Highway Addressable Remote Transducer(HART) Protocol

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***Abstract*—The HART (Highway Addressable Remote Transducer) protocol is widely employed in industrial process automation for effective communication between field devices and control systems. By combining analog and digital communication, it enables advanced functionality and data exchange. This paper presents an overview of the HART protocol, discussing its architecture, communication principles, and prominent features. It examines the physical, data link, and application layers, highlighting its advantages in terms of compatibility, industry acceptance, and cost-effectiveness. Real-world applications showcase the protocol's merits in process control, cost reduction, and remote configuration. This abstract provides a concise introduction to the HART protocol, catering to researchers and professionals engaged in industrial automation.**

***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

Automation and control systems frequently employ the HART communication protocol (Highway Addressable Remote Transducer).It mixes analog and digital transmission to enable two-way communication between intelligent field equipment and control systems.The FieldComm Group has since amalgamated with the HART Communication Foundation and developed the HART protocol in the 1980s. It was created as an upgrade for current 4-20 mA analog systems.It enables digital communication without requiring significant infrastructure changes.The HART protocol operates by transmitting digital information alongside with the standard 4-20mA analog signal. This is achieved by using Frequency Shift Keying (FSK) modulation, where digital information is encoded in the frequency variations of the analog signal. The digital information is superimposed on the analog signal, allowing compatibility with existing analog systems.HART enables control systems to communicate orders, as well as receive extra data from field devices in addition to receiving process variable data.With the help of this communication protocol, field devices can be remotely configured, calibrated, and diagnosed that eliminates the need for human on-site visits.The HART protocol provides a less costly solution for integrating digital communication capabilities into existing analog systems. It improved diagnostics,control of field devices and monitoring. HART protocol enhance the overall efficiency and reliability of industrial process automation . [7] [8] [9]

II. HART Protocol Architecture

HART protocol has a master-slave architecture.The master device communicates with one or more slave devices over a communication network.This indicates that each slave communication is started by a master communication device during an operation.

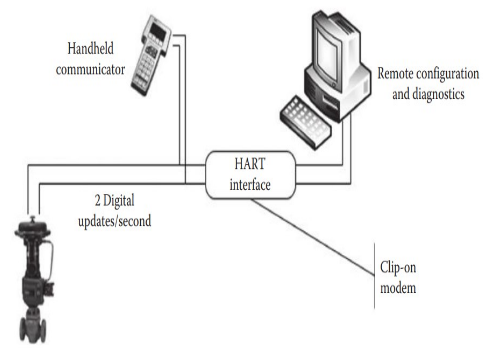

Fig. 1. HART System [1]

A. *Master Device*

The master device plays a crucial part in the communication network of the HART protocol. It serves as the main interface for field devices such sensors,transmitters, and actuators. The HART master device's main duties and functions include starting up communication with slaves, carrying out commands, gathering and monitoring data.The master device also integrate with control systems and identifying errors. It establishes contact and delivers instructions to the slave devices and carries out diagnostic and troubleshooting tasks. Overall, the master device in a HART network serves as the central point for industrial operations by handling communication, data collecting, and control of field devices.

B. *Slave Device*

Slave HART protocol devices serve as field devices for the HART network and communicate with the master device. These components, such as sensors, transmitters, and actuators, have important traits that support their function in industrial automation applications. They can communicate by using the HART protocol and a two-wire interface that allows for simultaneous analog and digital signal transmission.Slave devices can receive control orders to modify their operation or setpoints in addition to being in charge of measuring process variables and sending the gathered data to the master device.

C. Communication Mods

The HART protocol uses two communication mods.These mods are names Master - Slave Mod and Burst Mod.In Master - Slave Mod HART requires a master communication device to start every slave (field device) communication during normal operation. Each HART loop can support two master connections. Transmitters, actuators, and controllers that follow instructions from the primary or secondary master are referred to as slave devices.Burst communication mode is an optional feature supported by some HART devices. Faster communication is possible in burst mode. A Standard HART reply message is continuously broadcast by the slave device in burst mode, per the master's instructions. Until it tells the slave to cease bursting, the master receives the message at the 2 faster rate. [7]

D. Communication Network

The HART protocol combines analog and digital communication. Digital signals are modulated using Frequency Shift Keying (FSK) to be transferred onto the analog 4-20mA current loop. The command-response model of digital communication enables the control system to query parameters, configure devices, and retrieve diagnostic data using standardized commands. Device status, diagnostics, and identity are just a few of the extra information that can be transmitted. Burst mode communication makes it possible to communicate bigger amounts of data quickly. Digital connection improves process management and maintenance capabilities by enabling remote device configuration, calibration, and diagnostics. A complete solution for process automation and control systems is offered by the HART protocol's integration of analog and digital communication. [11]

E. Analog 4-20mA Current Loop

The analog 4-20mA current loop offers a dependable and durable means for conveying analog signals, with 4mA as the least value and 20mA as the maximum value. Digital communication capabilities are introduced through the HART protocol, which works in conjunction with the analog current loop. It enables operations like remote device configuration, calibration, and diagnostics by allowing the modulation of digital information onto the analog signal. This fusion of analog and digital technologies offers the advantages of dependable analog signal transmission while simultaneously enabling greater functionality and improved data access through digital communication. [10][11]

F. Field Devices

These are intelligent devices that are deployed in the field to measure process variables or regulate industrial processes, such as sensors, transmitters, and actuators. To communicate data with the control system, field devices have HART communication capabilities.

G. Hart Modem

The HART modem serves as an intermediary between digital communication and analog current loops. It transforms the HART protocol's digital signals into analog signals that can be sent through the current loop. Using the same communication channel, analog and digital communication can take place simultaneously with the HART modem.

III. HART Protocol Configuration

HART protocol configurations are tailored to specific application requirements, taking into account factors like network size, device types, communication distances, and system integration needs. Proper configuration ensures reliable communication, seamless integration, and efficient operation of HART devices within the industrial ecosystem.

A. Point to Point configuration

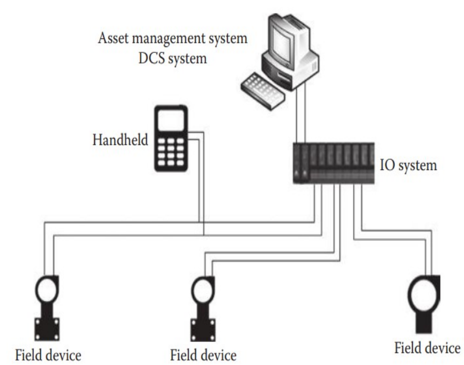

Fig. 2. Point to point system [1]

One process variable is transmitted in point-to-point mode using the standard 4-20 mA signal, while all other process variables, setup parameters, and device data are transmitted digitally using the HART protocol. The HART signal has no effect on the 4-20 mA analog signal, which can be used for control in the usual manner. Access to secondary variables and other data that can be used for operations, commissioning, maintenance, and diagnostic purposes is provided through the HART communication digital signal. [6]

B. Multidrop Configuration

A single communication loop connects many HART devices.The devices utilize twisted pair wiring as one of their common communication channels.Each device has a unique address that allows the control system to communicate with and address specific devices on the network.A single pair

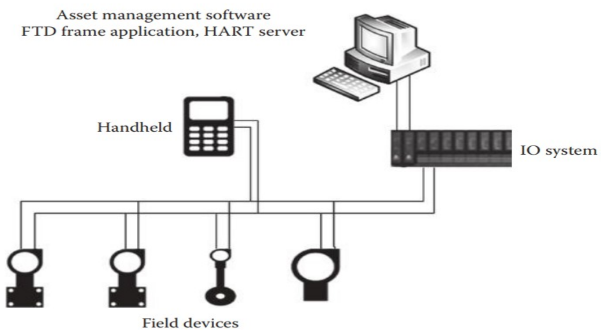

Fig. 3. Multidrop System [1]

of cables, any necessary safety barriers, and an additional power source are all that are needed for the multidrop mode of operation, which can power up to 15 field devices. All process values are digitally sent. In multidrop mode, the current through each device is fixed to a minimum amount and all field device polling addresses are greater than 0. [6]

IV. HART Signal

The foundation of the Hart Protocol communication is FSK(Frequency Shift Key). The major process variable (PV) measurement is transmitted by Hart devices using a common 4-20 mA analog signal. By modulating the frequency, the signal also carries digital information in addition to the analog information.[5]

Frequency Shift Keying is also known as FSK is use to transport digital data across a carrier wave, it is a digital modulation technique used in communication systems.

The carrier signal's frequency is changed between two preset frequencies in FSK to represent the binary data. Each frequency is associated with a unique binary value, commonly 0 and 1.

The fundamental idea of FSK is the use of two frequencies, one for the binary "0" and the other for the binary "1." The mark frequency (which represents a "1") and the space frequency (which represents a "0") are commonly used to encode the data.[5]

Based on the input data stream, the FSK modulator alternates between the mark and space frequencies during transmission. After that, the receiver demodulates the signal it has just received, identifying any frequency shifts and translating them back into binary data.

FSK is frequently employed in a variety of communication systems, including wireless communication, satellite communication, and landline connections for the transmission of digital data. It is renowned for being straightforward and strong against interference and noise, making it suited for a variety of applications.[1]

The communication process involves the following steps

- Master Device Request
- Field Device Response
- Frequency Shift Keying
- Master Device Interpretation
- Bi-Directional Communication

Hart Protocol, in general, combines analog and digital communication to give field devices more functionality and diagnostic capabilities, boosting the capabilities of process automation systems.

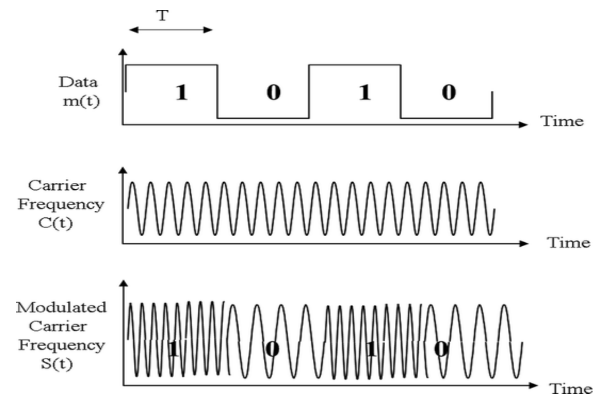

Fig. 4. Frequency shift keying

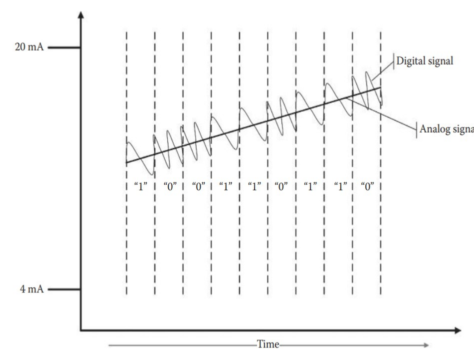

Fig. 5. Wired HART simultaneous analog and digital communication.[1]

V. HART Protocol Communication Standards

The HART (Highway Addressable Remote Transducer) protocol is designed with a loose alignment to the OSI (Open Systems Interconnection) seven-layer model for communication protocols. While HART does not strictly conform to each layer of the OSI model, it can be associated with specific layers to provide insight into its communication structure.

- Physical layer
  The physical layer in the HART protocol encompasses the electrical and signaling aspects of the communication. It defines the characteristics of the physical medium used for transmitting the HART signal and specifies the rules for encoding and decoding data to be transmitted. The primary physical medium is the 4-20 mA current loop, which is commonly used in industrial process control

systems.[1]

- Data Link layer

  The data link layer in the HART protocol provides a efficient and transaction-oriented communication channel for digital data transfer between field devices. It operates over twisted pair wires, which may also carry the 4-20 mA signals simultaneously. The data link layer is designed to handle errors caused by noise or disturbances on the communication links. It achieves this by using error detection techniques and an automatic repeat request protocol, which allows for the retransmission of corrupted data blocks. HART utilizes a master-slave protocol and is loosely based on the ISO/OSI seven-layer model for communication protocols. The data link layer communicates with the application layer above it and depends on services provided by the physical layer below it.[1]

- Transport Layer
  In the context of HART (Highway Addressable Remote Transducer) protocol communication, the transport layer operates within the framework of the OSI (Open Systems Interconnection) model. The transport layer in the HART protocol is responsible for ensuring reliable and efficient end-to-end communication between HART devices[1]

- Application Layer

  The application layer defines a set of standardized commands that allow the master device to send instructions and request information from field devices. These commands cover a wide range of functionalities, including setting parameters, reading process variables, performing diagnostics, and configuring devices.[1]

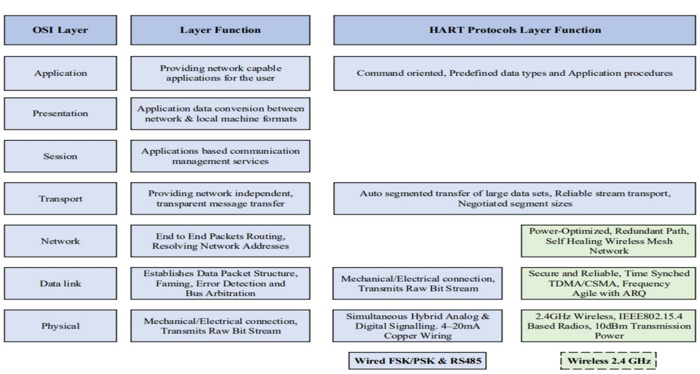

Fig. 6. OSI layer of wired and wireless HART [3]

VI. HART Protocol Implementation

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other.

VII. Wireless HART

WirelessHART is a specialized wireless communication protocol developed specifically for industrial process automation. It is designed to meet the unique requirements of industrial environments and is not intended for general-purpose wireless networking like WiFi. Operating in the 2.4 GHz ISM band, WirelessHART utilizes a mesh network topology to enable reliable communication among devices. Unlike WiFi, which follows the IEEE 802.11 standard, WirelessHART has its own distinct communication and networking specifications tailored specifically for industrial applications.[2][3]

To analyze and monitor WirelessHART networks, specialized tools and software provided by WirelessHART device manufacturers or dedicated process automation software are utilized. For instance, the ”HCF KIT-190” Wi-Analys Device, along with its accompanying software, is commonly used. This device is connected to a Windows PC via a USB cable. These tools are purpose-built to monitor the network’s overall health, collect diagnostic information, visualize the network topology, and analyze the communication patterns that are unique to WirelessHART devices and protocols.[1][3]

VIII. HART Protocol Advantages and Limitations

A. Advantages

1) Compatability: One of the main advantages of HART is its compatability with existing 4-20 mA analog systems. It can be implemented with traditional analog devices without the need for significant infrastructure changes.[1]

2) Cost-Effectiveness: Since the HART protocol is operating on existing analog wiring cost of the implementation is low.

3) Bidirectional Communication: HART Protocol enables bidirectional communication, Means that the analog and the digital data can be transmitted simultaneously. The analog signal carries the primary process variable,while digital communication facilitates access to secondary process variables,device configuration and other parameters[2]

4) New types of information: Traditional analog and discrete devices are limited in their communication capabilities as they can only transmit a single process variable, without providing any easy means of verifying the accuracy of the information being transmitted. However, with the introduction of HART protocol, devices can now transmit not only the process variable but also a wide range of additional information. Every HART device comes with standard information items numbering around 35-40. These include details such as device status, diagnostic alerts, process variables with their corresponding units, loop current and percentage range, basic configuration parameters, and manufacturer and device tags.

By having access to this additional information, HART devices that are digitally polled by a host can indicate whether they are correctly configured and operating properly. This eliminates the need for most routine checks and enables the detection of potential failure conditions before they lead to significant process issues.[2]

B. Limitations

1) Data Transfer Speed: HART operates at a relatively low data transfer rate, typically around 1200 bits per second (baud rate). This limited bandwidth restricts the amount of data that can be transmitted.[4]

2) Low Power: It is advisable to keep fresh or fully charged batteries readily available for HART communicators, as communication issues can arise before the low battery diagnostic flag is triggered. Being prepared with a power source ensures uninterrupted operation and helps address potential problems before they become significant.[4]

3) Signal Interference: Since HART utilizes analog signaling alongside digital communication, there is a potential risk of signal interference or noise affecting the quality of data transmission.[4]

IX. HART Protocol Comparison

HART protocol, Modbus, Profibus, and Foundation Fieldbus are widely used communication protocols in industrial automation systems. HART stands out for its backward compatibility with existing analog systems, allowing for seamless integration and cost-effective upgrades. Modbus, on the other hand, offers simplicity and versatility, supporting various network topologies and real-time data exchange. Profibus provides advanced functionality and a wide range of device support, while Foundation Fieldbus excels in its advanced features, flexibility, and larger data transfer rates. The choice among these protocols depends on factors such as existing infrastructure, required functionality, data transfer rates, and system complexity, allowing for a tailored solution that best suits the specific industrial automation needs.

Interface	Data rate	Range	Medium	Application
Ethernet	100 Mb/s, 1 and 10 Gb/s	100 m	Shielded or unshielded twisted pair; fiber cable option	Connecting field buses to existing business networks or the Internet
Foundation Field Bus	H1: 31.5 kb/s, HSE: 100 Mb/s, 1 Gb/s	1900 m max.	Shielded or unshielded twisted pair	Connect sensors, actuators, etc., in process control
Highway-Addressable Remote Transducer (HART)	1200 and 3600 b/s	< 10,000 ft..	Shielded twisted pair	Analog and digital sensor and actuator connections in process control
Modbus	9.6 & 19.2 kb/s	< 1000 ft.	Shielded or unshielded twisted pair	Monitor and control with PLCs
Profibus	9.6 and 31.25 kb/s, to 12 Mb/s	1200 m	Shielded or unshielded twisted pair	Monitor and control in process automation
RS-232	1.2 to 115.2 kb/s	< 50 ft..	Multiwire cable	Connections to PC peripheral and industrial devices
RS-485	100 kb/s to 10 Mb/s	40 to 4000 ft.	Shielded or unshielded twisted pair	Industrial and commercial networks

Fig. 7. Comparison with other communication protocols [5]

X. HART Protocol Applications

In the process automation industry, the HART (Highway Addressable Remote Transducer) Protocol is frequently used for a variety of applications.

- Device Configuration and Calibration: Field equipment can be remotely calibrated and configured using the HART Protocol. Updates to setup parameters, calibration values, and device settings can be made remotely from the control room, saving time and labor by avoiding the need to physically visit each device. It makes maintenance easier and cuts down on downtime.
- Asset Management: Field equipment having HART capabilities can provide alarms about potential problems as well as status updates and diagnostic data. The proactive maintenance, predictive analysis, and asset optimization made possible by this information increase the dependability of the equipment and save downtime.
- Device Monitoring and Troubleshooting: The HART Protocol allows operators and maintenance staff to continuously monitor field devices. They are able to retrieve data on the condition of the device, process variables, alerts, and error codes. Diagnostic data helps in swiftly detecting and addressing problems, making troubleshooting more effective.
- Safety Instrumented Systems (SIS): Additionally, safety instrumented systems employ the HART Protocol. Field equipment having HART capabilities can supply safety-related data, including status, alerts, and diagnostic data, allowing for better monitoring and reaction to critical conditions as well as assuring functional safety.
- Process Control: HART Protocol enables two-way communication between field equipment like sensors, transmitters, and control valves and control systems like PLCs or DCS (Distributed Control Systems). It makes it possible to monitor, regulate, and alter process variables including temperature, pressure, level, and flow in real-time, which enhances overall process control.
- Inventory Management: Field devices can be integrated into inventory management systems using the HART Protocol. It makes inventory management simpler and ensures proper documentation of the devices put in the plant by enabling the automatic identification, configuration, and tracking of equipment.[1][3]

XI. HART Protocol Future Developments

One of the key areas of improvement for the future of HART protocol lies in data transfer speed and capacity. As industrial processes become more complex and generate larger volumes of data, there is a growing need for faster and more efficient communication between devices. Future iterations of the HART protocol are expected to leverage advancements in communication technologies to offer higher data transfer rates, enabling real-time mon-

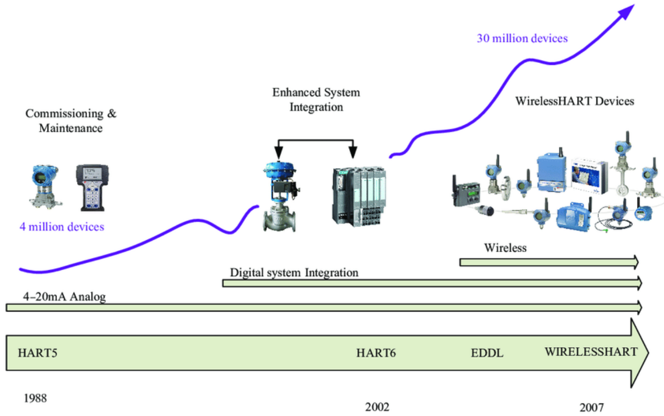

Fig. 8. Evolution of HART [3]

itoring, control, and diagnostics of industrial processes.

Due of its versatility and affordability, wireless communication is gaining major popularity in industrial automation. The HART protocol will probably support wireless in later versions, enabling the smooth integration of wireless field devices into already-existing HART networks. The ability to deploy devices in remote or inaccessible locations will be made possible by this invention, which will reduce the need for extensive wiring and increase the potential for automation across a variety of industries.

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