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PVIDSS: Developing a WSN-based Irrigation Decision Support System (IDSS) for Viticulture in Protected Area, Northern China

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Abstract: The vineyard management is evolving from manual mode to automatic information management, especially in protected area culture mode. The conventional irrigation technology is a kind of the inefficient water usage technology. This paper developed PVIDSS: an irrigation system based on Wireless Sensor Network (WSN) to provide an effective way to improve the irrigation efficiency. Firstly, the interview, survey and document review were carried out to identify the main factors affecting the vine's growth and exact the system requirement, irrigation rules. Then, the architecture of PVIDSS was design based on the function requirement. Integrating the WSN based on ZigBee, the system monitors the key parameters of vineyard accurately, such as temperature and soil moisture, and calculates a precision irrigation based on field data and the rule of vine's water requirement. The system test shows that the WSN-based decision support system is accurate in data processing and easy to install and configure, which supports the development of water-saving agriculture.

Keywords: Water-saving Irrigation, Decision Support System, WSN, Viticulture, Protected area.

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1 Introduction

The combination of crunchy texture and dry, sweet, tart flavor has made grapes an ever popular fruits and ranks in second place among the most important types of fruit, behind oranges and just ahead of bananas and apples. China has been the 2nd largest grape producing country in the world since 2007 and ranked first in the word for table grape production for more than 10 years [1]. The total viticulture area is 493.4 thousand hectares with 7,384,656 tons production in 2009, amounted to 11.03 percentage of world grape production In China, grapes are one of the most grown commercially and remunerative farming in most of provinces and Territories in a wide range of environments from temperate to tropical area due to the new high-efficiency cultivation technologies promotion: cultures in protected area(also known as greenhouse), which not only broaden the range of options cultivated grape varieties and area, but also improved grape quality and regulated grape growth period a prolonged period of table grape supply ranging from early April to lately December, compared with the open culture begins in late July to early October, thereby increasing the?economic?benefits for the growers. By the end of 2010, the area of protected cultivation viticulture is up to more than 60 thousand hectares, amounted to 12.16 percents of the total area of viticulture [2,3,4]. There are several types of protection cultures: forcing culture, delayed culture and rain-shelter cultivation. Among them, rain-shelter-cultivation ranks the first cultured area, which aims to protect the grape against cold or rain and to extend the harvest period and lies in the northern of China; forcing culture ranks the second, mostly concentrated in Bohai bay and northeast area; the last is delayed culture, distributed in northwest aridity area

No matter tradition or protection cultivation, there is the undoubtedly increased pressure and threats for careful resource management with climate change and water shortages, rapidly raising resource costs. It necessitated

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increasing management of water resources, while keeping landscapes green and healthy. The traditional surface irrigation was the most common and extensive means with a low water utilization closing to 45%. The protected cultures provide a kind of possibility artificially controlled the grape growth and allow water resources to be conserved and used efficiently and sustainable, which will ultimately improve the profitability of the grape production [5,6,7,8,9].

Irrigation is required to provide water to meet the crop growth and evapotranspiration (ET) requirements of the vine when there is insufficient water from rainfall or existing soil moisture, associated with the climate, soil, land use, crops, water availability, water distribution networks, management practices. Therefore, Irrigation management requires comprehensive knowledge for growers and multiple data, which spatially distributed and their integration and use in irrigation schedule and management.[10,11,12,13] Most of them have no enough expertise or experience to acquire enough data and make an accurate irrigation management. So it is evident for providing the help or tools for farmers on grape irrigation management.

As a cross-multidisciplinary, integrated, cutting-edge area of research, Wireless sensor network (WSN) has the ability of detection, calculation and net-construction, which means that it can detect the surrounding environment like temperature, moisture, light intensity, gas concentration etc. from sensor nodes, and transfer data to user.[14,15,16,17,18,19,20] In 2002, the first wireless vineyard in the world was built in Oregon by Intel Corporation, using WSN to detect the soil temperature, moisture and environmental moisture as the basic information of precision irrigation. [21]. Y. Kim et al. [22,23]developed an irrigation system based on sensors, using Bluetooth and GPS to monitor soil moisture, temperature, and other environment parameters. This system aimed at maximizing productivity and saving water. A.Matese [24]from Italy developed a NAV(Advanced Vineyard Network) system based on WSN to monitor and collect the micrometeorological parameters of the vineyard, which contains air temperature, soil temperature moisture and wind speed.

Based on above discussion, this research adopts WSN as the fundamental network infrastructure and develops an irrigation decision support system for protected viticulture (PVIDSS) to help growers optimize the irrigation plan and manage the vineyard. Moreover, it is required that the system will be customizable to allow easy adaptation to a specific model and parameters for simulating growth of grapes. With the trickle irrigation facilities, the system can calculate the irrigated area accurately, and in this way, to optimize the irrigation plan. In the following sections the system analysis is covered, the system design and implementations are demonstrated. The system evaluation and experimental result are presented later. This is followed by the conclusion, remarks from this research as well as future work.

2 SYSTEM ANALYSIS AND DESIGN

2.1 System requirement analysis

Taking into account requirements analysis is critical to the success of a development project, multiple methods were adopted for the users requirements including: document review, interview and survey.

- The documents about grape growth and irrigation principle, management guides were collected to determine the key parameters in system development. For example, soil type, soil density and its maximum water holding capacity vary at different position. The system must contain the data and knowledge.
- The face to face interview was conducted to explore the potential users requirement for the system and their basic experience to ICT application. A list of interviewees was formulated with experts from the Academy of Agriculture Science, China. They were required to describe whether they owned the greenhouses, how they decide to irrigate, and what they want in irrigation system.
- The survey was conducted to explore the system functional requirement and module functions, the irrigation method and possible adoption, barriers for ICT application.

Table 1 shows the results about the routine irrigation management technologies the farmers used at present. As a conventional irrigation technology, nearly half of the responders adopted flood irrigation as their routine irrigation management method. Flood irrigation is one kind of the inefficient water usage technology and waste more water resource. Furthermore, the irrigation time and water volume always dont meet the vine’s requirement properly in practice.

Table 1 The used routine irrigation management technologies the farmers at present

Irrigating method	Frequency	Percentage	Effective percentage
Flood irrigation	387	42.3	50.1
Sprinkler irrigation	143	15.6	18.5
Drip irrigation	156	17.0	20.2
Micro-irrigation	87	9.5	11.3
Total	773	84.5	100.0

More than 90% of interviewees agreed that a range of practices should be adopted in the vineyard to conserve and manage water resources efficiently and sustainable, which will ultimately improve the profitability of the grape production. But shortage of the knowledge of vine physiology and irrigation under protected area conditions is a major barrier to apply the new irrigation technology and ICT application. Therefore, a water-saving irrigation method should be adopted based on the integration of users' requirement, growth laws of vine, and the current field data.

The fundamental features, key modules and functions of the PVIDSS were extracted from the questionnaires and interviews, as listed in Tables 2 and 3.

Table 2 The scientific requirement of the PVIDSS

An Irrigation decision support system based on wireless sensor networks should:
• Be a platform integrating the hardware of automatically monitoring and the software of data transmitting and data processing with models and knowledge embedded. • Make and implement the irrigation decision, calculate the irrigation quantity. • Real-time upload and store records for irrigation and other operations. • Renew of tables about soil property, density and water holding capacity. • Allow users to manage information with the graphical user interface (GUI). • Improve decision support in viticulture enterprise.

Table 3 Functions Requirements of the PVIDSS

Function	Description
Data sampling and transmission	Collect and transmit environment indicators based on WSN.
Environment monitor	Real-time environment monitor based on the former functional module.
Warning and decision making	Give early warning signals when the indicator has the trend of exceed the threshold, define four drought levels to reflect needs of irrigation, irrigate when current level is higher than three.
Irrigation water calculation	Calculate irrigation water volume according to the situation of soil and plants.
Irrigation information recording	Upload and record daily operating information including irrigating, pesticide spraying and harvest based on wireless communication.
Statistics and decision support	Generate reports and charts for management reference in decision-making.

2.2 System architecture design

IDSS is a decision support system for use in planning and scheduling irrigation operations. The system can monitor the data, in combination with farm-specific information about fields, crops, and actual irrigation practices provided by irrigators, to estimate soil moisture conditions and to forecast irrigation schedules. The water requirements for individual fields are aggregated to estimate the potential command area water requirement, then sum up to determine the potential irrigation system demand. A queuing system is used to allocate available water to command areas and fields. Fig.1 illustrates the conceptual structure of PVIDSS, described as Dialog-Data-Model structure.

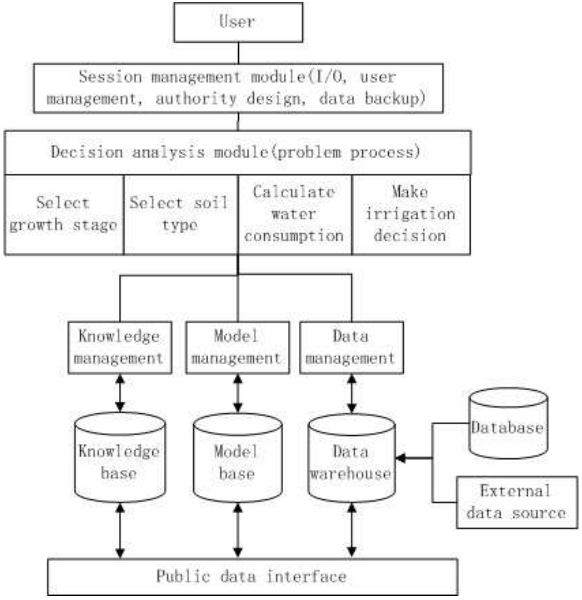

Fig.1. the conceptual structure of PVIDSS

2.2.1 The key manage system of VIDDSS

The database management system is responsible to manage the database, which contains large number of internal data (such as the field data, soil type data) or external data (such as the employees' information). All these data must be collected and analyzed to be useful in decision making, and for users to manage, analyze, and retrieve [25].

The **model base management system** integrates several decision models, analyses the internal and external data in database, and simulates the water tension in vineyard, to provide an irrigation decision schedule for users to choose. In this system, the model base is mainly used to estimate the vine's water tension and the irrigation water volume. Based on the user's input, the system chooses the proper model to work out an irrigation schedule. The **knowledge base management system** is responsible to solve some uncertain problems. The knowledge stored in base is signified and classified into fact base and rule base. The inference engine draws a conclusion based on the fact and rule-based knowledge.

For example, the fact base stores facts such as: "the growth stage S(a)=fruit set"; "the ratio of maximum water capacity to humidity underground R(a)= 30%”. The rule base stores a rule like: ”IF stage S=’fruit set’, AND the ratio of maximum water capacity to humidity underground $R < 30\%$, THEN Irrigation=true”. The inference engine processes data based on the following principle:

If ”stage S(a)=’ fruit set ’ ” and ”the ratio R(a)=30%” is true, and the regulation: ”IF stage S=’fruit set’, AND the ratio of maximum water capacity to humidity underground $R < 30\%$, THEN Irrigation=true” exists, then an irrigation schedule is achieved.

2.2.2 The system function and module

The system’s function is designed into three modules: vineyard foundational information collection and management, irrigation decision and management, system configuration and maintenance.

(1) Vineyard foundational information collection and management module

This module is responsible to collect and management the foundational information of the greenhouse. The sensor nodes are located in each greenhouse and identified as they belonged to different houses. For each house, the information contains two parts: the basic information and the history data of the house.

- **Basic information**. When users add a new greenhouse, a series of information including the detail address, greenhouse ID, house area, house structure and its build time should be input. When the greenhouses need to be sorted for batch management, this information is referred as the key index.

- **History data**. Both the current field data and records of field data and irrigation history are required for irrigation decision. All of the data are stored in the database and can be displayed or edited when needed:

  >Field data including temperature, soil moisture, and node power voltage, which is transferred from the sensor nodes.

  >Irrigation history including irrigation time, irrigation water volume, and greenhouse ID which is irrigated. The information can be inputted and updated by the managers, who take charge of maintaining and operating the greenhouse.

(2) Irrigation decision and management module

This module is the key component and responsible for collecting field data and making an irrigation decision. This module consists of data collection module and decision making module.

- **Data collection sub module** is responsible for collecting the data and storing in the database. The adopted device is Crossbow’s WSN suite. The transmission method is based on ZigBee protocol which is suitable in the application of wireless transmission and real time controlling. Sensor nodes in WSN monitor dynamically the key environmental parameters and transmit data to the sink node. Then, the sink nodes send data to central server and receive the command packets from server. When an irrigation decision made, the certain sink node receive the command from the server that indicate an irrigation device switcher integrated on the data board turned on or off.

- **Decision making sub module** is responsible to estimate the vine’s water tension and calculate the irrigation water volume to calculate a schedule. In decision making stage, the current environmental parameters of the monitored greenhouse is displayed on the screen. Then, the irrigation record will be saved as one part of the history data of greenhouse.

(3) System configuration and maintenance module

The system is developed under Microsoft .Net framework environment, and should be run at no less than .Net framework 3.0 with Internet Information Services (IIS) installed. The database platform adopted is Microsoft SQL Server 2005, of which the component ADO.NET entity framework has a good performance of retrieval efficiency.

To ensure the system’s running reliability, and improve the system’s adaptability to different environments, the system maintenance plays an important role in latter system operation stage. The main activities in system maintenance are the program modifying and extending, database backup and recovery, and sensor nodes’ replace.

2.3 The hardware architecture installation based on WSN

The wireless sensor network (WSN) plays an important role in the data collection and transmission function. Based on ZigBee protocol, the WSN has an advantage of self-organized network, short-distance, low-complexity and low power consumption, which is suitable in monitoring the greenhouse’ environment [26,27,28,29,30]. When a node doesnt work, the whole network can continue its own work due that the ZigBee protocol supports the dynamic routine algorithm.

The data collection and transmission module comprises:

- a Windows/SQL-based central data-web server;
- the Crossbow’s IRIS (MIB520) and MDA300 sensor and data acquisition boards based on ZigBee protocol.

WSN is composed of two kinds of nodes: wireless sensor node and sink node.

- **The wireless sensor node** is responsible to detect and collect specific environmental parameters. Then the data package is transmitted between each node in dynamic routine.
- **The sink node** is responsible to send the raw data to a database server through TCP/IP protocol. Each node consists of data acquisition modular (sensors, A/D translators), data process and control modular (microprocessor, memory), communication modular and power supply modular (battery, DC/AC power translator) and so on.

In PVIDSS, several MDA300 sensor nodes are located in greenhouse to detect environmental data such as temperature and soil moisture. These data package is assembled into a sink node(MIB520), and then transferred to the central server. On central server, the data package is analyzed and processed. The data relevant with sensor itself (board ID, board type, the parent board ID, socket ID et.al) is stored in the database, while the environment data (temperature, soil moisture, nodes power voltage et.al.) is stored in the database and transmitted to the user's terminal at the same time, and displayed on the screen. Figure 2 shows the entire the hardware architecture installation based on WSN in PVIDSS.

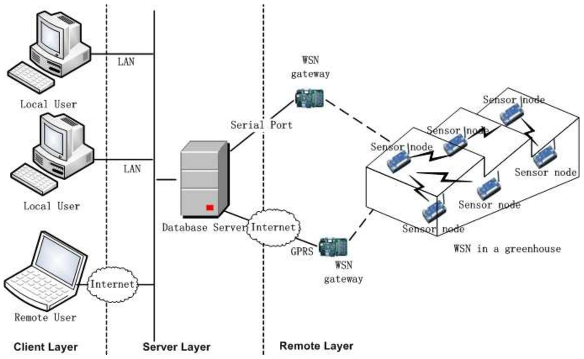

Fig.2. The hardware architecture installation based on WSN in PVIDSS

3 MODELING THE IRRIGATION DECISION IN GREENHOUSE

The key point of viticulture Irrigation decision includes: how thirsty the plant is and how much and when water should be irrigated. A decision model is designed to figure out an irrigation schedule depending on the identified factors that driving the water quantities, such as temperature, soil moisture, vine growth stage, soil characteristic. Figure 3 shows the modeling process.

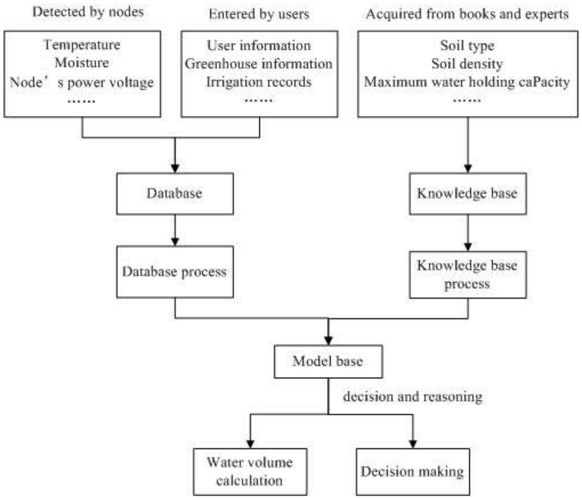

Fig.3. Process of decision making on irrigation management in PVIDSS

3.1 Ambient data acquisition and process based on WSN

The data acquired in the sensor boards were organized and grouped based on a specified rule in order to be transmitted correctly between different sensor boards. The data package comprises of four components: (a) TinyOS header of 5 bytes; (b) Xmesh header of 7 bytes; (c) Xsenser header of 4 bytes; (d) data payload. Table 4 shows the frame structure of MDA300 data package.

The TinyOS header(5 bytes) and the XMesh header(7 bytes) of the package is used only when the network is self-organized between the sensor nodes. The sensor board ID(1 byte) identifies the data boards' type. Board ID indicates what kind of parameters can be detected. Different board ID means different parameters and different data packet structure. The data payload component contains all the environment data that a certain board can detect. Take MDA300 for example, the sensor board ID is 129, which means the detected environment parameters are temperature, moisture and power voltage, and all these data is packaged in an original form in the data payload component.

In system's monitoring process, a new thread is allocated for listening the serial port. When a data package is received, the synchronization bytes are identified whether the package is correct. If it is correct, the data package is unpacked and processed into original data based on the data package rules. Fig.4 shows the flow of WSN data package process.

Table 4 Data package frame structure, the frame size measured in byte.

Name	Structure	Space occupied(Byte)	Description
TinyOS Header	Destination Addresss	2	Address of the destination node
	AM Type	1	Data type of the package
	AM Group	1	Group ID
	Length	1	Package length
XMesh Header	Source Address	2	Original address of the routine
	Origin Address	2	Original address of the package
	Sequence Number	2	Sequence number of the package
	Application ID	1	Identify different application
XSensor Header	Sensor Board ID	1	Identify different sensor board
	Sensor Packet ID	1	Identify the data package format
	Parent	2	The parent sensor node
Payload (MDA300)	Temperature	2	Temperature
	Humidity	2	Humidity
	Voltage	2	Voltage
	Others		

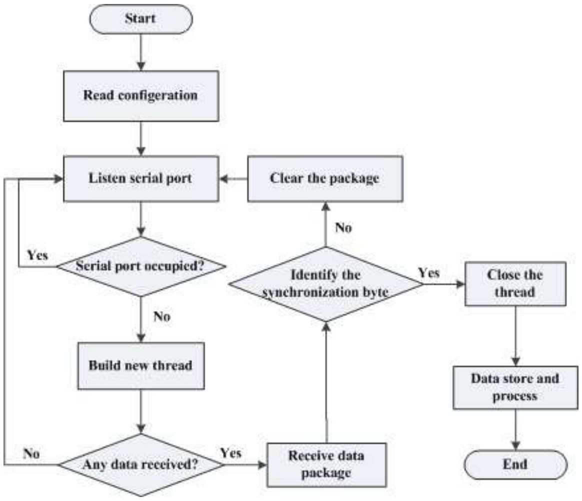

Fig.4. The WSN data process flow

The original data in packages are showed to users in an easier understandable form transformed from the following formulas:

$BV = RV * ADC\_FS/data$

$T = -39.4 + 9.8E - 3 * humtemp$;

$M = (0.01 * humtemp - 64.6) * (0.01 + 8E - 5 * moisture) - 4 + 0.0405 * moisture - 2.8E - 6 * moisture$

where:

$BV = Battery\ Voltage$;

$RV = Voltage\ Reference\ for\ sensor\ (1.223V)$;

$ADC\_FS = 1023$; $data = original\ data\ package$;

$BV = 1252352/data(mV)$

T= Temperature; humtemp = original data package(in decimal form)

M= Moisture; moisture=original moisture data

The original data package is represented in a form of hexadecimal data string, which should be processed and converted into decimal form based on the formulas above. For example, in MDA300 sensor board, a data package is received from the serial port as:

7e42 7d5e00 0b 7d5d1d 0000 0200 0000 33 8186 0000 bc01 3c06 201a ca0b 3e09 db09 0100 0100 0100 df857e

The original data package is represented above. The bytes in bold represents the key parameters in greenhouse as sensor power voltage, moisture and temperature. Take battery voltage for example, ”bc01” is a hexadecimal number which should be converted into decimal number ”444”. Based on the battery voltage formula, $BV = 1.2231023/444 = 2.817(Volt)$. Therefore, the battery voltage at present time is 2.817 volt.

3.2 Knowledge acquisition about the soil type and density, vine growth circle

Specifically, the decision ”to irrigate or not to irrigate” is taken based on a combination of ”soil moisture in the depth of 40cm underground”, ”density and water holding capacity of the soil” and ”the vine’s growth stage”. Irrigation schedule is calculated based on: soil moisture(H), which is in 40cm depth underground; temperature(T); irrigation area(A); irrigation depth(DP); the vine growth stage(S), which comprises pre-budding(pb), budburst(b), flowering(f), fruit set(fs), veraison(v), post harvest(h)[31]; maximum water holding capacity(C) and soil density(D), which are depended on the soil type(Table.5).

Table 5 Relation among soil type, soil density and maximum water holding capacity.

Soil type Parameters	Clay	Clay loam	Loam	Sandy loam	Sand
density	1.3g/cm3	1.3g/cm3	1.4g/cm3	1.4g/cm3	1.5g/cm3
maximum water holding capacity	25% 30%	23% 27%	23% 25%	20% 22%	7% 14%

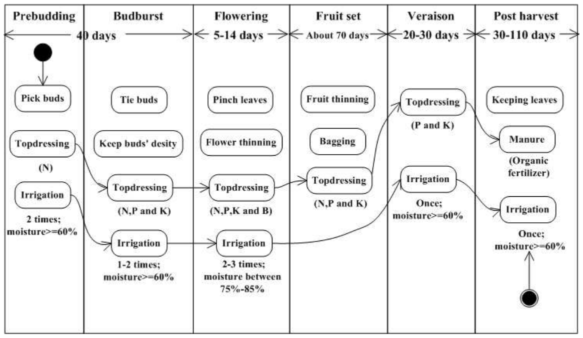

Fig.5. The vine growth circle and its manual process based on UML

3.3 The irrigation amount calculation model

The amount of irrigation water is calculated according to the water stress of soil. For different kind of grapes at different growth stage, the requirement of water is different. Vine cultivation requires large provision of water, which plays an important part in the growth of vine's organs. The soil moisture extracted by the root directly affects the growing and ripping levels.

The best soil moisture for vine's growth is 60%-80% of the soil maximum water holding capacity. When this ratio is less than 46%, the photosynthesis becomes weak, the water extracting and translating ability of roots is reduced either; when this ratio is larger than 95%, the oxygen concentration around roots is reduced, the carbohydrate concentration is increased, the water extracting ability and the vine's respiration is reduced either, all of which may lead to the asphyxia of roots, and destroy the vine growth.

In different stage of vine growth, the reference is different too. In pre-budding, budburst and fruit set stages, plant needs to be well-watered to maximize berry size, while in the flowering and veraison stages, the water quantity should be proper to promote shoot growth and to help sugars accumulate in the berries. The information about the soil type and the vine growth stage should be entered into system by users, while other information such as field data can be read automatically. The soil moisture underground and the temperature in greenhouse are transferred by the wireless sensor network to local database, which can be read at any time.

The decision is made mainly according to the soil moisture(H)temperature(T)vine growth stage(S)maximum water holding capacity(C). The water holding capacity is closely depended on soil characteristic, which reflects how much water can be held around soil particles and within soil pores (spaces). The less water the soil can hold, the more should be irrigated. The ratio of soil moisture(H) to maximum water holding capacity(C) is one of the important factors affecting decision-making, while the other factor is the temperature.

3.3.1 Irrigation decision method

When all of the information is obtained, the system judges the growth stage firstly:

i. if the plant is at pre-budding, budburst or post harvest stage, when the ratio of maximum water holding capacity to moisture underground is higher than 60%, or the temperature lower than 10 degrees, no irrigation schedule is suggested. While when the ratio is lower than 60%, an irrigation decision is suggested and the irrigation water quantity is calculated.
ii. if the plant is at flowering or veraison stage, when the ratio(H/C) higher than 40%, or the temperature lower than 10 degrees, no schedule is suggested, otherwise the decision will be made.
iii. if the plant is at budburst stage, when the ratio higher than 60% or the temperature lower than 20 degree, no schedule is taken.

While when the ratio is lower than 60%, a large amount of water should be irrigated to protect plant living through the winter. Fig.6 illustrates the decision process detailed above.

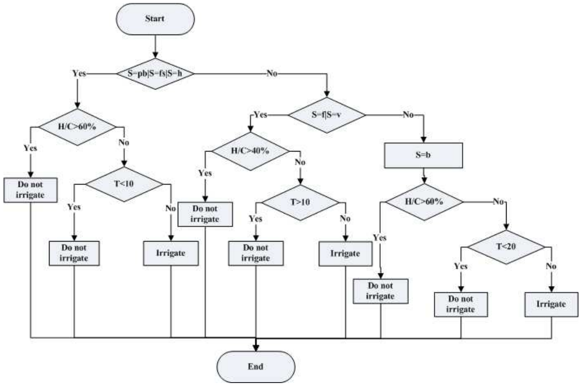

Fig.6. Decision process model for Irrigation decision

3.3.2 Water volume calculation

After the user agrees with the decision, the system begins to calculate the amount of water used per cubic meter and justifies whether the pre-defined threshold reached. The vineyard is irrigated until the current moisture reaching to 0.8 times of the ratio of maximum water holding capacity to moisture underground.

The system provides the grower with a designated tool to help him/her calculate the amount of water to be used in order to follow recommendation/personal choice and the amount of water actually used in each vineyard. The grower enters the phenology and soil type. The tool then gives the amount of water to be used, based on the following formula:

amount of water=area of irrigation*depth of irrigation*soil density*(maximum water holding capacity-moisture before irrigation)

In greenhouse, the transpiration effect makes higher moisture in air, therefore plant absorbs more water than open area viticulture. So the amount of water can be reduced to 50%:

amount of water=area of irrigation*depth of irrigation*soil density*(maximum water holding capacity-moisture before irrigation)*50%

4 SYSTEM IMPLEMENTATION AND EVALUATION

4.1 system implementation

The system was developed using the following tools:

- the systems' database is MS-SQL Server 2005;
- the system was developed using .NET Framework, programmed in C# language with Microsoft Visual Studio 2008 platform;
- the sensor network devices were from crossbow WSN suites.

The key functions are described as the following:

4.1.1 User information management

The administration authority is designed into two levels: administrators and basic users.

Administrator is the operator of the system, who is allowed to edit the knowledge table, renew the decision model when growing environment changes, and maintain the database server.

The basic users need to register in the system and submit the greenhouses' basic information at the first use. In client terminal, vineyard management which includes irrigation scheduling, recording, reporting, and greenhouse management can be checked and exported by basic users.

All the users can edit their personal information after authorized by the user name and password. The basic information contains user's name, sex, nationality, marriage status, ID card, birthday, telephone, political status, position, enter time(Fig. 7).

编号	姓名	密码	证件号	性别	民族
8	李芙蓉 ...	123	150101198807046140	女	汉
13	张雷 ...	135	320101198107017949	男	汉
14	韩愈 ...	123	320101198807048025	女	汉
15	李贺 ...	123456	410101198107018978	男	汉
16	韩玉冰 ...	456789	150101198807041577	男	汉

Fig.7. User management interface of VIDSS

4.1.2 Vineyard management

The module allows the addition/deletion/modification of vineyards managed by the system. A form for each vineyard is filled by the grower when the vineyards are added to the system or whenever vineyard characteristics are changed (infrequent activity). The description of the vineyards includes: length, width, area(m2), structure, build time, the vine's type. The system also allows a grower to add new vineyards and delete old vineyards.

地址信息	大棚编号	大棚结构	大棚面积	搭建日期	使用寿命
沈阳市苏...	1	单斜坡钢...	6.000	2000	9
沈阳市苏...	2	单斜坡钢...	5.000	1999	10
沈阳市苏...	3	单斜坡钢...	7.000	2000	9
沈阳市苏...	4	单斜坡钢...	20.000	2000	9
沈阳市苏...	5	单斜坡钢...	40.000	2006	20
沈阳市苏...	6	单斜坡钢...	7.000	2006	20
沈阳市苏...	7	单斜坡钢...	18.000	2006	20
沈阳市苏...	8	单斜坡钢...	10.000	2003	20
沈阳市苏...	9	单斜坡钢...	10.000	2001	20
沈阳市苏...	10	单斜坡钢...	18.000	2000	20

地址信息：沈阳市苏家屯区王纲乡新开汤村
大棚编号：5
大棚结构：单斜坡钢架棚
大棚面积：40 亩
搭建日期：2006 年
建造公司：
栽培种类：藤稔
使用寿命：20 年

Fig.8. Vineyard management module in VIDSS

4.1.3 Environment monitor

This module manages the field data collected from the greenhouse, including sensor board type, node power voltage, moisture, temperature, data collecting time, greenhouse ID and its irrigation history(Fig. 9).

采集板型号	节点电压	温度	土壤湿度	采集时间
134	2653	23	23	2010-9-22 22:15
134	2653	23	24	2010-9-22 22:15
134	2653	23	27	2010-9-22 22:16
134	2653	23	28	2010-9-22 22:16
134	2653	23	26	2010-9-22 22:17
134	2653	23	27	2010-9-22 22:17
134	2653	23	27	2010-9-22 22:18
134	2653	23	26	2010-9-22 22:18
134	2653	23	26	2010-9-22 22:19
134	2653	23	26	2010-9-22 22:19
134	2648	23	27	2010-9-22 22:20

大棚编号： 02
采集板型号： 134
土壤湿度： 23 %
温度： 23 摄氏度
节点电压： 2653 mV
采集时间： 2010-9-22 22:15
最近一次灌溉时间： 2010-09-07

Fig.9. Environment monitor interface in VIDSS

4.1.4 Irrigation management

Irrigation schedule is provided during the active growth stage. The data that the grower has to provide during decision making process are soil type and the vine growth stage. Soil moisture and temperature data are collected automatically from sensors in field. Recommendation is either to irrigate with a certain amount of water or not to irrigate(Fig.10).

当前温室： 2号棚
温度： 23 度
节点电压： 2653 mV
湿度： 27 %
土质： 粘土
灌溉面积： 3333.35 平方米
作物生长阶段： 浆果成熟期

大棚编号： 2号棚
节点电量： 中
等级： 3
干渴情况： 作物干渴
建议方案： 建议灌溉，灌溉水量为 2600.13 平方米
是否灌溉： 是

Fig.10. Irrigation decision interface in VIDSS

4.2 *System test and evaluation*

After system development, the system was tested and evaluated to avoid the possible system errors or wrong decisions. A good system test and correction can increase system quality, lower system risks and increase development efficiency. The system evaluation contains two phases: verification and validation. In the first phase, the logical correctness of the system must be guaranteed to make sure that the system will run smoothly. In the second phase, the developers should make sure whether the system output could meet the user's requirement or not. During the verification phase, the system was tested in: 1)data acquisition, 2)WSN test, 3)system calculation.

- In data acquisition test, one sensor node is accessed in the system. The test lasted for 30 minutes to check out how many data packages were lost during this time. The result shows that the ratio of package lost is 23%. But changing new battery can decrease the ratio effectively.
- In WSN test, three nodes of the same type are placed in distance of about 3m from the sink node. The sink node uploads the data from sensor nodes to PC. Each sensor node works steadily.
- In system calculation test, the data flow is checked and proved to be retrived correctly.

In the validation phase, the system requirement is simple and clear, which is to make an irrigation decision according to the environment data transmitted from WSN. The validation phase measures the current performance and provides the basis for future improvement of the system. The system evaluation on DSS was implemented in order to estimate the technological capacity, performance and system utilization. System improvement suggestion includes: 1) Accuracy of decision in irrigation, 2) Adoption of decision model in application, 3) Fine-tuning the system menu and interface design. Effectiveness analysis before and after application of irrigation DSS are shown below in Table 6.

5 CONCLUSION

This paper shows a WSN based irrigation decision support system for viticulture in protected area. The system is developed on the basis of successful experience of wireless sensor network and decision system in agriculture. The WSN technology enables a real-time and mobility data acquisition without network infrastructure. The data accuracy from sensors is satisfactory and even higher than that of conventional means.

Compared with the traditional system, the PVIDSS integrated WSN with decision support system can automate many tasks including environment monitoring and irrigation decision making. It provides a tool for farmers, system users, and viticulture enterprises, to improve the vineyard management efficiency.

The system test and evaluation proved itself as an effective viticulture management tool that leads to proper irrigating at proper time and recording of the viticulture work flow. It improves the grape productivity and reduces the water loss through monitoring the critical parameters in culture environment and making an irrigating decision in time.

As a result, PVIDSS not only increases economic benefits for the viticulture enterprise but also saves the limited water resources. The integrated system not only collects the environment parameter for irrigation decision

Table 6 Effectiveness analysis before and after application of irrigation DSS

Index number	Index content	Before deployment	After deployment
1	Management precision	/	Day/Week/Minute/Second
2	Data acquisition	Incomplete artificial collection	Automatic accurate mass capture
3	Employee management	Disordered	In order and being recorded
4	irrigation management	Artificial judgment with delay	Automatic real-time warning
5	Quality analysis	Empirically with delay	Accurate, real-time
6	Development and deployment efficiency	None	Code reusable, place to use
7	Maintainability	None	Modularity, replaceable code and nodes
8	User-friendliness	None	Well-designed interface, easy to use
9	Information security	Paper archives, easily damaged or lost	Database backup and recovery
10	Information sharing	Producer only	Producer and consumers

system objectively and scientifically, but also provides theoretical support for establishing data integration network and general framework of data collection through wireless sensor networks for decision support systems.

This work can be extended for future work in many directions. For example, as remote wireless sensor network through out the integration with GSM networks, automatic control of important issues for decision support systems through integration with irrigation and industrial control equipments.

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