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## Data Fusion Technology for Precision Forestry Applications

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**Abstract.** *Presently precision forestry is playing an important role in realizing sustainable development and improving societal and economical efficiency for forestry applications. Based on analyzing the features of precision forestry's information requirements, the data needed for precision forestry were classified and the characteristics of the different information were summarized. Data fusion for precision forestry was studied in this paper. The architecture for precision forestry information processing, which integrated information fusion and data mining, was put forward. New and emerging technologies such as Remote Sensing (RS), Geographical Information System (GIS),*

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*Global Position System (GPS), Data Base Management System (DBMS), Data Fusion, Decision Support Systems (DSS), and Variable Rate technology (VRT) are applied in forestry production as aids in producers' and managers' decision-making process. Precision irrigation, precision fertilizing, precision pesticide application, precision harvesting, and precision deforestation can promote the realization of minimizing resource inputs, minimizing environmental impacts, and maximizing forest outputs.*

**Keywords.** Data fusion, precision forestry, integration of information flow, sustainable development.

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## Introduction

Global concerns about greenhouse gas emission and absorption have led countries to examine the utilization of forests. Forests, which are managed in a sustainable manner, should contribute not only to avoid global warming but also to preserve biodiversity. Sustainable forest management is also of great significance to China in achieving the promising goal of increasing productivity to feed the population while decreasing production costs and minimizing environmental impacts. Adopting the notion of precision into forestry practice is imperative to achieve this goal. Precision forestry has been regarded as a promising research field which can realize scientific utilization of limited resources and reduction of the risk of environmental problems. In china, precision forestry is still in its infancy. Improving profitability and reducing environmental impact offer insights into the likely prospect for current precision forestry. Applying inputs more precisely may increase the percentage of the inputs uptaken by plants, and therefore reduce economic waste and emission to the environment without sacrificing yields (Zheng et al., 2004).

## Analysis of Precision Forestry's Information Features

The production and management of precision forestry require accurate, efficient, scientific, reasonable, and automatic operations according to the actual conditions and circumstances. Precision Forestry has been defined as "analyzing the spatial-temporal variability based on natural biology and environment resources (for instance, soil texture, topography, soil moisture content, microclimate, outbreak of diseases and insect pests, etc). Therefore, it may increase the efficiency of inputs by allowing producers to manage plants on both spatial and temporal basis. This information is used to plan and conduct site-specific forest management that will improve wood product quality and utilization, reduce waste, increase profits, and maintain the quality of the environment (Zhang et al., 2009)."

Precision forestry means applying the right amount of water, fertilizers, and pesticides in the right place at the right time. There is a consistent thread of data flow running through the whole process of precision forestry (Zhang et al., 2007). It's a suite of technologies rather than a single technology. Components in that suite of technologies currently include Remote Sensing (RS), Geographical Information System (GIS), Global Position System (GPS), Data Base Management System (DBMS), Data Fusion, Decision Support Systems (DSS), Variable Rate technology (VRT) equipment for seeding, fertilizers, and pesticides, grid soil sampling, low-volume irrigation, yield monitoring, sensors for weed populations, etc. The implementation process of precision forestry includes:

1. GPS and other sensors that are mounted on the forestry machinery;
2. GIS generated maps that combine the GPS information with RS ground information;
3. Analyzing distribution maps of plant's growth provided by GIS and acquiring the difference between plants;
4. Integrating the spatio-temporal data, attribute data, historical data and other data;
5. Establishing the trend model of plant growth according to accumulated experience and long-term knowledge of forestry practices;
6. Integrating the local soil, pest and climatic condition information into the system, and generating thematic maps and application maps with intelligent decision system to guide the variable rate application;

7. Realizing precision irrigation, fertilization, chemical application, harvesting, and deforestation based on variable rate technology.

It can be seen that the production of precision forestry is a data stream process, and some of these data sources serve more than forestry purposes (weather, geographic information, and positioning data. Other data structures (variable rate technologies, on-the-go sensors, and yield monitors) will be totally focused on forestry application and will need to be interfaced with non-forest source (Committee on Assessing Crop Yield. 1997). However, methods to facilitate this process and standardized formats for data collection, storage, and transfer are required to develop precision forestry to its full potential.

### ***Information source of precision forestry***

A significant characteristic of precision forestry is to provide, process, and analyze multi-source data with high spatial and temporal resolutions. Information required for precision forestry comes from different sources, including the following:

1. Digitized maps. Map digitizing is one of the main sources of geospatial data. Spatial data can be acquired directly through digital mapping or scanning a map (Rossmann et al., 2009).
2. Observation information. Data are acquired based on field survey and measurement, meteorological data, soil data, etc.
3. Experiment information. The simulation of ground objects and processes in the real world generates some results, including fertilizer efficacy data and pesticide deposition data.
4. RS and GPS information. Aerospace acquires RS data to improve quality and automation of image classification and extracting information (Anne et al., 1999). GPS accurately acquires the target's spatial location and provides an important way to inspect and verify the validity and reliability of other spatial data.
5. Theoretical reasoning information. In the event of failure to obtain data directly, theoretical reasoning is a way to acquire data, including distributions of forest and change of planting structure. Moreover, theoretical reasoning is available for data needed in the short term, for example, the losses from insect damage.
6. Historical information. Usually problems exist in data that are recorded in the historical document, such as uncertainty, omissions and redundancy, non-systematic, and non-standard. It needs to be revised based on professional and non-professional background knowledge, such as a disease index.
7. General survey information. Statistical data are transformed to geospatial data by relating them to spatial locations.
8. Integrating information. New data are acquired through existing geospatial data by merging, extracting, Boolean calculation, and filtering (Rian et al., 2003).

### ***Classification of the information***

Precision forestry information is a combination of space, time, and main content. Space segment represents the position and geometrical characteristics of the geographical entity. Time segment records the forest's age and the time of collecting GPS positioning data and meteorological data (Ross et al., 1998). The main content includes the attributes of the

geographical entity, for example tree species, unit accumulation, land type, forest pests and diseases, prevention methods, suitable plant protection machinery and irrigation machinery.

Due to the diversity of data content and form, the classification of precision forestry's information differs according to different focus and principles.

1. Initial data and production data. Initial data can also be called firsthand data because users can obtain the data directly from field observation, test, and investigation, for example, meteorological data (Sorin et al., 2004). Production data indicates the data is obtained after processing of the initial data, for example, most geographical maps, statistical data, historical data and RS data.

2. Point data, line data and polygon data. Point data includes tombstones and lighthouses. Line data includes roads, rivers and contour lines (Sun et al., 2003). Polygon data include administrative divisions, compartments, and sub-compartments.

3. Qualitative data and quantitative data. Qualitative data characterizes but does not measure the attributes, characteristics, properties, etc., of the object, for example, tree species and forest types (Wang et al., 2002). Quantitative data measures the attribute value based on the relative position of different standards. The unit is set according to certain level instead of equidistance, which could be ascending order or descending order, for example, age of trees and aesthetic evaluation of landscape ecology.

4. The information contents of precision forestry:

(a) Reference data for controlling what is used to determine the location of other geographical characteristic, such as controlling points and elevation;

(b) Direct measurement features that can be obtained by accurate measurement and precise position of RS and GPS data, such as roads and rivers (Oladi et al., 2010);

(c) Geometry features that contain the natural condition of land, utilization, management authority and change record which refers to the changes of space characteristic, time series and attributes;

(d) Zone boundary features, however the fuzziness and transitivity of the zone boundary are difficulties in expressing the features of zone boundary; and

(e) Physical features that explain the contents and the relation of these natural characteristics, which are subjected to geographic constraints.

### ***Characteristics of Information***

The realization of precision forestry requires the integrated application of different sensors. There are close relationships among the different elements in precision forestry, and the information for precision forestry has the characteristics of multi-source, heterogeneity, layer and complexity.

1. Multi-source

Information for precision forestry comes from a wide range of sources due to six reasons. Firstly, there are many main elements, which include operational object (trees) information, forestry machinery information, and microclimate information. Secondly, there is a great variety of temporal-spatial information that contains historical, real-time and predicted information as well as node, route and region information. Thirdly, there are many layers involved in the process of precision forestry, for example, design layers, developer layers, manager layers, user layers (forestry section). Fourthly, the information comes in different ways, for example,

GPS, GIS and RS. Fifthly, information categories are broad because it includes pests and diseases of trees, land type, tree species, fertilizer type, pesticide type, etc. Lastly, there is a variety of other information, for example, policies related to the application of pesticide, fertilizer and forestry machinery, laws and regulations regarding picking and logging.

## 2. Heterogeneity

The structures of information differ because they come from different application systems or platforms. The form of the information includes quantitative information (such as travel speed of the forestry machinery and forest stock) and qualitative information (such as outbreak and spread of the pests and diseases).

## 3. Layer

Based on the abstract layer, the information of precision forestry falls into four layers: fundamental data layer, characteristic attributes layer, state description layer and decision-making layer. The last three layers correspond to “is it the operational target of precision forestry (qualitative analysis)”, “how is the target distributed (position analysis)”, “how much water, fertilizer and pesticide does it need (quantitative analysis)”. The fundamental data layer obtains essential data from the different sources with particular attention to the collection and collation of data. Then the characteristic attributes layer collects statistical data about the operational target and growth state of the trees, which focus on identifying and making judgments from the data. Next, the state description layer gathers the data describing the soil nutrient and pests and diseases of trees. It attaches importance to analysis and predictions based on the data. Finally, the decision-making layer decides actions based on data (for example irrigating, applying fertilizer and spraying pesticide). It puts stress on the executing and implementing decisions based on the data.

## 4. Complexity

In summary, realizing precision forestry becomes very difficult because of the complexity and abundance of the data.

# Data Fusion Technology for Precision Forestry Application

Data fusion when used in precision forestry can reduce the uncertainty and the unmeasured variability to make the more detailed and timely decisions. Due to the characteristics of multi-sources, heterogeneity, layer and complexity, it is important that automatic and intelligent decisions should be made in forestry production to improve the stability and reliability of information processing. By taking full advantages of the redundancies and complementarities of multi-sources information and establishing algorithms oriented to the different layers of information processing, the analysis, planning and decision-making can be based on the integration system of the information flow. Information integration procedure is from data fusion to function fusion, then to application fusion. Therefore it covers the microscopic and the macroscopic fusion and realizes effective collecting, managing and storing various sources of information.

The principle, structure, layer and algorithm differ according to the target. Based on the layers of forestry information mentioned earlier, the data fusion mode of information flow falls into four layers: fundamental data layers, attributes layers, state description layers, and decision-making layers. Their functions, characteristics and methods are different (Fig.1).

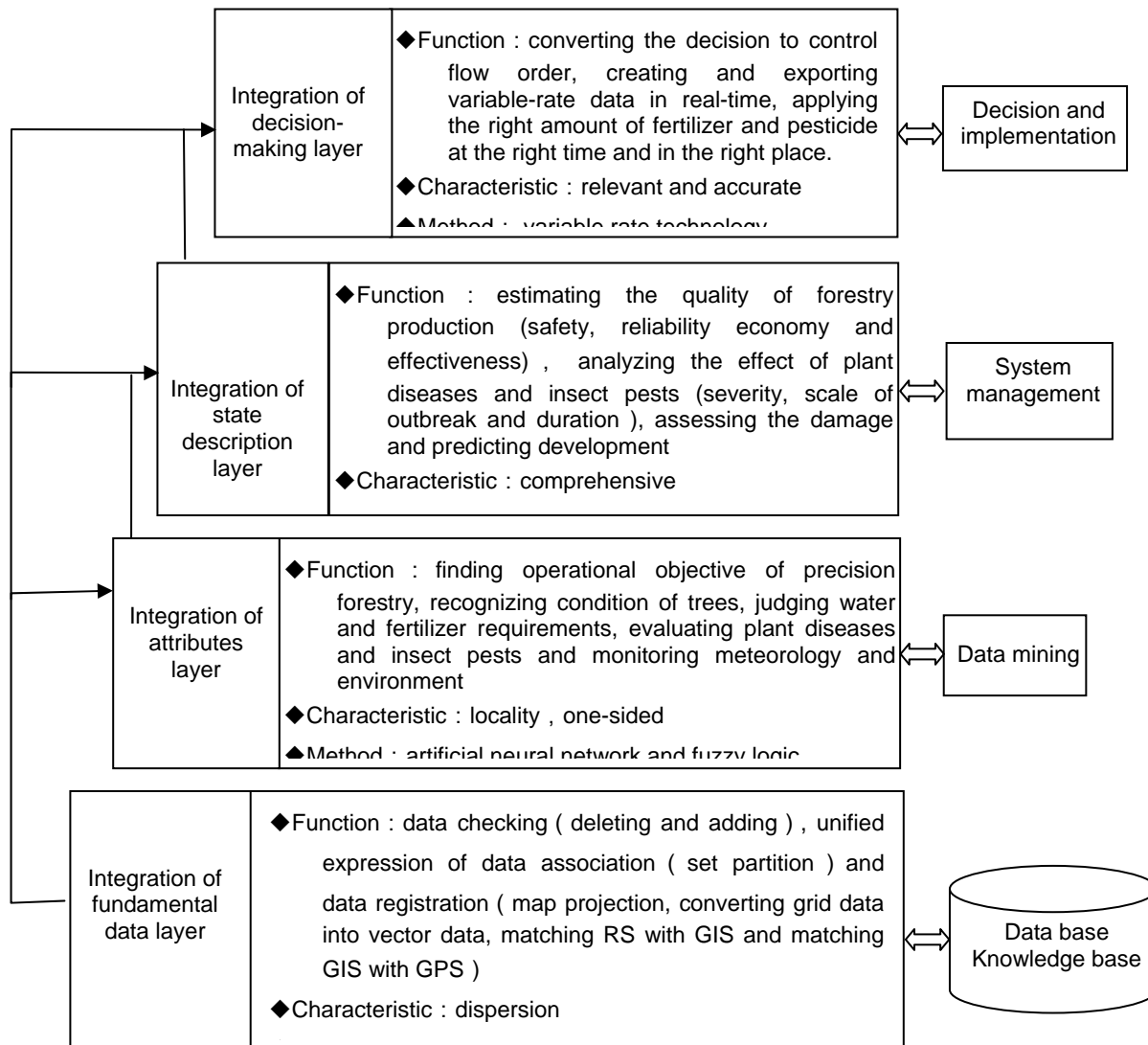


Fig 1. Processing mode for precision forestry's data fusion

### 1. Integration of fundamental data layers

In this layer the data is comprehensively analyzed before processing the original sensor data. In order to maintain more geo-information, the data processing includes data checking (deleting and adding), unifying the expression of data associations (set partition) and data registration (map projection, converting grid data into vector data, matching RS with GIS and matching GIS with GPS). Discreteness is its characteristic and artificial neural network, statistic correlation and posterior estimate are the methods.

### 2. Integration of attributes layer

After preprocessing of the information and extracting the characteristic, this layer aims at finding operational objects of precision forestry, recognizing condition of trees, assessing water and fertilizers requirements, evaluating the severity and range of plant diseases and insect pests and monitoring meteorology and environment. It has locality and unilateral features by using the method of artificial neural network and fuzzy logic.

### 3. Integration of state description layer

This layer reserves important information and compresses data to estimate the quality of forestry production (safety, reliability economy and effectiveness), analyses the effect of plant diseases and insect pests (severity, scale of outbreak and duration) and assesses the damage and predicts the development tendency. Artificial neural network and expert system can be applied to produce the features of entirety and comprehensiveness.

### 4. Integration of decision-making layer

The objective of this layer is to convert the decision result to control flow order; and exporting variable-rate prescription data in real-time. It is suited to the measurement of local conditions and how applying fertilizers and pesticides vary from time to time and place to place. It has the advantages of relevance and accuracy of variable rate technology. Optimizing decisions are made in accordance with certain standards and confidence, with the aim of developing reliability or fault tolerance, so that even if one or several kinds of sensors fail to function, the system can still work.

It can be seen that system management, databases, knowledge base and variable rate technology make up the unified structure of information processing. Work that processes layer by layer is essentially regarded as data fusion or pattern recognition. The lower layer is the basis for the processes and application of subsequent layers, while the higher layers are the synthesis of the previous layers.

According to the process of information management, there are two kinds of integration mode, parallel and serial control. Parallel control emphasizes the hierarchical relationship of information, where reasoning is developed from low levels to high levels and export is spread from special features to the general state. It therefore adapts to centralized architecture. Serial control layers stress on coordinating relationships, where results are an expression of dynamic combinations and export is a summary of every layer's result. It is therefore suited to the distributed architecture (Zhang. et al., 2003). Fig 1 shows that integration mode for information flow of precision forestry contains both parallel and serial controls. The advantage of this integration mode lies in its high adaptability to complicated information, good flexibility to production and easy algorithm modification to efficiently organize and manage multi-sources data.

## Conclusion

Following the rapid application of information technology into the forestry sector, the utility of data fusion in precision forestry in China has played an important role in advancing traditional forest industries and improving societal and economical efficiency. Forestry field work including forest type, diameter, tree height, growth stage and pests and disease level are stored in a relational database. Data fusion is an approach that can accommodate numerous aspects of precision management that are interrelated and vary in time and space. Using data fusion technology and integration of information flow can help ensure sustainable development of forests. Specific conclusions include the following:



1. There is a consistent thread of data flow running through the whole process of precision forestry.
2. Information comes from different sources and can be classified to several types according to different focuses and principles.
3. Information characteristics of precision forestry can be summarized as multi-sources, heterogeneity, layer and complexity.
4. Based on the layers of forestry information, the data fusion mode of information flow was divided into four layers, integration of fundamental data layers, integration of attribute layers, integration of state description layers, and integration of decision-making layers.

The adoption of precision forestry will be more widespread by more efficient and precise using of fertilizers, pesticides, and other inputs to simultaneously improve profitability and reduce negative environmental impacts. Using data fusion can enhance coordination among different technologies and overcome the isolated information island effect that can result from single sensors. Therefore, data fusion technology and the integration of information flow for precision forestry application will contribute to the protection and improvement of the ecological environment and help realize sustainable development.

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