An intelligent framework of Automatic Weather Station

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ABSTRACT
The traditional Automatic Weather Station (AWS) framework is generally composed of datalogger and sensors. A new framework based on Wireless Sensor Network (WSN) is proposed in this paper. There are two layers we called device layer and application layer respectively in the new intelligent framework. Analog signal acquisition, meteorological factor calculation and formatted output are assembled at the device frontend (or layer). The application layer is formed by at least one embedded system, which can be used for real time data collection, data quality control, extreme value statistic, information dispatch and other complex functions as well. We design and produce a comprehensive weather station named CAWSmart under the new framework. The CAWSmart has recognition intelligence, networking intelligence and diagnosis intelligence. With the metrological system, the CAWSmart can archive calibration intelligence. This novel structure has clearer layers, and better extensibility. Each observed factor will be more independent, flexible and anti-destroyed. The device layer focus on observing stability, meanwhile the application layer focus on functional extension. The observing system will be smarter with the increment of different embedded software.

KEYWORDS
Automatic Weather Station (AWS), System Integration, Smart Sensor, Wireless Sensor Network (WSN), Intelligent Framework

1 INTRODUCTION
The comprehensive observation plays a very important role in the meteorological modernization procedure, of which the meteorological surface observation is the fundamental and essential component. After about 20 years of rapid development, China has built a large-scale meteorological observation network with tens of thousands of AWSs. In this magical development process, we have the honor of taking part into, witnessing and contributing to the construction of the automatic meteorological station network from the very beginning.

We have successfully developed two generations of AWSs, and the third generation R&D is undergoing. In the 1990s, the first generation of AWS, named CAWS600, focused on system integration techniques. Electronic signals of temperature, humidity, air pressure, precipitation, wind direction, wind speed and other variables were converted to standard observation values using industrial dataloggers, as shown in Figure 1. Based on these observational values, the PC software generated a variety of weather messages and reports. The shortcoming of this kind of station is its inextensibility.
The second-generation AWS, named CAWS3000, started its implementation in 2008. It applied CAN (Controller Area Network) bus connection method and used a master datalogger to connect multiple sub-dataloggers. Because of the application of CAN bus, the flexibility of sensor access was greatly enhanced. It also had data quality control function. The CAWS3000 framework was shown in Figure 2. This kind of station was widely used in meteorological observations. But it also had its disadvantages, such as inconvenience of installation and maintenance and high use-cost.

With the rapid progress of electronic and information technology, especially the IoT (Internet of Things) technology, meteorological sensors are evolving towards high-precision, digitalization, energy-efficiency and miniaturization. All those provide a precondition for a new generation of AWS. In this paper, we propose a general idea of building the surface observation system based on WSN. Guided by this idea we make a weather station with intelligent comprehensive
observation model. This smart weather stations can respond to equipment diagnosis and numerical forecasting requirement.

2 INTELLIGENT AWS FRAMEWORK

Figure 3 shows the framework of intelligent meteorological station proposed in this paper. The functional areas are well connected. Various users with different roles operate at different specified layers. Under this framework, the system is divided into upper application layer and lower device layer by gateways. The functions of analog signal acquisition, meteorological element calculation and data output production are located in the device layer at the front end of the equipment. The application layer consists of at least one embedded system, which can operate data collection, data quality control, extreme statistics, information release and other functions. The gateway is a very important device for its function of enabling communications between two layers under communication protocols. The proper configuration of the gateway is a key part of the whole system.

![Figure 3: Intelligent framework of the new-generation AWS](image)

2.1 DEVICE LAYER

The device layer is centered on the embedded system, with intelligent and networked sensor units being assembled around. An embedded system is a dedicated computer system for specific intelligent tasks, such as controlling, monitoring and assisting etc. Device layer contains a large number of intelligent networked sensor units. Each sensor unit was composed of the acquisition module, processing module, communication module and power module etc. The acquisition module is the core part of the sensor unit by converting analog signal to digital
signal. The processing module consists of processor, memory, storage, interface and system software. It generally uses low-power chip for energy efficiency. The communication module includes radio-frequency circuits and wireless antennas to receive and transmit data. The power module provides power to the system. To save energy and prolong battery life, a power management software is installed in the processing module for dynamic power management. With the interactive cooperation of the four modules, intelligent networked sensors are capable of self-detection, self-correction and self-protection. Besides, it also has the capability of data judgment, decision and formatting output in terms of calculation and duplex digital communication.

2.2 APPLICATION LAYER

The application layer is the interface between application software and network to enable users to interact with the device. The layer is composed of many job-specified applications and software services. By all these application units, users can easily complete various interactions with device layers about data, information and configuration. Data service is the fundamental function in the application layer, as the high-quality data is essentially what users want from the observation system. In a narrow sense, the data service refers to sending the observational data to users through the network access port. In a broad sense, the data service is able to integrate the weather station network into a comprehensive observation network to complete the migration of bulk data from the observation system to the meteorological service system. With big-data management and cloud computation technique, the data could be well managed, while providing diverse user-friendly services. Identification and network services are mainly used to improve the efficiency of building and maintaining AWSs. Stringent security policy of WSN is adopted to inhibit illegal access. Under these security protocols, the operational meteorological sensor need to be authorized before connecting to intelligent weather station. The unauthorized sensors would be discerned and eliminated automatically from the system. At the same time, using multi-gateway technology and dual hot backup controller, sensors and terminal equipment can automatically choose secure routes to build reliable links for real-time data synchronization.

It is important to know the system status for timely responses to potential device and service failures. Such a function was achieved through status and diagnostic services. Specifically, the service interface displays real-time system status information and fault alarm report that weather stations generate automatically. Status information is important for data quality control and information push. As to the diagnosis service, users can interact with the device in depth to facilitate on-site debugging and maintenance by running a diagnostic program on intelligent terminals.

Metering calibration service includes built-in calibration parameter configuration modules, which work closely with automatic verification devices. Thanks to the service, it is convenient and efficient to complete the site and further laboratory calibration process for each element sensor. Under this novel framework, additional new service interfaces can be easily developed and implemented in the application layer, which makes this new framework attractive.

3 THE KEY TECHNIQUES AND STANDARDS

3.1 THE USE OF WSN TECHNOLOGY
WSN is a kind of distributed sensor network, which combines sensor technology, embedded processor technology, distributed information integration technology and communication technology. It enables remote real-time monitoring, gathering and analyzing the data and information by connecting to the internet. Since the WSN sensors communicating wirelessly, the network is flexible and scalable. Meanwhile, the device installation, replacement and usage can be very convenient by eliminating the limit on communications. From the aspects of transmission characteristics, QoS (Quality of Service) requirements and mobility, the WSN structure design should ensure the fairness of the nodes in the network and energy distribution balance in order that WSN can work continuously and efficiently.

IoT employs technologies such as RFID (Radio Frequency Identification), WSN and wireless data communication to construct a vast network of information that could theoretically identify everything in the world. Therefore, the IoT technology can flexibly support WSN networks in different sizes. WSN nodes can be merged into a certain size WSN network and then access to the mobile communication system. These WSN nodes can be also directly connected to sensors with a mobile terminal function through a mobile base station. Under this circumstance, these sensors are both WSN nodes and WSN gateways.

Wireless communication technology is the foundation of WSN technology. In this section, we will discuss the details of the wireless communication technologies and the standards used in meteorological applications.

These communication technologies include ZigBee, WiFi, GPRS/3G/4G in Wireless Communication as follows:

1. ZigBee: ZigBee technology defines the network and application layer protocols based on the IEEE 802.15.4 standard physical and MAC layer definitions. The definition is used to meet the requirements to design a wireless personal area network (WPAN) using low power radio-enabled devices. Due to its energy efficiency, low cost, and high reliability, the ZigBee technology is widely preferred for WSN-based applications in the agricultural and farming sectors. ZigBee also supports short-distance (10-20 m) data communication over multi-tier, decentralized, ad-hoc and mesh networks. The ZigBee-enabled devices have a low-duty cycle, which makes it suitable for the applications where periodic information update is required. For example, it is broadly used in agricultural applications like irrigation management, pesticide and fertilizer control, water quality management. Furthermore, it has other advantages such as requiring low specification hardware (such as microprocessor with 50-60 kb memory) and including security encryption techniques. However, ZigBee applications only support low data transmission rates of 20-40 kbps and 250 kbps at respectively 868/915 MHz and 2.4 GHz frequencies of ISM band.

2. WiFi: WiFi is a wireless local area network (WLAN) standard for information exchange. It also enables Internet connection wirelessly based on the IEEE 802.11 standards family (IEEE 802.11, 802.11a/b/g/n). Currently, it is the most widely used wireless technology in devices ranging from smartphones and tablets to desktops and laptops. WiFi provides a decent communication range in the order of ~20 m (indoor) to ~100 m (outdoor) with data transmission rate in the order of 2-54 Mbps at 2.4 GHz frequency of ISM band. In agricultural applications, WiFi broadens the use of heterogeneous architectures by connecting multiple type of devices over an ad-hoc network.

3. GPRS/3G/4G: GPRS is a packet data service for GSM based cellular phones. A data rate of 50-100 kbps is achieved in the 2G systems. However, in GPRS, throughput and delay are variable, which depend on the number of users sharing the same resource. The biggest advantage of GPRS...
is to relieve the communication range limitation of wireless devices. Any two devices can communicate as long as they are within the GSM service area. It is worth noting that it is better suited for the periodic monitoring applications than the real-time tracking-type applications. The advanced version of GPRS is Enhanced Data rates for Global Evolution (EDGE), which offers increased data transmit rate with no hardware/software modifications in the GSM core networks. 3G and 4G are the third and fourth generations of mobile communication technology. The corresponding data transmit rate achieved in these technologies are 200 kbps and 100 Mbps-1 Gbps in respectively 3G and 4G.

In Table 1, we compare the different communication technologies with their characteristics and performance. The suitable meteorological applications of each technology are also mentioned. In fact, in the last two years, LoRa and NB-IoT have also been more and more popular technologies in the field of meteorological observation.

TABLE 1: Comparison of different communication technologies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Frequency band</th>
<th>Data rate</th>
<th>Transmission range</th>
<th>Energy consumption</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zigbee</td>
<td>868/915MHz, 2.4GHz</td>
<td>20-250kbps</td>
<td>10-20m</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>WiFi</td>
<td>2.4GHz</td>
<td>2-54Mbps</td>
<td>20-100m</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>2.4GHz</td>
<td>1-24Mbps</td>
<td>8-10m</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>GPRS/3G/4G</td>
<td>865MHz, 2.4GHz</td>
<td>50-100kbps/200kbps/0.1-1Gbps</td>
<td>Entire GSM coverage area</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>WiMAX</td>
<td>2-66GHz</td>
<td>0.4-1Gbps (stationary)</td>
<td>≤50km</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>LoRa</td>
<td>150MHz-1GHz</td>
<td>0.3-50kbps</td>
<td>1-20km</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>NB-IoT</td>
<td>800</td>
<td>100kbps</td>
<td>Entire</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>
The factors associated with WSNs that need further attention are listed as follows.

**Cost**
A low-cost solution is always in need for increasing the applicable scope and outreach of WSNs.

**Autonomous Operation**
The future solutions should include the provision for autonomous operations surviving for a long time.

**Intelligence**
An inherent intelligence will enable the futuristic solutions to dynamically react to multiple challenges, from conserving energy to real-time response.

**Portability**
For easy use of an application, portability is essentially required. Recent advances in embedded systems, such as System in package (SiP) and SoC technologies will definitely help in this regard.

**Low Maintenance**
It is important to design a system which would operate with minimum maintenance effort. Low maintenance will certainly minimize the average cost in the long run.

**Energy-efficiency**
To extend the system lifetime of autonomous operation, the solutions need to be more energy-efficient by incorporating low-power chips and intelligent algorithms.

**Robust Architecture**
A robust and fault-tolerant architecture for the emerging applications is required to ensure sustained operation and low maintenance effort.

**Ease of Operation**
Typically, the end users of these applications are non-technical persons, whose might not fully understand underlying structures and theories. Therefore, applications need to be user-friendly with low learning curve.

**Interoperability**
Interoperability between different components and different communication technologies will enhance the overall functionality of the system. [11]

### 3.2 THE USE OF IEEE1451 STANDARD

IEEE1451 standard series, launched by IEEE and NIST, set up a general framework of the intelligent networked sensor to solve the interoperability between different smart sensors and interchangeability. The IEEE1451 specifies the sensor, converter, machinery and network to build a common interface between compatible and interchangeable converter. Such a structure can ease the sensor manufacturers in designing the interface and enable them focus on the development of sensor itself. The standard has greatly promoted the development of networked intelligent sensor technology. Based on IEEE1451 standard, the IP sensor has developed the
intelligent sensor information model. The IP sensor has retained the smart transducer interface module (STIM) structure and function of the IEEE1451 standard. Instead, they extended the TEDS to communicate with TCP/IP network protocol, which lowered the use threshold and cost. \[12\]-\[13\] Under IEEE 1451, a sensor/actuator system is divided into two parts, a Transducer Interface Module (TIM) and a Transducer Electronic Data Sheet (TEDS). The TIM contains the sensing, actuating element and signal-conditioning circuits. Each TIM is connected to a network-capable applications processor (NCAP), which provides an interface to any network by a subset of the IEEE 1451 standard. The TEDS digital data identifies the type of sensor, its calibration information, and scale factor etc.

The sensor output signal of meteorological element are in three major types of digital, analog and circuit parameter. In order to make the sensor module adapt to the meteorological operations in different meteorological observation, STIM needs to rely on the type of sensor for the reconstruction of the front-end signal conditioning circuit, electronic technology. For example, programmable gain amplifier may be used in the process. Under the control of the microcontroller module, we can realize functions of meteorological sensor hot-plug, automatic identification, self-check, calibration and zero set etc. It can help smart sensors adapt to multiple communication networks by integrating the ZigBee submodule and TCP/IP submodule in the network adapter module. The technical route adopted in the smart wireless sensor is shown in the Figure 4.

![Figure 4: Architecture Diagram of Smart Wireless Sensor](image)

4 CAWSmart WEATHER STATION

Based on the new observing system architecture, we develop the CAWSmart weather station device. The monitor is fully compatible with CIMO guide and surface meteorological observation specifications. It has the functions of automatic surface meteorological data acquisition, storage, processing and transmission. Furthermore, it is environmentally tolerant and remarkably stable and reliable. The main controller of the CAWSmart monitor adopts embedded system technology. Its core is the high performance 32-bit microprocessor, which can ensure the real-time performance of the system. Through the intelligent technology of sensor and the main controller technology, the reliability of the multi-factor intelligent meteorological station system was reliably guaranteed and significantly improved. It also worth noting that the system has fully independent intellectual property rights owned by Huayun company. The product is shown in figure 5.
The system can meet the needs of both weather and climate observations. It is able to observe
the following meteorological elements as wind direction, wind speed, temperature, humidity,
precipitation, air pressure, ground temperature, soil moisture, frozen soil, evaporation, snow
depth, total radiation and net radiation, reflected radiation, diffuse radiation, direct radiation,
sunshine, cloud cover, cloud height, visibility, freezing rain and weather phenomenon. Specifically,
the weather phenomena of precipitation and ground coagulation can also be directly given by
the sensor. Other types of weather phenomena can be given by the comprehensive discriminant
algorithm embedded in the system. The system adopted the modular design. The sensors can
automatically identify and access the wireless sensor network to realize the adaptive intelligent
network. The users can select the sensor and auxiliary equipment of relevant elements according
their observation needs. These sensors and equipment can be easily assembled into a
professional observation station suitable for different station types. The sensor intelligent
technology has the functions of automatic zero adjustment, compensation, calibration, quality
control, equipment status report and self-diagnosis. The system uses low power consumption,
high accuracy, high stability measurement technology and short distance wireless communication
technology. These technological features lay a solid foundation for the intelligence and reliability
of the surface observations.\textsuperscript{[14]}

Product measurement performances are as follows in Table 2.

\textbf{Table 2: Sensor measurement specification}

<table>
<thead>
<tr>
<th>Measure elements</th>
<th>Measurement range</th>
<th>Resolution</th>
<th>Maximum permissible errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>-60～60℃</td>
<td>0.1℃</td>
<td>±0.1℃</td>
</tr>
<tr>
<td>Humidity</td>
<td>5～100%RH</td>
<td>1%RH</td>
<td>±3%RH (≤80%) ±5%RH (&gt;80%)</td>
</tr>
<tr>
<td>Air pressure</td>
<td>450～1100hPa</td>
<td>0.1hPa</td>
<td>±0.25hPa</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Tipping bucket: 0～4mm/min</td>
<td>0.1mm</td>
<td>±0.4mm (≤10mm) ±4% (&gt;10mm)</td>
</tr>
<tr>
<td></td>
<td>Weighting: 0~400mm</td>
<td>0.1mm</td>
<td>±0.1%FS</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------</td>
<td>-------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Wind speed</strong></td>
<td>0~75m/s</td>
<td>0.1m/s</td>
<td>±0.5m/s (≤5m/s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±10% (&gt;5m/s)</td>
</tr>
<tr>
<td><strong>Wind direction</strong></td>
<td>0~360°</td>
<td>3°</td>
<td>±5°</td>
</tr>
<tr>
<td><strong>Ground temperature</strong></td>
<td>-50~80°C</td>
<td>0.1°C</td>
<td>±0.5°C</td>
</tr>
<tr>
<td><strong>Soil temperature</strong></td>
<td>-50~80°C</td>
<td>0.1°C</td>
<td>±0.3°C</td>
</tr>
<tr>
<td><strong>Soil moisture</strong></td>
<td>0~100%RH</td>
<td>1%RH</td>
<td>±5% (in field)</td>
</tr>
<tr>
<td><strong>Evaporation</strong></td>
<td>0~100mm</td>
<td>0.1mm</td>
<td>±0.2mm (≤10mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±2% (&gt;10mm)</td>
</tr>
<tr>
<td><strong>Snow depth</strong></td>
<td>0~150cm</td>
<td>0.1cm</td>
<td>±1cm</td>
</tr>
<tr>
<td><strong>Cloud cover</strong></td>
<td>0~100%</td>
<td>1%</td>
<td>±5%</td>
</tr>
<tr>
<td><strong>Cloud height</strong></td>
<td>0~15km</td>
<td>10m</td>
<td>±10m (≤100m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±10% (&gt;100m)</td>
</tr>
<tr>
<td><strong>Visibility</strong></td>
<td>10m~35km</td>
<td>1m</td>
<td>±10% (10m~10km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±15% (10km~35km)</td>
</tr>
<tr>
<td><strong>Sunshine duration</strong></td>
<td>0~24h</td>
<td>1min</td>
<td>±0.1h</td>
</tr>
<tr>
<td><strong>Radiation</strong></td>
<td>0~2000W/m²</td>
<td>5W/m²</td>
<td>±5%</td>
</tr>
</tbody>
</table>

The characteristics of the product are:
(1) Data acquisition unit and sensor processing unit are intelligently packaged. Data acquisition unit and sensor processing unit fulfill automatic identification, automatic access and automatic inspection.
(2) The unity and security of data processing are further improved by using standard communication protocol stack technology and microelectronic chip technology to solidify standard communication protocol stack.
(3) Self-detection, self-diagnosis and self-calibration techniques are employed, increasing the monitoring function of intelligent data collector and intelligent sensor.
(4) Dedicated embedded operating system and data transmission protocol are used to achieve flexible networking.
(5) Low power consumption, high accuracy and high stability. Meteorological sensor network is effectively managed. The product adapts to extreme environment conditions, and is convenient to install and deploy.

5 CONCLUSIONS
Intelligent observation technology is likely to change the management mode and business layout of the automatic weather observation system operation. Qualitative leap could happen especially in the areas of automation, unattended, and metrological verification. These changes can significantly improve the effectiveness and accuracy of meteorological observations, and meanwhile dramatically reduce labor intensity. The study on new observational methods and new technology products are very important in the development of the fully automation of the surface meteorological observation.
Based on WSN, the surface comprehensive observation system has features of high reliability, low
power consumption, improved expansibility and controllable cost. With such a system, various observational data of surface meteorological elements could be obtained and stored in nearly real time. By integrating a large number of such observational systems, we could have a new technical solution for the construction of massive earth observation system. Thanks to its superior augmentability, the system has a strong potential for further development. Considering all of its advantages, we could well expect the system to create fruitful social and economic benefits and broad application prospects.

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