DROUGHT MONITORING AND FORECASTING METHOD BASED ON GOOGLE CLOUD COMPUTING SERVICE PLATFORM
/
基于 GOOGLE 云计算服务平台的旱情监测预测方法

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ABSTRACT
As a progressively accumulating and dynamically changing process, agricultural drought stress is influenced by various factors, such as atmospheric environment, hydrogeology and vegetation. To master the change laws of soil drought, we proposed a novel soil drought monitoring forecasting method based on Google cloud computing service platform. The Google cloud computing platform Google App Engine was analysed. This computing platform was utilized for drought monitoring. A three-layer back-propagation neural network was used for the forecasting analysis of corresponding soil drought. The accuracy of the method was verified through an experiment. Results demonstrate that all the relative errors of the method were lower than 10% and thus it has a high monitoring precision. These findings can be used as a theoretical basis for formulating strategies for drought resistance. The proposed method provides a good prospect to drought monitoring and forecasting strategies using other cloud computing platforms.

摘要
农业干旱影响是渐进累积、动态变化的过程，它是受大气环境、水文地质、植被等诸多因的素影响，为了了解掌握土壤旱情的变化规律，本文提出了一种基于 Google 云计算服务平台的土壤旱情监测预测方法。首先，对 Google 云计算平台 Google App Engine 进行了分析。然后，利用 Google 云计算平台对旱情进行监测并利用三层 BP 神经网络对相应土壤旱情进行了预测分析，通过实验验证了该方法的正确性。研究结果表明该方法对土壤旱情预测的相对误差均小于 10%，监测精度较高。该研究成果可作为制定抗旱策略的理论依据，对基于其它云计算服务平台的旱情监测与预测的研究提供了一定参考。

INTRODUCTION
With the development of computer technology especially rapid development of the Internet and Geographic Information System (GIS) technology, agricultural information monitoring technology has enjoyed rapid development. As the giant of Internet search, Google has promoted its own cloud computing platforms, the Google App Engine (GAE), which enable developers to run applications on the basis of the Google framework and extend them according to traffic and data storage *(Sadiku M.N.O. et al, 2014; Correa J.D.Y. et al, 2014)*. WebGIS is an important technology realizing mutual operation with GIS and uses the product of GIS and World Wide Web technology. A GIS cloud provides spatial data access and exchange, spatial information inquiry, spatial information analysis, and spatial information application interface services through the Internet in the form of Web service. Drought disaster is one of the natural disasters with high occurrence frequency, broad scope of influence and considerable loss. As an important path of relieving loss and influence caused by agricultural disaster, agricultural drought monitoring and forecasting is one of the weak links of drought study. At present, a series of productive research work has been conducted in various countries (*Sheffield J et al, 2014; Magno R et al, 2014; Yue P et al, 2013*). America founded the National Centre of Drought Reduction and established several drought monitoring and research institutes in local regions in America and within a global scope. Similarly, China established drought monitoring institutes, such as the Meteorological Satellite Centre of State Meteorological Administration, Hydrological Bureau of Ministry of Water Resources, and National Disaster Reduction Centre of China for drought monitoring and forecasting (*Yin Y.P., 2004*). However, agricultural drought involves numerous fields, such as agriculture, meteorology, hydrology and plant

physiology. Meanwhile, agricultural systems are interweaved natural and artificial systems; Therefore, developing agricultural drought monitoring is faced with a large theoretical or technical bottleneck (*Liu X. F et al, 2016*).

Cloud computing applications have recently become a focus of research in the field of the Internet. Google (*Wang D., 2015; Lawton G.,2008; Han W et al, 2012*) was the first to propose the concept of cloud computing. As a cloud computing service promoted by Google Corporation, GAE is a Web application platform integrating development and trust and is the most mature product in the PaaS platform with the most complete functions. Developers can run their compiled online applications on Google resources without worrying about the additional resources used by the running application because Google provides all platform resources needed for application operation and maintenance. "Open for Questions" of the White House in the US has realized processing of approximately million-level traffic within several hours by using GAE. Many foreign libraries have established business services that used GAE to facilitate mutual contact to improve working efficiency and reduce IT cost. For example, Elibrary, which was established by the Western State College of Colorado, can be used by students and teachers as well (*Liu Y.X et al, 2014; Han P et al, 2012*). In May of 2012, China's Ministry of Industry and Information Technology issued "The 12th Five-Year Plan Development Plan in Communications Industry," which positioned cloud computing as a key technology and development orientation for the establishment of a national-level information infrastructure and realization of an integrated innovation. Tsinghua University (*Wang J.J et al, 2010; Liu P, 2017*) is the first university to participate in the Chinese cloud computing plan. It has cooperated with Google to set up a "large-scale data processing" course, which mainly helps researchers learn to create pragmatic Internet-scale application programs under cloud computing environments. Taking GAE as the development platform, Zhenxin Qu and Wenchang Zhu (*Qu Z. X and Zhu W.C., 2013*) effectively solved problems, such as planning task management, multitask trigger, and high concurrency, with the help of multiple cloud services provided by the platform. However, multitask concurrent execution was not realized. Xiaoyu Shi (*Shi X.Y, 2011*) used the infrastructure supplied by GAE to establish and deploy application programs in order to achieve split-type data de-enveloping and storage, mainly implementing applied research on system query speed. Hua Ma (*Ma. H., 2015*) used an Android technology to realize mobile application service at client end based on the cloud service end of GAE. However, he did not study safety in the implementation process of mobile service, namely, evading access of privileged users. Currently, innovative data technologies are used for monitoring soil moisture content, particularly through the use of ZigBee, gathering soil moisture content data into the radio network gateway, and uploading data to Wanwuyun for analysis and processing (http://www.sohu.com/a/208613429610696).

Studies on drought monitoring through GAE are rare. Domestic and foreign drought monitoring research modes remain stand-alone independent operation modes, mainly using computer for data processing, developing databases, and employing various technologies, such as image processing, data analysis, decision-making support, and expert system. Monitoring information related to agricultural condition is of poor openness and transparency; thus, addressing users' diversified and informatization requirements are difficult. For example, America (*Wang Y., 2011; Zhang L et al, 2017*) has built a network system for real-time monitoring, simulation, and evaluation of soil moisture content, soil release, and climatic conditions. Zhang et al. (*Zhang X.F et al,2013)* used the German SIMPEL model to calculate potential evaporation amount, soil water-holding capacity and wilting coefficient in a farmland according to moisture balance principle and forecasted soil moisture content at wheat root in the German Osnabrueck region. However, many input parameters, which were difficult to acquire in reality, were found in the model. Zongzhou Wen (*Wen Zongzhou and Li Ying et al, 2015*) designed a remote metering terminal based on STM32 drought information acquisition and data teletransmission. In this terminal, acquired data were transmitted to junction centre through the GPRS wireless network, the junction centre conducted comprehensive evaluation of the drought through back-propagation (BP) neural network algorithm model, and data processing was implemented on local machine with poor sharing property. Yongxue Huang et al. (*Huang Y. X et al, 2010*) developed a WebGIS-based drought disaster monitoring and analysis system and used GIS technology to conduct fine drought simulation and monitoring through meteorological factors in a station-free region. This system introduced WebGIS technology into drought monitoring and management system, gained access to data in GIS through a browser, and conducted visualization research with low system transmission rate without data processing in a complicated space.

Acquiring long-term record of soil moisture content in drought research is difficult because most data concentrate in a local machine, and this situation considerably restricts information sharing.

Although information acquisition through computer networks has evidently improved and become more time efficient than traditional methods, the workload is still large and mostly single-point test. Therefore, basing on the analysis of the Google cloud platform, we utilized communications network technology, computer technology, sensor technology, GIS technology and data mining technology to establish a drought monitoring and forecasting method. We constructed a forecasting model by designing a three-layer neural network to conduct simulation analysis of soil drought within one year. With the continuous development of technologies, such as IoT, mobile internet, and sensor technologies, addressing the requirement for mass data processing through traditional drought monitoring mode in stand-alone independent operation is difficult. Therefore, a preliminary exploration of drought monitoring and forecasting method based on the Google cloud computing service platform was conducted in this study. Drought information and resources are integrated to improve data processing speed, timely and effectively forecast agricultural drought development, and provide important decision-making basis for relevant departments to formulate drought prevention and resisting measures and organize disaster relief.

The remainder of this study is organized as follows: Section 3 describes the framework of the service platform and establishes a drought monitoring and forecasting model based on Google cloud service platform under GAE framework. Section 4 conducts drought monitoring and networking release through Google cloud service platform and uses a back-propagation (BP) neural network for the forecasting analysis of drought information. The final section summarizes this study and provides relevant conclusions.

MATERIALS AND METHODS

Overall Framework of Drought Monitoring and Forecasting Based on Google Cloud Computing

(1) Design objectives of information management system

On the one hand, complicated changes in soil moisture and climatic environment affect daily life and agricultural production. On the other hand, decision-makers can accurately master drought information by monitoring soil moisture information and determine how to guide agricultural production. Therefore, establishing a drought monitoring information management system is urgent. For a long time, many problems have existed in drought monitoring information systems (soil moisture), such as old monitoring equipment, backward technology, poor real-time property and long monitoring time. The research in this study is implemented on the basis of monitoring equipment selection, data transmission, and software development according to physical truth. A reliable and advanced drought monitoring information management system suitable for local conditions is then designed and developed. This system adopted advanced modern technologies, such as data fusion processing, computer network communication, modern sensor technology and intelligent decision for automatic data acquisition, storage and transmission. Computer is used for the simulation analysis of soil drought information. Data information is calculated on Google cloud platform and released under computer networking condition.

(2) Design principles of information management system

Standardization is the foundation of information system. For the convenience of system extension, upgrading, and optimization, the system design conforms to industry standard and design standardization principle to realize seamless connection to other systems.

According to software engineering theory, system maintenance is the longest process in the entire software life cycle. Therefore, improving system flexibility and extendibility is an important measure of the performance enhancement of the entire system. The development of science and technology and the improvement of management level have results in the changes in the requirements of information management systems. This drought monitoring information system lays a foundation for realizing multi-network integration by designing all kinds of extendible interface, especially interfaces of information system.

This system realizes the comprehensive perception of soil drought through sensor technology, completely develops the effects of already built automatic monitoring stations and future stations, and regards monitoring points as front-end data perception equipment of cloud computing for drought monitoring. An online monitoring system is established for various aspects, such as water resources. This system conducts the online automatic monitoring and data transmission of rainfall, water level and water quality through wireless transmission to provide a scientific basis for comprehensive decision-making related to soil drought. On the cloud business management platform, alarm information is generated through the analytical computation of automatically monitored data to improve drought monitoring efficiency. The structure of drought monitoring and forecasting based on Google cloud computing is shown in figure 1 and drought monitoring interface is shown in figure 2.

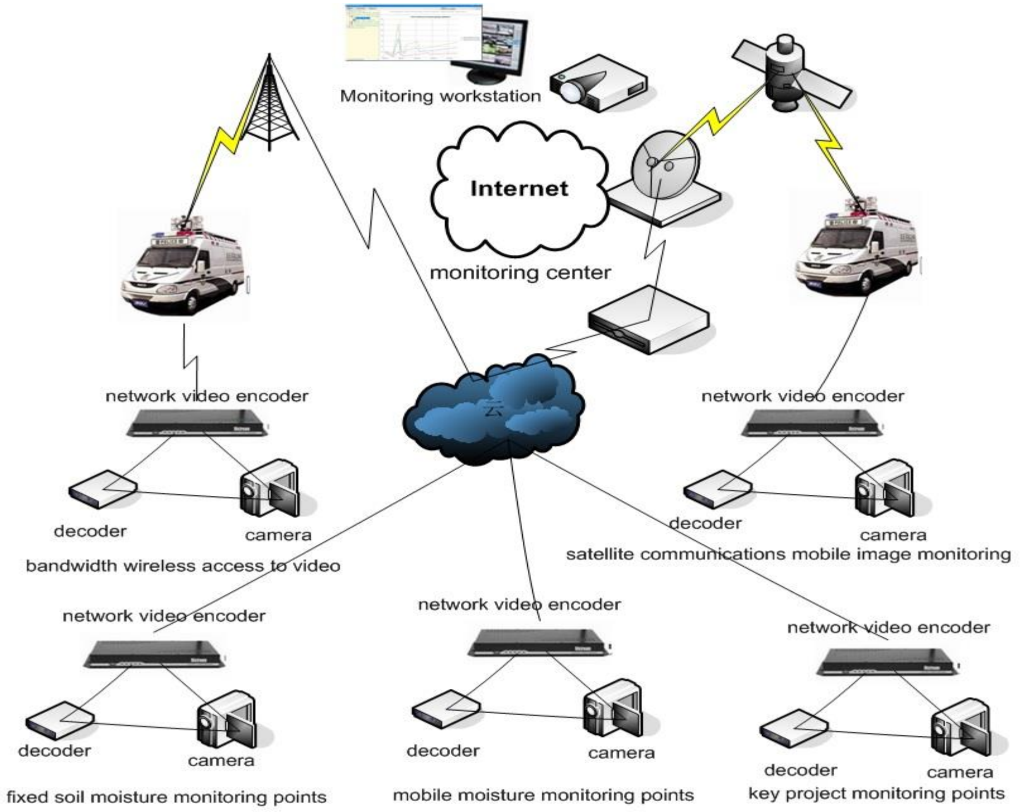
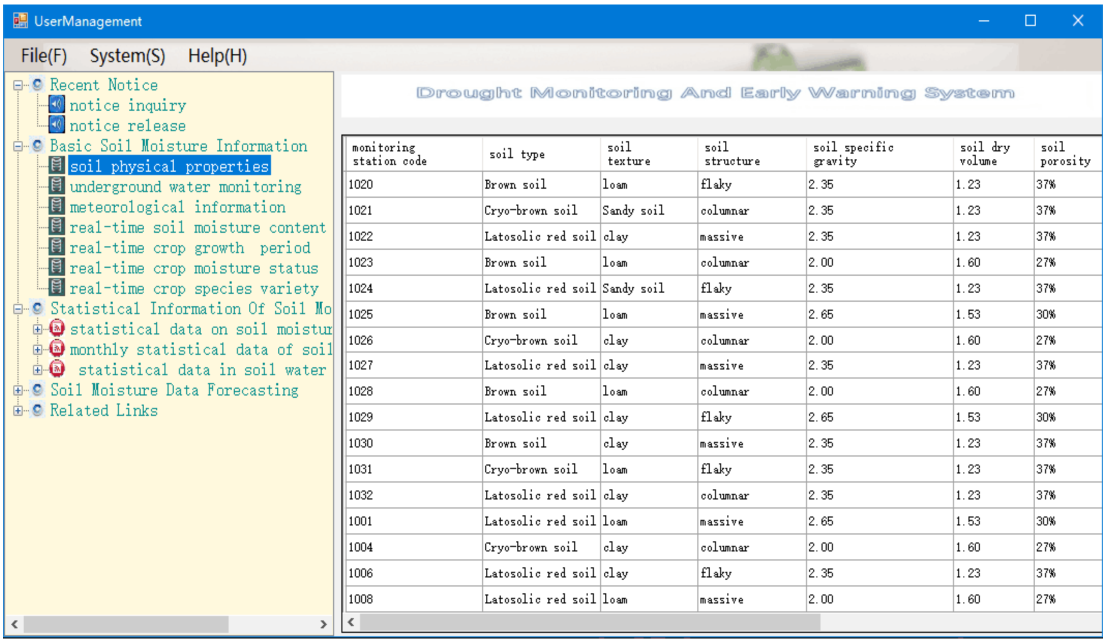


Fig. 1- Illustration of overall monitoring system plan based on Google cloud computing



monitoring station code	soil type	soil texture	soil structure	soil specific gravity	soil dry volume	soil porosity
1020	Brown soil	loam	flaky	2.35	1.23	37%
1021	Cryo-brown soil	Sandy soil	columnar	2.35	1.23	37%
1022	Latosolic red soil	clay	massive	2.35	1.23	37%
1023	Brown soil	loam	columnar	2.00	1.60	27%
1024	Latosolic red soil	Sandy soil	flaky	2.35	1.23	37%
1025	Brown soil	loam	massive	2.65	1.53	30%
1026	Cryo-brown soil	clay	columnar	2.00	1.60	27%
1027	Latosolic red soil	clay	massive	2.35	1.23	37%
1028	Brown soil	loam	columnar	2.00	1.60	27%
1029	Latosolic red soil	clay	flaky	2.65	1.53	30%
1030	Brown soil	clay	massive	2.35	1.23	37%
1031	Cryo-brown soil	loam	flaky	2.35	1.23	37%
1032	Latosolic red soil	clay	columnar	2.35	1.23	37%
1001	Latosolic red soil	loam	massive	2.65	1.53	30%
1004	Cryo-brown soil	clay	columnar	2.00	1.60	27%
1006	Latosolic red soil	clay	flaky	2.35	1.23	37%
1008	Latosolic red soil	loam	massive	2.00	1.60	27%

Fig. 2 - Drought monitoring and early warning system

Study of Google Cloud Service Platform Based on GAE Framework

This study is conducted on the basis of the Google cloud computing platform. Cloud application program is developed on a GAE platform. The infrastructure solution of the cloud platform is necessary and GAE includes three main components: runtime environment, data storage and data compression.

(1) Operating environment

To complete an application program in the entire operation procedure, processors handle different requests and do not influence each other while the application program operates in a sealed “sandbox” environment. An application program is prohibited to write data in the file system server during the operating process. A socket cannot open or directly gain access to other hosts and will not be generated into a subprocess or thread and the system is not allowed to deploy other servers. The operating environment is independent from server hardware, operating system and location. This approach ensures the safety and reliability of the operating environment.

After the code and resource file of the application program are loaded, they are stored in the application program memory. This process facilitates direct reading in the memory and improves processor speed.

Although the application program can read its own files through the file system, it cannot write or read other documents from other application programs. The application program can also gain the access to an independent system through API to obtain corresponding service, improve code recycle rate and reduce complexity of developing application programs.

GAE request processing framework is shown in figure 3, where front-end, application and static file servers are all server clusters comprising multiple servers. After the Web sends the request, it passes through the front-end server and is allocated by a load balancer in the optimal form to one of the front-end servers. This server determines the target application program of the request according to domain name of the received request and then confirms the process of the request according to the configuration files of the application program. If a request URL path matches the paths of the static files, such as images of the application program or JavaScript code file, then the request is allocated to a static file server. If the request URL path matches the request processor path of the application program, then the request is allocated to the application program server. If the request URL path cannot be mapped to anything in the application program, then an HTTP 404 (Not Found) error response is returned directly to the client.

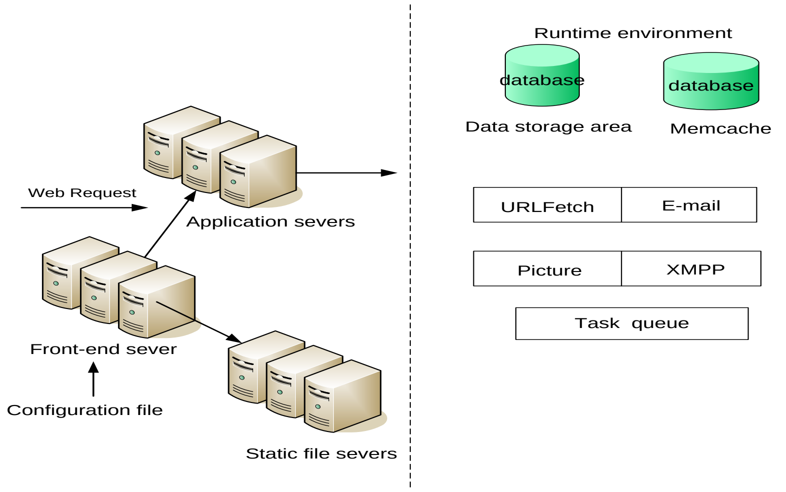


Fig. 3- GAE request processing framework Data storage of GAE

(2) Data storage of GAE

Data storage can save data objects called entities. Each entity has its own key and one or multiple properties. The key of each entity is its unique identification, which can be automatically generated by the application program in data storage area. Properties are used for expressing the properties of data objects, which can be character strings, integers or quotes and one property can have one or multiple different values.

The application program can extract data from data storage in two ways: using key or executing inquiry matches of data properties. Most database systems check records in the database and execute computation for result inquiry through specialized inquiry system. However, the inquiry system of GAE is different. That is, it scans a list of relational databases, also called indexes, and uses these indexes to screen, sort and store results in the query table. Data and indexes are distributed on multiple servers, all of which scan indexes in a parallel way. The GAE does not require the execution of a complicated clustering operation to return the inquiry results of each server to the application program.

(3) Extendible service

GAE provides all kinds of extending services. A standard API and a low-level API application that uses standard API, which can be easily moved in or out of the GAE, are usually established. The application program and GAE server are "separated" and low-level API application program can be directly used in the application program or implemented in a new interface adapter. The GAE service is a kind of application program that uses specific API to gain system access independent of the runtime environment in order to realize common operations, such as data storage, caching and access to network resources.

Data storage service: Data storage service offers reliable and extendible data storage. However, disk addressing is time consuming for high-performance Web application programs. Thus, disk addressing is usually used in caching, and data are kept in a storage unit for high-speed caching. Nevertheless, simple storage and retrieval operation are faster than data storage. Therefore, data storage mode is suitable for frequently read or accessed data.

Caching service: GAE provides a distributed memory cashing service Memcache, which is a keyword storage service that acquires corresponding value through keywords. Multiple values can be set or acquired once through a batch of operations with faster speed than that of the execution of multiple operations. However, total data size cannot exceed one terabyte (TB). The key consists of 250 bytes and the number of its bytes can reach nearly one TB. The Memcache API is allowed to use a large key, which can be converted into 250 bytes with an array algorithm. Data in caching can be saved under general circumstances. If memory cache is insufficient, then the values recently used in caching are cleaned up. Storage time can be set to automatically clean up the value when storage time is exceeded.

Structural Design of Information Management System

According to relevant standard and actual demand, drought information monitoring management system should be able to realize automatic functions, such as drought information statistics, analysis, and inquiry, on a computer platform. Information monitoring management system is designed and established in this study according to actual situations. In this system, a user can rapidly and flexibly view images and changes in monitored drought-stricken regions at client end and browser user interface. The user can also accurately calculate, analyse, and forecast the generation and development of a drought disaster. According to the preceding requirements, system structure is of browser/server (B/S) architecture. The overall framework design is divided into three layers: Web service layer, application layer and data link layer.

The web service layer is the human–machine interface between a user and a software application. Its function is to construct the software application environment of the system. The concrete requirement is application software operation, which includes the parameter inputs and outputs of operation results.

The application layer is the core layer of the system and provides information statistics, analysis and query necessary for all kinds of business analyses, information processing and data management. According to actual requirements for drought monitoring, the system application layer is divided into three functional modules: graphic display, information service and drought forecasting.

The data link layer provides data and data storage functions by using the database on the Google cloud computing platform.

RESULTS

Topsoil moistures at different depths are automatically acquired through the monitoring system, and data are transmitted to the drought information monitoring centre for the observation of drought development in different regions and acquisition of timely and accurate data for drought forecasting.

Change Curves of Soil Moisture Content Within One Year

Changes in soil moisture content in a farmland is caused by the joint effects of multiple complicated factors but can generally be divided into two major types, namely, water consumption and water retention capacity. In this study, a soil drought event in a region in China is used as an example, and soil drought change is explained.

Change of soil moisture content in one year is shown in Fig. 4. Initially, the soil moisture content increases with time, reaching maximum values in July, August and September. Thereafter, the values start to steadily decrease with time. The results show that the change of soil moisture content in one year can be divided into three stages.

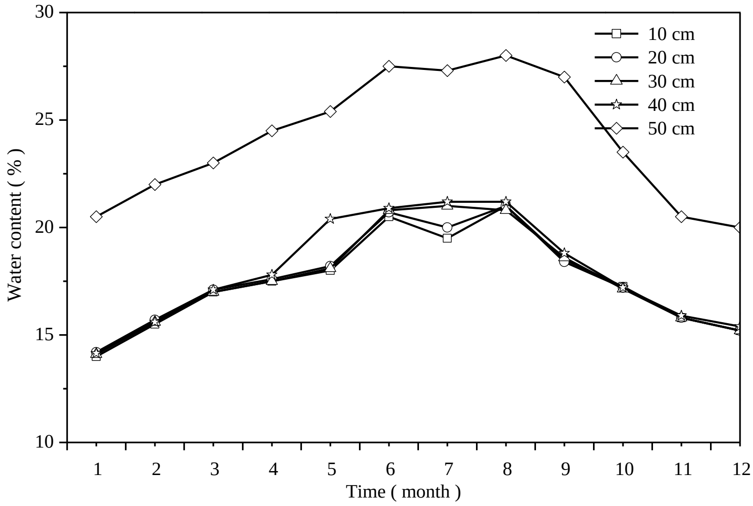


Fig. 4- Change curves of soil moisture content within one year

Large changes in soil moisture content is observed in May and October mainly because of the sufficient rainfall from May to October. As the soil has high moisture content, soil moisture retention capacity rapidly increases. However, given that soil moisture content in this stage is large, water consumption is also large when the temperature rises. Therefore, when water retention capacity is larger than water consumption in this stage, soil moisture content increases; when soil moisture retention capacity is smaller than water consumption, soil moisture content reduces.

Soil moisture content is relatively stable from November to January in the subsequent year. During this stage, air temperature continuously decreases with time while rainfall and evaporation capacity gradually reduce. When the temperature is lower than zero, water turns into ice, the land surface is frozen and soil humidity on the surface is relatively stable.

Soil moisture slowly changes from February to April. During this stage, soil starts thawing as the temperature gradually rises and rainfall slowly permeates the soil, gradually increasing soil moisture content.

Soil Drought Forecasting Model Based on BP Neural Network

The BP neural network algorithm is also called error back-propagation algorithm. Nerve cell transmission conforms to an S-type function and can map the relationship between any nonlinear input and output. BP neural network has been extensively applied to many research fields in recent years. Many researchers have employed this network in soil moisture forecasting and obtained favourable effect. Improved BP neural network is utilized to study data based on drought information management system and its effectiveness is verified through simulation results.

Soil data acquired based on soil moisture sensor data at different soil depths in May of 2017 are selected as study objects. Soil moisture forecasting model of the improved three-layer structure of BP neural network is then established. The moisture contents in daily average layers of 10, 20, 30, 40, and 50 cm selected at the 1st day are used as input variables. Soil moisture contents at 10 and 20 cm forecasted 3 days later are used as output variables. The structure of the BP neural network is shown in Fig. 5. The quantity of nerve cells is calculated according to the empirical formula

$$Z = \sqrt{a + b + c} \tag{1}$$

where Z is the quantity of nerve cells, a is the input of nerve cells, b is the output of nerve cells, and $c \in (1,10)$ is the constant quantity. Number 12 of nerve cells at the hidden layer is optimal through analysis and verification.

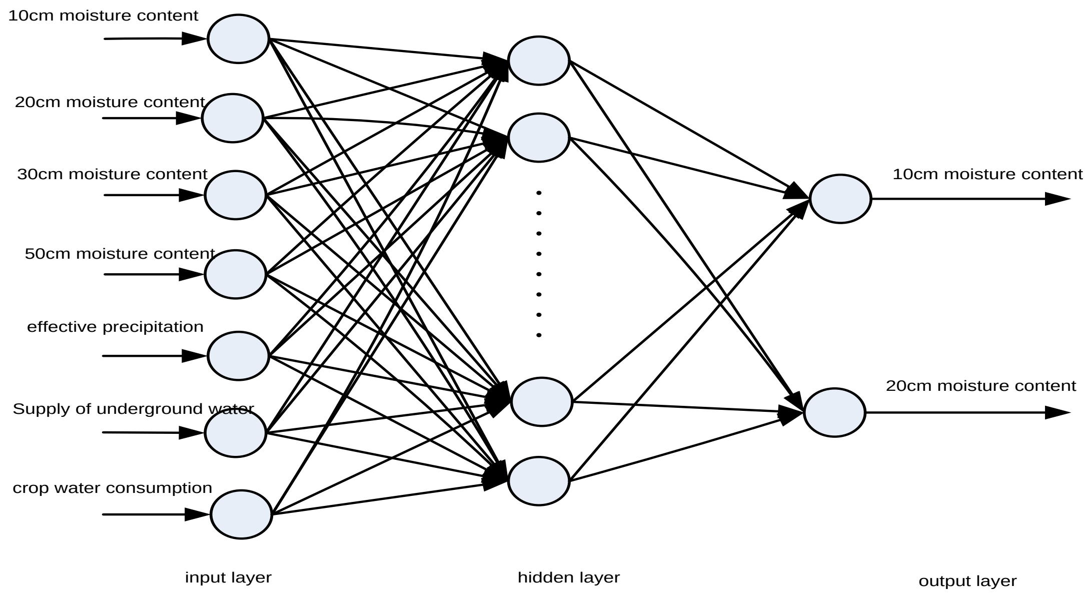


Fig. 5 - Structural model of BP neural network

Soil Moisture Forecasting Based on BP Neural Network

After the weight training of the Google neural network, error definition is shown in Formula (2) to verify the accuracy of the BP neural network.

$$\eta = \left(\frac{predicted}{real}\right) * 100\% \tag{2}$$

where η is relative error, predicted is predicted value, and real is measured value.

Corresponding data are obtained through input training of 15 groups of measured values, which are shown in Tables 1 and 2. Relative errors are obtained through Formula (2).

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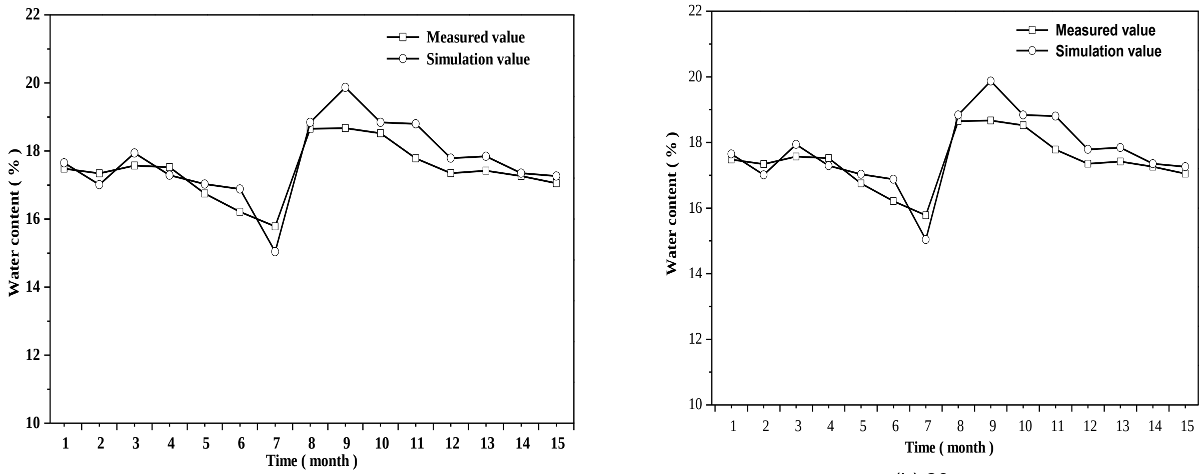
Table 1

Measured and predicted values

Measured and predicted values at 10 cm			Measured and predicted values at 20 cm		
Measured value (%)	**Predicted value (%)**	**Relative error (%)**	**Measured value (%)**	**Predicted value (%)**	**Relative error (%)**
17.52	18.06	3.08	17.48	17.65	0.97
17.40	18.83	8.22	17.34	17.01	1.90
17.58	16.67	5.18	17.57	17.94	2.11
17.56	18.53	5.52	17.52	17.29	1.31
17.03	17.81	4.58	16.75	17.03	1.67
16.82	17.64	4.88	16.21	16.88	4.13
16.32	15.76	3.43	15.78	15.04	4.69
18.60	17.32	6.88	18.65	18.84	1.02
18.69	17.76	4.98	18.67	19.87	6.43
18.57	18.02	2.96	18.52	18.84	1.73
17.83	19.65	10.21	17.78	18.80	5.72
17.43	16.32	6.37	17.35	17.79	2.54
17.45	17.24	1.20	17.42	17.84	2.41
17.27	17.96	4.00	17.26	17.35	0.52
17.08	17.68	3.51	17.05	17.26	1.23

Table 1 is transformed into curve forms as shown in Fig. 6(a) and Fig.6(b), respectively, to display errors intuitively.



(a) 10 cm (b) 20 cm

Fig. 6 - Curves of measured and predicted values

The simulation result shows that the relative forecasting errors of the improved BP neural network are all smaller than 10%, thereby confirming the feasibility of the BP neural network in soil drought forecasting. This result also indicates that a forecasting analysis study of BP neural network can be implemented by using additional data.

CONCLUSIONS

To improve agricultural drought monitoring and forecasting accuracy, we studied a monitoring and forecasting method for acquiring agricultural drought information on the basis of a Google cloud computing service platform. BP neural network was used for agricultural drought forecasting analysis. The following conclusions were drawn:

(1) Google cloud platform service monitoring components were selected in this study for soil drought monitoring analysis in one region. Data were acquired and integrated under complicated conditions with real-time property, stability, and intelligence.

(2) Drought can be forecasted by using the designed three-layer BP neural network. All the relative errors were smaller than 10%. The simulation verified the effectiveness of BP neural network in soil drought forecasting.

A present hotspot related to agricultural problems was selected. We investigated drought monitoring and forecasting on the basis of the Google cloud computing service platform to provide technical support for the system and deploy other cloud service platforms. Nevertheless, we focused more on the methods for soil drought monitoring and forecasting than on data storage and visualization of agricultural drought data. Therefore, studies considering data storage and agricultural drought data visualization are necessary.

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