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Implementation of an Ultra-Low-Power Temperature and Pressure Detection System Based on the HART Protocol

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Abstract: This paper presents a condensed design of an ultra-low-power temperature and pressure detection system based on the Highway Addressable Remote Transducer (HART) protocol. The study targets industrial scenarios in which temperature and pressure must be measured in real time under harsh conditions while maintaining low power consumption and reliable long-distance transmission. The proposed system adopts a two-wire architecture and integrates an MSP430 microcontroller, an AD7794 signal acquisition chip, an AD5700 HART modem, and an XTR115 current-loop interface. Temperature and pressure signals are sampled, digitized, processed, and then coupled to a 4–20 mA loop carrying superimposed HART digital communication. On the hardware side, the design emphasizes sensor interfacing, HART-compatible signal transmission, and current-loop integration. On the software side, it implements system monitoring, data acquisition and conversion, communication management, and CRC-based data verification. A low-power control strategy combining sleep and wake-up mechanisms is further introduced to reduce the overall energy demand of the instrument.

Keywords: temperature and pressure detection; HART protocol; ultra-low-power design; current loop; MSP430; industrial

1. INTRODUCTION

Temperature and pressure are key state variables in petroleum exploitation and industrial process control. When these variables deviate from the normal operating range, they may directly affect process stability, equipment safety, and maintenance cost. For this reason, industrial instrumentation increasingly requires continuous measurement, remote transmission, and timely diagnosis rather than local manual reading alone [1], [2].

Compared with conventional standalone gauges, intelligent transmitters can convert measured variables into standard signals suitable for long-distance transmission and upper-computer management. Among field communication methods, the HART protocol has clear practical value because it superimposes digital information on the traditional 4–20 mA loop. This mechanism preserves compatibility with existing analog infrastructure while adding bidirectional communication, remote parameter setting, device diagnosis, and multi-node access capability [2],[3].The module is composed as shown in Figure 1 below.

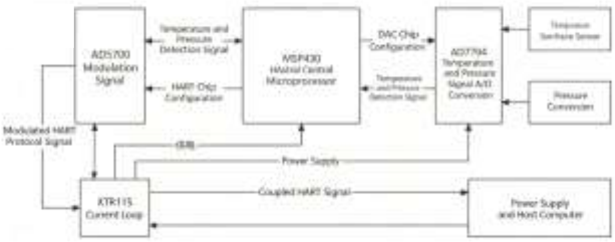

Figure. 1 Hardware block diagram of ultra-low power temperature and pressure detection system

2. OVERALL STRUCTURE DESIGN

2.1 System Architecture

The system adopts a modular architecture composed of a sensor unit, a signal acquisition unit, a microcontroller-based processing unit, a HART communication unit, and a current-loop output unit. Temperature and pressure signals are first generated by the sensing elements and then delivered to the AD7794, which performs high-resolution analog-to-digital conversion. The sampled digital data are processed by the MSP430 microcontroller, which executes compensation, conversion, state management, and communication scheduling. The processed data are subsequently transmitted to the AD5700, and the HART modulated signal is finally coupled into the 4–20 mA current loop through the XTR115 interface [3]–[7].

2.2 Operating Principle

The complete working path can be summarized as measurement, processing, communication, and output. In the measurement stage, temperature and pressure are converted into electrical signals suitable for acquisition. In the processing stage, the MSP430 obtains digital samples from the AD7794 and reconstructs physical quantities through calibration and computation. In the communication stage, the AD5700 superimposes Bell 202 FSK signals on the analog loop, where 1200 Hz and 2200 Hz represent binary states without disturbing the average loop current. In the output stage, the loop current provides both power supply and information transmission, which makes the architecture especially suitable for field instruments requiring compact wiring and low energy consumption [2],[3],[7].

According to the original design targets, the system is intended to support two-wire power supply, 4–20 mA current-loop output, HART-compatible digital communication, temperature accuracy of ±1 °C, pressure accuracy of ±2%, and low-current operation below 4 mA under normal conditions.

These indicators define the boundary conditions of both the hardware and software design.

3. HARDWARE DESIGN

3.1 Signal Acquisition and Control Core

The core hardware chain is centered on the MSP430 microcontroller and the AD7794 acquisition chip. The MSP430 is responsible for control scheduling, peripheral management, data conversion, and low-power state switching. The AD7794 performs multi-channel acquisition of sensor signals and provides the resolution required for temperature and pressure measurement. In the reconstructed paper, the focus is not on alternative-chip comparison, but on the completed signal path itself: the pressure signal is introduced through a differential input channel associated with a bridge-based sensing structure, while the temperature signal is measured through another differential channel combined with a PT100-based resistance measurement method. This arrangement enables both variables to be integrated into a unified acquisition framework.

SPI communication is used between the MSP430 and the AD7794. Through register configuration, the microcontroller sets the operating mode, gain, channel selection, and excitation-current parameters of the acquisition chip. The digitized results are then read back and used for subsequent physical-quantity calculation. This structure separates analog acquisition from digital processing and thereby improves overall design clarity and measurement stability [4],[9].

3.2 HART Communication and Current-Loop Interface

The communication and transmission part of the hardware is realized by the AD5700 and the XTR115. The AD5700 serves as the HART modem and translates controller-side digital information into a HART-compatible modulation signal. In physical-layer terms, this signal is coupled to the loop as a small-amplitude FSK component whose average value is zero, so it does not alter the conventional analog current representation. This is the essential reason why HART can simultaneously preserve analog compatibility and provide digital communication capability [2], [3], [10].

The XTR115 provides the current-loop interface and also supports the two-wire supply concept of the instrument. After signal conditioning and level adjustment, the HART-modulated information is injected into the loop and converted into an output current suitable for field transmission. At the same time, the reference voltage of the loop interface can provide excitation and supply support for internal modules, which helps simplify the overall circuit organization. As a result, the hardware architecture combines measurement, communication, and power supply within a compact loop-oriented design [6], [7].

3.3 Low-Power Hardware Considerations

Low-power capability is an integral hardware objective rather than an isolated add-on. In this design, it is reflected in the use of a low-power controller, HART-compatible low-current communication circuitry, and loop-based integrated power delivery. The system avoids unnecessary external modules and reduces circuit complexity by directly organizing acquisition, communication, and output around the current loop. This approach is especially meaningful in downhole or remote industrial environments, where battery replacement, maintenance frequency, and thermal stress all place additional constraints on instrument power consumption [1],[5].

4. SOFTWARE DESIGN

4.1 Software Architecture

The software design can be divided into three coordinated layers: a monitoring program, a measurement-and-control program, and a communication program. The monitoring program initializes timers, serial interfaces, watchdog functions, and interrupt mechanisms, and it maintains the cyclic scheduling logic of the whole instrument. The measurement-and-control program is responsible for sensor data acquisition, data conversion, variable reconstruction, and output preparation. The communication program executes HART-oriented data framing, receiving, transmitting, and verification.

4.2 Data Acquisition and Variable

The AD7794 is controlled by register read/write operations through the serial interface. Initialization includes channel selection, gain setting, polarity configuration, and excitation-current management. Once conversion is completed, the microcontroller reads back the digital result and reconstructs the corresponding physical value. For temperature processing, the original thesis uses a PT100-based lookup-table method with linear interpolation. In the condensed form of this paper, the key point is that the acquired resistance value is mapped into the temperature domain through segmented interpolation, which balances computational simplicity and engineering accuracy for embedded implementation [4],[9].

Pressure processing follows the same general logic: the acquisition chain provides a digitized electrical quantity, and the software converts it into the corresponding engineering unit through calibration and inversion. The final measurement results are then formatted for analog-loop output and digital HART transmission.

4.3 Communication Management and Data Verification

Because HART communication follows a master–slave model, the transmitter normally responds after receiving a command from the host. The software therefore relies on interrupt-driven serial communication so that frame reception and response can be handled in real time. After initialization, the communication module waits in a receive-ready state, parses incoming preambles, delimiters, addresses, command codes, and data-length fields, and then organizes the corresponding response frame according to the protocol logic.

To improve communication reliability under industrial interference, the reconstructed scheme retains CRC-based verification from the original work. Compared with simple parity checking, CRC provides stronger error-detection capability and is better suited to longer frames and harsher transmission environments. In this design, CRC verification is used to judge whether the received frame is valid before execution and response, thereby reducing miscommunication and improving robustness[8].

4.4 Low-Power Control Strategy

The low-power strategy of the software is built around the operating modes of the MSP430. During normal operation, the controller maintains only the clocks and modules required by the current task. When no acquisition or communication task is pending, the system enters a low-power or sleep mode and waits for timer events or external interrupts to wake it. This mechanism allows the instrument to maintain responsiveness while significantly reducing average energy consumption.

From an implementation perspective, low-power control requires coordinated configuration of status-register bits, interrupt service routines, and wake-up logic. Different operating modes can be selected according to the state of measurement, communication, and idle waiting. The engineering value of this design lies in the fact that low-power operation is not achieved by sacrificing function, but by matching active time to actual task demand. This is one of the most important features that distinguishes the system from conventional higher-power field instruments [1], [5].

5. CONCLUSION

This paper reconstructs the realization of an ultra-low-power temperature and pressure detection system based on the HART protocol. The paper shows that the system logic can be clearly summarized as a sensor–acquisition–processing–communication–current-loop chain. On the hardware side, the design integrates the MSP430, AD7794, AD5700, and XTR115 into a two-wire HART instrument architecture. On the software side, it implements acquisition control, variable reconstruction, interrupt-driven communication, CRC verification, and sleep-based low-power management. The reconstructed paper therefore demonstrates a practical design route for industrial instruments that must simultaneously satisfy measurement accuracy, communication compatibility, remote configurability, and low energy consumption. Future work may further improve intelligence, environmental adaptability, and communication security on the basis of this scheme.

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