Application of MADC system in spatial distribution information extraction of *enteromorpha prolifera*

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Abstract: In recent years, the green tide caused by *enteromorpha prolifera* bloom with fast growth rates became one of the ecological disasters. In the monitoring of Qingdao *enteromorpha prolifera* bloom disaster using remote sensing technology, the Multi-mode Airborne Digital Camera (MADC) system played an important role in the algae reducing planning. It provided the data source for the quick extraction of *enteromorpha prolifera* information. The *enteromorpha prolifera* monitoring results, such as the distribution, area and density, were provided to the government in time for decision. In this paper, the components and characters of MADC system are introduced, and the quick extraction technology and work flow are set up based on the analysis of the spectral and image features. The key technologies in the data process and information extraction are studied and the final remote sensing monitoring results are introduced. The feasibility of prospect application in marine disaster monitoring such as the red ride monitoring of MADC system and advices for the improvement of MADC are introduced at last. The information extraction method will play an important role in the marine environment monitoring especially in the contingency environment disaster monitoring.

Key words: MADC, *enteromorpha prolifera* bloom, remote sensing monitoring, information extraction

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1 INTRODUCTION

In recent years, the frequent breakout of red tides has become a common marine coastal disaster. It has great influence on coastal economy, the local residents, and our ecological system (Tang *et al*., 2004; Wang *et al*., 2006). The green tide proliferated by ulvaceae algae has also become one of the world's common ecological phenomena (Merceron *et al*., 2007). We can also see abnormal proliferation and accumulation of macroalgae occur in China (Liang *et al*., 2008). The development of remote sensing techniques makes quick dynamic monitoring of marine coastal disasters possible, especially aerial remote sensing. Aerial remote sensing has a lot of advantages: flexibility, vast coverage, high spatial resolution, which makes it very suitable for monitoring coastal waters. It is an important platform for monitoring marine environment and coastal disasters (Ma *et al*., 2002; Fan *et al*., 2003).

Since May 2008, a lot of floating *enteromorpha prolifera* appeared in the middle Yellow Sea, and they were gathering towards Qingdao coast. On June 12th, there was about 8 km^2 of *enteromorpha prolifera* along Qingdao coast. On June15th, *enteromorpha prolifera* invaded the coastal area ranging from Laoshan island to Xuejiadao. The follow-up remote sensing monitoring showed that a large amount of Enteromorpha prolifera was invading Qingdao in strips (Qiao *et al*., 2008). The outbreak of *enteromorpha prolifera* bloom invaded the coastal areas in Qingdao and its surrounded waters, which severely affected the athletes' training and posed a threat to Olympic sailing regatta. MADC system was deployed to monitor the dynamic change of algae from July 2. MADC system is a novel airborne digital camera developed by Institute of Remote Sensing Applications of Chinese Academy of Sciences. We took MADC system and other remote sensing equipment to Qingdao, participated in aerial remote sensing monitoring and controlling of *enteromorpha prolifera* in Olympic sailing venue.

2 MADC SYSTEM

MADC system was developed by Institute of Remote Sensing Applications of Chinese Academy of Sciences since 2003. Several airborne experiments have been done with different modes and aviation parameters to test the stability of MADC

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(Fang, 2003). MADC can choose different modes for different application purposes to capture images of remote sensing and other assistant data (Fang, 2005; Wei, 2005). The main parts of MADC are four large array CCD cameras, and the system could capture wide field, multi-spectral and stereo images through different mechanical interface. The single CCD pixel size is 9μm, analog-to-digital conversion takes up 12 bits, and the shutter speed is 1/4000—32s. The main technical parameters are listed in Table 1.

Table 1 Main technical parameters of MADC

	Wilde field mode	Multi-spectral mode	Stereo imaging mode
Field of view / (°)	26×75	26×26	26×26
Swath@9Km altitude / (km^2)	4×12	4×4	4×4
Spatial resolution@9Km altitude / m	1	1	1
Analog-to-digital conver sion/ bit	12	12	12

In this monitoring process, the multi-spectral mode was used to capture images especially with IR band because of the obviously characters of *enteromorpha prolifera* in IR band. In order to capture the color images, an additional color digital camera with 24mm lens was also mounted with the IR digital camera. A POS (Position and Orientation System) was used to provide the flight parameters and altitude. In this paper, we analyze the spectrum of *enteromorpha prolifera* and MADC images, and set up a quick workflow to automatically extract *enteromorpha prolifera*. The extracted information of *enteromorpha prolifera* was for decision-making of controlling algae outbreak. Our workflow was also employed in two cases: red tide monitoring in late August, and spilled oil monitoring in middle September. All these cases prove that MADC system and our information extraction techniques have great application potential in marine environment monitoring.

3 SPECTRUM, IMAGE CHARACTERISTICS, AND EXTRACTION MODEL

3.1 Spectrum of *enteromorpha prolifera*

Enteromorpha belongs to one genus of ulvaceae family, chlorophyta phylum. Its frond stands upright. It has hollow tubular frond, or at least the handle and the edge of its frond is hollow. The tube consists of single-layer cells. Normally it is a single frond or its frond has branches. Its shape can be cylindrical, sometimes flat. It often grows in the inter-tidal rock marsh or mud on the beach of gravel, and sometimes can also be epiphytic algae in a large frond (Lin, 2007). *Enteromorpha* is not poisonous, but the large scale outbreak of *enteromorpha prolifera* would severely destroy the landscape and make it inconvenient to do exercises above water. People now call the outbreak of macroalgae “green tide”, consider it as one of marine disasters (Pedro *et al.*, 2008). Since mid-June, vast areas of floating *entermorpha prolifera* appeared in the middle of Yellow Sea, and they were gathering towards Qingdao coast. It’s an unusual *entermorpha* natural disaster. In this paper, we study the spectral characteristics of *entermorpha prolifera* and MADC images, which provide the basis for building a model to identify and extract *enteromorpha prolifera*.

The reflectance spectra of *enteromorpha prolifera* and sea water along Qingdao coast are shown in Fig.1. The reflectance spectrum of *enteromorpha prolifera* is very similar to that of vegetation, while it’s very different from the spectrum of sea water, especially in the IR band. Within VIS bands, the spectrum of fluctuates greatly, while that of sea water is relatively flat. Our model identification and extraction is based on these spectral characteristics within VIS-IR bands. Therefore, the color images and IR images of MADC are very useful for extracting *enteromorpha prolifera* information.

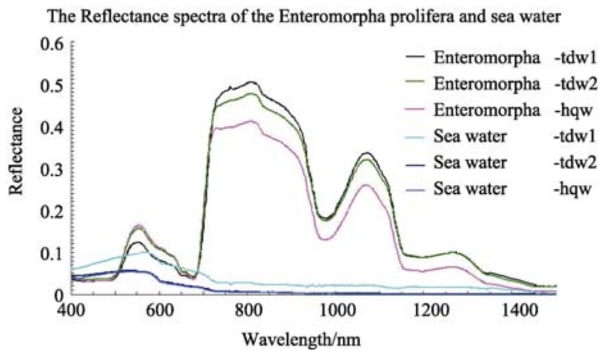

Fig. 1 Reflectance spectra of *enteromorpha prolifera* and sea water

3.2 Image characteristics

The infrared image of MADC (band range: 750—850nm) and color image (blue, green, and red, contrast enhanced) acquired in good weather conditions are shown in Fig. 2. In both IR image and color image, we can obviously see that *enteromorpha prolifera* differs from sea water in color. However, because of specular reflection by the sea, hot spots, the edge of distortion, image noise and other factors, threshold segmentaion method would not be suitable for precisely extracting *enteromorpha prolifera*. In addition, visual interpretation is too slow to get a quick monitoring result. However, in the color images acquired when sea fog existed, the difference between *enteromorpha prolifera* and seawater is not obvious, then the infrared data can be used as a useful supplement.

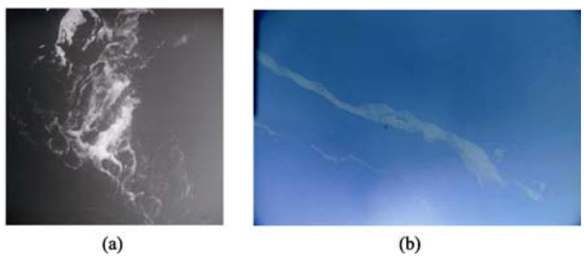

Fig. 2 Example of IR image (a) and color image (b)

We can see that *enteromorpha prolifera* and seawater have a lot of difference in the spectrum, so differences surely exist in the three visible bands of MADC, which can be used to set up a model to identify and extract *enteromorpha prolifera*, thereby promoting automatic and semi-automatic information extraction technique. The image spectra of *enteromorpha prolifera*, sea water, and other main features in the color images are shown in Fig. 3.

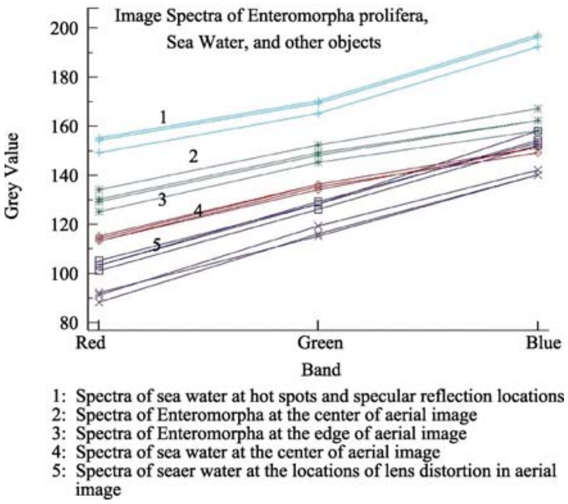

Fig. 3 Image spectra of *enteromorpha prolifera* and sea water

3.3 Information identification and extraction model based on color images

In remote sensing, we often build a model to identify and extract surface objects according to their spectral characteristics and image features. Because the registration technique is limited, the color images and IR images cannot be used simultaneously to extract *entermorpha prolifera* information. In this paper, we mainly introduce our extraction model based on the color images of MADC.

By analyzing the spectral characteristics and differences of *enteromorpha prolifera*, sea water, and sea wave mirror in Fig. 3, we can build a model to identify and extract these surface features. Integrating all these characteristics together by a decision tree, the hot spots, specular reflection and the effects of lens distortion can be removed and *enteromorpha prolifera* information can be accurately identified and extracted.

(1) Set up indices based on spectral characteristics to identify *entermorpha prolifera*

① $B-G<a$, a is the threshold, its empirical value is 24. It can differentiate *entermorpha prolifera* from sea water.

② $(B-G)/(B+G)<a$, make ① normalized, a is the threshold, its empirical value is 0.09, it can be used to identify *entermorpha prolifera*.

③ $(2\times G)-(R+B)>a$, a is the threshold, its empirical value is 0, it can be used to distinguish *entermorpha prolifera* from sea water.

(2) Generally speaking, the locations of hot spots and sea waves have bigger grey values. In the blue band, the difference between *entermorpha prolifera* and sea water is more obvious. Therefore, we can perform threshold segmentation method in the blue band to identify hot spots and specular reflectance: B>a, a is the threshold, its empirical value is 160.

(3) The edges of the lens distortion are the marginal zones of aerial images, their grey values are relatively small. We can employ the threshold segmentation method in red band: $R<a$, a is the threshold, its empirical value is 90.

R, G, B in the above descriptions represent the grey values in red band, green band, and blue band respectively, a is the threshold, which can be modified according to the actual situation.

4 EXTRACTION WORKFLOW AND KEY TECHNIQUES

4.1 Extraction workflow

Aerial remote sensing monitoring of *entermorpha prolifera* means deploying boarded MADC to obtain spatial distribution area and density information of *entermorpha prolifera* quickly, for the purpose of providing data support for decision making and controlling. In this paper, we propose two workflows based on IR images and color images respectively. Firstly, we determine whether the quality of MADC data is good or not. If the quality of color images is not satisfying, for example, severe sea fog effect, obscure color images, then we use the IR data. The workflow based on IR data includes data preprocessing, visual interpretation, and thematic mapping, among which the efficiency of visual interpretation is too low. However, if the quality of color images is satisfying, then we can employ the model mentioned in Section 3.3 to implement automatic and semi-automatic information extraction; this workflow based on color images is shown in Fig. 4. It consists of four major parts: data acquisition, data preprocessing, algae information extraction, and thematic mapping. Data acquisition is carried out in any feasible day by MADC with POS on the Ocean surveillance plane #3843 platform. Data preprocessing mainly includes POS extraction, data format converting, ortho-rectification and ortho-image mosaic. The key work in the data preprocessing is ortho-image map making (Wei, 2005). Information extraction based on ortho-images has these steps: de-noising, constructing indices, building a decision tree, extracting information, convert classified map to vector file, etc. Firstly, we remove the salt-and-pepper noise (CCD effect), wave (mirror reflection) and imaging mode (dark edge); and then perform decision tree method to produce a classified map, *enteromorpha prolifera* is one of the classes. Finally, we convert this raster classified map to a vector file. This workflow realized the quick automatic and semi-automatic extraction of *enteromorpha prolifera*, and won a lot of valuable time for emergent monitoring.

4.2 Key techniques and strategies

In the workflow mentioned above, the key techniques are constructing indices, giving an appropriate threshold for each index, and establishing a decision tree based on these indices. Decision tree (DT) classification method is a hierarchical classification method that compares each pixel value to the threshold in each hierarchy; the threshold value is set according to the actual data and target-related knowledge. This method can perform classification task in a very short period of time (Tong *et al*., 2006). Our DT tree is shown in Fig. 5.

Some optimized strategies were taken in data processing and information extraction workflow in order to achieve fast and accurate monitoring results of *enteromorpha prolifera*. One strategy is data parallel processing: divide the data into blocks according to flight lines, allocate these data blocks to a few

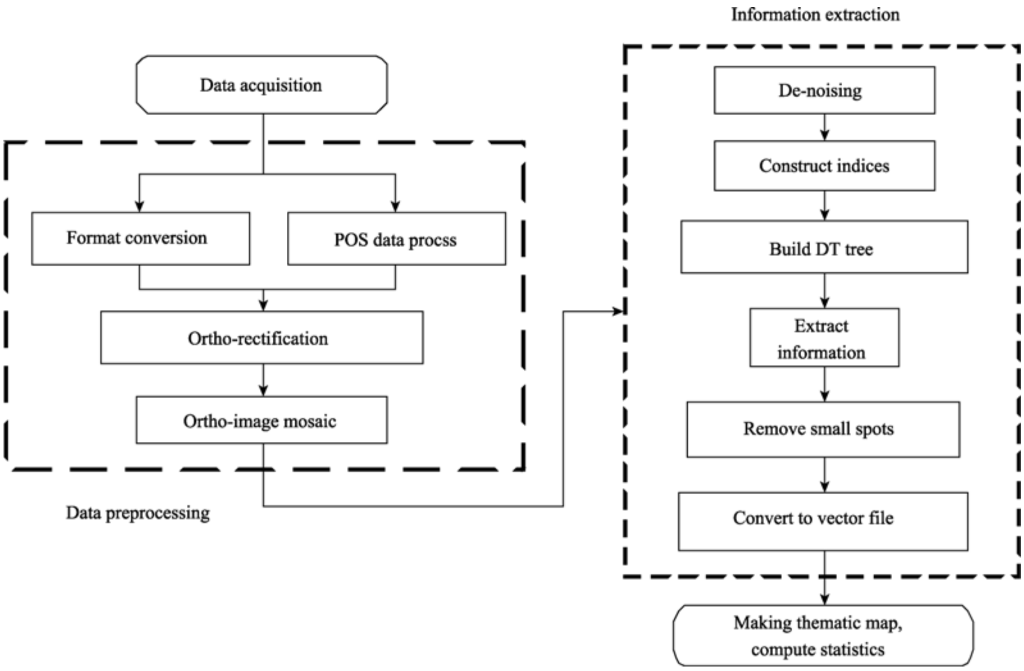

Fig. 4 Work flow of *enteromorpha prolifera* information extraction based on color images

computers to perform data preprocessing and information extraction simultaneously, then import the *enteromorpha prolifera* vector file into ArcGIS software to compute statistics and make mornitoring maps. Another strategy is the de-noise of the mosaic image by using median filter method Moreover, before vectori- zation, we removed the little spots so as to speed up vectorization. All these strategies saved a lot of time and improved the processing efficiency.

5 RESULT AND DISCUSSION

Thematic maps and statistical reports of *enteromorpha prolifera* information were done by employing our information extraction method and strategies. Some monitoring results are shown in Table 2, including the monitoring water area (aerial photo coverage), *enteromorpha prolifera* area in monitoring waters and in alert water zone (Olympic sailing competition venue), and density.

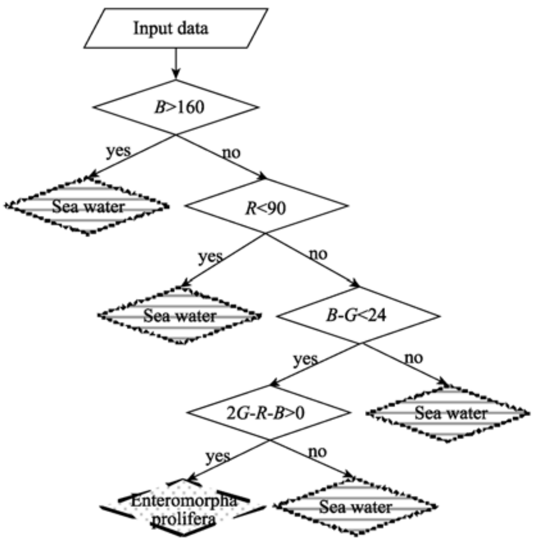

Fig. 5 Decision tree of *enteromorpha prolifera* information extraction

The thematic map of algae in July 6, 2008 is shown in Fig. 6. Compared to the monitoring result on July 4th, we can see that the density on July 6th is smaller, especially after artificial salvage, the number of e*nteromorpha prolifera* significantly reduced. Based on these results, we proposed that we should not only perform more artificial salvage, but also speed up the construction of oil containment along the periphery of the alert water zone; meanwhile the spatial distribution information provides a basis for salvage. Fig. 6 shows that *enteromorpha prolifera* mainly gathered at the southeast and southwest direction of the alert water zone. Northern Sea Forecast Center utilized information about ocean currents and wind direction to forecast the drift dynamics. Our monitoring results on July 13th showed that all *enteromorpha prolifera* within the alert water zone have been salvaged clearly. Our MADC-based *enteromorpha prolifera* information extraction workflow were successfully applied to aerial remote sensing monitoring of marine red tide and oil spill at sea. It proves that the MADC system is fit for the monitoring of the marine environment and disaster emergency response, because MADC is multi-modal, multi-spectral, flexible and easy to install.

However, as a prototype system, MADC still needs some improvements when it is applied to disaster monitoring: first, improve accurate registration technique among different cameras of MADC to make best use of its multi-mode cameras in order to establish a more effective information extraction model; second, develop MADC image processing system to perform ortho-rectification, mosaic, lens distortion correction, de-noising, information extraction, and other functions, in order to realize fast response.

6 CONCLUSION

The practice has proved that aerial remote sensing is an important tool for monitoring red tide, green tide, and other marine

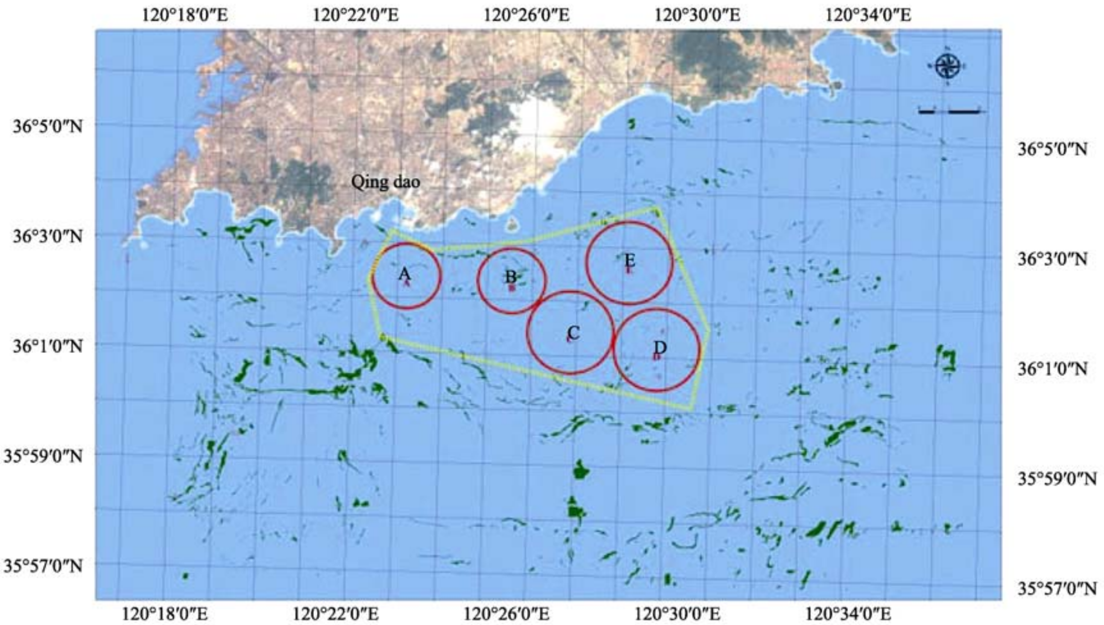

Fig. 6 Thematic Map of Algae on July 6, 2008

Table 2 Monitoring result of *enteromorpha prolifera*

Monitoring time	Monitoring water area /km^2	Area in monitoring waters / km^2	Density in monitoring waters /%	Area in alert water zone /km^2	Density in alert water zone / %
Jul 4th, 2008	306.5	13.2	4.31	1.12	2.26
Jul 6th, 2008	479	10.7	2.23	0.679	1.37
Jul 13th, 2008	480	2.5	0.52	0.0075	0.015

environmental disasters. In the monitoring of *enteromorpha prolifera* in Qingdao, our aerial MADC remote sensing system provides area, density and other monitoring information to the headquarters. The MADC system has great application potential in marine environment monitoring. Furthermore, the fast and accurate information extraction method based on spectral and image characteristics of *enteromorpha prolifera* were also successfully applied to the monitoring of red tide and oil spills. Given that MADC system is multi-mode, multi-spectral, flexible and easy to install, it should be assimilated into national disaster response system, so that remote sensing can play a significant role after disaster. Admittedly, as a prototype, MADC and its image processing software need to be further improved.

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REFERENCES

Fan X W, Zhang H D and Sun X W. 2003. The application of hyperspectral data to the detection and identification of red tides. *Remote Sensing for Land & Resources*, (1): 8—12

Fang J Y. 2003. Airborne digital camera system with multi-mode andlarge format array CCD. Journal of Remote Sensing, 7: 22—27

Fang J Y. 2005. A novel airborne digital camera system. Remote Sensing of the Environment. 15th National Symposium on Remote Sensing of China, Proceedings of SPIE

Liang Z Y, Lin X Z, Ma M, Zhang J, Yan X B and Liu T.2008.A prel-minary study of the enteromorpha prolifera drift gathering causing the green tide phenomenon. *Periodical of Ocean University of China*, **38**(4): 601—604

Lin W T.2007.Development and utilization of entermorpha.*Food and Nutrition in China*, **9**: 23—25

Ma Y, Zhang J, Zhang H D and Liu Y Z. 2002. Advances in application research on the marine airborne hyperspectral remote sensing in China. *Advances in Marine Science*, **20**(4): 94—98

Michel Merceron, Virginie Antoine, Isabelle Auby and Philippe Morand.2007. In situ growth potential of the subtidal part of green tide forming Ulva spp. Stocks Michel. *Science of the Total Environment*, **384**: 293—305

Pedro H. de Paula Silva, Shannon McBride, Rocky de Nys and Nicholas A. Paul. 2008. Integrating filamentous ‘green tide’ algae into tropical pond-based aquaculture. *Aquaculture,* **2842**: 74—80

Qiao F L, Ma D Y, Zhu M Y, Li R X, Zang J Y and Yu H J.2008.The status of algae bloom in Yellow Sea at 2008 and the measurements. *Advances in Marine Science*, **26**(3): 409—410

Tang J W, Ding J, Wang Q M and Ma C F.2004. Research of the effects of atmospheric scattering on red tide remote sensing with normalized vegetation index. *Acta Oceanological Sinica*, **26**(3): 136—142

Tong Q X,Zhang B and Zheng L F.2006. Hyperspectral Remote Sensing. Beijing: High Education Press

Wang Q M, Ma C F, Tang J W and Guo M H.2006.A method for detecting red tide information using EOS/MODIS data. *Remote Sensing Technology And Application* , **21**(01): 6—10

Wei Z. 2005. Application of POS in correcting images of aero-digital camera with large format array CCD. Remote Sensing of the Environment: 15th National Symposium on Remote Sensing of China, Proceedings of SPIE

MADC 在浒苔空间分布信息提取中的应用

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摘 要: 在青岛浒苔灾害遥感监测中, 搭载于海监飞机上的多模态航空数字相机(MADC)为及时快速地提取浒苔信息提供了数据源, 所提取的奥帆赛区警戒水域及周边海域浒苔分布面积、密集度等应急动态监测信息, 为决策部门提供了准确的数据支持和决策依据, 在浒苔治理中起到了重要的作用。介绍了 MADC 系统的特点, 通过对浒苔光谱及其 MADC 影像特征的分析, 建立了快速提取浒苔信息的技术方法和流程, 并对信息提取的关键技术和结果进行了分析。MADC 系统包含高分辨率、宽(多)视场、多(高)光谱、立体观测等多种成像模态, 可以根据不同的应用需求快速灵活地设置成不同的工作模态, 浒苔的光谱和植被非常相似, 与海水的差异明显, 容易建立浒苔的识别和提取模型。实践证明 MADC 系统在海洋赤潮等灾害监测中具有很大的应用潜力, 文中最后对 MADC 系统的改进提出了建议。

关键词: MADC, 浒苔灾害, 遥感监测, 信息提取

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Li Q T, Liu H X, Fang J Y, Liu X and Zheng L F. 2010. Application of MADC system in spatial distribution information extraction of *enteromorpha prolifera*. *Journal of Remote Sensing*. **14**(2): 283—293

1 引 言

近几年来, 中国沿海赤潮的发生越来越频繁, 已经成为一种常见海洋灾害, 它的发生给沿海经济、居民生活和生态系统造成了很大影响(唐军武等,2004; 王其茂等,2006)。由石莼科绿藻大量增殖形成的绿潮也已成为全球常态发生的生态现象之一(Merceron 等, 2007), 中国近年来也发生了浒苔等大型海藻异常增殖和聚集的现象(梁宗英等,2008)。遥感技术的发展为快速、有效地动态监测海洋赤潮和绿潮灾害提供了可能, 特别是航空遥感具有机动灵活、覆盖面广、空间分辨率高等特点, 特别适用于近岸海域的监测, 是重要的海洋环境灾害遥感监测平台(马毅等,2002; 范学炜等,2003)。

2008 年 5 月底以来, 黄海中部出现了大面积漂浮浒苔, 并向青岛及周边海域聚集, 6 月 12 日青岛近海出现面积约 8 km^2 浒苔聚集区, 6 月 15 日, 青岛近海崂山头至薛家岛岸段出现浒苔上岸并在岸滩上堆积, 其后的卫星遥感监测表明, 外海浒苔多呈条带分布, 源源不断地向青岛近岸漂移(乔方利等, 2008)。青岛及周边海域暴发的大面积浒苔灾害, 严重影响了奥帆赛区运动员的训练, 并威胁到奥帆赛的如期举行。为辅助浒苔治理, 中国科学院遥感应用研究所应国家海洋局紧急支援的请求, 于 7 月 2 号派遣航空遥感分队携带自主研发的多模态数字相机(Multi-mode Airborne Digital Camera ,MADC)等遥感设备奔赴青岛, 进行浒苔灾害及治理情况的航空遥感监测, 及时提供了奥帆赛区警戒水域及周边海域浒苔分布面积、密集度等应急动态监测信息。

2 多模态数字相机介绍

多模态数字相机(MADC)是本次遥感数据获取的主要设备。MADC 以 3—4 台 4k×4k 大面阵 CCD

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相机为基本组成单元，包含高分辨率、宽(多)视场、多(高)光谱、立体观测等多种成像模态，根据不同的遥感科学实验目的和应用需求，快速灵活地设置成不同的工作模态，可选择性地获取具有多种优良几何特性、多种覆盖宽度和多种光谱分辨率及波段组合的数字影像，做到一机多能，高效率地为遥感科学基础实验以及多种遥感应用提供高质量的航空遥感数据和应用产品(Fang，2003，2005)。相机中单CCD的大小为9 μm，量化位数为12位，快门速度为1/4000—32s，各模态的主要技术参数如表 1。

表 1　**MADC** 各模态的主要技术指标

	宽视场模态	多(高)光谱模态	前-后视立体摄影模态
视场/(°)	26×75	26×26	26×26
幅宽@9km 高度/km	4×12	4×4	4×4
分辨率@9km 高度/m	1	1	1
量化位数/bit	12	12	12

在本次应用中，搭载了一台彩色相机和一台红外相机，利用了 MADC 的多光谱模态和轻便灵活的特点，可以获取单波段的红外图像和红绿蓝三通道的彩色图像。本文中，结合浒苔的光谱特征和图像特征，建立了基于 MADC 的浒苔信息快速提取的方法和技术流程，所提取的浒苔分布和密度信息为浒苔打捞规划和监测提供了决策依据。建立的技术流程应用于 8 月底和 9 月中旬的海洋赤潮和溢油的监测，显示了 MADC 系统及其信息提取技术在海洋环境监测应用中的巨大潜力。

3　浒苔的光谱和图像特征及其提取模型

3.1　浒苔的光谱特征

浒苔是绿藻门石莼科的一属，拉丁文学名：*enteromorpha prolifera*，藻体直立，管状中空或者至少在藻体的柄部和藻体边缘部分呈中空，管状部分由单层细胞组成，藻体单条或者有分枝，圆柱形，有时部分扁压，常生长在潮间带岩石上或石沼中，或泥沙滩的石砾上，有时也可附生在大型海藻的藻体上(林文庭，2007)。浒苔虽然无毒，但是大规模爆发会严重影响景观，干扰旅游观光和水上运动的进行。现在国际上已经把浒苔一类的大型绿藻爆发称为“绿潮”，视作和赤潮一样的海洋灾害(Pedro 等，2008)。从6月中旬开始，大量浒苔从黄海中部海域漂移至青岛附近海域，造成了历史罕见的浒苔自然灾害。研究浒苔的光谱特征和 MADC 图像特征，建立识别模型，是进行浒苔信息快速准确提取的基础。

青岛海域浒苔和海水的反射率光谱如图 1，可以看出，浒苔的光谱和植被非常相似，其与水体光谱差别十分明显，特别是在近红外波段浒苔与水体的差异最大，在可见光区域，浒苔光谱波动剧烈，水体光谱相对比较平缓，根据浒苔在可见光和近红外区域与海水的光谱差异可以构建浒苔的识别和提取模型，因此 MADC 的彩色图像和近红外图像对于浒苔信息的提取非常有利。

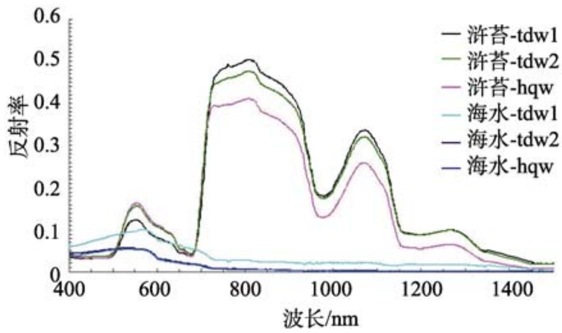

图 1　青岛海域浒苔与海水的反射率光谱

3.2　浒苔的图像特征

在较好的天气条件下 MADC 获取的红外图像(波段范围 750—850nm)和彩色图像(蓝绿红 3 个波段，拉伸增强后)如图 2，图像中浒苔和海水差别明显，但是受到海水镜面反射、热点、边缘畸变和图像噪声等因素的影响。在红外图像中浒苔的特征虽然非常显著，由于受到以上因素的制约，阈值分割等方法不能够准确地提取浒苔信息，只能够进行目视解译，难以满足快速出结果的需求，在海上雾大的情况下，可见光彩色图像中浒苔和海水差别不明显，红外数据可以作为一个有力的补充。从浒苔和海水的光谱中可以看出，浒苔和海水在蓝绿红波段光谱存在差异，在彩色相机的数据蓝绿红 3 个通道中存在差异，据此建立浒苔的识别和提取模型，实现浒苔信息的自动和半自动提取。彩色航片中浒苔海水等主要地物的图像光谱如图 3。

3.3　基于彩色图像的浒苔信息识别和提取模型

遥感地物识别和提取往往要依据地物光谱和图像特征的差异构建识别模型。由于 MADC 相机系统

图 2 MADC 获取的红外图像(a)和彩色图像(b)

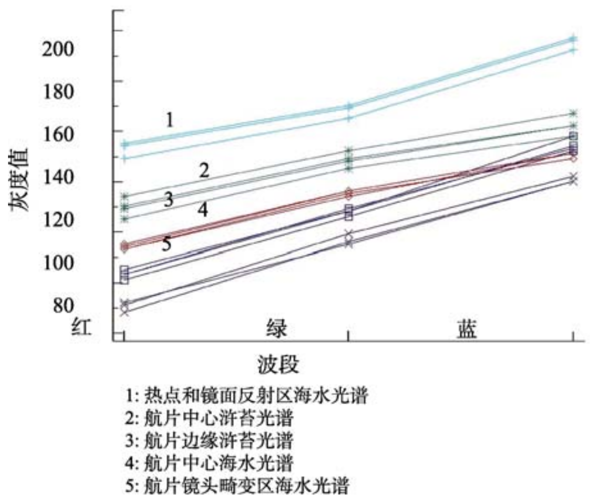

图 3 浒苔海水等目标的图像光谱

彩色和红外数据配准问题，浒苔信息的提取不能同时利用彩色和红外数据。虽然在红外图像中浒苔的特征显著，但对于数据，只能够采用目视解译的方法，难以满足快速出结果的需求，本文主要介绍了基于彩色相机数据所建立的浒苔识别和提取模型。通过分析图 3 中浒苔、海水、海浪镜面的光谱特性和差异，建立它们的识别和提取模型。通过建立决策树把这些模型整合，去除热点、镜面反射和镜头畸变的影响，精确地识别和提取浒苔信息。

(1) 根据其与海水的光谱差异，构建指数识别模型进行浒苔识别。

① $B-G<a$, a 为阈值，经验值为 24，可将浒苔和海水分开。

② $(B-G)/(B+G)<a$，将①归一化，a 为阈值，经验值为 0.09，识别浒苔。

③ $2G-(R+B)>a$, a 为阈值，经验值为 0，可将浒苔和海水分开。

(2) 一般热点区和波浪造成镜面反射区位置的灰度值比较大，特别是在蓝光波段与浒苔和正常海水的差异明显，可通过对蓝光波段的阈值分割进行热点和镜面反射的识别：$B>a$, a 为阈值，经验值为 160。

(3)镜头边缘畸变区主要是航片的边缘区，灰度值一般较小，可通过对红光波段的阈值分割进行识别：$R<a$, a 为阈值，经验值为 90。

以上模型中 R、G、B 分别为图像的红绿蓝 3 个波段的灰度值, a 为阈值，可根据实际情况进行调整。

4 浒苔信息提取的技术流程和关键技术

4.1 浒苔信息提取流程

浒苔航空遥感监测目的是利用 MADC 数据快速精确地获取浒苔分布和密度信息，为浒苔打捞治理提供决策依据，本文基于红外数据和彩色数据建立了两套工作流程，获取数据后首先对数据质量进行判断，如果彩色数据质量不高(如海上雾太大，彩色图像模糊)则利用红外数据，基于红外数据的工作流程主要包括数据预处理、目视解译和专题图制作，但目视解译的工作效率低；如果彩色数据的质量能满足要求，则利用上文建立的模型实现浒苔信息的自动和半自动的提取，其工作流程如图 4，主要包括 4 个部分，数据获取、数据预处理、浒苔信息提取和专题图制作。数据获取通过搭载在中国海监 3843 飞机上的多模态航空数字相机和 IMU/GPS 定位定向系统完成。数据预处理主要包括 POS 数据处理、图像格式转换、图像正射校正和正射影像镶嵌。图像预处理中的主要工作是基于 POS 的正射影像图制作(Wei, 2005)。基于正射影像镶嵌图进行浒苔信息提取，主要包括去噪、指数构建、决策树构建、信息提取、分类图矢量化等步骤。首先通过滤波去除 CCD 产生的椒盐噪声，然后通过执行决策树产生分类图，浒苔作为其中一类，实现浒苔信息的提取，最后把浒苔栅格分类图转化为矢量图，以利于在地理信息系统软件中数据的统计和专题图制作。此技术流程实现了浒苔信息的自动和半自动快速提取，为应急监测赢取了宝贵的时间。

4.2 浒苔信息提取的关键技术和策略

浒苔信息提取流程中的关键是指数构建并确定合适的指数阈值，以及基于所构建指数的决策树的建立。决策树分类法是以各像元的特征值为设定的基准值，分层逐次进行比较的分类方法，比较中所采用的特征的种类和基准值是按照实际数据及与目标物有关的知识等做成的，可以在很短的时间内进行分类处理(童庆禧等, 2006)。本文中所建立的决策树如图 5。

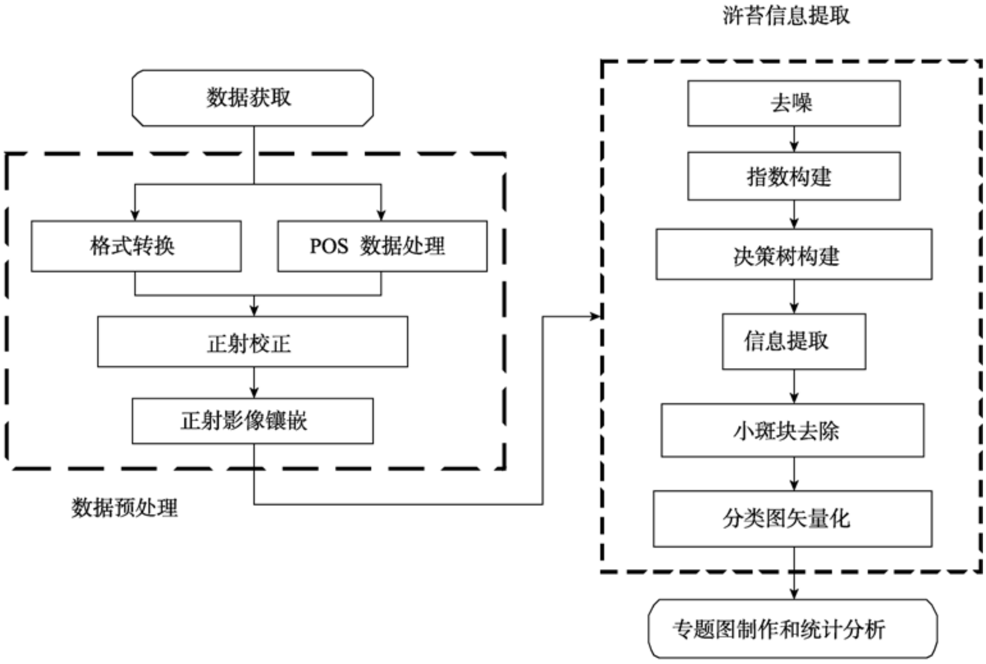

图 4 基于彩色图像的浒苔信息提取流程

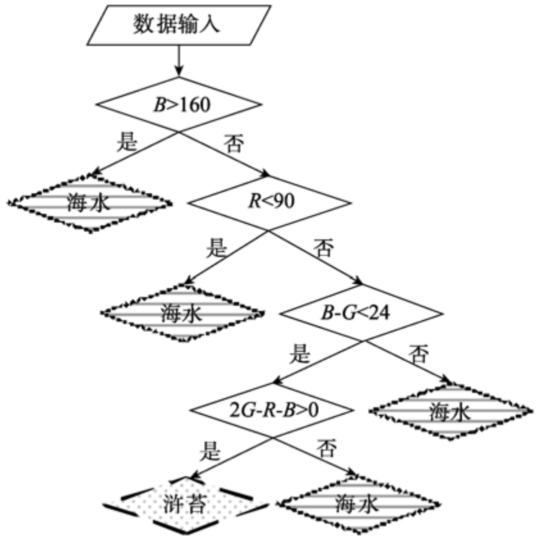

图 5 浒苔信息提取决策树

由于每次航空数据的数据量很大，为了完成浒苔应急监测的快速精确出成果的需要，在数据处理和信息提取中采取了一些优化策略。如数据的并行处理，按照行带把数据进行分块，分配给几台计算机同时进行图像的预处理和信息提取，最后把各分块的浒苔矢量数据导入 ArcGIS 软件统一编辑出图和统计；采用中值滤波对镶嵌图进行去噪，消除了图像中的椒盐噪声，提高了分类精度；另外在栅格分类图的矢量转化前，对其进行小斑块去除，大大提高了矢量化的速度，对分类精度的影响小于 1%，这些策略大大节约了时间，提高了数据处理效率。

5 浒苔信息提取结果和讨论

利用以上信息提取方法和策略，得出浒苔分布专题图和统计报告，表 2 展示了部分监测结果，包括监测水域面积(航片覆盖面积)、监测水域浒苔面积，警戒水域(奥帆赛比赛场地)浒苔面积及其密集度信息。2008-07-06 的浒苔分布图如图 6。对比 7 月 4 日和 7 月 6 日的监测结果(表 2)，可以发现 7 月 6 日较 7 月 4 日浒苔的密集度有所减小，特别是警戒水域通过人工打捞后浒苔明显减少，据此建议在加强警戒水域内的人工打捞外，应加快沿警戒水域外围的围油栏的建设，把浒苔阻挡在警戒水域之外，同时浒苔的分布位置也为打捞船的调度提供了依据，如从图 6 中可以看出浒苔主要分布在警戒水域的西南和东南。北海预报中心结合洋流和风向信息，对浒苔的漂移动态进行了预报。这些信息为浒苔打捞治理决策提供了准确的数据支持和决策依据。7 月 13 日的监测结果显示警戒水域的浒苔几乎被打捞殆尽。所建立的基于 MADC 的浒苔灾害遥感监测技术流程被成功的应用于海洋赤潮航空遥感监测和海上溢油遥感监测，显示出了 MADC 系统在海洋环境灾害应急遥感监测中的优势，这也是其所具有的多模态、多光谱和轻便灵活易安装的特点决定的。但 MADC 作为一个新研发的原型系统，在应急灾害中还存在以下缺点，需要进一步改进：一是要从硬件上解决不同相机间影像的精确配准，完善多光谱模

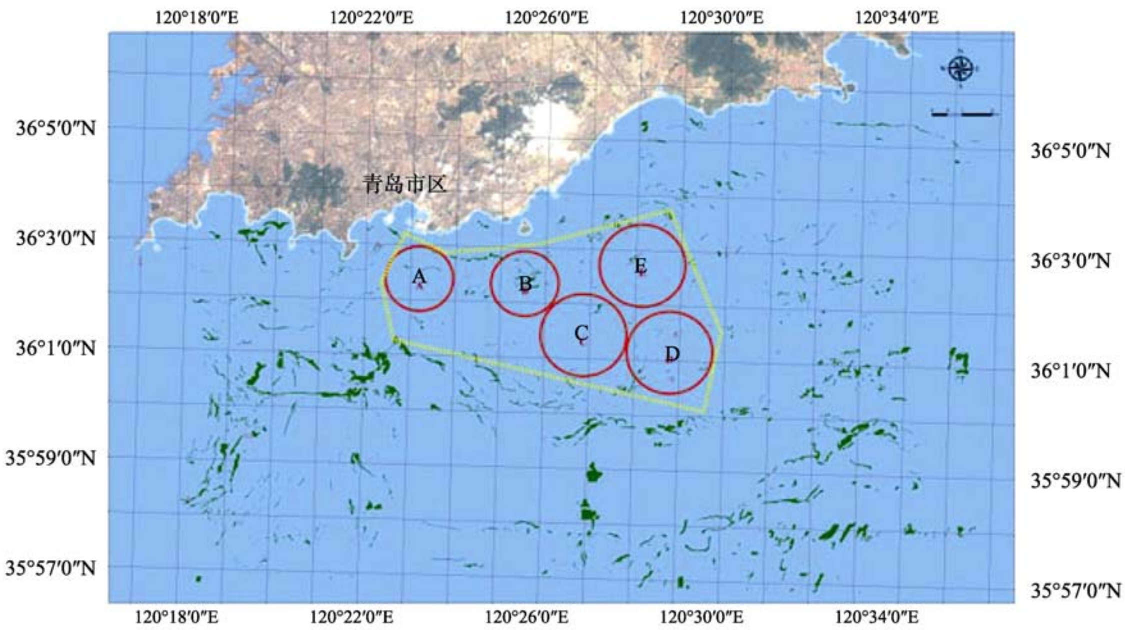

图 6 2008-07-06 浒苔分布专题图

表 2 浒苔分布监测结果

监测时间	监测水域面积 /km^2	监测水域浒苔面积 /km^2	监测水域浒苔密集度 /%	警戒水域浒苔面积 /km^2	警戒水域浒苔密集度/%
2008-07-04	306.5	13.2	4.31	1.12	2.26
2008-07-06	479	10.7	2.23	0.679	1.37
2008-07-13	480	2.5	0.52	0.0075	0.015

态，以利于建立更有效的信息提取模型；二是要开发与其匹配的图像处理系统，完成数据的正射、镶嵌、镜头畸变纠正、去噪、信息提取等功能，提高数据处理的效率。

6 结 论

实践证明，航空遥感是进行海洋赤潮和绿潮等环境灾害监测的重要手段，在青岛浒苔灾害应急遥感监测中，以多模态数字相机(MADC)为主的航空遥感系统提供了奥帆赛区警戒水域及周边海域浒苔分布面积、密集度等重要信息，为青岛市进行浒苔打捞提供了决策依据，保障了奥帆赛的顺利举行，显示出其在海洋环境遥感监测应用中的巨大潜力。通过对浒苔光谱及其 MADC 影像特征的分析，所建立的快速提取浒苔信息的技术方法在海洋环境灾害监测中有巨大的应用价值，并成功地应用于后来的海洋赤潮和海上溢油监测。鉴于 MADC 可快速灵活地设置成不同的工作模态、成本低、轻便易安装的特点，有必要把 MADC 系统纳入国家灾害应急监测业务运行体系，以使遥感能在灾后第一时间发挥作用，为决策服务。另外，MADC 作为一个原型系统，仍需要进一步改进和完善，并开发与之匹配的数据处理软件。

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REFERENCES

Fan X W, Zhang H D and Sun X W. 2003. The application of hyperspectral data to the detection and identification of red tides. *Remote Sensing for Land & Resources*, (1): 8—12

Fang J Y. 2005. A novel airborne digital camera system. Remote Sensing of the Environment. 15th National Symposium on Remote Sensing of China, Proceedings of SPIE

Fang J Y.2003. Airborne digital camera system with multi-mode and large format array CCD. *Journal of Remote Sensing*, **7**: 22—27

Liang Z Y, Lin X Z, Ma M, Zhang J, Yan X B and Liu T.2008.A prel-minary study of the enteromorpha prolifera drift gathering causing the green tide phenomenon. *Periodical of Ocean Uni-*

versity of China, **38**(4): 601—604

Lin W T.2007.Development and utilization of entermorpha.*Food and Nutrition in China*, **9**: 23—25

Ma Y, Zhang J, Zhang H D and Liu Y Z. 2002. Advances in application research on the marine airborne hyperspectral remote sensing in China. *Advances in Marine Science*, **20**(4): 94—98

Michel Merceron, Virginie Antoine, Isabelle Auby and Philippe Morand.2007. In situ growth potential of the subtidal part of green tide forming Ulva spp. Stocks Michel. *Science of the Total Environment*, **384**: 293—305

Pedro H. de Paula Silva, Shannon McBride, Rocky de Nys and Nicholas A. Paul. 2008. Integrating filamentous ‘green tide’ algae into tropical pond-based aquaculture. *Aquaculture*, **2842**: 74—80

Qiao F L, Ma D Y, Zhu M Y, Li R X, Zang J Y and Yu H J.2008.The status of algae bloom in Yellow Sea at 2008 and the measurements. *Advances in Marine Science*, **26**(3): 409—410

Tang J W, Ding J, Wang Q M and Ma C F.2004. Research of the effects of atmospheric scattering on red tide remote sensing with normalized vegetation index. *Acta Oceanological Sinica*, **26**(3): 136—142

Tong Q X,Zhang B and Zheng L F.2006. Hyperspectral Remote Sensing. Beijing: High Education Press

Wang Q M, Ma C F, Tang J W and Guo M H.2006.A method for detecting red tide information using EOS/MODIS data. *Remote Sensing Technology And Application* , **21**(01): 6—10

Wei Z. 2005. Application of POS in correcting images of aero-digital camera with large format array CCD. Remote Sensing of the Environment: 15th National Symposium on Remote Sensing of China, Proceedings of SPIE

附中文参考文献

范学炜, 张汉德, 孙幸文. 2003. 成像高光谱数据在赤潮检测和识别中的应用研究. 国土资源遥感, (1): 8—12

梁宗英, 林祥志, 马牧, 张静, 闫晓波, 刘涛. 2008. 浒苔漂流聚集绿潮现象的初步分析. 中国海洋大学学报, **38**(4): 601—604

林文庭. 2007. 浅论浒苔的开发与利用.中国食物与营养, **9**: 23—25

马毅, 张杰, 张汉德, 刘宇中. 2002. 中国海洋航空高光谱遥感应用研究进展. 海洋科学进展, **20**(4): 94—98

乔方利, 马德毅, 朱明远, 李瑞香, 臧家业, 于洪军. 2008. 2008年黄海浒苔爆发的基本状况与科学应对措施. 海洋科学进展, **26**(3): 409—410

唐军武, 丁静, 王其茂, 马超飞. 2004. 大气散射对采用归一化植被指数进行赤潮遥感监测的影响研究. 海洋学报, **26**(3): 136—142

童庆禧, 张兵, 郑兰芬.2006. 高光谱遥感——原理、技术与应用. 北京: 高等教育出版社

王其茂, 马超飞, 唐军武, 郭茂华. 2006. EOS/MODIS遥感资料探测海洋赤潮信息方法. 遥感技术与应用, **21**(1): 6—10