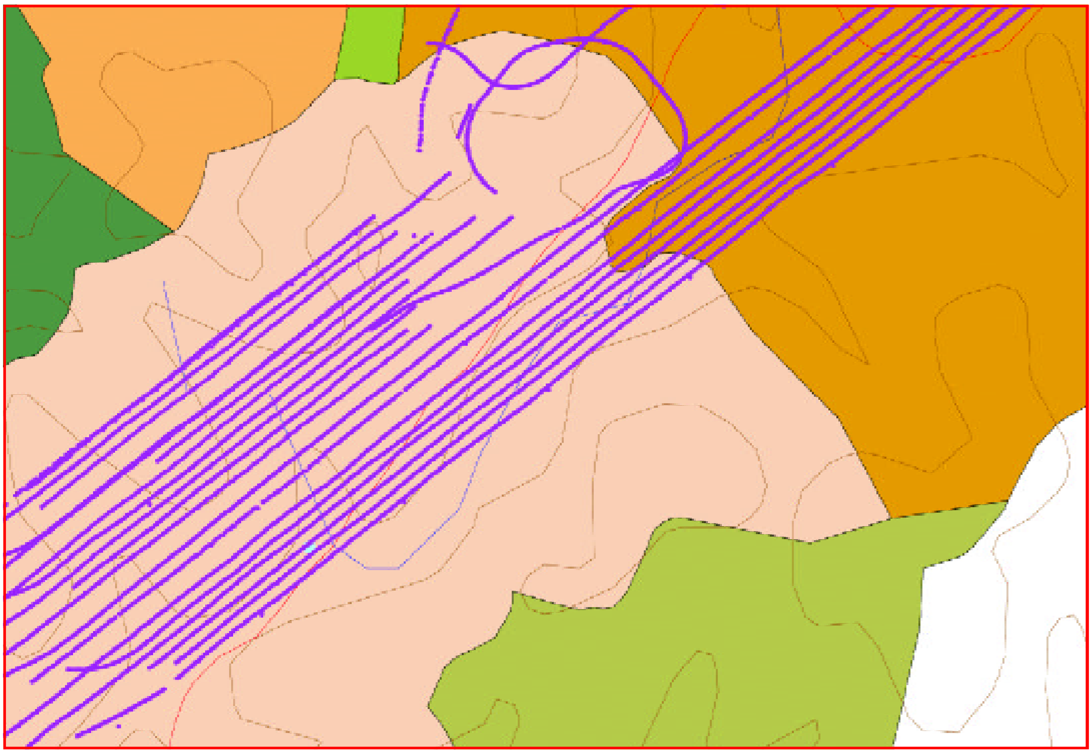


Fig.2.11 Overlay of the track point with thematic map

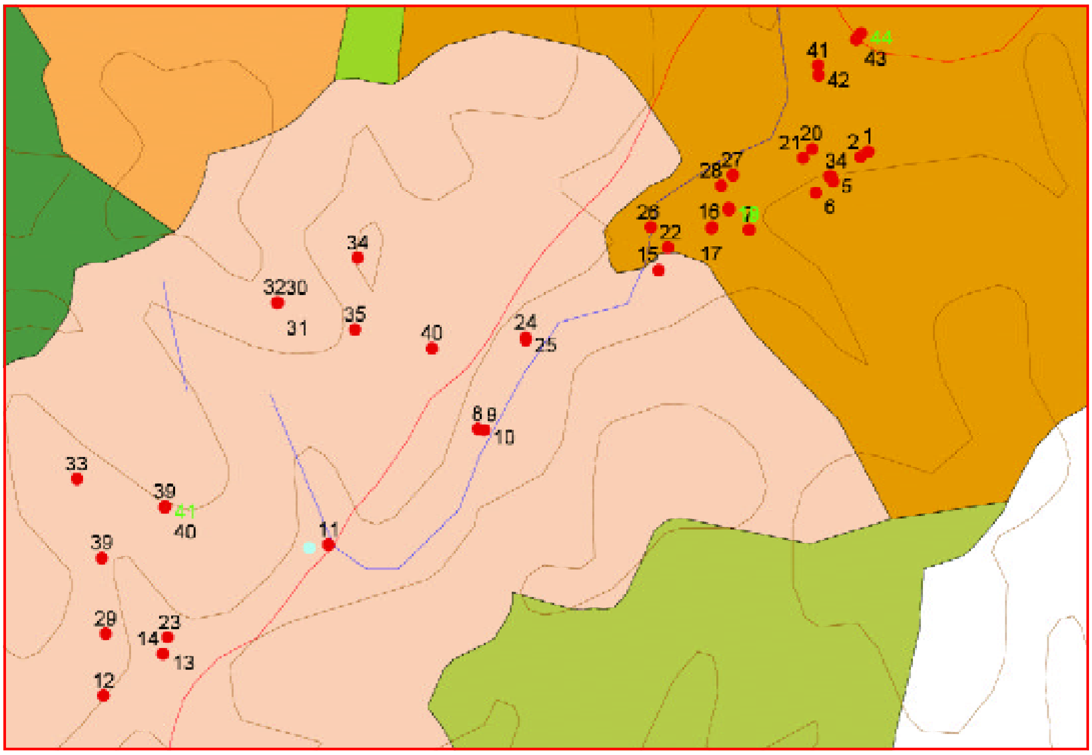


Fig.2.12 Overlay of single dead tree and themetic map

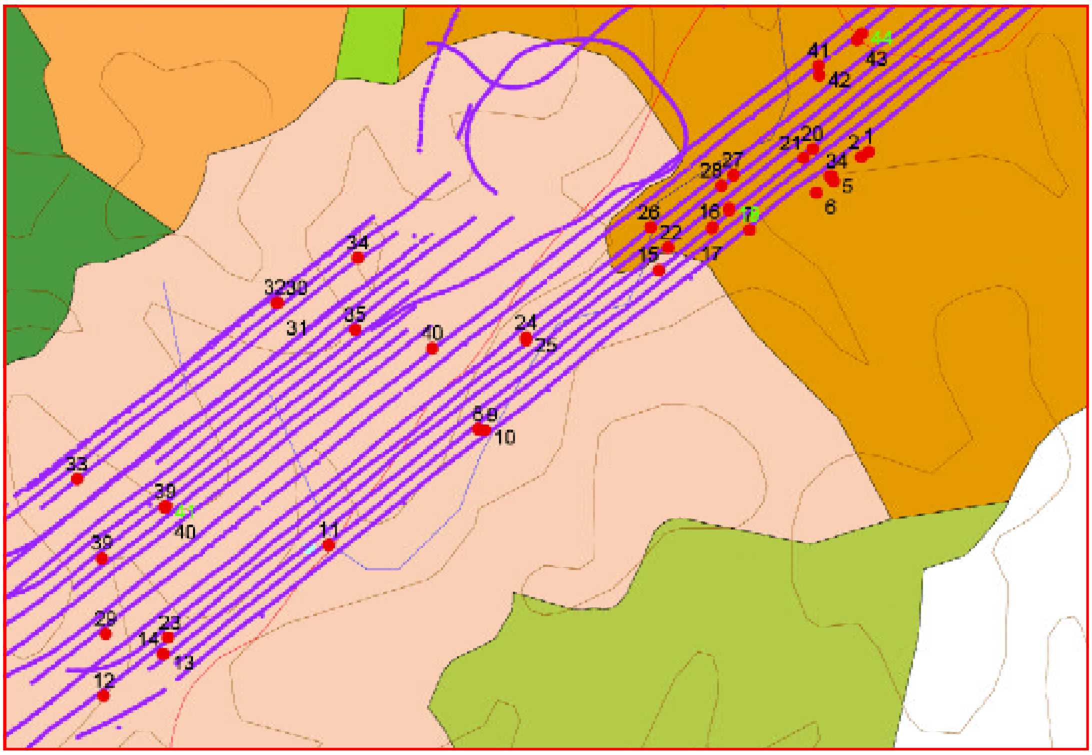


Fig. 2.13 Overlay of frame center, dead tree position and thematic map

After acquiring hazard data, ARC/INFO's ungenerate command can be used to output coordinates of hazard points.

1	674893.0625	3365094.25
2	674401.0625	3364422.25
3	673377.0625	3362374.25
4	672509.5	3360564.5
5	672649.5	3360564.5
6	675367.0625	3364858.25
7	675209.0625	3364766.25
8	674809.0625	3364206.25
9	674133.0625	3362862.25
10	673141.0625	3361346.25
11	673616.5	3361557.5
12	673623.5	3361576.5
13	673643.5	3361601.5
14	672296.0	3364192.5
15	672893.0625	3364774.25
16	672709.0625	3364600.25
17	672627.0625	3364624.25
18	668399.0625	3356800.25
19	668095.0625	3356522.25
20	667243.0625	3354530.25
22	672760.0	3364152.5
24	667527.0625	3354510.25
25	673252.0	3363444.5
26	673530.0	3363892.5
27	673532.0	3363904.5
28	674105.0625	3364354.25
29	673703.0625	3363810.25
28	668851.0625	3355164.25
29	670022.0	3356876.5
30	670036.0	3357066.5
31	670092.0	3356966.5

END

And then to transform them into WGS-84 coordinates with GPStran, and they can be used in navigation (see following figure).£.

Serial number	Spot name	Latitude with WGS-84	Longitude with WGS-84	Change reason
1	1	3015.9588	11841.2166	
2	2	3015.9451	11841.2762	
3	3	3015.9254	11841.2908	
4	4	3016.2938	11841.7996	
5	5	3016.6704	11842.423	
6	6	3016.0947	11841.758	
7	7	3016.1032	11841.7656	
8	8	3016.0934	11841.6906	
9	9	3016.0628	11841.7101	
10	10	3015.9821	11841.594	
11	11	3015.424	11841.7332	
12	12	3015.072	11841.3332	
13	16	3016.0204	11842.4424	
14	17	3016.1121	11842.7158	
15	15	3014.7089	11841.1301	
....	....	....	....	

Fig. 2.14 Investigation table for field detection

6.2 Detection disaster in vast region

In the zone of equator or sub-tropic, for plenty of rain, it is difficult for traditional optical remote sensing data to detect forest insects and diseases, that is to say, the data can not be sufficiently ensured. Therefore, in order to periodically monitor the forest quality, aerial remote sensing technology is necessary. So we began our detection research and experiment to masson pine caterpillar in Guangxi Autonomous Region in China and made great progress.Fig.2.15, Fig.2.16, Fig.2.17, Fig.2.18 are the stand images of damage areas. Fig.2.19 is damage map of Guangxi.

7. Acknowledgments

The research described in this chapter was sponsored by National Forestry Administration, Anhui Province, Guangxi Zhuang Autonomous Region and Guangdong Province of the People Republic of China. The work was carried out in the Xuancheng region, Huangshan region of Anhui Province, Nanning region of Guangxi Zhuang Autonomous Region, Huiyang region of Guangdong Province. We wish to acknowledge the contribution of Wu Jian, ShiJin, Xue Zhennan, Chen Murong, Tang Jian, Jiang Liya, Luo Jitong, Wang Fugui, Yang Xiuhao, Ma Shengan, Zhang Hong, Zhang Zhijian, Gao Shu, Ma Xiaoming, Li Shiming, Zheng Wei, Chen Jiwen, Xie Cheng and others whoworked during the course of airborne videography.

Fig. 2.15 Stands with less than 30% needle loss (Yellow green region)

Fig. 2.16 Stands with 50% need loss (Orange region)

Fig. 2.17 Stands with 70% needle loss (Brown region)

Fig. 2.18 Stands with above 90% defoliation (Dark brown region)

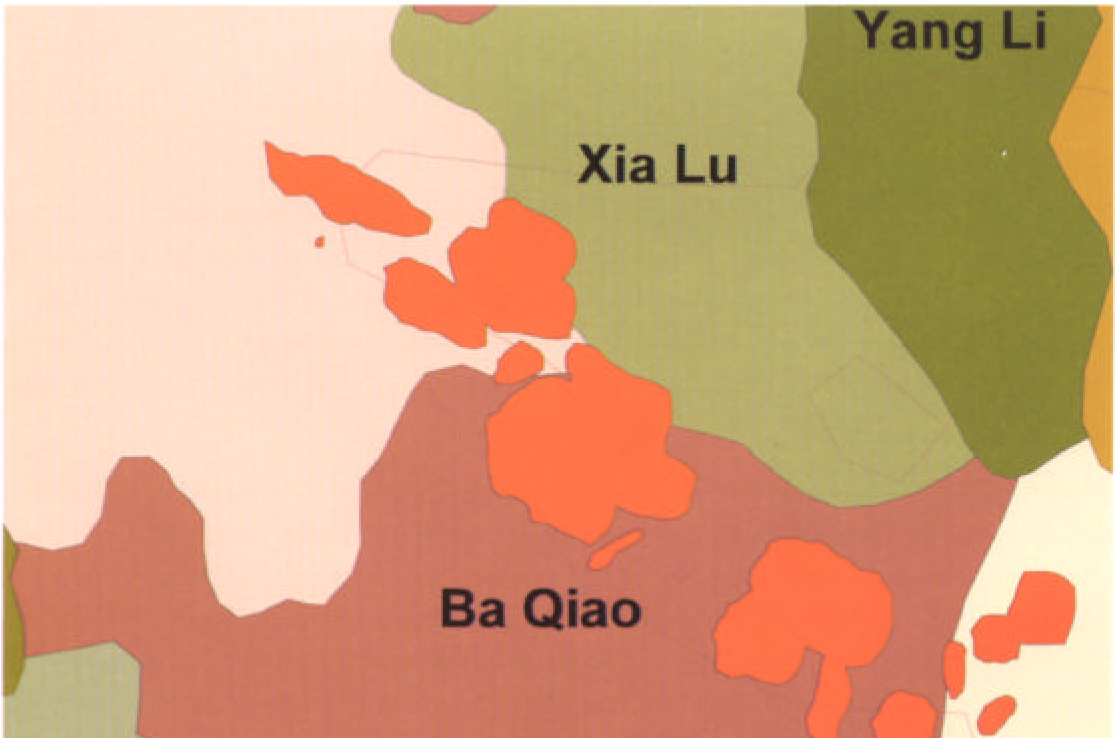


Fig. 2.19 Overlay of damage area and thematic map

Chapter 3

GPS and Its Application

GPS, Global Positioning System, is an advanced technique well developed and widely applied in recent years. By receiving the signals from the GPS satellite, it is easy to get the three-dimensional position information for any point on the earth. Because of its ability of all-weather, global, three-dimensional positioning, the coordinate system used should not be a local coordinates of any country or region, but a global coordinates. At present, the coordinates used by GPS is WGS-84, which is a global uniform geographic coordinates. WGS-84 belongs to protocol coordinate system and its origin located at centroid of the earth is also perfectly defined.

An important problem in GPS measurement application is to determine the difference of benchmark of geographic measurement between local coordinate system (for example, China 1954 Beijing coordinate system and 1980 national coordinate system) and global coordinate system and take transformation between them. In order to get highly precise absolute position and navigation, we have developed a GPS coordinate transformation software with Visual C to process the data rapidly. Because of the difference among the independent coordinate system in different country, the error among the coordinate systems should be seriously treated during the application of GPS data. In other word, if higher precision is required, the coordinate transformation is necessary.

In order to apply GPS in precise detection and controlling forest damage, we have developed the GPS coordinate transformation software and flight line design software, and so on.

1. GPS coordinate transformation system software

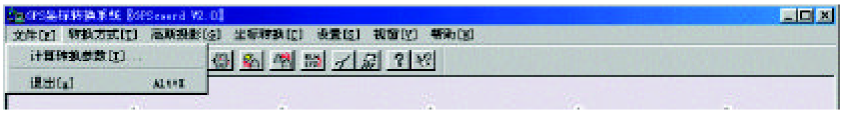
This software has a friendly user interface and can be directly installed on the computer with Windows 95, Windows 98, and so on. The following figure is a illustration of the interface.

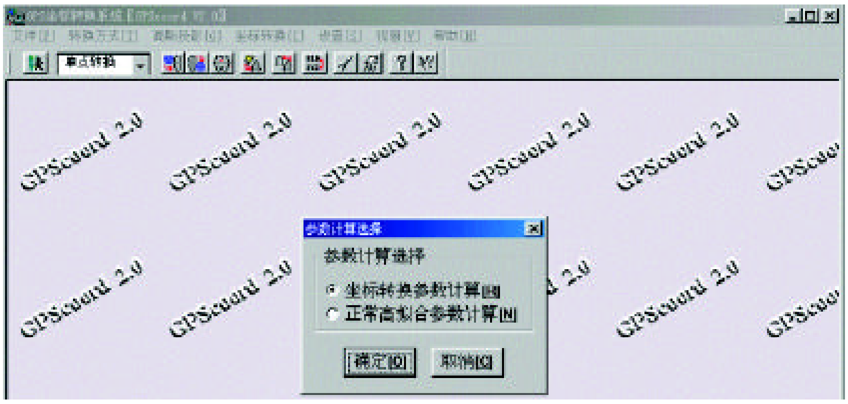
In terms of the difference in the data transformation mode, this software can be divided into two parts: single point mode and file mode, and their functions also vary respectively.

1.1 Main function of single point transformation mode

1.1.1 Calculation of transformation parameters

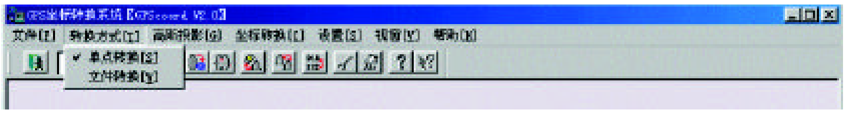
This software sets the lower precision coordinate and elevation transformation parameters that are suitable for country range as default parameters inside. At the same time, it provides users the interface to calculate local coordinate and elevation transformation parameters. Users take coordinate and elevation transformation in local region with data existed to get a special transformation parameter as local value that will be used in high precision transformation





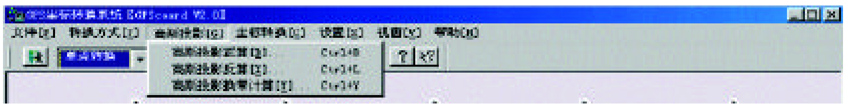
1.1.2 Choice of transformation mode

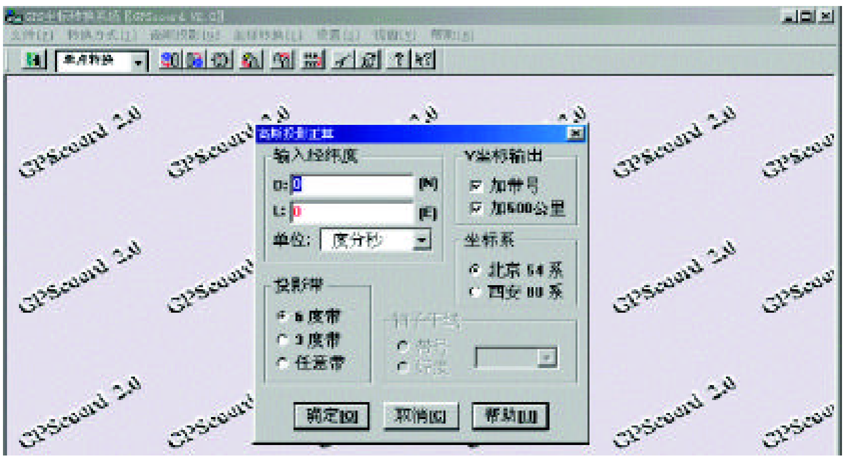
According to the magnitude of data, users can choose different data organization mode.

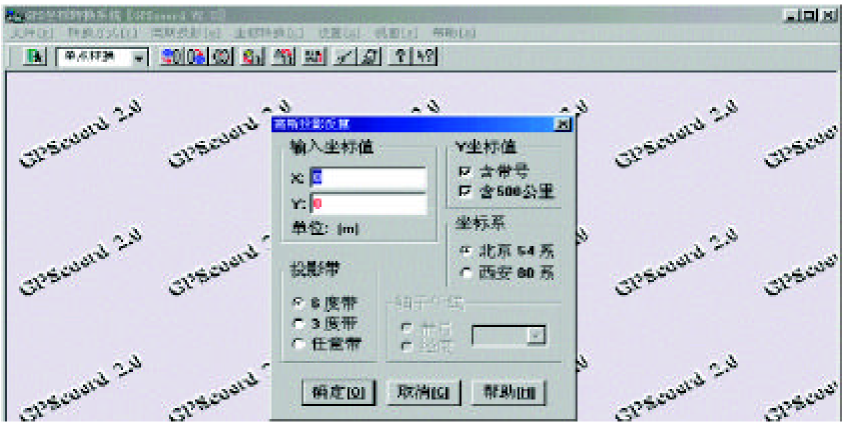


1.1.3 Gauss projection's positive and negative calculation and zonal change calculation

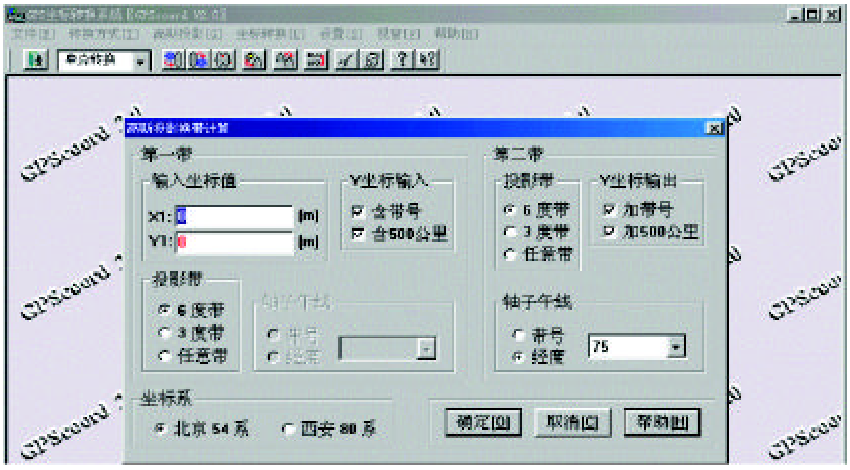
The topographical map series in each country adopt UTM or Gauss projection mode. Because topographical maps are often basic map for management in forest production, the problems of positive and negative calculation to coordinate often occur.





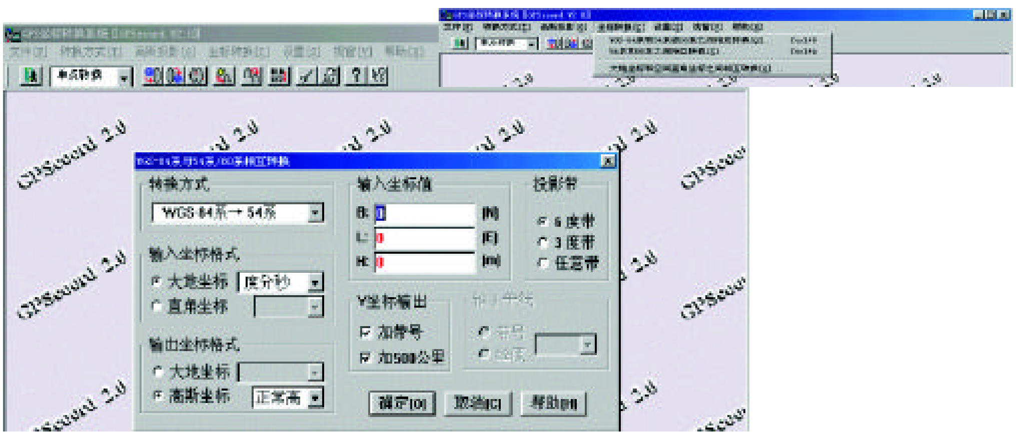


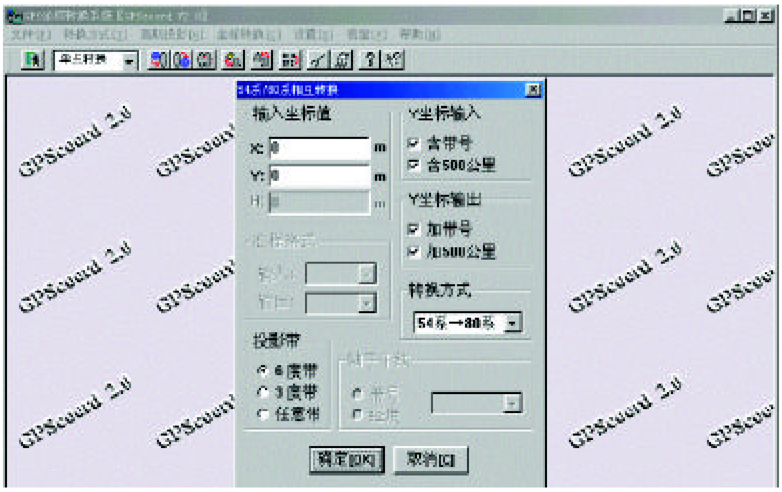
Because the UTM and Gauss-Kruger projection adopt zonal projection mode and has distinction between 3 degree zone and 6 degree zone, users will encounter the problem about the right angle coordinate system when they use the different scale topographical map or make operation at the edge of different zone. For the facility of analysis, it is necessary to make the zonal transformation calculation to uniform the coordinate system.

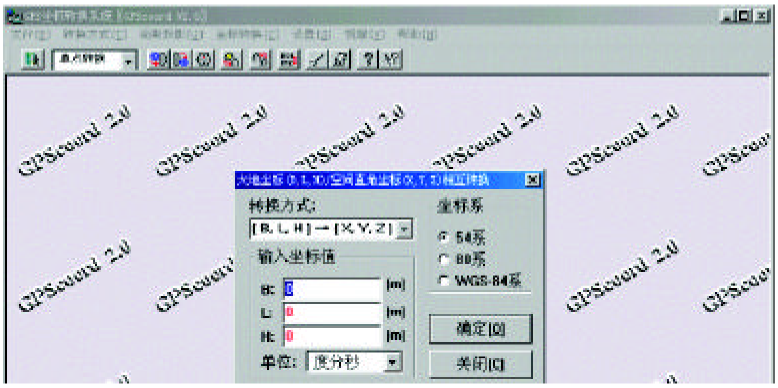


1.1.4 Cross transformation among WGS-84, Beijing 1954 and Xi'an1980 coordinate system

Because the topographical map surveyed at different time adopt different coordinate, users often confront the problem of transformation and joining. We must resolve the problem that exits in the high precise cross coordinate transformation of geographic coordinates, Gauss-Kruger coordinates, spatial right angle coordinates among different systems.

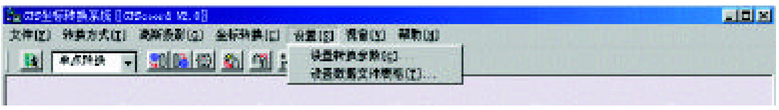


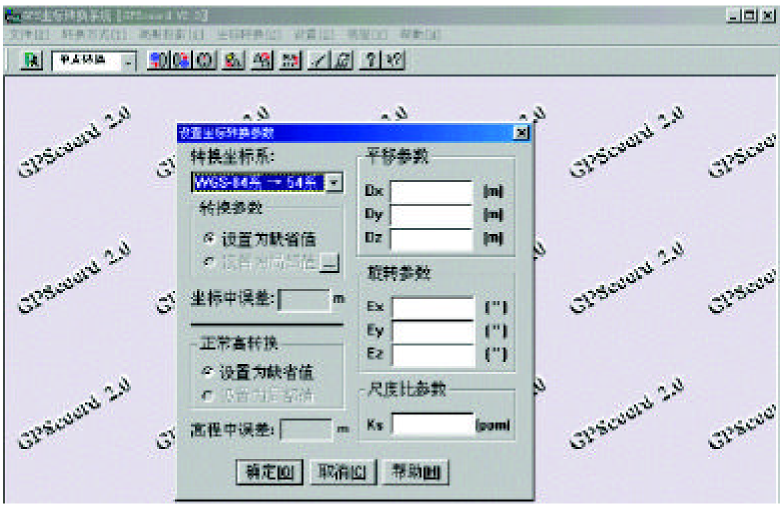




1.1.5 Setting transformation parameters

Users can set the coordinate and elevation transformation parameters (for example, provided by the third attendee) as default value or local value.





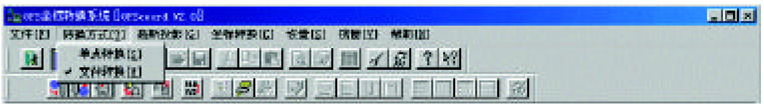
1.1.6 Setting data file table

For the facility of understanding and output, users can make diverse setting for the data table.

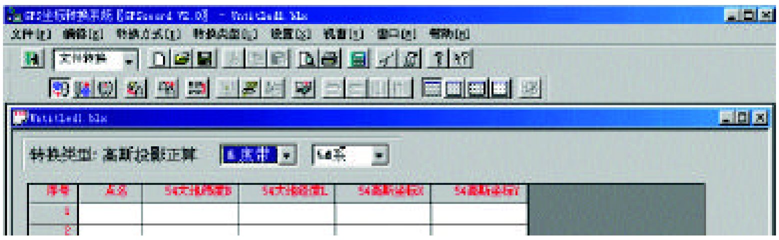
1.1.7 Windows and Help

Convenient tool buttons and illustration for help.

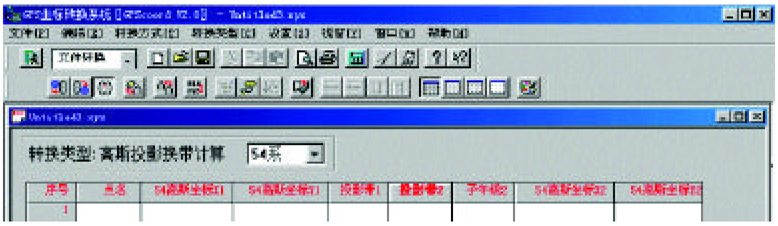
1.2 Main function of file conversion mode



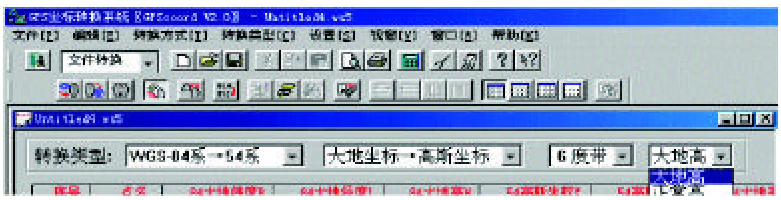
1.2.1 Gauss-Kruger projection's positive and negative calculation



1.2.2 Gauss-Kruger projection's zonal change calculation

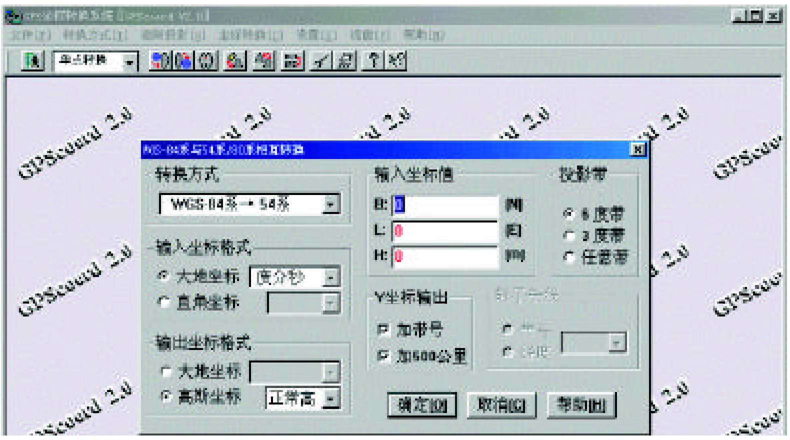


1.2.3 Cross transformation among the three coordinate systems

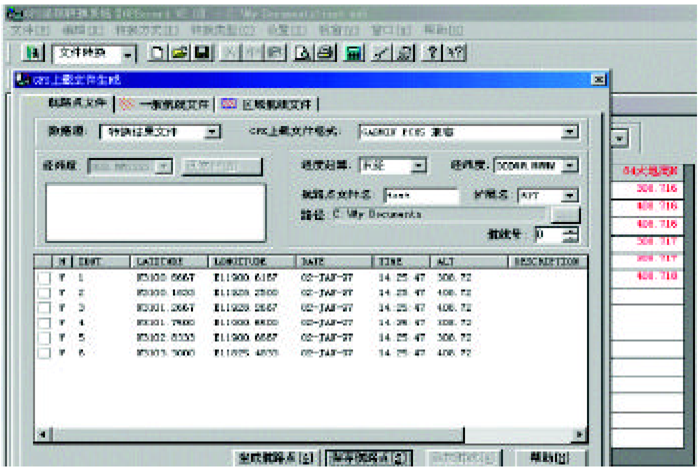


1.2.4 Conversion NMEA-0183 real-time outputting data to 54 or 80 system

The main aim is to realize the integrity of GPS and GIS through converting the 0183 data provided by GPS receiver to plane right-angle coordinate system matching with topographical map data.

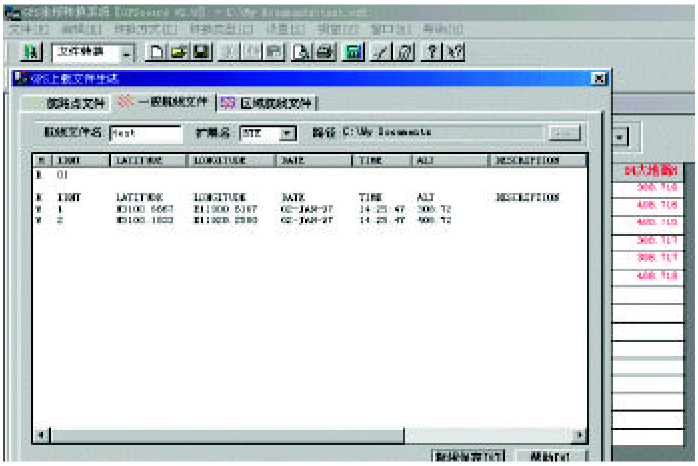


1.2.5 Calculation of GPS waypoint is the basic data for GPS navigation.



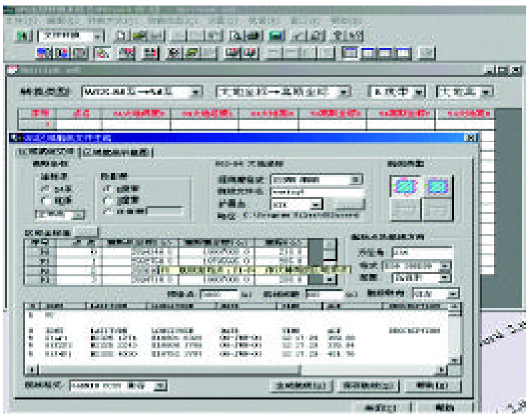
1.2.6 Calculation of flight line file with waypoint

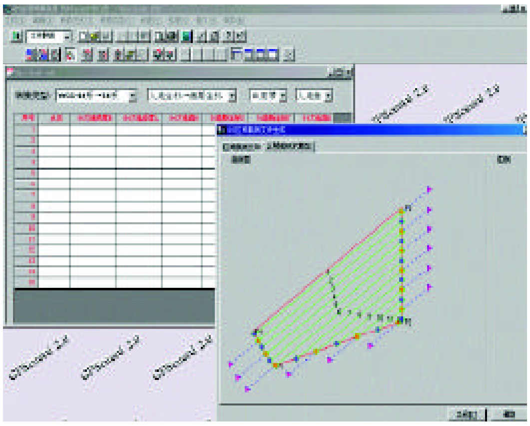
To compile flight line (or route) file with selected waypoint data.



1.2.7 Calculation of route file with flight line type

Forest flight task usually chooses its flight mode according to the topographic condition, such as double direction flight, single direction flight, interval flight, and so on. So different flight line sequence will come into being in the same task region with different flight type.





1.3 Upload of flight line and download of flight track

In forest production department, most users use the GPS receiver of GARMIN Company as navigation tool. Our receiver is GARMIN GPS 195, and the flight waypoint or flight route file can be directly converted to the data format (*.RTE) recognized by GARMIN receiver.

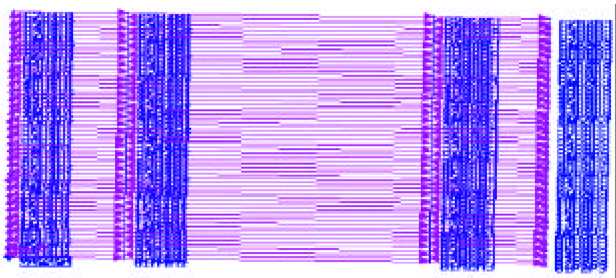
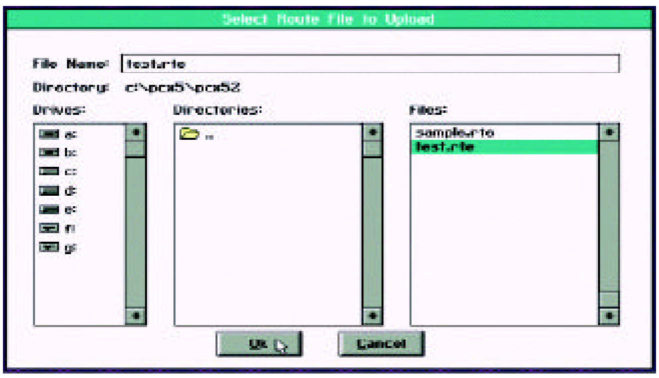


Fig. 3.1 Route, waypoints and preparatory waypoint



At the same time, we can upload the data (for example, flight track data) from the receiver for analysis.

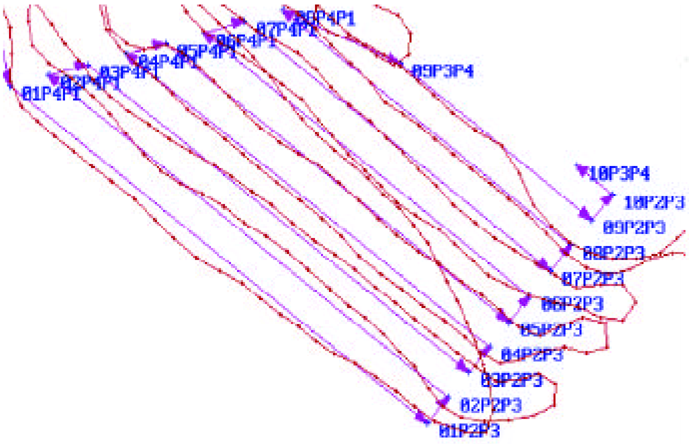


Fig. 3.2 Comparison of route and track

2. Differential GPS positioning

Since May 1st 2000, the United State has abrogated the SA policy, which promotes the precision of GPS real-time positioning from 100m to 15m or so, but for more precise positioning and navigation task (for example, air spraying), DGPS technology that is better must be adopted to improve the positioning precision to meter level or sub-meter level.

DGPS is a technology with base station at known point, amendatory value of observation were measured and conveyed to the mobile station through digital radio system. Mobile station observes the satellite pseudo-distance code that can be used for positioning calculation after differential amendment.

To well understand the GPS and the technology related with GPS and rapidly apply them in practice of the flight detection, preventing and controlling of forest diseases and insects, we used three suits of real-time dynamic differential GPS system whose basic components are displayed as follow:

Base station	NovAtel 3151R
Mobile station	Garmin 195 (Navigation), TRIMBLE AgGPS 132 (Positioning)
Digital radio station	TM32
Amplifier	RFA96£-35W
Antenna	full direction 15DB (used in base station)
	Knife antenna (used in mobile station onboard aeroplane)
	Scourge antenna (used inside forest)
GPS antenna	Mp surveying antenna (ST430 in base station, ST410 in mobile station)

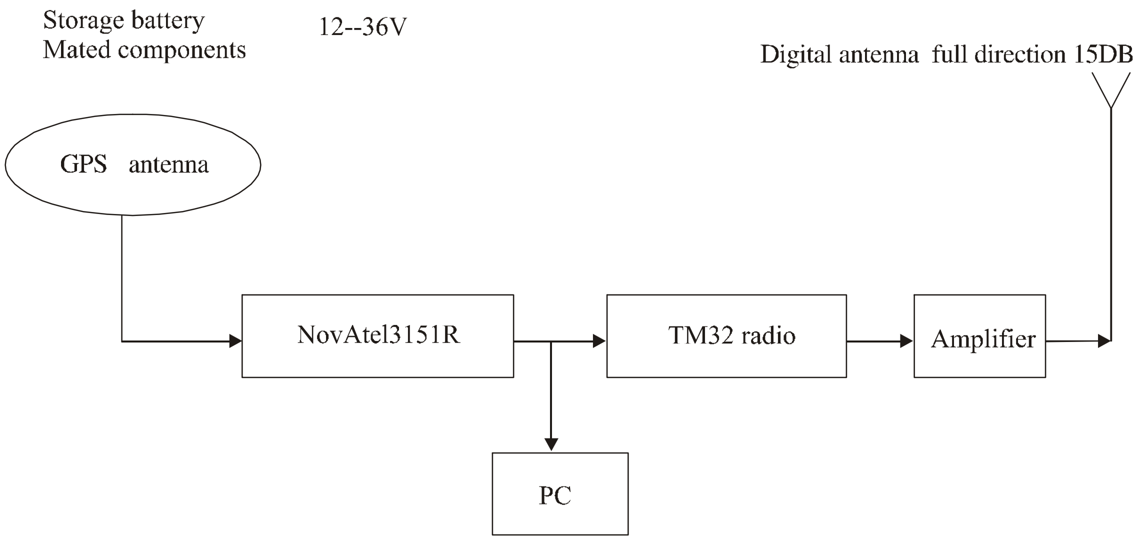


Fig. 3.3 The structure of the base station

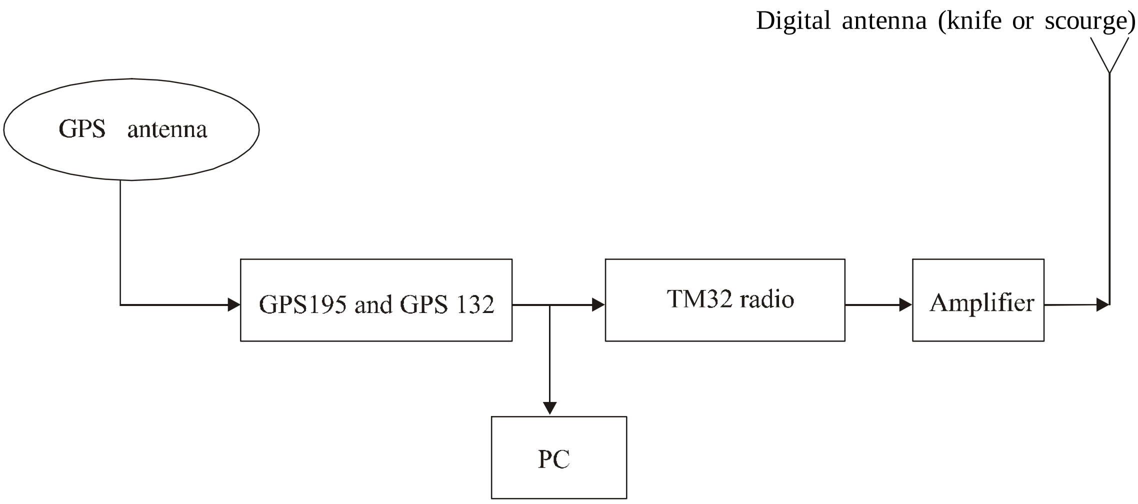


Fig. 3.4 The structure of the mobile station

GARMIN GPS 195 is a 12 channel navigation product, which obviously can satisfy our request of highly dynamic real-time navigation, and also mainly is used in navigation in practice. TRIMBLE AgGPS 132 receivers are combined with high-performance GPS reception with radiobeacon DGPS capability. Additionally, AgGPS 132 receiver contains The Choice™ technology, enabling OmniSTAR and Racal LandStar real-time differential capabilities. Users can get sub-meter positioning precision, so it is a good choice for high precision positioning.

For insuring the data quality and lowering error rate, high frequency communication equipment (frequency is 450-470Mhz) is adopted. Because its signal can be transmitted directly, it is especially suitable for air real-time navigation. The baud rate of data transmission is usually 9,600.

Fig. 3.5 DGPS and its application

3. Flight quality assessment

After the ground static, ground vehicle mobile, air flight mobile test of DGPS' software and hardware installed, we participated the practice of the flight monitoring, preventing and controlling of forest diseases and insects in many provinces in China, such as Anhui Province, Guangdong Province, Guangxi Zhuang Autonomous Region. Our tasks mainly lie in applying the DGPS technology in flight navigation to completely replace the traditional practice mode of manual navigation that costs so much manpower and material resources, and take flight evaluation to assure the quality of detection, prevention and controlling in terms of the recorded flight track data. Two figures beneath are two tracks in a practice of prevention and controlling, one is without GPS navigation(Fig.3.6) , the other is with GPS navigation. The flying quality greatly improves(Fig.3.7). Combined with GIS, we can get the precise position and range of regions that are omitted or repeated during spraying(Fig.3.8).

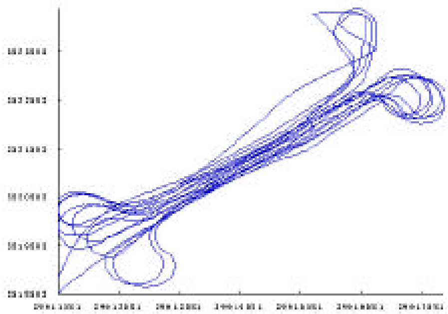


Fig. 3.6 Plane track in protection without GPS navigation

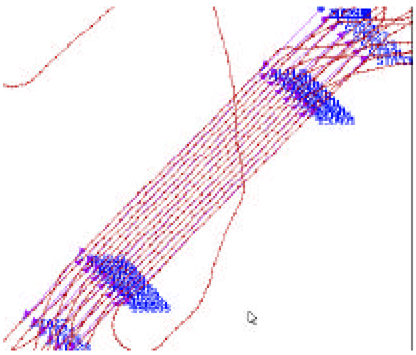


Fig. 3.7 Plane track in protection with GPS navigation (purple–designed flight line, red–flight track)

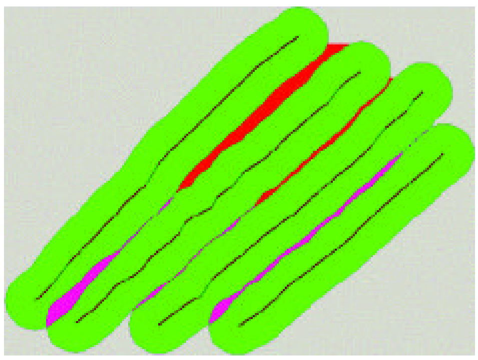


Fig. 3.8 Integration of GPS and GIS in flight assessment

4. Applications of DGPS in management of forest insects and diseases

Through whatever detection method, airborne or satellite remote sensing, we can get different scale hazard point or region. As for forest protection managers, sufficient information of disease and insects is important to choose correct prevention and controlling measure. How to rapidly and precisely determine the correct location where hazard happens and correctly analyze the cause is crucial to lowering loss of forest damage. GPS's function of navigation and positioning provides possibility and technological assurance for the rapid positioning of the calamity location.

4.1 Navigating in air prevention

To prevent forest insects and diseases by plane is a widely used technique and it is usually navigated by ground people or by the experience of the pilot. The backward navigating method has caused that some areas are not sprayed while some other areas are double sprayed. This has greatly impeded the efficiency of prevention. Since the 1990s, the technique of GPS has been widely used in various fields, and it provides a possibility to improve the navigating system of the aerial prevention system.

Since 1998, DGPS has been introduced into the aerial prevention system in China, the efficiency has been heightened and the cost has been reduced. The most important is that high spurting accuracy is achieved so that measures can be taken for the areas that are not spurted. With the application of intelligent spurting system, the aerial prevention techniques will be highly heightened.

4.2 Positioning and repositioning of damage point

In satellite remote sensing monitoring, DGPS should be utilized to accurately position the coordinates of control points so as to obtain the better rectification and registration of multi-temporal images. It can also be used to position the investigation point *in situ*. DGPS is also essential in airborne video monitoring. It is used to correct and join the images so that the damage point can be accurately positioned. Once the damage area has been detected by remote sensing, the navigating capacity of DGPS should be utilized to find the individual damaged trees so that measures can be taken accordingly.

Fig. 3.9 GPS application in hazard point recovery and investigation

State Administration of Forestry is now equipping GPS for all the monitoring stations in China. It can be sure that GPS technology will be widely used in the monitoring and prevention of forest insects and diseases.

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Charter 4

Airborne Spraying Based on GPS

1. Spraying in Guangxi based on GPS

In order to effectively prevent and cure the forest insects and diseases, we have developed the aerial prevention and control system based on light plane and made an experiment in Guangxi Zhuang Autonomous Region. 24 and 48 hours after aerial spraying, we investigated the number of living and dead insects on sample trees in 5 forest regions. We mainly checked the number of dead insect under the crown and calculated the effect of prevention and controlling. After investigation of 5 forest regions, we found that there are 200-400 dead insects under the crown and very few living insects on the sample trees, even zero on some individual trees. It showed that fog drop subsided equably, little areas during spraying are neglected and the rate of killing insect is beyond 99%. The practice demonstrates that this system is feasible in preventing and controlling forest diseases and insects in forest region. This technology is applied in practice in Guangxi Zhuang Autonomous Region and Anhui Province, China.

The worker is planing flight line (see Fig.4.1). And we use light plane to spraying (Fig.4.2) .

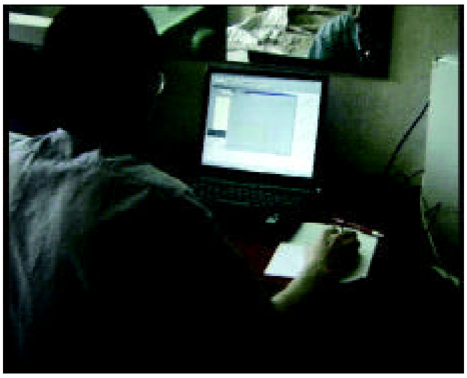

Fig.4.1 Planning flight lines before spraying

Fig. 4.2 Airborne high efficiency spraying system

In summary, with social and technological development, the protection of limited forest resources and ecology has drawn wide attention among most countries. As an important means in monitoring and protection of forest resources, airborne remote sensing technology should be improved greatly.

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Chapter 5

Applications of GIS in Trend Analysis of Forest Insects and Diseases

Geographic Information System (GIS) is a technological system which provides the functions supported by computer software and hardware to enter, store, update, inquire, manipulate, analyze, synthetically apply, display, map and output the data describing the real world. At present, GIS has been applied in many fields, such as checking and management of resource and environment, and come into being colossal technological industry. Many domestic forest industries have taken the GIS as the important tools in forest management which can not only accomplish general data management, but also establish the professional model for growth, forecast, management and decision based on spatial attribute table and select the best management scheme through simulation, evaluation and comparison for all kinds of management process. If combined with GPS and RS technology, GIS can survey the forest resource dynamic change. But now, there is no GIS for survey and management of forest diseases and insects in true sense in our country.

1. Forest damage forecasting based on GIS

Remote sensing has been used to monitor the damage caused by insects and disease. However, forest protection units are more concerned about the state of insects. There is a relation between the damage and insects, but it is not the same. It is necessary to obtain insect information from damage data. GIS has provided a strong tool manipulating spatial data. Based on the roles of damage occurrence and development and its relation with ecological factors, the state of insect distribution can be obtained with the help of expert knowledge. By using GIS's simulation capability of diffusion, dynamic damage diffusion models can be established, and it can be used to analyze and predict the damage trend. Taking the severe pine caterpillar(*Dendrolimus punctatus* Walker) and pinewood nematode(*Bursaphelenchus xylophilus*) damages in China as examples, analysis and researches have been done. We find that it is still far away to fully integrate Remote Sensing, GIS and GPS in the monitoring and prevention of forest insects and diseases.

2. Management information system of forest pest based on GIS

Now we have built management information system for forest diseases and insects based on GIS in China. The main functions of the system are :

1) Management of basic data of forest diseases and insect pests

Because many investigations and general surveys are carried out by countryside units, we entered the basic maps of roads, water system, terrain and forest distribution with a higher rank than all-provincial district and town rank with countryside unit and built the database corresponding to the image library with all information achieved by many years survey of forest diseases and insects, which can realize the rapid inquiry for past years data and plain display. Now the database mainly includes: all symptom images of forest diseases and insects, all ecological behaviors information of forest diseases and insects and past year's occurrence information which are stored with many style, such as image, word, graph, sound and video, and so on.

2) Processing of basic data of forest diseases and insect pests

With the development of RS technology, it is more and more applied in surveying forest insects and diseases, and at the same time many methods, such as gender enticement, have been introduced to survey and investigate the forest diseases and insects to mend the disadvantage of manual ground investigation. The investigation results of all approaches need to be rapidly analyzed and processed to make scientific decision.

3) Diffusion of forest diseases and insects decision support

Diffusion of forest diseases and insects is a spatio-temporal dynamic process which need relevant spatial data tools and models to research its occurrence and the relationship with natural and human environment. The perfect spatial analysis function of GIS provides a good condition for this requirement. In the past ten years, many overseas research achievements have firmly supported the efficient management. But in our country, this field is still a undeveloped area.

4) Result output

With the database and image output function of GIS, we can measure the areas with forest diseases and insects, make statistical analysis to the relative data, draw the graph of distribution of forest diseases and insects and the tendency graph of diffusion and extension, and so on.

3. Acknowledgments

The research described in this chapter was sponsored by National Forestry Administration, Anhui Province of the People's Republic of China. The work was carried out in the Anhui Province. We wish to acknowledge the contribution of Wu Jian, Wang Yang, Shi Jin, Tang Jian, Jiang Liya, Guo Lianhong, Ye Qinwen, Li Shiming, Ma Xiaoming, and others who worked during the course of GIS application.

Chapter 6

CONCLUSIONS

Airborne sketch-mapping method has been used for about 80 years, and it has been an important tool for collecting data of individual forest insects and diseases. Color and NIR aerial photography have been in use for more than 30 years. Video camera and digital camera systems have been developed for 10 years. Satellite remote sensing data with middle spatial resolution such as Landsat TM has being used in forest health protection for more than 20 years. Therefore remote sensing has been an operational system in collecting data of forest insects and diseases in different scales for over 80 years. And it is a necessary means and useful tool in support of decision making to improve forest health for the forest protectors. There have been many successful applications of remote sensing in forest health protection in China, great potentials of this technology have been demonstrated, and it is substituting traditional ground surveying method all over the world.

There are four distinct characteristics in the evolving process of forest diseases and insects. The first is intuitiveness of forest change, usually appears as a change of color of all or a portion of the leaf. Therefore NIR, multi-spectral remote sensing image or data can be used to identify forest damage condition because near infrared band is very sensitive to changes of vegetation chlorophyll concentrations and vegetation water content. The second is the periodicity of forest insects and disease, it happens in specific time interval of a year, and we must choose best data acquisition time when it is concurrent with the life cycles of insects and diseases. The third is multi-scale in monitoring different type of insects and diseases. We should use remote sensing data of different resolution according to the monitoring goals, such as damage areas caused by pine caterpillars can be monitored with TM data, whereas damage areas caused by pine wood nematode disease (*Bursaphelenchus xylophilus* Nickle) should be monitored with airborne remote sensing data or high resolution satellite data. The fourth is the accumulation of forest damages. Insects and diseases of different generations and types often damage the trees continuously. It is the major influential factor that limited the monitoring accuracy. In other words, the remote sensing technique is more suitable for assessing the forest damage.

Now we have remote sensing data acquisition systems in two kind of platforms, the satellite platform and the airborne platform. Satellite data can be classified into three classes, coarse resolution, middle resolution and fine resolution. Airborne data can also be obtained with different sensors such as airborne video, airborne visual sketch-mapping, airborne digital camera and airborne photography. Each of them has its own strengths and weaknesses, and we must choose among them with great care in forest health protection (Table 6.1)

Aerial visual sketch-mapping is a low-cost, highly flexible method for data collection, but its results are subjective and its accuracy is difficult to validate. Airborne videography is a tool that provides similar flexibility and low cost as aerial sketch-mapping, and can permanently record forest conditions at any time. Videography has lower resolution than aerial sensors, and it is more difficult to distinguish subtle damage symptoms. Digital camera systems can provide higher resolution product than airborne video cameras at relatively low cost. It is a pity there is no professional infrared digital camera available in China and some developing countries. Instead, we have to use the commercial digital cameras.

Satellite remote sensing can cover earth surface at regular intervals and has the advantage of currency and large dimension. It can be classified into different types according to spectral resolution and spatial resolution. Landsat

TM, SPOT and IKONOS are well-known satellite remote sensing data, and they have found wide applications. Landsat TM data has proved to be good mean of monitoring severe forest insects and diseases, and it is also a good method to assess the damage caused by forest insects and diseases. With fine resolution comparable to airborne remote sensing, IKONOS data (high-resolution satellite data) can be used effectively to detect individual tree damages caused by dangerous forest insects and diseases, and it has good potentials in the protection of forest (Table 6.2).

Geographic information system (GIS) technology is now widespread in forest managements and is increasingly indispensable. Recent use of global positioning systems (GPS) offers the possibility of collecting the exact coordinates of geographic positions. GPS now permits the establishment of a link between a map and a real, physical location on Earth surface, whether it refers to an area, a moving object in the air, ocean and land. The GPS+GIS combination thus permits flexible, real-time management of forest resources at the landscape level. In the field, two types of positioning are commonly used during surveys: static and dynamic. These are most often carried out with georeferrenced information such as the specification of sampling plots, the actual damage region for treatment, or the track and instantaneous position of a flight. Therefore GPS is an indispensable technique to forest health specialists. GPS and remote sensing data is the main resource for GIS data updating. The integration of remote sensing, GIS and GPS will create a new era of forest health protection.

Table 6.1 Comparison of alternative remote sensing systems in forest health protection

Criteria	Sensor Type				
	Airborne sensor			Satellite sensor	
	Sketch-mapping	Digital videography	Digital camera	Landsat	IKONOS
Acquisition cost	Medium	Medium	Medium	low	High
Spatial resolution	High	Medium	High	low	High
Spectral range	Visible	Visible	Visible, Near-IR(some systems)	Visible,Near-, mid-, Thermal-IR	Visible,Near-
Temporal resolution	Use-and Weather-defined	Use-and Weather-defined	Use-and Weather-defined	16 days	3 days
Reliability of data	Difficult to measure	High	High	Medium to low	Medium
Probability of acquisition During specified biowindow	High	High	High	Medium to low	Low
Data in digital format	Difficulty in the developing countries in resent years	yes	yes	Yes	Yes
Currently operational	Yes-widely used	Yes-widely used	Yes-on project basis	Yes-in some forest damages	Under development

Table 6.2 use of alternative remote sensing systems in forest health protection

Criteria		Sensor Type				
		Airborne sensor			Satellite sensor	
		Sketch-mapping	Digital videography	Digital camera	Landsat	IKONOS
Damage detection	Large scale				operational	operational
	Middle scale	operational	operational	operational		operational
	Small scale	operational	operational	operational		operational
Damage mapping	Large scale			possible	operational	operational
	Middle scale		possible	possible		operational
	Small scale		possible	possible		operational
Damage orientation	Large scale				operational	operational
	Middle scale	operational	operational	operational		operational
	Small scale	operational	operational	operational		operational
Damage quantity	Large scale	operational	operational	operational	operational	operational
	Middle scale					operational
	Small scale					operational
Damage assessment	Large scale				operational	operational
	Middle scale	operational	operational	operational		operational
	Small scale	operational	operational	operational		operational

Large scale means that we cannot accurately detect the damage areas less than 1 hectare.
Middle scale means that we cannot correctly detect the single tree damages.
Small scale means that we can exactly detect the single tree damages.

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