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Abstract. To monitor and control locusts efficiently, an information platform for locust control based on the global positioning system (GPS), remote sensing (RS), and geographic information systems (GIS) was developed. The platform can provide accurate information about locust occurrence and control strategies for a specific geographic place. The platform consists of three systems based on modern pest control: field ecology (locust occurrence) and GIS in a mobile GPS pad, a processing system for locust information based on GIS and RS, and a WebGIS-based real-time monitoring and controlling system. This platform was run at different geographical locations for three years and facilitated locust control in China with high efficiency and great accuracy. [DOI: 10.1117/1.JRS.8.084899]

Keywords: locust control; design; information platform; 3S technologies; geographic service.

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1 Introduction

Along with floods and droughts, locust swarms are the cause of devastating agricultural/biological disasters in China.[1] The dominant locust species is *Locusta migratoria manilensis*. More than 2 million ha of agricultural land in China is affected by the invasion of these species annually.[2] Choosing the best strategy for controlling locusts and grasshoppers requires a complex and extensive analysis of information, including the biological characteristics of locusts, vegetation, humidity, and pesticides.[3] The rapid development of computer technology has made this objective relatively easy to achieve.[4] An increasing number of information systems for pest control have been implemented, and these systems have played an important role in pest control. However, China still has no feasible information system for locust control. To address this issue, we developed an information platform for locust control that can be applied in China. We report on the design and implementation of the platform in this article.

2 Demand for Locust Control and Information Platform Tasks

Developing the platform started with data collection. Data on locust habits, climate, and manpower in a specific location were collected using the global positioning system (GPS), remote sensing (RS), and meteorological sites. The data were transferred to the data processing center of the platform through the Internet. The processing center automatically processed and integrated all the information collected from different locations. With the collected data, analysts forecast the locust situation and build a prescription map for an airplane or a large mechanical instrument to spray insecticide over affected areas accurately. The directors of the locust control could dispatch locust trucks and airplanes loading insecticide, locust control people, and locust control funds needed based on the location information from the locust control stations and airports (Fig. 1).

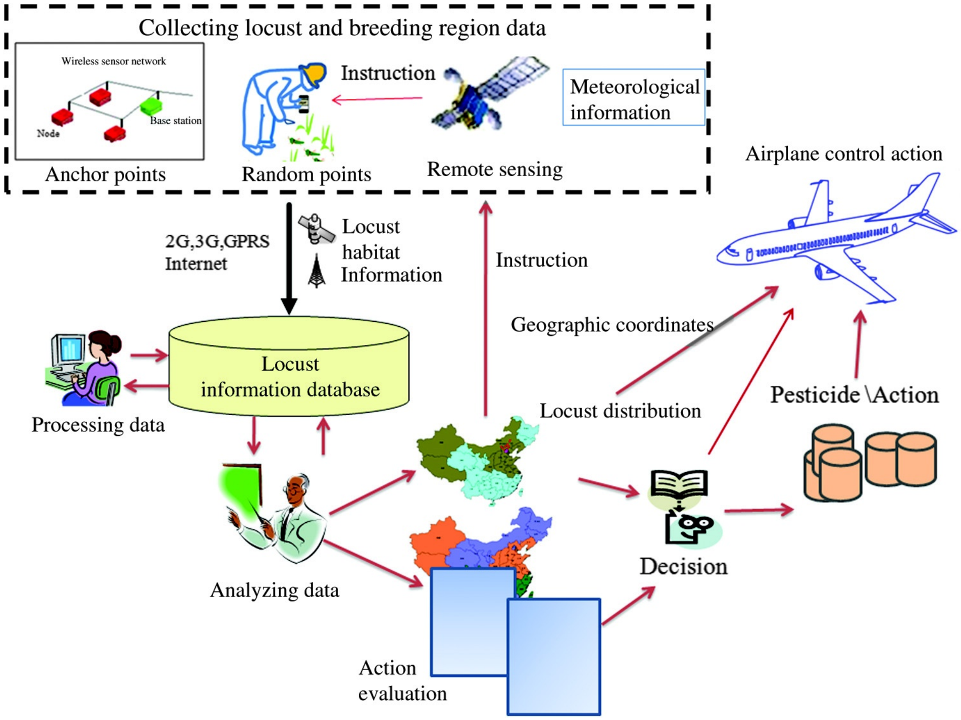

Fig. 1 Technical route of a monitoring and controlling system for locusts.

The entities responsible for controlling locust outbreaks are the central and local governments. The level of administrative government involved in the action is based on the degree of locust occurrence. Therefore, an information platform should be designed to fit the requirements for decision making at different administrative levels (i.e., the central, provincial, prefecture-level city, and county levels). Administrative levels are assigned different tasks, such as locust monitoring, preventive measures, and controlling locust damage. Thus, the information platform should have the following functions. (1) For statistical analyses and provision of locust occurrence information, data on locust occurrence and control should be normalized by setting up data input/output standards and indexes for quick searches. (2) All operations on the platform, such as collecting locust information in the field and processing or analyzing data online, should be convenient. (3) The platform should provide the precise location of locust occurrence and control to allow for the accurate spraying of pesticide. (4) Users should be able to monitor the process of spraying pesticide and the sprayed areas in real time online. Finally, the platform and the databases should be run securely and be error free.

3 Structuring/Architecture and Functions of Designed Platform

Based on the required functionality of the platform, we designed it with three systems: a collecting system used to use a personal digital assistant (PDA) for collecting ecological (locust occurrence) and geographic information in the field, a processing system for locust information based on geographic information system (GIS) and RS, and a real-time monitoring and controlling system based on WebGIS. Users at the county level collect locust data with the collecting system. They then upload the collected data to the database at the processing center of the platform through the general packet radio service (GPRS), 2G, 3G, or other network. By accessing the monitoring and controlling system online, users can manage their own data that are stored in the information management subsystem. Online checking is conducted by users at the municipal and provincial levels in the decision-making analysis subsystem of the monitoring and controlling system. The administrators at the data processing center analyze and synthetically calculate the ground survey data, RS, and GIS data to build a locust control prescription map, produce various thematic maps, and transfer these maps into the database of the processing

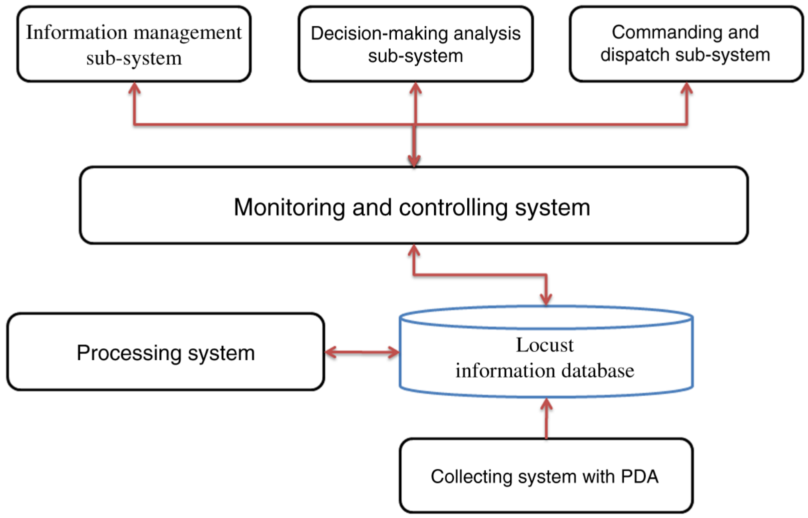

Fig. 2 Overall architecture diagram of the platform.

system. Users from all administrative levels can download the thematic maps, generate statistical figures and tables with the ground survey data, and input the locust control prescription map into the control center of a plane or another vehicle using the decision-making analysis subsystem to guide the accurate spraying of pesticide. Users can allocate locust control resources from the command and dispatch subsystem of the monitoring and controlling system by commanding and monitoring the process of spraying pesticide (Fig. 2).

4 Key Technical Problems and Platform Development

4.1 *Spatial Database Design*

The spatial information is stored in the file geodatabase using the WGS84 coordinate system. The information includes basic geographic data, RS data, meteorological data, and locust thematic data (Fig. 3).

Basic geographic data include information on basic geographical elements, such as administrative districts, terrains, residences, roads, railways, and river systems. The RS data include vegetation coverage, soil moisture, soil humidity, and land coverage (i.e., woodland, grassland, wetland, desert, and farmland) interpreted from RS data. Meteorological data include

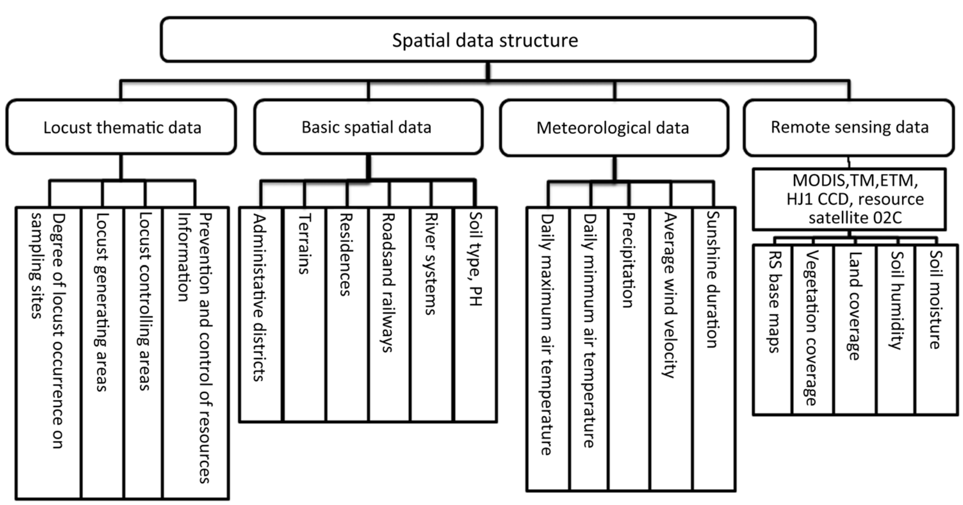

Fig. 3 Spatial database structure diagram.

information on daily maximum air temperature (°C), daily minimum air temperature (°C), precipitation (mm), average wind velocity (m), and sunshine duration (h). In this work, 1:4,000,000 national soil spatial data were used to provide information on soil type, pH values, and so on. The thematic spatial data on locust occurrence contain information on the degree of locust occurrence on sampling sites, locust generating areas, locust breeding regions, obstacles location, locust controlling areas, locust control supplies stations, locust control special airports, and work stations of locust control teams.

4.2 *Collecting System with PDA Design*

4.2.1 *Collecting system with PDA function design*

Figure 4(a) shows that the system consists of data about the breeding region, occurrence, and prevention of locusts; the ecological systems, and the biological characteristics of locusts. Specifically, information on these biological characteristics, including population density, species, breeding season, developmental stages, nymph bands, swarms, and phases, is the core of the system.[5] Information on locust prevention includes control type, control mode, spraying dose, personnel investment, and funding. The inquiry system for the biological characteristics of locusts can provide users with knowledge of the biological properties of locusts and grasshoppers as well as related control measures. The system features real-time software upgrade, mobile-end database maintenance, and communication network settings.

4.2.2 *Working flowchart and implementation of the collecting system with PDA*

The collecting system using a PDA runs on the Android operating system. Users can use it to collect and upload data in real time [Fig. 4(b)].[6]

Users can use a PDA to collect data on locusts, including pictures, and information about their occurrence and control. The information can be stored in the PDA database or uploaded

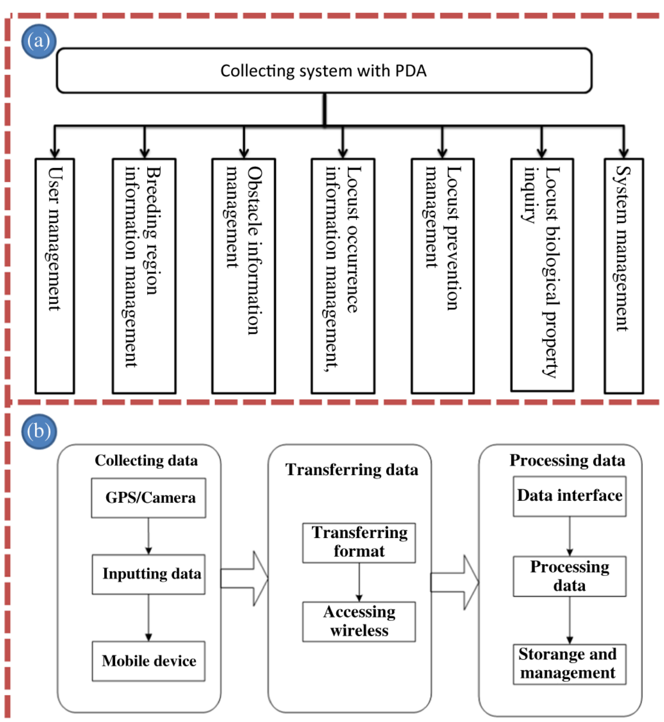

Fig. 4 Collecting system with personal digital assistant (PDA) design diagram. (a) Collecting system with PDA function diagram. (b) Working flowchart of collecting system with PDA.

to the locust database stored in the server. The functions of the collecting system include transferring field-acquired data to the server and retrieving the information back to the PDA in a data transmission module. All data are transformed to extensible markup language (XML), and the data in XML are then transferred to the data center server by the web service running the server. The communication between the PDA and the server is based on the GPRS, wideband code division multiple access, and 3G. Whether the uploaded data match the criterion is automatically checked. If the data conform to the rules, they can be stored in the locust database, and a "successful upload" message is sent to the PDA. Otherwise, an error message is returned. The system is implemented using the Java language.[7]

4.3 *Processing System Design*

4.3.1 *Processing system function design*

The processing system is aimed at spatial data management and at the spatial analysis and creation of thematic maps as well as the locust control prescription map [Fig. 5(a)]. Spatial data, which include information on sampling point, border of locust breeding region, and locust location, are made up of administrative region spatial data, RS data, and climatic data. The system can calculate and edit the above spatial data to generate thematic maps, including locusts' density point diagram, locusts' development progress point diagram, distribution of locust area diagram, and locust control prescription maps. These maps are available to users at all levels.

4.3.2 *Design and implementation of software architecture*

The processing system was developed based on the ArcGIS Engine and implemented using the C language. It contains three layers: a data access layer, a business logic layer, and a presentation layer [Fig. 5(b)].

Data access layer. The data access layer provides access to different types of data according to the data division in the locust control system; examples of these data types are spatial data, attribute data, and configuration files. Similar to the spatial data stored in the file geodatabase, spatial and attribute data are stored in Microsoft SQL© 2005.

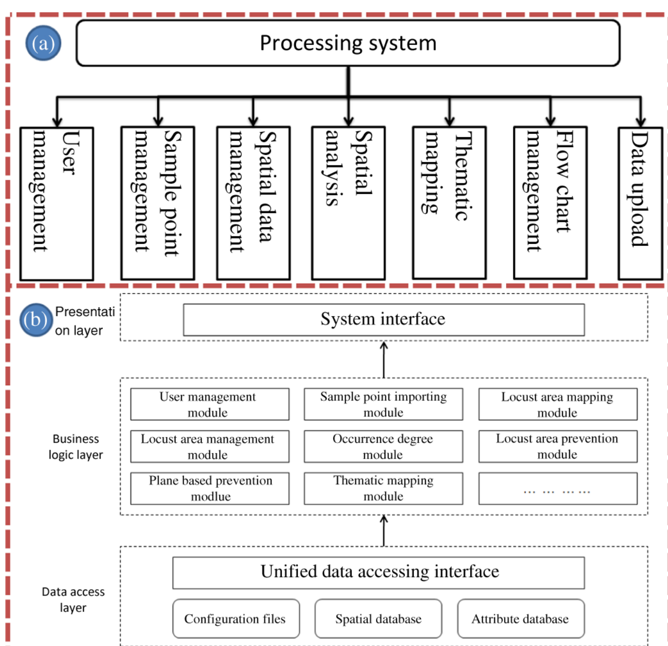

Fig. 5 Processing system design diagram. (a) Processing system function diagram. (b) Software architecture diagram of processing system.

Professional work logic layer. The professional work logic layer in the system contains the following function modules that provide results for the presentation layer: user management, sample point introduction, locust area, locust generating area, locust prevention, airplane locust control, and thematic charting.

Presentation layer. The presentation layer is the system interface. All functions built in the platform can be accessed in this layer. The interface can be configured according to user preference.

4.3.3 *Division of locust occurrence regions*

A locust occurrence region (i.e., locust zone) can be categorized into three types according to the degree and frequency of occurrence: locust breeding region, accidental occurrence zone, and dispersal zone. A locust breeding region with optimum environmental conditions for locust breeding is also known as a perennial occurrence area. This area regularly maintains high locust population density; locusts spread out from here in massive occurrences. An accidental occurrence zone is a normal region with low locust activity and slight changes in annual locust density numbers according to weather conditions. Massive occurrence of locusts in this area is far less frequent than that in a locust breeding region, unless weather conditions are suitable. Normally, a locust dispersal zone with a high locust death rate is unsuitable for locust breeding. However, this zone temporarily becomes a locust occurrence zone if conditions are suitable for the locusts, such as in cases of serious drought and floods. The geographic coordinates of locust zone boundaries are obtained by using the collecting system with the PDA software running on the PDA. The locust zone is circled by locusts' zone boundaries. The accidental occurrence and dispersal zones are determined by analyzing natural environmental conditions in the locust zone and the locust species. In general, the buffer radius from a locust breeding region to the outer boundary of the accidental occurrence zone is 3 km, and that from the accidental occurrence zone to the outer boundary of the diffusion area is 7 km. A thematic map of the locust zone in Huang Hua, Hebei Province, is shown in Fig. 6(a).

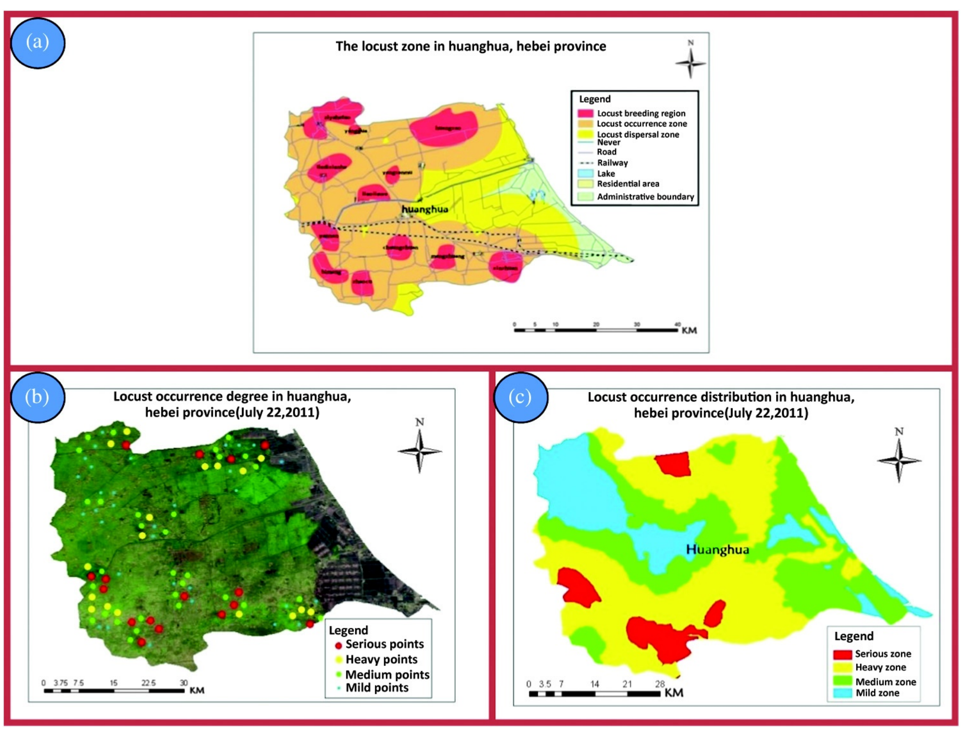

Fig. 6 Thematic map of locusts. (a) Thematic map of locusts' habitat in Huang Hua. (b) Thematic map of locusts' infestation sampling points in Huang Hua. (c) Thematic map of locusts' infestation distribution in Huang Hua.

4.3.4 *Analysis of degree of locust occurrence*

The degree of locust occurrence can be described by two thematic maps: the point diagram and the area diagram. To generate these maps, all field sampling sites were set up based on the "sandwich" model of Wang et al.[8] The sampling points' locations and number in the locust zone were confirmed by spatial analysis. Each sample site was then investigated by PDA. Finally, the thematic maps of the locusts data were generated by spatial interpolation technology to express continuous change of locust species, growth period, and population density on the space. The system provides various interpolation algorithms to users: reverse distance weighting interpolation, kriging interpolation, adjacent point interpolation, spline function interpolation, professional digital model, trend surface interpolation, and variation function interpolation [Fig. 6(c)].[9,10]

4.4 *Monitoring and Controlling System Design*

4.4.1 *Monitoring and controlling system function design*

The WebGIS-based system includes (1) a data management subsystem that allows data input, revision, verification, and inquiry on locust occurrence and their control; (2) a decision-making subsystem that automatically generates statistical analysis, strategy analysis, and statistical chart for users at all levels; (3) a command and dispatch subsystem that optimizes the path for material resource dispatching, real-time monitoring of prevention measures, recalling historical operational routes, calculating the actual locust control area, and cost auditing; and (4) China locust control information web that is a news and locust knowledge outlet that the central administrative and each provincial administrative can release the news of locusts occurrence, prevention and control, and knowledge of how to control locust. [Fig. 7(a)].

4.4.2 *Software architecture design and implementation of monitoring and controlling system*

This system runs on transmission control protocol/internet protocol (TCP/IP)-based protocol Internet/intranet. The cores of the services provided to the web for this system are data business and map business. Adopting the browse/server and client/server hybrid modes, the system consists of three layers: the client-side, middle ware, and database layers [Fig. 7(b)].[11]

4.4.3 *Implementation of commanding and dispatch subsystem*

All personnel, vehicles, airplanes, and resource allocation are monitored in real time in commanding and dispatch subsystem. The operational functions of the system are based on web service and ArcGIS Server.[12] The main procedure is as follows: (1) The location of the moving object is identified by running a program on a PDA (based on GPS), the interval between two points of the moving object is determined by the time and the two points distance. (2) The GPS of the moving object is uploaded to the locust database through GPRS, 2G, or 3G network. (3) The data are analyzed on the server and stored in the database. (4) The track of the moving object on the client is sent every second by the program running on the server.[13] The track is shown on WebGIS in real time.

4.5 *RS Technology Subsystem*

According to the characteristics of all kinds of the RS information sources, National Oceanic and Atmospheric Administration (NOAA), moderate-resolution imaging spectroradiometer (MODIS), and Geostationary Meteorological Satellite (GMS) are applied in full coverage and dynamic monitoring. Landsat ETM and SPOT are applied to key regions, such as the Huang–Huai–Hai region, the Xin Jiang and Nei Meng steppe area, and the Hai Nan and Xi Zang area in China. The RS data are used to monitor locust habitat conditions and to evaluate disaster losses.[14]

Land surface temperature, soil moisture, normalized difference vegetation index (NDVI), plant coverage are obtained using real-time RS. For instance, the habitat of oriental migratory

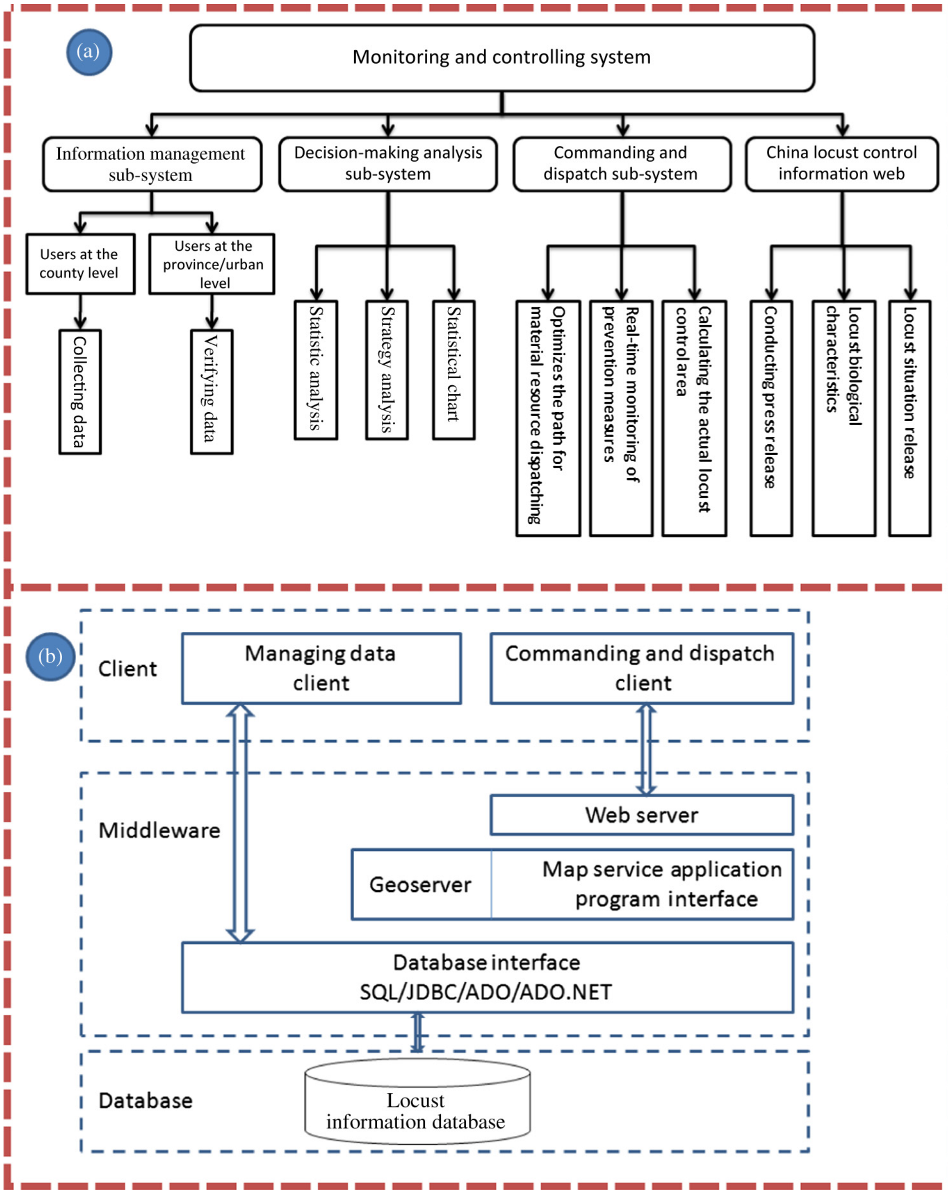

Fig. 7 Monitoring and controlling system design diagram. (a) Monitoring and controlling system function diagram. (b) Software architecture diagram of monitoring and controlling system.

locusts in the Huang–Huai–Hai region is monitored by MODIS. The earth resource data analysis system is edited in interface description language based on ENVI, and its algorithm is adopted from Ma et al.[14] The RS data are used to set investigation sample points. The RS data overlie the collecting system with PDA data to produce a similar map of grasshopper distribution. The similar map can serve as a guide in grasshopper control. The flowchart of MODIS 1 byte data processing is ε shown in Fig. 8.[14]

NDVI, plant coverage, land surface temperature (LST), soil moisture are calculated by the follow steps:[14]

(1) Calculating NDVI and emissivity

Input data: MODIS 250 m, include wave band 1 and wave band 2; 31, 32 wave band 1 km.

(2) Processing step

Step 1: Calculating the angle of the sun
Step 2: Calculating emissivity in 31, 32 wave band

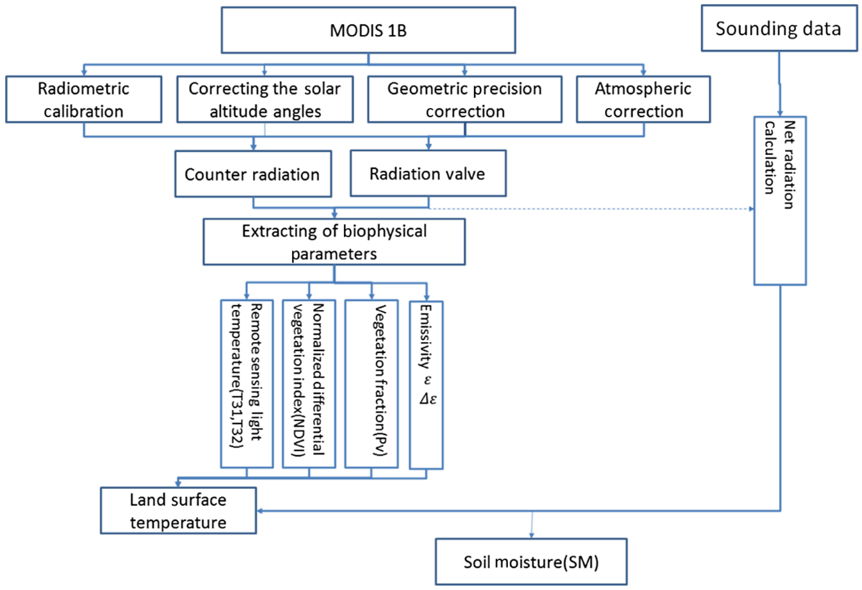

Fig. 8 Flowchart of MODIS 1B data processing.

(a) NDVI < 0.2

$$\varepsilon = 0.980 - 0.042\rho 1 \quad \Delta\varepsilon = -0.003 - 0.029\rho 2. \tag{1}$$

ρ_1 and ρ_2 are wave the angle of the sun on band 1 and wave band 2. ε is emissivity. $\Delta\varepsilon$ is error value.

(b) 0.2 ≤ NDVI ≤ 0.5

$$\varepsilon_{31} = 0.968 + 0.21P_{\text{V}} \quad \varepsilon_{32} = 0.974 + 0.0.15P_{\text{V}}$$
$$\varepsilon = \Delta\varepsilon_{31} + \varepsilon_{32}\Delta/2 = 0.971 + 0.018P_v \quad \Delta\varepsilon = (\varepsilon_{31} - \varepsilon_{32}) = -0.006(1 - P_{\text{V}})$$
$$P_{\text{V}} = \frac{(\text{NDVI} - \text{NDVI}_{\min})^2}{(\text{NDVI}_{\max} - \text{NDVI}_{\min})^2} = \frac{(\text{NDVI} - 0.2)^2}{0.09}. \tag{2}$$

ε_{31} and ε_{32} are the emissivity on 31, 32 wave band, is plant coverage, $\text{NDVI}_{\max} = 0.5$, it is all the vegetation, $\text{NDVI}_{\min} = 0.2$, it is bare earth.

(c) NDVI > 0.5

$$\varepsilon_{31} = \varepsilon_{32} = 0.985 \quad \varepsilon = \varepsilon_{31} = \varepsilon_{32} = 0.985 + C_i \quad \Delta\varepsilon = 0.$$

C_1 is the proportion of vegetation.

Table 1 Surface coverage under the condition of different soil moisture inversion parameters.

	Model	R^2
1	$\text{SM} = 0.0827 - 0.0101T_C + 0.0035T_g$	0.65
2	$\text{SM} = 0.025 + 0.002\text{IR} - 0.00114T_g$	0.70
3	$\text{SM} = 0.0532 - 0.0091T_C + 0.0011\text{IR}$	0.72
4	$\text{SM} = 0.0381 - 0.0056T_C + 0.0047T_g + 0.0016\text{IR}$	0.73
5	$\text{SM} = 0.0344 - 0.0048T_C - 0.0071T_g + 0.0020\text{IR} - 0.0100\mu$	0.75

(3) Step 3: Calculating LST in using Ulivieri et al.[15] and Becker and Li[16]

$$T_0 = [T_{31} + 1.8(T_{31} - T_{32}) + 48(1 - \varepsilon) - 75\Delta\varepsilon]$$
$$T_{b1} = \left\{1.274 + \left[\frac{T_4 + T_5}{2}(1 + 0.1561\varepsilon_{1b1} - 0.482\varepsilon_{2b1}) + \frac{T_4 - T_5}{2}(6.26 + 3.98\varepsilon_{1b1} + 38.33\varepsilon_{2b1})\right]\right\}.$$

(4) Soil moisture inversion model. Soil moisture is measured in inversion applied temperature-vegetation index of ground environment measurement by Samuel,[17] as Table 1.

$$\mathrm{SM} = 0.025 + 0.002 \times \mathrm{IR} - 0.00114 \times T_g.$$

SM is soil moisture; IR is net surface radiation; T_c is LST (K); T_g is canopy temperature.

The main habitat characteristic of locusts and locusts in all developmental stage are monitored continuously by RS data in multiple spatial-scale. The relationship between habitat RS feature changes and population density of locust populations, breeding is revealed, dynamic change correlation models between locust plague and RS factors are built. Locust can be forecasted and locust plague can be evaluated.

5 Conclusions and Prospects

The workflow of the platform is that locusts are monitored using a RS technology subsystem, a PDA-based collecting system, and national meteorological stations. Locust control prediction and decision making is implemented in a processing system; Locust control is monitored in real time by a monitoring and controlling system.

For example, occurrence sampling data are collected as in Fig. 6(b); the locusts occurrence area [Fig. 6(c)] data are deduced from the sampling data and habitat information (from RS and meteorological stations) in the processing system; the locust control area data are a prescription map, and it is inputted into pesticide spraying system on an airplane. The flow from monitoring to controlling is digitization. As the platform meets the need of locust monitoring and controlling, it can also be used as a reference for pest monitoring and controlling.

Annually, the oriental migratory locust *L. migratoria* infested >1.4 million ha in 16 provinces in China; other grasshoppers infest >40 million ha in more than 19 provinces in China. The platform for locust control has been used since 2008 and was updated in 2013. It is currently being used in 16 provinces in China. The platform has been accepted by users at different administrative levels who are responsible for locust control. Before the platform was used, the locust control method was very extensive. According to some sample information, pesticide was equally sprinkled everywhere in a locust zone. Meanwhile, a large number of workers on land were required to conduct locust control through the system equipped in the airplane. The process of finding locusts and controlling them was time consuming, and valuable manpower was wasted. After the platform was used, 3s was utilized to collect and transfer locust information on a sample point. For example, the Guang Li Village locust zone is about 20 km^2 from Huanghua City, Hebei Province. Investigating 11 sample points took about 2 h. Building a prescription map and inputting the map into the airplane controlling system took 5 min. Only then could the airplane perform locust control using the prescription map. The process from collecting to controlling takes about 2 h 5 min. The precision of the prescription map is above 85%.[18] Thus, the proposed system is efficient, accurate, and intelligent.

However, the platform needs to be improved further in terms of its real-time monitoring system that functions by monitoring locust occurrences and affected areas via RS and by monitoring locust density and development via the auto-recognition system and wireless sensor network. Through these improvements, the platform can successfully monitor, forecast, and conduct locust control.

Acknowledgments

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Lin Li is mainly engaged in exploration and application of information technologies on agriculture.

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Sijing Ye became a PhD student of China Agricultural University in 2012. In recent years, his research focuses on application of spatial information technologies on the domain of agricultural informatization.

Long Zhang is mainly engaged in research on biological pest control and the locust ecological features.