Research on Evaluation Factors of Intelligent Level of Dam Safety Monitoring System

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Abstract. With the continuous improvement of intelligence level, intelligent evaluation of a safety monitoring system has become the key to system evaluation. In order to improve the pertinence of evaluation, according to the application environment and demand of dam safety monitoring, this paper makes an in-depth study on the evaluation factors of the intelligent level of dam safety monitoring system from the system occurrence environment, system composition, network communications, system function and performance, channel protection and power control, remote maintenance, system parameters, running log, statistical analysis, rule discovery, hidden trouble diagnosis, maintenance advice, method and expert recommendation algorithm, intelligent query and human-computer interaction, etc., providing a beneficial reference for the evaluation of improving the intelligent level of dam safety monitoring system.

Keywords: Dam safety; Automatic monitoring system; Intelligent level; Factors; Evaluation.

1. Introduction

The automation system of water engineering safety monitoring represented by the dam safety monitoring system is a key link to obtain dam safety information. Its reliability and effectiveness are directly related to the accuracy and effectiveness of the acquisition of engineering safety information. Without effective information, no matter how good the data analysis method is or how high-level the expert system is, it is difficult to play its role. Therefore, the comprehensive evaluation method and application research on the effectiveness of the dam monitoring system is the key to give full play to the role of the dam monitoring system.

The comprehensive evaluation of the dam monitoring system has been studied by Wuhan University, Nanjing Hydraulic Research Institute and Nan Rui Group Co.ltd.. Wuhan University[1] adopts analytic hierarchy process (ahp) to analyze and study the monitoring system, and gives the comprehensive index of multi-factor evaluation, but it does not link the dam monitoring system with the acquisition of specific dam information. The evaluation of the dam safety monitoring system by Nan Rui Group Co.ltd. is mainly from the perspective of management and equipment and facility maintenance, which does not rise to the height of information acquisition. The ministry of water resources of China has recently issued the "technical specification for appraisal of dam safety monitoring system (SL 766-2018)" [2], which evaluates whether the monitoring facilities can meet the requirements of dam safety monitoring mainly through on-site inspection and data verification, considering the engineering characteristics and actual needs, and based on the reliability and
completeness evaluation of monitoring facilities. Recently, Switzerland has proposed a series of new approaches from another perspective, mainly focusing on preventing the risk of possible accidents in the whole life cycle of the dam, finding the weaknesses and deficiencies in all aspects of the activities in the three stages (L1: Daily, weekly or monthly audit of completed inspection and monitoring shall be completed by field operators; L2: Review completed by field operators shall be supervised weekly or monthly or the evaluation of the dam performance shall be conducted every one to two years by high speciality technology person; L3: Conduct high dam safety assessment every 5 to 10 years (low dam depends on need), including comprehensive inspection of the dam and foundation, dam performance evaluation and failure mode analysis, design and construction review, etc. If necessary, check the stability, discharge capacity, seismic safety, etc.)of dam monitoring, strengthening personnel training and capacity building, improving the level of organization and management, and strengthening the three lines of defense[3].

With the application of intelligent sensor, self-organizing network and intelligent algorithm, dam safety monitoring system is gradually becoming intelligent. The intelligent system carries on the information transmission through the wireless terminal equipment and the Internet to realize the intelligent information identification, positioning, tracking, monitoring, calculation, management, simulation, prediction and management. Through the combination of Internet of things, wireless broadband, cloud computing and other emerging technologies and engineering security information management system, the intelligent system can improve dam security information from thorough perception to the depth of the application.

The evaluation of dam safety monitoring system is based on the general automation system in the related specifications of dam safety monitoring[4-9] and the existing research, while the evaluation of the intelligence level of automatic monitoring system is rarely involved. In fact, comprehensive evaluation methods, such as fuzzy comprehensive evaluation, analytic hierarchy process, set pair analysis and other mathematical methods, have been studied thoroughly. The key is that the intelligent factors of the automatic monitoring system for dam safety have not been deeply studied. Therefore, based on the intelligence level of the existing automation system, this paper carries out systematic research from the aspects of the occurrence environment of the monitoring system, the composition of the monitoring system and its functional performance index, system operation and maintenance, data statistical analysis and so on, so as to provide a reference for the intelligent evaluation of the automatic monitoring system.

2. Intelligence Level Evaluation Factors

The monitoring system is generally analyzed by the sensor layer, the local station layer and the rear calculation and analysis of the man-machine interface layer. The equipment includes the replaceable part and the non-replaceable part. In order to effectively improve the overall intelligence level of the safety automatic monitoring system, automatically give the possible fault types of the system and analyze the cause of fault and set up fault database to facilitate retrieval, statistical analysis and knowledge mining, firstly, the automatic monitoring system is required to monitor the status of the occurrence environment and the data acquisition equipment, so as to realize the preposition of intelligent discrimination of automatic failure of the automation system itself; Strengthen the data acquisition module to the sensor data it collected intelligent discrimination and targeted response; Further, the software is applied to automatically conduct convenient and intelligent query and retrieval, intelligent report, hierarchical and effective prompt alarm, statistical analysis and rule mining of monitoring data.

2.1. Thorough perception and preventive measures

2.1.1. Occurrence environment

According to the system composition, since the sensor layer environment is not suitable or can not be changed, the occurrence Environment mainly refers to the local station and the rear human-machine interface layer. The actual operating environment of the installation point of the local station and the rear human-machine interface is very important for the long-term stability of the station or the normal operation of the equipment such as computer and data security. In order to avoid the failure of automatic monitoring system, when the relevant indicators do not meet the requirements of safe
operation or there is a big risk, it should be able to intelligent self-start warning and self-protection functions, to avoid causing greater system failure and harm. Therefore, the realization of the operation environment monitoring is the premise of the system intelligence level, the main evaluation factors include the following aspects:

a) Operating environment temperature, humidity and electromagnetic environment
For different equipment of the safety monitoring system, the corresponding physical quantities, such as temperature, humidity and electromagnetic environment, are perceived according to the corresponding operating environment. For dam safety monitoring systems, due to the large number of supplementary angles in field and corridor measurement points, the author found in the research that some corridor equipment has the situation that water drops drop directly on the vertical coordinate instrument. Therefore, corresponding sensing methods should be provided for conditions such as exposure to the sun, rain, and soaking in water to avoid aging, short circuit and other things that affect the normal operation of the system.

b) Fire prevention, guard against theft, preventing the moving and other man-made damage
The measures of setting up smoke alarm, intrusion video and distributed optical fiber vibration detection are adopted to ensure the security of communication lines and other equipment and data. Many water engineering equipment need to be installed in the open environment such as the field, and the activities of the surrounding personnel are complicated. In order to prevent human damage, door magnetic equipment can be set on the door of the protection box to monitor the opening and closing state of the door to ensure that it is in the closed state. According to a higher degree of security needs, the object position monitoring equipment can be further installed, the corresponding positioning module is embedded, and its own position information is periodically read or reported, and it is monitored whether the relevant is moved or damaged due to artificial or support deformation.

c) Station access monitoring and auxiliary lighting control
When the location of the relevant DAU (Data acquisition node equipment) station is not illuminated or is in a dark environment for a long time, the lighting control subsystem based on the light intensity and the opening and closing state of entrance guard of the box can be designed in the box body, and the built-in auxiliary lighting device can be automatically opened to facilitate the operation and maintenance of the equipment by the operation manager.

d) Power supply system of the station
The communication, power supply, data acquisition equipment and other equipment of the automatic system all require electricity. If the system works for a long time under high temperature and other environments, serious abnormalities may occur, such as cable aging, failure of electronic components, which may lead to equipment failure, power short circuit and even fire. Therefore, in important monitoring stations, it should carry on current, temperature, fume monitoring, and can alarm in real time.

e) Station vibration and acceleration monitoring
Vibration monitoring sensors can be installed in the dam safety monitoring system in earthquake-prone areas. When a large acceleration vibration occurs that is distinct from the normal vibration, the monitoring device reports the acceleration value to the central data acquisition computer and starts the relevant emergency mechanism intelligently, such as actively encrypting location DAU measurement frequency, continuously reading acceleration value of vibration sensor, reading the current DAU battery voltage, continuously monitoring whether the wired and wireless communication links are unblocked, etc. The backup of all real-time measurement data is stored in the measurement unit Flash, and the memory power is cut off in time to avoid misoperation and facilitate post-earthquake analysis.

2.1.2. System structure and functions
f) Data acquisition node equipment (DAU)
Real-time monitoring of electronic equipment for dam safety monitoring data acquisition can effectively evaluate the intelligence level of the system. The evaluation factors mainly include the following points:
i) Monitoring of current consumption
Monitoring the standby and measurement current of the DAU data acquisition module is helpful to find out whether the standby current of the acquisition module itself is too large due to the damage of components, whether the instrument damage leads to the abnormal measurement current, and whether it is possible to damage the common measurement circuit chip.

ii) Monitoring of battery power
Monitoring the battery can effectively assess the health of the battery itself and whether the charging circuit is working properly; In case of insufficient sunshine due to long periods of rain or power failure in a long period of time, we can judge the supportable duty hours according to the battery information and make power supply planning in advance and prepare spare batteries and other equipment, so as to avoid the situation that power failure cannot continue to work during flood season or when monitoring data is needed.

iii) Moisture proof and waterproofing
The protection box of data acquisition node equipment is designed according to waterproof and sealing requirements. When the sensor cable is connected from the wire hole, due to field conditions, it is often impossible to seal well. Changes in the temperature and humidity of the field application environment will lead to changes in the environment inside the protection box. When the temperature and humidity are high, water vapor condenses on the circuit board. When the temperature is below 0℃, the surface may freeze. Due to the highly integrated electronic chip pin spacing is very small, under the combined effect of external dust and humidity, it is easy to induce a short circuit between pins, leading to various unpredictable abnormal reset, restart, power off and other phenomena. In order to avoid the above failure as far as possible, on the one hand three anti-measures of Circuit board should be strengthened. High performance silicone sealing ring is adopted to strengthen the sealing treatment of box inlet. On the other hand, temperature and humidity sensors can be used to monitor the small environmental parameters in the DAU box. If the internal environment temperature is lower than the operating requirements of the equipment, the heating device can be started automatically; If the humidity inside the DAU is too high, the dehumidifier fan can be opened automatically, and the dehumidifier can be closed when the humidity inside the cabinet returns to normal. These measures can effectively improve the operating environment of the equipment, avoid the unrecoverable damage of data acquisition module components, and improve the environmental adaptive ability of the automation system.

In case of emergency, the DAU box installed in special parts may be flooded due to local water level rise. Therefore, on the one hand, the relevant boxes must have a certain level of waterproof, on the other hand, these sensitive DAU boxes can be added to the water sensor monitoring equipment. When the box is submerged and there are water accumulated, seepage and other conditions in the box, the remote alarm will be given at first time and operation and maintenance staffs can deal with it at the first time to prevent the electronic equipment inside the box from flooding and scrapping.

iv) Judgment and detection of dead halt
The detection of whether the DAU data acquisition module is dead can be combined with the relevant standby current and the period of watchdog signal. The specific analysis is as follows: When the standby current is abnormal for a long time, it may be that the relevant task is not finished and the machine freezes, resulting in the relevant chip being always energized; The absence of the watchdog pulse signal may be caused by the level clamp of the watchdog signal pin due to the crash, which causes the watchdog chip to fail; If the watchdog signal is normal but the current is too high, the program may be in a dead loop. Although feeding-dog still occurs, The program may go into a nested loop containing a feeding-dog program, at which point the data acquisition module should be powered off and repowered. At present, most of the DAU in use can only be restored by operation and maintenance staffs to the site to shut off the power and restart the DAU. As the data acquisition equipment is widely distributed and in large quantity, it is inefficient for personnel to operate on site in person. Therefore, combined with wide-area public network and short-distance local area wireless communication technology, the DAU remote power monitoring module based on mobile public network, wi-fi or LoRa technology was designed in the system to achieve APP remote control of DAU power on and off. In the thunderstorm weather operation and maintenance staffs can manually
interrupt the communication line and the power supply of the test station to avoid the equipment being damaged by inductive lightning.

g) Acquisition module

i) Multi-functional universal design

The acquisition module can collect different types of physical signals from a variety of sensors, such as sine wave, square wave frequency, voltage, current, switch signal and digital signal, etc. There are many kinds of monitoring sensors used in dam safety monitoring industry. In previous applications, a type of sensor needed to be matched with a type of measurement circuit board for data reading, which was very wasteful and inconvenient to maintain. Often, a special instrument was configured with a data acquisition module, which would idle and waste the rest of the channel in the module. After the generalization, a measurement module can be used to read multiple instruments at the same time, and each measurement channel can measure a variety of different types of instruments, realizing intelligent access and intensive utilization of resources. In specific circuit design, independent analytical processing circuits can be designed at the back end of the common channel for different physical quantity measurement, and different relay switching modes can be designed for different instrument types, so as to achieve the goal that different types of sensors can be measured.

ii) Intelligent power control

The module is controlled to be powered on when it is used and power off the module when it is not needed. The core microprocessor should plan to enable the relevant interrupts during low-power standby and can intelligently reduce the main frequency or switch to a low-frequency crystal oscillation to reduce power consumption, and wake up and enter the working state after receiving the relevant interrupt signals. On the premise of satisfying the relevant performance index, the design of each circuit function module should adopt low power consumption chip as far as possible to save the use of electric energy to the maximum extent.

iii) Channels and protection of instrument against lightning and damage intelligent detection

For the instrument connected to each channel of the data acquisition module, before the signal of the instrument enters the processing circuit, it should first go through series or parallel lightning protection and surge protection circuit, and the on-off of the channel can be detected intelligently on a regular basis. Relevant sensors connected to each channel can judge the quality of the instrument, judge the hardware damage of the channel and whether each sensor is normal or not by measuring the range of resistance and power supply current, and can report to the computer for recording and prompt the operation and maintenance staffs to deal with it in time.

iv) The internal program adds intelligent judgment and processing of the measured value of relevant sensor

According to each instrument type, range and output signal, relevant threshold values are set to automatically judge the measured values. It is necessary to make additional measurements in time when the over-limit and abnormal measured values are found. Repeatedly measuring and analyzing the measured value range and determining the true value can effectively eliminate the occasional sudden jump of measured value caused by power supply, static electricity interference, lack of preheating and pre-excitation. For some instruments, precise measurement can be carried out by continuously reducing the excitation range, or by averaging after performing A/D conversion digital filtering multiple times. For example, the frequency range of a vibrating wire instrument is generally $400\sim6000\text{Hz}$, and the temperature range is $-20\sim60^\circ\text{C}$. In many cases, if a wide range full-frequency excitation is used, the frequency measurement may have a few Hz jump. If the initial installation uses $400\sim6000\text{Hz}$ full-frequency excitation, and then continue to use the reduced frequency measurement based on the approximate frequency range obtained, such as $400\sim1000$, $1000\sim3000$, $2000\sim6000\text{Hz}$, etc., more stable and more accurate frequency measurements can be obtained. At the same time, the data acquisition module can record the actual excitation frequency band required by each instrument, which is convenient for subsequent excitation measurement to obtain higher quality data.

v) Communication circuit module working mode control

When the data acquisition module in the DAU reports data using wireless communication networking, in order to save electricity, the working mode of the related communication circuit module can be
controlled by the acquisition module. When data needs to be reported, the communication circuit is powered on or wakes up the network for data transmission. After the transmission is completed, the central acquisition computer sends related instructions to the acquisition module to control the power-off or sleep of the communication circuit. In the sleep mode, the central acquisition computer can remotely wake up the communication circuit module in the relevant DAU. In applications on important occasions, the DAU should have multi-channel transmission capabilities, which can be switched according to the signal strength of specific channels to ensure that monitoring data is sent to the relevant acquisition computer equipment safely and reliably.

h) Communication link

Automatically diagnosing the reliability of the communication link, automatically selecting the optimal communication link, and realizing the ad hoc network of the system are important indicators of the intelligence of the dam safety monitoring data collection network. In order to achieve the above functions, the following points must be provided:

i) Monitoring of wireless signal strength and links. If the system uses wireless communication, it can detect the signal strength and send related heartbeat packets to test the wireless link status before the watch on standby or remote reporting and perform related actions when the signal is normal and the link is open. When the signal strength is insufficient or the wireless communication link is abnormal, it can reconnect or design delay actions. In specific applications, a communication interface splitter can be used to monitor related communication channels without affecting normal work. In the measurement result message that is normally reported to the center acquisition computer, information about the strength of the wireless signal can be distributed, allowing the user to grasp the network operation status of the device, reminding the user to take appropriate measures in time, and troubleshooting the hidden danger. In order to avoid the use of GSM, GPRS, CDMA, LTE and other wireless public network communications to stop the service due to SIM card arrears, resulting in the lack of monitoring data, in the management software of the automation system, the function of counting the remaining charges in the communication card can be designed, which is convenient for recharging in time to ensure the normal communication.

ii) Monitoring of wired communication link conditions. When the dam monitoring data acquisition system is connected to the network by wired communication, the heartbeat packet can also be used to test the link status on a regular basis. At the same time, relevant power monitoring devices can be added to monitor the power supply of optical fiber terminals, RS-485 communication converters, network switches, etc. to obtain the working status of each communication node device in the communication network.

i) Application software intelligent feedback

The computer software of the data collection center is the most important medium for human-computer interaction. The intelligence level of related acquisition and information management analysis software is very important for reducing the workload of operation and maintenance staffs, improving the efficiency of operation and maintenance, and improving the level of analysis and prediction influences.

i) The central computer software should be able to calibrate the DAU built-in clock autonomously and regularly. The built-in clock chip of the field data acquisition equipment is affected by the temperature and the accuracy of the crystal oscillation. There is inevitably a cumulative error. Long-term accumulation will cause the system measurement to be out of sync. At this time, the host software needs to be monitored. The DAU automatically performs clock calibration according to the real-time clock information in the data message, and it is performed at least once every month during the measurement cycle interval. The clock of the monitoring host can be automatically updated through the clock server time.windows.com on the Internet.

ii) The computer software of the center should be able to independently determine the integrity of the messages reported by the monitoring module and respond effectively. Due to the influence of various abnormal factors on-site DAU, the module may not collect or save data according to the set cycle frequency, resulting in missing data. The software should be able to retrieve and find the abnormal module as soon as possible according to the integrity of the timing measurement data and input the supplementary test in time. When the message loses characters due to the problem of the on-site
communication link, the software can first extract the normal and effective measurement points, and make up the incomplete measurement points of the message in time and save them.

iii) The computer software of the center should be able to automatically count the loss of self-reported measurement data every time and timely report to the management personnel. In the practical requirements and acceptance regulation of the dam safety monitoring automation system, the effective data loss rate within the statistical period is required to be less than 3%[8]. Only by strictly controlling the daily operation of the automation system and controlling the rate of data loss can we obtain qualified data that meets the statistical analysis specifications. In the daily actual operation of the automated system, the daily and weekly data missing rate can be counted. When the missing rate is greater than 0 or 3%, the relevant personnel shall be notified in stages to deal with it in time.

iv) The central computer software should be able to determine the type of failure. According to the set data collection frequency, the amount of data measured at all the measuring points, and the missing measuring points are counted, so as to further determine whether it is a single instrument, monitoring equipment (DAU), a single branch communication line, or a problem with the entire system. The monitoring statistics briefing report reports to the user to promptly deal with it. With reference to the code of operation and maintenance for hydrological remote measurement system[9], the failure of the telemetry station can be indirectly judged according to the lack of data. The analysis is as follows:① When all the stations of the dam safety monitoring automation system have no data, it can be preliminarily judged that the communication line master node, monitoring center equipment, etc. have failed; ② When there is no data in the DAU under the same station, it can be preliminarily judged that the optical terminal, serial level converter, serial splitter, MOXA card, wireless communication DTU and other secondary equipment failure or the power supply problem of the station; ③ DAU does not report data at the set time, and there is still no data after the host computer software actively sends a command, then the DAU itself is initially determined to be faulty. The central computer software can intelligently provide primary fault judgment to operation and maintenance staffs based on self-reported or call-up test results.

v) The central computer software should have the basic logical judgment and statistical analysis functions of the sensor measurement data. The quality of the measurement data is judged according to different instrument types and determined ranges. If it exceeds the threshold or there is a gross error, it prompts the user to deal with it in time. Similarly, according to the location of each measuring point, reference to engineering experience can also be used to initially determine which interval the measured value will be in. For example, the water pressure inside the dam is generally not higher than the reservoir water level, no negative pressure should occur, and the temperature inside the dam is generally not lower than 0 °C. When doing specific statistical analysis, based on the latest historical measured values, use mathematical statistical methods to determine whether there is a gross error in this measured value. Commonly used statistical discrimination methods include Laida criterion (3σ criterion) [10], Grubbs criterion[11], Dixon criterion[12], t-test (Romanovsky criterion) [13] and so on. It should be noted that the mathematical statistics method does not take into account changes in the environment, state, and other conditions. It uses a purely mathematical algorithm, and it is easy to misjudge the true mutation measurement as an abnormal value. For example, the measured value of the sudden jump may be due to a large change in the independent variables such as water level and air temperature, or an abnormal real response to the dam behavior. Therefore, the measured values cannot be simply deleted, otherwise it is easy to miss important information on dam safety anomaly characterization. For data loss, system failure, over-limit and out-of-tolerance failures, the supporting center computer software should be able to automatically form a summary and report it to the operation and maintenance staffs, and form a log to be stored in the database for subsequent analysis. The management software proposes a guided exception handling scheme based on the knowledge base, so that the operation and maintenance staffs can eliminate the shortage in time, reduce the dependence of the system operation on personnel, and solve the problem efficiently.

2.1.3. Operation and maintenance
The ability to automatically establish logs, report output, quick retrieval, statistical analysis of fault characteristics, and establishment of a fault diagnosis rule base for system operation and operation is a basic function that must be possessed by an intelligent system. In the next step of system intelligence, algorithms such as recommendation algorithms and data mining algorithms will be introduced to implement tasks such as fault self-diagnosis and solution intelligent recommendation. System operation and maintenance staffs will be able to realize remote diagnosis of the system, information query, online help, and classification and retrieval through mobile terminals and other methods.

2.2. Key technology

2.2.1. Sensor wide compatibility
Sensors compatible with various signal outputs and different excitation methods are the basic requirements for system intelligence, including temperature, pressure, acceleration, angular velocity and other sensors based on micro-electromechanical systems (MEMS) technology, silicon resonance sensors, piezoelectric ceramic sensors, and field effect sensors, etc.

2.2.2. Using advanced practical electronic technology
Advanced microelectronic technology not only greatly increases the speed of information processing, but also integrates sensors such as temperature and vibration in the chip, which can be directly used to monitor the small environment in the DAU. High-performance processors have rich external interfaces and internal function modules. While having the characteristics of low power consumption, mainstream microprocessors are equipped with multiple serial ports, A/D converters, real-time clock, power loss storage, power supply monitoring and other internal function modules. Some specialized chips also integrate wireless radio frequency communication modules such as Bluetooth, Wi-Fi or 433MHz. Today, TMS320, MSP430, ARM-based STM32 and other microprocessor chips widely used in the dam safety monitoring industry have made a qualitative leap compared to the MCS-51 series microcontrollers used many years ago. The dam data acquisition system developed on the basis of these chips can realize the collection of more physical signals from sensors, the selection of communication methods, the implantation of intelligent algorithms, and the monitoring of projects.

2.2.3. Compatible with multiple wireless communication technologies
The development of low-power wireless communication technology has provided convenience for data transmission of the monitoring system, and is the development direction of future dam safety monitoring system equipment. Data transmission distance and bandwidth requirements for data volumes are the main considerations for the selection of wireless communication. Local wireless networking technologies currently applied in the industry include ZigBee, LoRa, microwave, etc. Wireless wide area network networking technologies include GPRS, CDMA, LTE, NB-IoT, etc. When designing the wireless network supporting the data acquisition system, based on the consideration of signal strength and compatibility, the power supply method and power consumption needs to be considered. No. 5 AA alkaline dry batteries, large-capacity disposable lithium batteries, lead-acid batteries, solar panels, and utility power lines should be reasonably configured.

3. Concluding Remarks
Intelligence is the development direction of dam safety monitoring system. The study found that intelligent evaluation should start with the system's occurrence environment its own state perception, real-time response, and human-machine collaboration and other functional and performance indicators, in order to establish a scientific intelligent evaluation factors system and promote intelligent development healthily.

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