Research on key technologies for industrial field communication quality analysis

Zhen Wang*, Dantao Han, Yanjie Gong and Yanling Zhao
Instrumentation Technology and Economy Institute (ITEI), Beijing 100055, China

*Corresponding author. Email: wangzhen@tc124.com

Abstract. With the widespread application of intelligent manufacturing and industrial internet technologies, higher requirements for the reliability, stability and robustness of industrial communication networks have been put forward. To achieve these requirements, the detecting and evaluating diagnostic technology for industrial field communication is essential. This paper analyzes the key technologies and difficulties of detecting and evaluating diagnostic technology from the four aspects of access, collection, communication and evaluation & diagnosis and proposes some feasible solutions to provide a new perspective for further in-depth research.

1. Introduction
In the context of intelligent manufacturing, industrial communication networks provide basic technical support for the digitalization and networking process of manufacturing enterprises. It is the infrastructure to realize horizontal and vertical integration of the information island in industrial field. Industrial communication networks mainly include fieldbus and industrial Ethernet. Currently, there are nearly thirty kinds of fieldbus and industrial Ethernet technologies in the market. While, common problems such as harsh environment, complex network structure, improper installation can cause frequent instability and abnormal communication, which seriously affect stable operations of factories. For now, the operation and maintenance of industrial communication networks is mainly completed manually by experience owing to lack of effective methods and tools for comprehensive and systematic analysis and evaluation & diagnosis of industrial field communication quality. This paper studies the key technologies of quality analysis based on a thorough understanding of the industrial field communication conditions.

The first part introduces main factors that affect industrial field communication quality and summarizes key technologies and difficulties of carrying out quality analysis, the second to the fifth parts respectively elaborate on the four technologies, which are access, collection, communication and evaluation & diagnosis, the final part is conclusion and prospect.

2. Main influencing factors
Various uncertain problems such as nonstandard wiring, loose interfaces, cable aging, improper grounding and electromagnetic interference are the main factors affecting the communication quality in industrial field. By changing the line impedance or introducing disturbance signals, they can cause problems like physical signal distortion and protocol content error, leading to frequent occurrences of communication instability, failures and other abnormalities.
2.1. Electromagnetic interference
Besides mechanical vibration and environmental temperature fluctuation, electromagnetic interference is the major disturbance in industrial field. It mainly comes from supply voltage fluctuation, magnetic radiation from powerful equipment, current fluctuation of power cords and strong electric signal wires, as well as ground potential fluctuations. As Figure 1 shows, the formation of interference must include three basic factors, which is interference source, coupling channel and receiving circuit sensitive to the interference signal.

![Figure 1. Causes of interference.](image)

Generally, the interference can be formed in the following ways:
(1) Conduction coupling. When the wire is in an interference condition, it will be interfered by the voltage disturbance, for instance grid interference introduced through the power line of the system.
(2) Common impedance coupling. When the currents of two or more circuits flow through the common impedance at the same time, there will be an interactive influence on the impedance.
(3) Electromagnetic coupling. It is the phenomenon that electric or magnetic field generated by the current of one signal wire is coupled to another wire through distributed capacitance or inductance.

2.2. Network failure
Lack of caution in laying communication lines and safety debugging of related equipment can easily lead to network failures, such as poor contact caused by incorrectly installing the interface, communication performance degradation caused by aging and corrosion of laying cable and excessive line joints and higher energy consumption caused by complex network design. These greatly reduce the quality of communication.

3. Key technologies
Above is overall analysis of the main factors affecting industrial communication quality and causes of interference. To tackle the problem, a number of equipment vendors have already launched several quality measurement and message analysis tools for special communication network. Representative examples include the Dutch company PROCENTEC, which developed the mobile troubleshooting and maintenance tool ProfiTrace, and the German company Softing, which launched Network Management Tools. These products do realize the debugging, monitoring and troubleshooting of industrial networks, but they are only applicable to specific networks and cannot be promoted in more scenarios. Currently, there is still need for quality analysis system that can be applied to multiple industrial communication networks.

Based on analysis of existing technical methods, this paper proposes the architecture of industrial field communication quality analysis system as a general solution. As shown in Figure 2, detection access must support multiple communication protocol access and self-adaptation, data collection should realize the acquisition of physical signal data, the measurement of voltage/current, voltage difference, rise/fall time, etc., as well as data storage and forwarding, data communication must ensure efficient communication and interaction between collection and evaluation & diagnosis, evaluation & diagnosis needs to realize the measurement of key indicators and real-time indicators of the network, analysis of protocol message and comprehensive evaluation & diagnosis of communication quality, and display the results. Moreover, this paper analyzes the key technologies and difficulties from the four aspects of access, collection/acquisition, data communication and evaluation & diagnosis (Figure 3). The following is further explanation.
3.1. Access
Technology that connects detecting device and detected target is the basis for implementing industrial field communication quality analysis. Usually, traditional access will affect the collected signals and lower the reliability of signal restoration. And due to the coexistence of multiple bus protocols and many types of interfaces in the industrial field, it is almost impossible using only one device to analyze the communication quality of all networks. This leads to the following two critical problems that need to be solved:

1. Noninterference access. It is designed to achieve no interference or negligible interference to the original detected target when the detection probe is connected. One feasible solution is to embed
probes in advance during the network construction phase to avoid interference, the other is to develop new probe technology to reduce interference.

(2) Self-adaptive interfaces. There are more than 30 kinds of communication protocols in the industrial field, and the main interface forms include DB-9, RJ-45, etc., as Table 1 shows. In order to realize quality analysis of multiple communication protocols, the access should be able to adapt to different forms of physical interfaces.

| Interface Type               | Fieldbus/ Ethernet          |
|------------------------------|------------------------------|
| DB-9                         | Profibus-DP, CC-Link, Modbus etc. |
| RJ-45                        | Ethernet protocol           |
| 3-wire bus interface         | Profibus-PA, FF              |
| 2-wire bus interface         | CAN                          |

3.2. Collection
The noninterference access ensures reliability and accuracy of the collected data source, while the collection focuses on acquisition, storage, and preprocessing of physical signals to ensure its integrity and restoration ability, providing a reliable physical layer data source for industrial communication diagnosis and analysis. The key technical difficulties to be solved include:

(1) Data acquisition. There are two commonly used methods. One is MAC layer chip or PHY chip technology, which can quickly complete data collection and processing of industrial communication protocols. The other is the direct acquisition of A/D physical signals, which can better capture the form, attenuation and other information of physical signal to achieve more accurate analysis. The integration of two acquisition technologies can support comparative analysis of digital and physical signals, which helps identify problems and provides intuitive and accurate data information.

(2) Data storage. Effective detection of industrial communication quality requires long-term signal acquisition in order to capture a certain number of typical and abnormal signals, and the collected data needs to be stored for further analysis and diagnosis, which puts high demands on storage performance. However, limited by chip writing technology, the storage has capacity constraint. When writing is faster than storage, it will cause data coverage or loss. On the contrary, if writing is slower than storage, it will reduce the acquisition efficiency as well as the ability to capture abnormal signals. Therefore, it is crucial to balance acquisition and storage.

(3) Excitation source input. It is an effective method to detect the topology and impedance of industrial field bus, and will have a certain impact on the industrial communication bus. Thus, it is necessary choosing the proper form and timing of excitation source input. For example, using waveforms that are easy to separate signals, such as sine wave, square wave, etc., and choosing the right time of system working or shutting down for maintenance to reduce the impact.

(4) Impedance measurement. Measuring impedance parameters of industrial communication lines can help identify problems caused by impedance mismatch, which is important to quality diagnosis. Although the conventionally used power-down method can accurately measure the impedance value, the application conditions are strictly limited and can only be carried out during the maintenance period of production line.

3.3. Data communication
Data collection is a highly time-sensitive process, which determines that the collected data must be timely and effectively transmitted to evaluation & diagnosis module via a special communication technology. The key technologies include:
(1) Communication protocol developing. Industrial field communication quality detection and evaluation & diagnosis as an emerging technology, has no relevant specifications. Therefore, it is necessary to establish a special communication protocol, which can specify the data organization, key fields and verification methods to facilitate data decomposition and transmission and then establish an interaction mechanism between data collection and analysis.

(2) Communication technology selecting. USB 3.0 technology or gigabit network communication technology can be adopted to meet the requirements well for speed and bandwidth in the transmission process.

3.4. Evaluation and diagnosis
Evaluation and diagnosis realizes the detection and assessment of industrial communication quality through comprehensive analysis of physical signals and protocol data. As Figure 4 shows, taking the ISO OSI information model as an example, evaluation and diagnosis perform detection and analysis of abnormalities on the physical layer, data link layer, network layer and above layers. The key contents include:

![Figure 4. Industrial communication network protocol hierarchical structure and typical abnormal problems.](image)

(1) Physical layer. Physical layer communication is based on the physical transmission medium. Typical abnormalities include signal amplitude, width, slope and other distortions. Accordingly, physical layer abnormalities need to be detected by signal waveforms. Only if the waveform meets the requirements of a specific protocol or is within the allowable range of signal distortion, the electrical signal can be converted into semantic data.

(2) Link layer. Typical abnormalities at the link layer include error frame types and structures, etc. Abnormalities are mostly manifested as formal static errors, such as data format inconsistency and incorrect content. Accordingly, keyword comparison method should be adopted to check the content and format of data frames to detect link layer communication abnormalities.

(3) Network layer. Typical abnormalities include nodes and connections failures, which are mostly related to network resource allocation and network configuration. Accordingly, the abnormalities should be identified based on the parsed corresponding message content.

(4) Transport layer and application layer. Typical abnormalities include non-update of application data, unresponsive nodes, packet loss, disorder, etc. Abnormalities often occur as semantic and functional errors in message interaction, which are dynamic errors. Accordingly, abnormalities can be inferred by analyzing the corresponding application layer message using contextual analysis methods based on protocol functions.

4. Conclusion
This paper analyzes the key technologies and difficulties of industrial communication quality analysis from four dimensions of access, collection, communication and evaluation & diagnosis, meanwhile, describes the common problems and proposes some feasible solutions. It is hoped that this paper can
help researchers in related fields to better understand the situation, and major breakthroughs in core
technologies are expected in follow-up researches.

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