Dynamic Monitoring and Yield Estimation of Crops by Mainly Using the Remote Sensing Technique in China

Jiulin Sun

Abstract
In recent decades, using remote sensing and other techniques to dynamically monitor crop growth and estimate crop yields has become an important research trend in China, which is one of the most important applications of remote sensing in agriculture. In this article, the author first reviews the history of research on crops yield estimation, then introduces the main contents of the research and explains how to establish an operating system for remote sensing, including the key techniques and solutions. Finally, on the basis of experience, some theoretical and technological problems that need to be further studied are put forward after the discussion on how to establish an efficient cost-effective and operational system.

Introduction
With progress in science and technology and the improvement of social requirements, remote sensing technique can scientifically, quickly, and dynamically monitor and predict the growth, area, yield, and spatial distribution of crops. The growth environment and yield of crops are affected by many complex factors, including those habitat factors that can be controlled by man, and other factors such as natural disasters that occur suddenly and are beyond man's control. Though remote sensing can provide reliable information dynamically and quickly, it is not enough to monitor growth and estimate the yield of crops when there is no other information. Thus, we realized that, in addition to remote sensing, we should comprehensively use many other techniques such as GIS, soil analysis, and ground observations.

Methods
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The Research Process
The process of this research can be divided into the three steps shown in Figure 1. The first step is to acquire remote sensing data, historical background data, and ground survey data; the second step is to analyze the collected data according to different objectives; and the third step is to get results through analysis.

In China since the late 1970s, research programs of this nature have been undertaken (Chen, 1993). At the beginning of these studies, in order to test these new methods, experimental yield estimations of single types of crops were carried out in some small regions. In the mid-1980s, research on growth monitoring and yield estimation of wheat (Liu, 1987) was carried out by the Civil Aviation Administration of China in 11 provinces in north China. A system was then established for estimating the yield of a single type of crop in a large area using information obtained by meteorological satellite remote sensing and ground investigation. Since the 1990s, based on past experience in this field, the Chinese Academy of Sciences (CAS) has brought together experts from various fields to perform intensive research on yield estimation of many types of crops over large areas by using remote sensing techniques. In addition, an information system has been established for monitoring the growth and estimating the yield of crops. At present, on the basis of the above achievements, this research has spread to the rest of the country, and the crop types have been extended from wheat, corn, and rice to other crops such as cotton, soybeans, and rape. Furthermore, the accuracy of growth and yield estimating has improved steadily.
improving the accuracy of the research. The selection of sample sites should conform to the principles of mathematical statistics, geographic spatial features, crop characteristics, and budget constraints.

Multi-Source Data Integration
There are many kinds of data in this research, including remote sensing data, GIS data, sound data, and graph data which make data integration/fusion an important research issue. Data integration/fusion mainly includes:

- The matching and overlay of traditional data such as statistical data and multi-spectral, multi-resolution, multi-temporal remote sensing data, with the support of a geographic information system; and
- The integration/fusion of multi-temporal remote sensing data (Quarmby and Townshend, 1993) from different platforms such as NOAA AVHRR and Landsat TM.

Expert Knowledge for Dynamic Monitoring and Yield Estimation
An expert's knowledge about remote sensing and crops, when introduced into the system, can improve the reliability of growth monitoring and yield estimation. With the support of an expert's knowledge, the remote sensing image can be interpreted more precisely, the changing trend of dynamic monitoring can be easily found, and the integration of many kinds of information can be realized.

Crops Yield Estimation Model
Crop area and yield estimation models have been studied for a long time, and many good models have been developed (Lu, 1983; Wan et al., 1984; Wang, 1990). But these traditional models have been developed mainly from the point of view of biology or meteorology without consideration of remote sensing, and thus cannot meet the demands of today's society. Based on our studies of other methods (Lamington and Sorensen, 1984; McCloy et al., 1987; Gallego and Defince, 1993), we have developed a model based mainly on remote sensing, which meets the requirements for speed and management over large areas; hence, it is different from the traditional models.

Key Techniques and Solutions
Different crops have different characteristics such as spectral reflectance and growth periodicity, and different regions have different conditions such as landform and cloud cover. Therefore, though we want to reach the same goals of crop growth monitoring and yield estimation, the key techniques and solutions for different crops in different regions may be different (Chen and Sun, 1997). Table 1 shows the key techniques and solutions for yield estimation of three main crops (wheat, corn, and rice) for large areas based on our practical research (Wan and Xu, 1996; Wang et al., 1996; Zhao et al., 1996).

Case Study: Practical System in China
The final aim of the above research was to establish an automatically operating system for daily work, which is different from former studies which lacked automatic and fast-processing computer systems. Based on practical experience, we introduce an example of establishing a system for dynamic monitoring and yield estimation of multiple types of crops in a large area.

The project "Growth Monitoring and Yield Estimation Using Remote Sensing in Main Crops Area of China" was a state key project in the "Eighth Five-Year Plan" period (1991-1995). The objectives of this project can be summarized as follows: (1) to use advanced "3S technology" (RS, GIS, and GPS) to monitor the growth of crops and give advice on agricultural management, such as on insects and drought; and (2) to estimate crop yields quickly before they are harvested and, thus,

Figure 1. The process of dynamic monitoring and yield estimation with remote sensing techniques.
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support the decision-makers on food prices, food supply, international trade, and so on.

The Process of System Development
The process (Figure 2) can be divided into three stages:

- **Overall plan of the system**, including the identification of goals and determination of limitations to the development of the plan;
- **System design**, including the optimal plan based on an object-oriented analysis; and
- **Putting the system into use**, including its debugging and running.

The Logical Structure of the System
The logical structure of the system (Figure 3) can be taken as a further division of the process (Figure 2), as well as the summary of all the above research.

Information Model of the System
Figure 4 shows the structure of important information models in the yield estimation system. Parameters such as leaf area index, head number, grain number, and weight per 1000 grains, which are acquired from ground observations, and the green index number (GIN) (Best and Harlan, 1985), which is obtained from remote sensing, are the indispensable parameters of the per-unit-area yield model. The planting area of different crops can be acquired through remote sensing and ground statistical data. If the per-unit-area yield and planting area are known, then the total yield can be determined.

Data Stream of the System
Figure 5 shows how the data stream flows in this research. From the figure, we can know what the role is of each kind of data and its effect on the whole system. For example, ground survey data are directly stored in the background database and are used for sowing area extraction, yield model establishment, and so on. Furthermore, all of the analysis results are stored in the computer system, and they can be extracted quickly for further use in this project, which is very important in an operational system.

Functional Integration of the Application System
The entire system for growth monitoring and yield estimation consists of several different functional modules which can be called on demand (Xiong and Ni, 1996). Figure 6 shows those major modules such as automatic extraction of planting area, per-unit-area yield estimation, automatic growth monitoring, and so on. These modules can be run under the support of the computer-aided system, which makes up the whole operational system in daily work for the users.

Conclusion and Discussion
Using remote sensing to carry out dynamic monitoring and yield estimation of many types of crops in large areas has a lot of promise, and some excellent results have been achieved in several crop applications. Based on our practical experience and results of our research, we believe that NOAA coverage along with selective TM sampling and ground observation sampling sites is an efficient and cost-effective method. However, some theoretical and technological problems need to be studied further, especially in China, which is a developing country without enough funds. These problems are summarized as follows: integration techniques for multi-source data; yield modeling and planting area extraction under the influence of complex geographic conditions; construction of an expert system for yield estimation; decreasing the number of ground sample sites, to reduce the cost for establishing and running the system; improving the accuracy of yield estimation, and so on.
Acknowledgment

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References


(Note: The customary western practice of listing author's family names last, except in the list of references where only the first author's name is listed family name first, is followed herein.)

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