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Assessment of rice fields by GIS/GPS-supported classification of MODIS data*

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Abstract: The new Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite image offers a large choice of opportunities for operational applications. The 1-km Advanced Very High Resolution Radiometer (AVHRR) image is not suitable for retrieval of field level parameter and Landsat data are not frequent enough for monitoring changes in crop parameters during the critical crop growth periods. A methodology to map areas of paddy fields using MODIS, geographic information system (GIS) and global position system (GPS) is introduced in this paper. Training samples are selected and located with the help of GPS to provide maximal accuracy. A concept of assessing areas of potential cultivation of rice is suggested by means of GIS integration. By integration of MODIS with GIS and GPS technologies the actual areas of rice fields in 2002 have been mapped. The classification accuracy was 95.7% percent compared with the statistical data of the Agricultural Bureau of Zhejiang Province.

Key words: Areas of rice fields, Moderate-Resolution Imaging Spectroradiometer (MODIS), Geographic information system (GIS), Global position system (GPS)

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INTRODUCTION

In the last decade, remote sensing has been increasingly identified as an objective, standardized, possibly cheaper and faster methodology for crop production surveys than conventional field investigations (Bauman, 1992). Much progress has been made through intensive studies on inventory and production forecasting for major crops, such as wheat, rice, cotton and maize (Tennakoon *et al.*, 1992; Ray *et al.*, 1994; Fang *et al.*, 1998).

China, a developing country with 1.2 billion people, has been paying close attention to its existing and future food production. Crop production forecasting using remote sensing techniques for large areas is already one of the key projects in China. One of the key aims of crop production forecasting is to estimate areas of paddy fields. Satellite-based remote sensing techniques can be effectively applied for estimating areas of rice fields and for accurate assessment of the dynamic crop characteristics.

The launch of Terra MODIS was an important milestone in moderate resolution remote sensing, providing a marked increase in observation capabilities. Many workers have analyzed vegetation indices derived from MODIS data for comparison with NOAA/AVHRR data (Ferreira *et al.*, 2000; Fensholt *et al.*, 2002). The two 250 m bands provide the moderate spatial resolution from MODIS and

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unique daily observations of the land surface. The use of these data for land cover change detection was explored by Zhan *et al*.(2002). Introducing multi-temporal and multi-thematic spatial data supported the development of agricultural information systems based on GIS technologies. Janssen *et al.* (1990) observed an improvement of more than 12% in overall classification accuracy of agricultural fields when integrating topographical data from GIS with the classification of Landsat TM (Thematic Mapper) satellite data.

In this paper a method for estimation of the extension of areas of rice fields in Zhejiang Province in 2002 is presented. The integration of MODIS, GIS and GPS increased the classification accuracy of areas of paddy fields. The location of paddy fields was defined by GIS and after training samples were selected by GPS, the areas of rice fields were then extracted by the classification of MODIS data.

MATERIALS AND METHODS

Study area

The study area is located in China's Zhejiang Province (118°01′ E to 123°10′ E, 27°06′ N to 31°11′ N) with area of 10 530 000 ha and 71.6% hilly and mountainous regions, 22.0% plains and 6.4% rivers and lakes. The mean annual precipitation is 1320.9 mm and mean annual temperature is 16.2 °C. The soils are mostly red soils and paddy soils. Paddy fields cover most of the irrigated farm land. Agricultural production is comprised mainly of cereal crops such as rice, wheat and maize.

Acquisition of image data

The MODIS instrument onboard NASA's Terra satellite is a scanning radiometer system with 36 spectral bands extending from the visible to thermal infrared wavelengths (Running *et al*., 1994). The first seven bands are primarily designed for remote sensing of land surfaces providing spatial resolutions of 250 m for band 1 (red, 620−670 nm) and band 2 (near infrared, 841−876 nm), and 500 m for bands 3 to 7 (459−479, 545−565, 1230−1250, 1628−1652, 2105−2155 nm, respectively). Orbital parameters of the Terra satellite and MODIS viewing geometry produce daily global coverage with a revisiting frequency of approximately 1.2 days. MODIS data have higher spatial resolution than NOAA/AVHRR with similar temporal resolution. For this study band 1 and band 2 of MODIS imagery were used to map areas of rice fields. According to the farming practice in the study area MODIS data of July 24th and September 1st, 2002 covering the whole of Zhejiang Province was acquired with the support of the Remote Sensing Application Centre at the Chinese Academy of Science. This date correspond with the late rice planting season (transplant stage and elongation stage).

The software packages used for image and geo-information analyses were ENVI 3.4 and ARC/INFO 8.1. Topographic maps, 1:250000 scale land maps, recently produced maps of vegetation types, land cover / land use maps and other ancillary geo-information were also used in the study. GPS was applied to register the training samples.

Image processing

Data processing was performed by using ENVI 3.4 software. Twenty-six ground control points (GCPs) extracted from a 1:250000 digital topographic map were used for geocoding the image data. Radiometric correction was carried out. Co-registration accuracy of the image was better than 0.5 pixel in both x and y directions.

The 1:250000 land use map of Zhejiang Province was digitized and a land use mask was created. Afterwards the potential rice cultivation areas or the land use class rice fields were extracted.

The MODIS image of Zhejiang Province was superimposed on the mask of potential areas of rice fields. According to investigations in the rice cultivation regions, the training samples were selected by using GPS. Classification of the specific subsets of MODIS data allowed for the assessment of the actual area of paddy fields. Fig.1 illustrates the whole process of information extraction.

RESULTS AND DISCUSSION

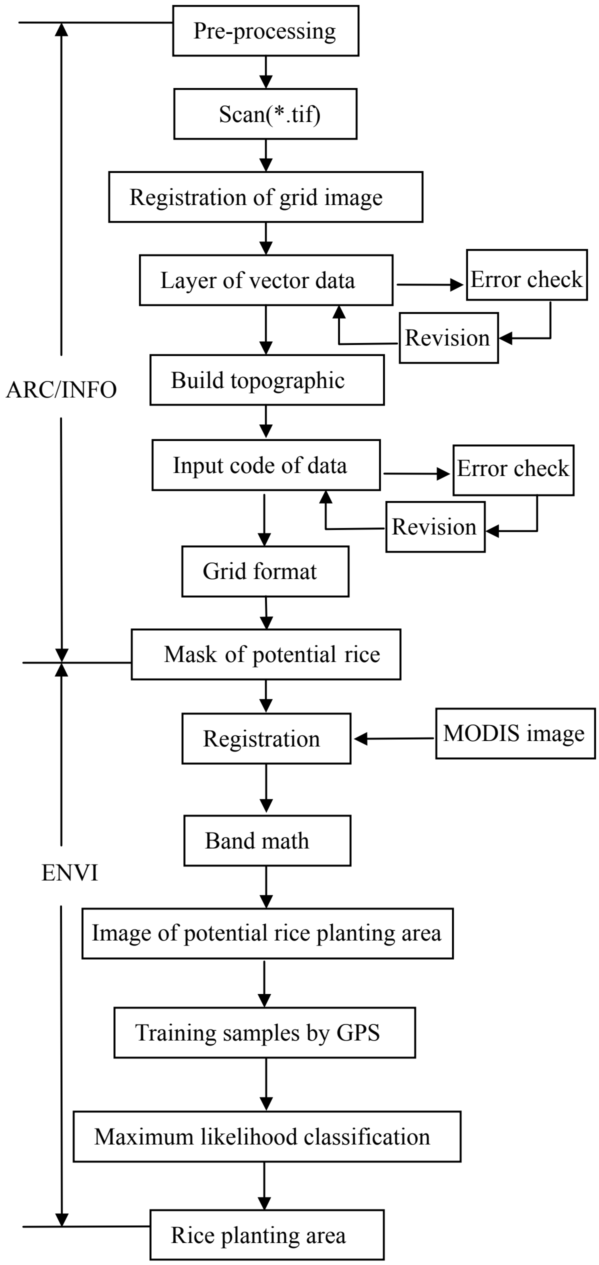

Fig.1 Flow chart of GIS/GPS-supported classification of MODIS data

Assessment of rice fields areas using MODIS data

The training samples were selected according to the land use map and the features in the MODIS image, additionally taking into account the variations of geographical and climatic conditions. Nineteen training samples of rice, dry land, water, forest and town were selected. The supervised approach of Minimum Distance Classification was conducted. Table 1 highlights the classification results. Because areas of rice fields are distributed all over the province and were thus hardly to be identified and separated from other sorts of vegetation coverage, the accuracy of results was poor.

Assessment of areas of potential rice fields by integrating GIS

Although the quantitative results of the Minimum Distance Classification using MODIS data seemed good in terms of extracting areas of rice fields, it is difficult to guarantee that the classification results obtained really belong to early rice and not to other vegetation types. The objective of this study was to extract areas of paddy fields using MODIS data. It was not aimed to classify all land use categories. Thus the potential areas of rice cultivation were extracted to avoid misclassification of rice fields versus forest, water and other land use classes.

The potential areas of rice fields indicate the locations of areas of cultivation of rice as well as of rice rotation. Thus the potential areas of rice fields were usually larger than the actual areas.

According to the regulations of the Zhejiang land use map, the cultivated land is divided into irrigated land, land of rainfed agriculture and dry land. The irrigated land and the land of rainfed agri-

Table 1 Classification results based on Minimum Distance Classification of MODIS imagery

Name of type	Minimum distance classification			
	Statistical area (ha)	Pixels	Area (ha)	Relative error (%)
Rice area	957 293	183 827	1 148 918	20.0%
Dry land	278 713	72 608	453 800	62.8%
Forest	5 587 535	546 781	3 417 381	−38.8%
Water area	912 357	14 076	87 975	−90.4%
Town area	559 293	30 112	188 200	−66.4%

culture are potential areas of rice cultivation. Thus these two classes were extracted from the digital land use map (Fig.2).

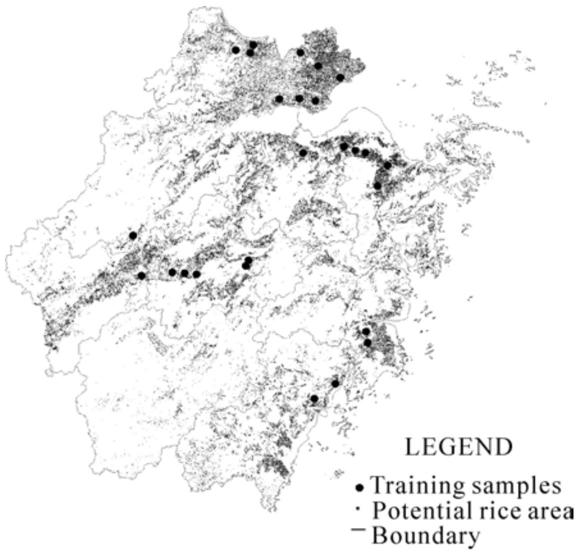

Fig.2 Potential rice cultivation areas and training samples

GPS-supported selection of training samples and subsequent extraction of areas of rice fields

Although the extraction of potential areas of rice fields allowed for the removal of land cover classes such as dry land, forest, water and settlements, the effects of embedded land use features like roads, villages and field ridge could not be removed. Therefore the MODIS image and the potential areas of rice fields were overlaid in order to extract the corresponding subsets of imagery. Afterwards the actual late rice area were distinguished from non-rice area and extracted.

In this paper, specifically, two MODIS 250 m scenes were analyzed; since, at this spatial resolution, only the Red and NIR bands are available.

Different studies proved that after transplanting, the tillering number of rice increase with rice growth (Wang, 1996; Shen *et al*., 1996). With the increase of rice canopy, the reflectance in NIR wavelength increases. When the effects of background weaken, the reflectance in Red wavelength in rice field decreases. So, vegetable indices in the rice field increase until the heading stage of rice. Therefore, the normalized difference vegetation index (NDVI) was used in this paper, and the difference of two times NDVI was calculated as follows:

$$\Delta VI_{ij}^{k} = VI_{ij}^{k}(t_2) - VI_{ij}^{k}(t_1) \quad (1)$$

Where VI_{ij} is vegetable indices (VI) of two times, k is wavelength, i and j are samples and lines of pixels, t_1 and t_2 are the first and second times.

For the image of potential rice cultivation area, ΔVI_{ij}^{k} corresponding to indices of two times pixels must be greater than zero.

According to the farming practice in the study area, MODIS data of July 24th correspond to the transplant stage of rice growth in Zhejiang Province and MODIS data of September 1st correspond to elongation stage. In the transplant stage, the reflectance of rice which is young is weak, but in the elongation stage the reflectance of rice which is in active growth is stronger. Eq.(1) was used to calculate the difference of MODIS NDVI of July 24th and September 1st, 2002. The values of 23 520 pixels were less than zero and these pixels must be deleted from this image. The classification map was created using two bands at 250 m of MODIS data of September 1st and the ΔVI_{ij}^{k} image.

The supervised classification approach of Maximum Likelihood Classification was applied to extract the rice fields.

In a supervised classification the spectral characteristics of the selected training samples are used to sharpen the classification algorithm towards mapping of specific land use/land cover classes based on the image data (Jensen, 1986). Once a representative number of training samples is selected, multivariate statistical parameters calculated from each training sample are used to classify each pixel. Each pixel is assigned to a land use class following its likelihood of membership. The quality of training samples is of utmost importance for achieving accurate classification results. According to investigations in the rice cultivation regions, 26 training samples were selected and registered by using GPS (Fig.2).

Maximum Likelihood Classification achieved the best results in assessing areas of rice fields in hilly regions of Southern China compared to other classification methods (Lai and Yang, 1998). Therefore this study also applied the Maximum Likelihood Classifier for image analysis.

The results showed that the late rice cultivation areas in Zhejiang Province in 2002 extended over 998 456 ha (Fig.3). The relative error of estimation of area is 4.3% compared to the data of the Agricultural Bureau of Zhejiang.

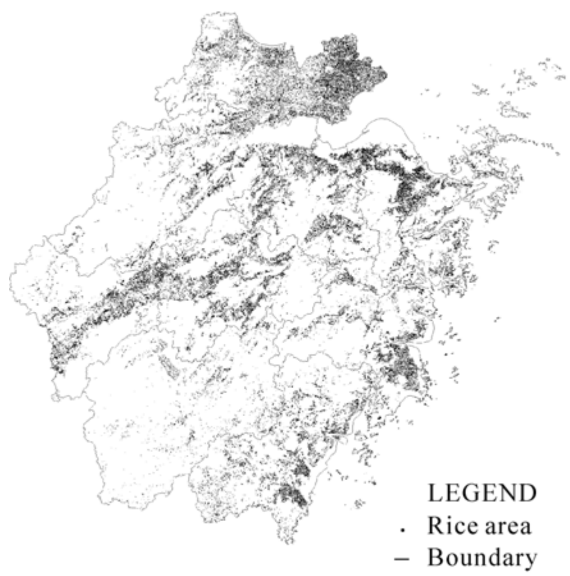

Fig.3 Area of late rice cultivation in Zhejiang Province

The quantitative accuracy of this method was enhanced up to 95.7%, and the spatial accuracy of rice location was also enhanced. Since late rice is planted in paddy fields and the results of this study were derived from MODIS imagery of these paddy fields, the probability of detecting areas of late rice was highest.

CONCLUSION

The introduced methodology is promising. It enhanced the quantitative accuracy from 80.0% for MODIS-based image classification to 95.7%. It ensured that the late rice cultivation areas were exactly extracted. The concept of GIS was employed to support spatial information management, and analysis of spatial data combined with related MODIS data was used to support the rice area extraction process. Using GPS for registering the training samples allowed for accurate calculation of spectral parameters of land use classes and especially of areas of rice fields. GIS was a very helpful tool to pinpoint the location of potential areas of rice fields. The classification accuracy of areas of late rice cultivation by means of remote sensing techniques was thus significantly increased.

The two 250 m bands of MODIS provide moderate spatial resolution and daily observation of the land surface. It could be verified that these data are well suited for mapping areas of rice fields and for assessing growth parameters of rice.

Using the integration of GIS, GPS and MODIS-based image analysis enhances the quantitative and qualitative accuracy of classification of rice fields. The methodology proved to be feasible, repeatable, and fast, since the GIS database and GPS were available. The range of relative error of classification was small. The methodology can be effectively used for the accurate classification of rice fields based on daily available MODIS earth observation data.

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References

Bauman, B.A.M., 1992. Radiometric measurements and crop yield forecasting – some observations over Millet and Sorghum experimental plots in Mali. *International Journal of Remote Sensing*, **9**(10):1539-1552.

Fang, H.L., Wu, B.F., Liu, H.Y., Huang, X., 1998. Using NOAA AVHRR and Landsat TM to estimate rice area year-by-year. *International Journal of Remote Sensing*, **19**(3):521-525.

Fensholt, R., Sandholt, I., Rasmussen, M.S., 2002. Earth Observation of Vegetation Status in A Semi-arid Environment: Comparison of Terra MODIS and NOAA AVHRR Satellite Data. *In*: Proceedings of IEEE International Geoscience and Remote Sensing Symposium. Toronto, Canada, (4):2205-2207.

Ferreira, L.G., Huete, A., Yoshioka, H., Sano, E., 2000. Preliminary Analysis of MODIS Vegetation Indices over the LBA Sites in the Cerrado Region, Brazil. *In*: Proceedings of IEEE International Geoscience and Remote Sensing Symposium. HI, USA, (2):524-526.

Jensen, J.R., 1986. Introductory Digital Image Processing. Englewood Cliffs. Prentice Hall, New Jersey, p.177-230.

Janssen, L.F., Janorsma, M.N., Vander Linden, E.T.M., 1990. Integration topographic data with remote sensing for land-cover classification. *Photogrammetric Engineering and Remote Sensing*, **56**(3):1503-1506.

Lai, G.Y., Yang, X.W., 1998. Analysis of feasibility of professional operating on estimating rice planting area of hilly region in southern China using remote sensing technique. *Remote Sensing Technology and Application*, **13**(3):1-7 (in Chinese).

Ray, S.S., Pokharna, S.S., Ajar, E., 1994. Cotton production estimation using IRS-1B and meteorological data. *International Journal of Remote Sensing*, **15**(5):1085-1090.

Running, S.W., Justice, C.O., Salomonson, V.V., Hall, D., Barker., J., Kaufman, Y.J., Strahler, A.H., Huete, A.R., Muller, J.P., Vanderbit, V., Wan, Z.M., Teillet, P., Carneggie, D., 1994. Terrestrial remote sensing science and algorithms planned for EOS/MODIS. *International Journal of Remote Sensing,* **15**(17):427-439.

Shen, Z.Q., Wang, K., Wang, R.C., 1996. A study on dynamic changes of rice reflective characteristics in growth period. *Remote Sensing for Land & Resources*, **30**(4):40-45 (in Chinese).

Tennakoon, S.B., Murty, V.V.N., Eiumnoh, A., 1992. Estimation of cropped area and grain yield of rice using remote sensing data. *International Journal of Remote Sensing,* **13**(3):427-439.

Wang, Y.Y., 1996. The relationship between vegetation index and rice growth and rice yield components. *Remote Sensing for Land & Resources*, **30**(1):56-59 (in Chinese).

Zhan, X., Sohlberg, R.A., Townshend, J.R.G., DiMiceli, C., Carroll, M.L., Eastman, J.C., Hansen, M.C., DeFries, R.S., 2002. Detection of land cover changes using MODIS 250 m data. *Remote Sensing of Environment*, **83**(1-2):336-350.