Current situation and development trend of intelligent instruments

Yuan Guo¹,², Chang Zhang¹,³, Xinyuan Chen¹,² and Cancan Yi¹,²

¹ The Key Laboratory of Metallurgical Equipment and Control Technology Ministry of Education, Wuhan University of Science and Technology, Wuhan 430081, China
² Hubei Key Laboratory of Mechanical Transmission and Manufacturing Engineering, Wuhan University of Science and Technology, Wuhan 430081, China
³ E-mail: 379494336@qq.com

Abstract. With the development of human’s cognition of the world, the rapid development of artificial intelligence in the current era of informatization will profoundly change the world and the social life of mankind. The new generation of intelligent instrument is a significant part of artificial intelligence and plays a very important role in building a scientific and powerful nation. The limitations of traditional instruments cannot satisfy the academic requirements. Human desires for the knowledge of the world promote the rapid development of intelligent instruments, and the growth of them will also promote the development of science and technology and intelligent manufacturing. This article will briefly introduce the structure of intelligent instruments, features, as well as discuss the theory and technology of their miniaturization, virtual reality, high performance, green intelligence and so on, and provide reference for the research and development of a new generation of intelligent instruments.

1. Brief introduction of intelligent instruments

With the continuous development of microelectronics technology, small-sized and highly integrated circuit chips such as single-chip microcomputer (SCM) have promoted the development of measurement technologies and produced intelligent instruments. Intelligent instruments can achieve "hardware’s softening" under the microprocessors’ operation, making the software replace many of the traditional "fixed function module + connection" hardware. They are widely used in aerospace, marine, military, medical, manufacturing, smart home life and other fields with their powerful processing capabilities, supplemented by artificial intelligence technology and internet big data.

1.1. The composition of intelligent instruments

1.1.1. Hardware. The hardware of the intelligent instrument mainly includes host circuit, analog conversion channel and external device interface [1]. The hardware composition of them was shown in figure 1.

The host circuit usually consists of a microprocessor, memory, input and output interface circuits, and etc. It mainly deals with data calculation, processing and storage, and also has certain functions to achieve control by the program.
The analog conversion channel is used to process the input and output analog signals, mainly composed of Analog-to-Digital (AD) converters, Digital-to-Analog (DA) converters and related analog signal processing circuits.

The external device interface usually consists of a power interface, a human-machine interaction interface, and a communication interface. The power interface is used for the power supply of instruments and specific circuits; the human-computer interaction interface is used to connect functional auxiliary devices such as keyboards, mice, and monitors to achieve more convenient human-machine interaction; and the communication interface is used to connect instruments and computers to realize the function of computer-controlled instruments.

![Intelligent instrument hardware diagram](image)

**Figure 1.** Intelligent instrument hardware diagram.

1.1.2. Software. The software of the intelligent instrument is composed of three major parts: monitoring control program, interface transmission program and data processing program [1].

The monitoring control program is mainly responsible for storing or recording replacement parameters, monitoring the operation status of the instrument, controlling the switching program, and displaying the processing results.

The interface transmission program is used to connect and identify external devices, receive keyboard input signals or computer control signals, and transmit the resulting signals to a display or a computer.

The data processing program mainly processes and organizes data, including mathematical calculations and logic operations such as filtering and integration, and management functions such as big data storage, analysis, and retrieval.

1.2. The working principle of intelligent instrument

The working principle of the intelligent instrument is as follows: The sensor is used to convert the measurement into an electrical signal, and filter the interference generated during the sampling measurement, and then send it to the analog switch. Under the influence of the SCM selecting, the gated electrical signal is processed by the amplifier and the AD converter, and then enters the microprocessor as well as performs the set operation processing. At length it is converted into corresponding data for transmission, display and printing. In addition, the SCM can store these data on the flash read only memory (FLASH ROM) or electrically erasable programmable read only memory (EEPROM); and it can also convert and output the corresponding control signals according to the relay contact or alarm triggering requirements to achieve intelligent control. What is more, the intelligent instrument can be used as an external function device of the personal computer (PC) to collect and initially
process various measurement signals and data, and then transmit it to the PC through the communication interface according to the protocol. In this way, the PC can integrate multiple data for subsequent analysis and unified management [2, 3].

1.3. Intelligent instrument development status at home and abroad

Intelligent instruments appeared in the 1970s is a product of the integration of microelectronics technology with modern test technology requirements. Since the test instrument contains a microcomputer or a microprocessor, the instrument has the characteristics of calculation, analysis, logic judgment, and automatic operation control in terms of functions. Obviously, it has an intelligent function to replace people's operations to some extent, and thus it is named as "intelligent instrument". After the end of the 20th century, their changes are mainly manifested in the following aspects: The increase in the level of manufacturing and the advancements in microelectronics technology have changed the design patterns of intelligent instruments to a large extent, making them in the direction of miniaturization. Since the advent of digital signal processing (DSP) chips, the data processing capabilities of instruments have become more efficient and diversified. Image processing technologies have gradually integrated into them to diversify their expressions. VXI bus [4, 5] and Profibus-DP field bus [6] are used widely: data transmission is simpler and more reliable.

1.3.1. Foreign development status. Scientific instruments have received great attention in innovative countries and have given them human, material and financial support. Europe, the United States, Japan, and other countries will develop state-of-the-art scientific instruments as national strategies, which shows the importance of scientific instruments for scientific research. In foreign countries, intelligent instruments are gradually moving toward the direction of artificial intelligence, enabling them to have expert systems, and to realize the instrument's autonomous control of inference, analysis, decision-making and optimization. At present, due to the requirements, applications, and influences of them in different disciplines and fields, they not only incorporate computer technology, but also high technologies such as nanotechnology, micro-electromechanical systems (MEMS), bionics, and intelligent algorithms are gradually being incorporated into scientific instruments. At the same time, some high-precision military technologies have begun to open up to civilian technologies. This move has greatly improved their technology and quality. The rapid development of them also benefits from the melioration of instruments and the frequent replacement of new generations of instruments. It is often a period of 3 to 5 years for a generation of instruments, and less than a year for short ones.

1.3.2. Domestic development status. The development of intelligent instruments started late in China, but the development was extremely rapid, breaking the situation where many intelligent instrument products were monopolized by foreign countries, and China's related factories gradually became an instrument exporter. However, compared with developed countries, there are still some problems and deficiencies in China's intelligent instruments. First of all, China's capacity for independent research measurement chips is insufficient. Some core chips need to be imported from abroad. There is a lack of innovation with independent intellectual property rights, and chips, as key technologies of intelligent instruments, have become a stumbling block to their development in China. Secondly, most Chinese enterprises put too much emphasis on the research and development of new products. There are few researches on production process technologies, and neglecting the upgrading of hardware equipment [7], which makes the quality of material processing in our country slightly less than that of foreign countries, and it largely affects their life and ability to withstand harsh environments [8]. There is still much room for improvement in domestic intelligent instruments. This requires manufacturers to strengthen the investment of capital and technology and the innovation, and focus on material quality, chip core technology, and production line technology research to develop instruments with independent intellectual property rights to enhance competition [9].
2. The advantages of intelligent instrument

Traditional instruments include manually operated observation measurement tools such as microscopes, balances, vernier calipers, and electronic instruments that use simple electronic circuits to convert measurement data, such as electronic scales, multimeters, and electronic thermometers. These instruments have such features: Through intuitive data display, records are read by human, data storage and subsequent processing cannot be performed directly, and manual calculations, comparisons, and analysis are required to obtain the measurement results or conclusions. However, due to their limited accuracy, they are often used in occasions where the measurement accuracy is not too high, and their cost is relatively low, and there is still a place in the existing market. Compared to them, intelligent instruments contain microcomputers or microprocessors, and therefore they have the following advantages.

2.1. Convenient operation

The whole system of intelligent instruments is controlled by a microprocessor to perform a series of operations, thus making the operation of the instrument more convenient. On the one hand, they implement certain measurement functions by means of function buttons or key-in instructions. During operation, they can automatically perform switch control, range selection, and data acquisition, which avoid the need to switch switches by human in traditional instruments, and require no manual intervention to automate the process. This can greatly improve efficiency and safety. On the other hand, they display the operation status or fault location of the instrument and data results through the display screen to facilitate the use of the operator. In addition to the rapid development of touch screen technology, buttons, keyboards, and displays can be integrated, which makes human-computer interaction features more friendly and intelligent and the operating methods more convenient.

2.2. Fast measurement

The measurement speed refers to the length of time it takes for the instrument to start from measurement acquisition, through processes of signal amplification, rectification, data processing, analysis, and output of results [1] The faster the measuring speed, the shorter the time is required. And the more measurement data can be collected in the same working time, which makes the efficiency more high. This is also the basis for real-time monitoring, otherwise, the timeliness of results is poor to a certain extent. And high-speed measurement has always been one of the goals pursued by the measurement system. At present, the PC's CPU frequency can reach 3.7 GHz, and AD converters have been developed to ultra-high speed. These components are conducive to intelligent instruments to achieve high-speed acquisition, high-speed storage, high-speed reading and high-speed processing. In addition, in the current era of big data, some devices are moving toward high-speed goals, such as high-speed communications, graphics, and printing [1]. All of these hardware foundations provide favorable conditions for high-speed detection of them.

2.3. High measurement accuracy

The accuracy of the instrument is getting higher and higher due to the progress of science and technology. Accuracy is one of the major factors affecting the accuracy of the instrument, and it is called “a miss is as good as a mile.” At present, fields such as communications, navigation and positioning, metrology, and physical law verification have extremely high requirements for time accuracy. Taking satellite navigation and positioning as an example, the computer calculates the pseudo-range (time × speed of light) to determine the position by collecting the synchronization error between the satellite and each receiver clock. Therefore, the higher the precision of the time is, the higher the accuracy of the spatial position is. China's Beidou III satellite adopts a new generation of rubidium atomic clock, its stability reaches E-14 magnitude, which makes the positioning accuracy of Beidou III from the original 10 meters reach the level of 2.5 to 5 meters. At present, the ultra-high accuracy is only achieved in frontier fields such as scientific research and aerospace. Accuracy in actual production and application is not so high, and it is still far from the requirements of intelligent
precision manufacturing. Intelligent precision manufacturing also requires equipment upgrades and integration with intelligent instruments to do real-time monitoring [10], and feedback processing.

2.4. Multifunction
Multifunction is a feature of intelligent instruments. In practical projects, it is often necessary to monitor a variety of data, but adding too many measuring instruments may have a certain impact on the system. Therefore, multifunctional intelligent instruments will reduce this effect and improve accuracy. At the same time, their multifunction makes data centralized and facilitates uniform processing. Secondly, their multifunction has solved problems in a variety of ways and analysed problems from multiple perspectives, thereby solving problems accurately and thoroughly. For example: Samsung Composite Bio-Signal Processor can monitor five kinds of biological signals, including heart rate changes, body composition, mood changes, respiratory abnormalities, body surface temperature and so on. The health status is accurately understood through the composite of these five signals. At present, with the improvement of living conditions, people begin to pay attention to health: more and more people are enthusiastic about sports. Intelligent equipment with different functions is used to understand the sports status and health indicators in more detail.

3. Technical features of intelligent instruments
Intelligent instruments work with microprocessors as the core. With the corresponding programs, they can implement some automated specific functions.

3.1. Self-check function
Self-check is mainly to run the inspection program. The operation of each component is known, and the type and location of the fault can be determined through the inspection process and results, which makes the maintenance staff greatly convenient and improves the inspection efficiency [11].

In general, the inspection program will perform a series of functional checks on ROM, RAM, bus, display, keyboard, operating circuits and so on. The more items detect, the more convenient the maintenance of the instrument is, but the more corresponding hardware modules need and the more complicated the software program is.

3.2. Automatic measurement function
Intelligent instruments usually include functions such as automatic measurement range conversion, automatic zero correction of the instrument, automatic zero-point calibration, and automatic trigger level adjustment, which eliminates manual adjustment and improves the test accuracy.

3.2.1. Automatic range conversion. They can automatically adjust the range of the instrument in a short time according to the measurement data under the control of the program, thereby improving the accuracy of the measurement. The block diagram of the automatic range conversion is roughly shown in figure 2: During measuring, the system will quickly determine from the maximum range and narrow range gradually until the optimal range is selected for the measurement.

3.2.2. Automatic zero correction. As a measuring instrument, the components and circuits of them are affected by other unstable factors, and there is a temperature drift and time drift, which cause the measurement a zero drift error. They are automatically controlled by the microprocessor to offset the zero offset by a correction amount, which effectively reduces the effect of zero drift on the measurement results [12].

3.2.3. Automatic zero calibration. Regular calibration is an important part of ensuring the accuracy of the instrument. At present, they use automatic calibration systems for self-calibration. The auto-calibration system consists of a controller, calibration source, and calibrated instruments that form an automated test system via the GP-IB bus.
3.2.4. Automatic trigger level adjustment. It is important to set the trigger level of instruments such as oscilloscopes and counters. In the past, it was difficult to quickly and accurately find the ideal trigger point. However, with the help of a microprocessor and hardware support, this function can be well implemented. The principle of regulation is shown in figure 3.

![Figure 2. Automatic range conversion block diagram.](image1)

![Figure 3. Automatic trigger level adjustment schematic.](image2)

4. Development trend of intelligent instrument

4.1. Miniaturization
With the demands of function on intelligent instrument, people also put forward requirements for their volume. Considering that the instrument volume may affect the measurement, miniaturization will become the future trend of them, and at the same time, they will ensure simple operation. Their whole development trend can be expressed as: laboratory instrument → movable instrument → portable instrument → handheld instrument → lab-on-a-chip [13]. Miniaturization, personalization, and simplification of operations will make the application of scientific instruments more universal and popular. The direction of miniaturization mainly depends on the discovery and production of materials and new components. It is like that the computer has evolved from the large computer equipment which originally occupies several rooms to the current personal computer. By finding new materials and manufacturing new components to solve the problems of processing speed and heat dissipation after the integrated processor is miniaturized, the miniaturization of intelligent instruments will also be easier. Miniaturization will also benefit military aviation, biotechnology, medical devices and other applications. With the improvement of the technological level, micro-intelligent instrument technology will also gradually mature.

4.2. Wireless
The trend of integrating wireless technologies into intelligent instruments is unquestionable, especially where cable cannot be used. However, to make them use wireless technologies, this must require the improvement of the reliability of connections, the determinacy and real-time nature of communications, and the compatibility of wireless technologies. Secondly, software programs are also required to screen and interpret a large number of wireless signals and make effective real-time responses [14]. Taking a wearable device as an example, the device cannot execute commands as normal devices to type through the keyboard, but instructions can be sent through the brainwaves. How to connect brainwave signals and equipment, using a helmet to take a wired approach can achieve this goal, but this approach is not beautiful and convenient, which may affect the user's
psychology to a certain extent. At this point, wireless technology can solve this problem very well. With the ever-increasing micro-technology, we will be able to implant a chip instrument under the skin of the brain to read the brain wave signal, and the chip and the wearable device will transmit signals through a specific wireless transmission protocol to achieve wearable device controls. However, wireless does not completely replace wired communications. Because the cable is stable, reliable and safe. Only the combination of wired and wireless can improve the function of intelligent instruments.

4.3. Embedded modular
The Institute of Electrical and Electronics Engineers (IEEE) defines an embedded system as "devices used to control, monitor or assist the operation of equipment, machinery or plants". Domestically, it has specific interpretations: The embedded system is based on computer technology and is developed for product applications. It has a tailorabile hardware and software configuration and is suitable for computer systems with requirements of building modules independently, achieving specific functions, reliability, functions, and scale. The role played by intelligent instruments is very much in line with the definition of embedded systems. In the future, a new generation of intelligent instruments will be developed towards embedded modularity, and each function will be organized and packaged into individual modules. Each module can work independently, even if a single module fails, it will not affect the entire system [15]. In this way, intelligent instruments can use a unified interface to combine component modules with different functions, and decompose a complex practical application problem into several small problems with strong independence, small influence, and interaction. Then the application of each function is solidified in ROM to use the embedded technology [16], so that they will have better hardware adaptability.

4.4. Virtual Labs and network instruments
The concept of Virtual Lab (V-Lab) is to digitalize and virtualize some teaching and basic experiments, exploit a simulation environment of teaching experiment with Virtual Reality (VR) technology, and use Web technology to build an open, interoperable, shared virtual teaching-experimental platform. For many expensive scientific instruments cannot be fully configured, but based on virtual teaching-experimental platform, limited resources can be integrated, so that both researchers and college students can conduct research and learning through V-Lab. It can be seen that building a virtual laboratory has a very broad development prospect and application market. To achieve this goal, we need to fully improve basic theories - virtual instruments and the Internet, as well as key technologies - virtual reality technology and network software.

The virtual instrument is that the input and output of the signal is based on the computer hardware platform and the rest is completed by computer software. For the same hardware platform, different software can be used to accomplish different functions. Through the development of the hydraulic valve performance testing system software, it is found that for the same hydraulic system, the change of test valve and the modification test program can achieve different performance tests. The V-Lab can integrate teaching experiments with similar functional structures to build a huge hardware and software system. When a particular experiment is carried out, according to the relevant software, the system activates the corresponding hardware and circuit like the switch to complete the experiment.

At present, the instruments are networked with embedded micro internet technology (EMIT) and wireless sensor network technology [17, 18]. EMIT is to embed the Internet function module into the instrument and equipment, and realize the functions of on-site collection of remote transmission cloud processing, remote intelligent control, and upload/download of data files. Wireless sensor network technology uses multiple sensors as transmission nodes to form a multi-hop self-organizing network system with a wide range of monitoring coverage. Plug-and-play features can easily change the position and quantity of the instrument. The wireless personal area network (WPAN) technology is becoming more and more sophisticated, and future networked intelligent instruments will be widely
used in home automation, industrial automation, building control, intelligent metering and research and development of large-scale, complex and high-precision equipment [16].

4.5. Intelligentization
With the proposal, realization and development of "Industry 4.0", intelligent instruments will play an indispensable role. "Industry 4.0" will develop in the direction of "Intelligent Factory" and "Intelligent Manufacturing." Intelligent instruments for wireless network transmission will be an important tool for implementing "Intelligent Factory" to realize intelligent perception and measurement. Then, artificial intelligence technology will gradually be integrated into intelligent instruments to achieve high-speed, high-efficiency, multi-functional performance through neural networks, chaos control, evolutionary computing and other intelligent technologies. And expert control system (ECS) will become the focus of the "Intelligent Factory" related technology [19]. Compared with traditional manufacturing, "Intelligent Manufacturing" has the functions of self-discipline, learning ability, self-maintenance, and human-machine integration, and intelligent features such as process analysis, fault determination, and production decisions will be put into the manufacturing process to increase manufacturing efficiency and quality [20]. "Intelligent Manufacturing" needs to improve hardware, optimize software, and establish production consulting systems, which requires intelligent development of the instrument. Its development requires the support of big data intelligence theory, hybrid enhanced intelligence theory, swarm intelligence theory, and brain-like intelligence technology theory, and combination with robotics and digital manufacturing technologies to realize the goal of intelligent production and precision manufacturing, and move toward a new era of manufacturing.

4.6. Greenization
At the same time as technological development, we must also pay attention to the environment, look at technology in a long-term perspective, and develop science and technology on the premise of not destroying the ecology and protecting the environment. At present, China’s socio-economic development is undergoing full-scale transformations. Among them, one of the important transformation goals is “greenization”. Green science and technology require that we not only consider the enormous contribution that technology brings to human life, but also pay more attention to the ecological impact of technology, such as environmental pollution and ecological degradation. With a long-term perspective, we will grasp the direction of science and technology, take the green concept as the guidance, and promote the positive energy of green development.

First of all, as a product, research and development of intelligent instruments must take into account the noise, gas, energy, recyclable materials and other factors, so as to ensure energy conservation and environmental protection. And also it takes into account whether electromagnetic radiation will affect people's health to ensure the safety of users. Secondly, they will become a tool for closed-loop control to achieve precise monitoring of pollutants. Contaminants are not simply treated. It depends on whether the effect of the treatment meets the standards, which requires the detection of the instrument and control system to achieve green emission treatment [21, 22].

In addition to solving pollution, waste, and reducing energy consumption, green manufacturing can also be implemented in paperless production. We can adopt paperless management, use paperboard-type intelligent instruments and write on board to record, and then the instrument will record the relevant information by the two-dimensional code or bar code technology to save, upload to intelligent management platform. Paperless management drastically reduces artificial circulation caused by paper documents and production processes, thereby reducing paper waste, eliminating file and data loss, and facilitating centralized sharing and real-time tracking.

For discrete manufacturing enterprises, tablet computers will help to achieve paperless production. With the development of flat panel technology and ultra-thin technology, intelligent instruments will be most likely to be flat device and equipped in every process. According to the characteristics of each process, they can have own special functions. Plate instruments don’t require complex functions such as process card, material list, quality document and so on and it is possible to edit and transmit files.
For other parts like blueprints as well as 3D models, they need other functions such as hand drawing, modeling, and so on. For pipelined manufacturing enterprises, delivery information acquisition device (DIAD) can be used like logistics industry. The products are coded in production. And intelligent instruments embedded in the equipment are identified when each process is completed, and record the operating conditions of the equipment and the quality of the products. All the intelligent instruments accomplish the centralized production of information under the connection of factory LAN and realize paperless production.

5. Conclusions
In summary, intelligent instruments combine computer technology and instrument measurement technology, and use microprocessors to implement a series of functions such as complicated data processing, self-checking, automatic measurement, and program control, which are convenient for people's operation and use. And they will be widely used in military aerospace, industrial manufacturing, biomedical fields and so on. Countries have placed their development in an important position, leading the intelligent era through artificial intelligence. With the improvement of technology, they can be realized in miniaturization, wireless, modularization, and networking, which can be used in home appliances to build an intelligent home network system, and applied to teaching with VR technology to realize visualized teaching and experiments of physics and mathematics. Secondly, the intelligent development of the instrument will also promote the realization of the "Industry 4.0" goal by using the Internet of Things technology to upgrade the plant and intelligent instruments to monitor the manufacturing process, through the expert control system for analysis and decision-making, to achieve precision product manufacturing, information processing, intelligent production facilities, and green manufacturing technics. There is still much room for the development and application of them. We need to dig into it to form a new generation of artificial intelligence instrument theory and technology system, which will lead to breakthroughs in the development of brain-intelligent instruments, autonomous intelligent instruments, and hybrid intelligent instruments. It is beneficial for our country to speed up entering the ranks of the industrial powers.

References
[1] Jiang YZ 2007 Summary of Intelligent Instruments and Their Development Prospects Mechanical Engineer 2007(8):79-81
[2] Yang LQ and Ma Z 2013 Functional Theory and Development Trend of Intelligent Instruments Technology Innovation and Application 2013(28): 84-84
[3] Liu JQ 2014 Intelligent Instrumentation and Its Development Trend Science and Technology Innovation Herald 2014(16):217-217
[4] Tan WB and Zhao W 2012 On the New Definition of Intelligent Instrument Electrical Measurement & Instrumentation 49(5):1-5
[5] Li T and Yu ZX 2015 Virtual Instrument Technology Review and Development Chinese Society of Astronautics 2015
[6] Xia LL, Qiu C, Fu ZL and Pan XY 2012 A novel design of Profibus-DP communication interface card for the intelligent instruments of field network IEEE International Conference on Automation & Logistics 382-385
[7] Shi ZS 2012 Intelligent Manufacturing: Challenges and Opportunities for Instrumentation Industry China Instrumentation 2012(s1):25-27
[8] Chen G 2017 Intelligent Instrumentation Technology Prospects and Applications Electronic test 2017(14)
[9] Zhu WL 2012 Development Status and Trend of Intelligent Instruments in China Heilongjiang Science and Technology Information 1(2):70-75
[10] Ma LB 2008 Real-time Monitoring System Based on Kingview and VB for Intelligent Instruments Process Automation Instrumentation 2008
[11] Li Z, Shi M and Qi ZT 2008 Laboratory intelligent instrumentation and control system
maintenance of new ideas and methods Modern Instruments 14(4): 63-65

[12] Xue W 2013 Application of Computer in Intelligent Instruments and Meters Urban Construction Theory Research 2(26):45-47

[13] Lin J 2002 Modern Scientific Instruments and Their Development Trends Journal of Jilin University (Information Science Edition) 20(1):1-7

[14] Li K 2013 Application of Intelligent Instruments in Wireless Communication Test and Measurement Practical Electronics 2013(14):130-130

[15] Clark DL 2009 Powering intelligent instruments with Lua scripting Autotestcon 101-106

[16] Antony J, Mathuria DS, Chaudhary A, Datta TS and Maity T 2017 Design details of Intelligent Instruments for PLC-free Cryogenic measurements, control and data acquisition Materials Science & Engineering Conference Series 171

[17] Cámara L, Ruiz O, Herms A, Samitier J and Bosch J 2004 Automatic generation of intelligent instruments for IEEE 1451 Measurement 35 (1):3-9

[18] Sveda M and Vrba R 2003 Integrated smart sensor networking framework for sensor-based appliances IEEE Sensors Journal 3(5):579-586

[19] Xiao JL 2014 Application and Development of Intelligent Automation Instrumentation in Industry China Petroleum and Chemical Standard and Quality 34(8):232-232

[20] Knuth KH, Erner PM and Frasso S 2007 Designing Intelligent Instruments. AIP Conference proceedings 954, 203(2007)

[21] Ding W 2013 Promote the simultaneous development of energy conservation and emission reduction and instrumentation technology with a new cognitive framework China Instrumentation 2013(2):23-25

[22] Tai H, Ding Q, Li D and Wei Y 2017 Design of an Intelligent PH Sensor for Aquaculture Industry Ifip Advances in Information & Communication Technology 347: 642-649