Smart Temperature Sensors for Measurement and Control

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Abstract: The paper describes implementation of temperature smart sensors (TSS) at the model of distributed measurement and control systems (DMCS). On the laboratory stand of hot-air aggregate (model of air-conditioning plant) - see Fig. 1 there were used three types of TSS (DS 1820, SMT 160-30 and LM 35). Some results will be present with design, structure and properties of temperature smart sensors connected to the microcomputer PIC 16 C65A. This measurement subsystem is interconnected by ILAN with industrial PC. It is supported with SCADA/MMI program PROMOTIC that enable to reach very good functional parameters with higher flexibility, reliability and testing.

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1 Introduction

Smart sensors (SS) and smart actuators (SA), industrial local area networks (ILAN) and program support SCADA/MMI software for PC computers introduce importance alternatives to implementation of modern configured multilevel measurement and control systems.

To the main advantages of smart sensors and actuators belong:

- Compact form with common supply and standard output signals, with good functionality at hard conditions.
- Minimization and compensation of the disturb influence to measuring transducers and to the output signal (static characteristic non-linearity, transfer disturbing, temperature influence).
- Function testing and data validation.
- Local signal processing with duplex communication.
- Subsystems are interconnected with microcomputers and controllers by ILAN.
- SCADA/MMI program support that enable to reach very good functional parameters with higher flexibility, reliability, testing and maintenance.

All devices on the separate measurement and control levels are connected together by bus structured industrial net ILAN (for instance AS-I, CAN, PROFIBUS, ...). Industrial buses (Fieldbus) are digital, full duplex serial net connecting separate measurement, control and operate unites (see Fig. 1). Distributed measurement and control systems (DMCS) consist:

- Multilevel structure
- Transfer of „intelligence“ to the pre-processing (SS, IMC, PLC)
- Network connection (ILAN, LAN, WAN)
- Interpretation and visualization of the date to the lower levels of control (PC)
- Installation of microcomputers and PLC direct to the technological aggregates.
2 Smart sensors in measurement and control systems

ISA Expo 98 Conference in Houston demonstrated first specification of the smart sensor communications standard. The document, IEEE 1451, specifies a standardized output from smart transducers and other types of sensors. It includes performance parameters so it will greatly simplify calibration that can be a time-consuming task when systems are installed or sensors are replaced. The interface also simplifies system design by providing a single interface for sensors from various providers.

Smart sensor has the basic characteristics [SMUTNÝ 2000]:

- **MULTISENSING** - the ability of the single transducer to measure more than one physical variable (for instance piezoresistive pressure transducer with pressure signal and temperature signal outputs).
- **DIRECT COMPUTATION** of the physical magnitude of a measurement at the transducer level after correcting for parasitic effects
- **SELF-CALIBRATION, COMPENSATION AND DIAGNOSTICS** for proper operation and preparation of data for maintenance assistance (offset, drift, non-linearity, zero and span adjustment, temperature compensation)
- **COMMUNICATION** between the smart sensor and host data collection system by ILAN (master-slave, two-way communication (token passing, client server, interrupt output).
A prototypical smart sensor node consists of three elements: a physical transducer, a network interface, and a processor/memory core (see Fig. 3). The transducer senses the physical quantity being measured and converts it into an electrical signal. Then the signal is run into an A/D converter, and is now ready for use by the microcontroller. The microcontroller will perform some signal processing on the data, and depending on how it is programmed, may send the resulting information out to the network. The network (communication) interface block handles network transactions.

The development of new types sensors (produce for instance by silicon technology) enables physical transducers to be integrated with control and signal processing electronics in a single, compact package. These types of "smart" sensors revolutionize the design of distributed sensor and control systems. It will become easier, cheaper, and faster to design a sensor system, and the resulting systems will be more reliable, more scaleable, and provide higher performance than traditional systems.

These benefits are gained by embedding computing resources on the sensor itself. The processing of data is performed within each individual sensor, rather than at a central system controller as in most traditional systems. While a sensor in the traditional sense outputs raw data, a smart sensor outputs only useful information. Furthermore, smart sensors may be dynamically programmed as user requirement change. This will decrease the need for expensive, application-specific sensors, as cheap, programmable, general-purpose sensors will be adequate for most applications [CHAPMAN 1996, SMUTNÝ 2000].

3 Smart Temperature Sensors

On the Department of Control Systems and Instrumentation VŠB-TU Ostrava were designed and implemented smart temperature sensor, optical fibre sensor with frequency output and other types of smart sensors (ultrasonic proximity sensor, humidity sensor, …).

3.1 Temperature transducer SMARTEC SMT 160-30

Transducer SMT 160-30 [HY-LINE 2000] is compact temperature transmitter with output signal in pulse width form, suitable for computer processing (see Fig. 3). Transducer has 3-pin package with 2 pins for voltage (5 V) and one pin is for output signal. Basic parameters of temperature transducer SMT 160-30 we can see on the Tab.1.
<table>
<thead>
<tr>
<th>Type of package</th>
<th>TO 18</th>
<th>TO 92</th>
<th>TO 220</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading voltage [V]</td>
<td>4,75 – 7,00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current from loading source [µA]</td>
<td>160 - 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working temperature [°C]</td>
<td>-45 až + 130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total error [°C]</td>
<td>&lt; 0,7</td>
<td>&lt; 1,2</td>
<td>&lt; 1,7</td>
</tr>
<tr>
<td>-3 - +100 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-45 - +130°C</td>
<td>&lt; 1,2</td>
<td>&lt; 2,0</td>
<td>&lt; 1,7</td>
</tr>
<tr>
<td>Non-linearity [°C]</td>
<td>&lt; 0,2</td>
<td>&lt; 0,4</td>
<td>&lt; 0,5</td>
</tr>
<tr>
<td>Output signal frequency [kHz]</td>
<td>1 - 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impedance [Ω]</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time constant [s]</td>
<td>1 - 60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Relation calculates resulting temperature:

\[
t_d \div t_p = 0,320 + 0,00470 \cdot T_M,
\]

where \( T_M \) - measured temperature [°C], \( t_d \) - width of pulse in \( U = U_{CC} \), \( t_p \) - period of output signal [s] (see Fig. 4).

For provision of required measurement precision must be measured the values \( t_d \) and \( t_p \) much more and by this way will be noise filtered also.

Temperature error \( dT \) caused by signal sampling (quantization error) is given by form [NAJVERT 2000]:

\[
dT = \frac{213 \cdot t_s}{\sqrt{6 \cdot t_m \cdot t_p}},
\]

where \( dT \) is quantization error [°C], \( t_s \) - period of sampling [µs], \( t_p \) - period of output signal [µs], \( t_m \) - total measurement time [µs]

Minimal measurement time for given quantization error is:

\[
t_{\text{min}} = \frac{30,25}{f_s^2 \cdot dT^2} \quad [\mu s],
\]

where \( f_s \) is sampling frequency [MHz], \( dT \) is given quantization error [°C].

Connecting of temperature transducer SMT 160-30 to the microcontroller PIC is shown on the Fig. 4.
Fig. 3 Output signal of temperature sensor SMT 160-30

Fig. 4 Connecting of temperature sensor SMT 160-30 to the microcontroller PIC

3.2 Temperature transducer National Semiconductor LM 35

Temperature transducer National Semiconductor LM 35 is compact temperature transmitter with analogue voltage output +10 mV/°C. Output signal is on the whole range linear and is calibrated on °C. This output signal is ideal for digital signal processing by A/C converter (for instance 8 bit approximation converter will have the error ±0,5 °C). Basic parameters of the temperature transducer LM 35 are shown on the Tab. 2.

Tab. 2: Basic parameters of the temperature transducer LM 35

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output linear voltage signal</td>
<td>+10,0 [mV/°C]</td>
</tr>
<tr>
<td>Producer guaranteed error</td>
<td>0,5 [°C]</td>
</tr>
<tr>
<td>Range of measurement temperature</td>
<td>-55 až 150 [°C]</td>
</tr>
<tr>
<td>Loading voltage</td>
<td>4 – 30 [V]</td>
</tr>
<tr>
<td>Source loading</td>
<td>60 [µA]</td>
</tr>
<tr>
<td>Non-linearity</td>
<td>±0,25 [°C]</td>
</tr>
</tbody>
</table>

Temperature transducer LM 35 is connected to microcontroller PIC across the external serial 8-bits A/D converter (for instance ADC 0804) and in our example we can measure temperature at the range from +2 to +128 °C. Maximal output voltage is 1,28 V and it means that A/D converter can convert the temperature with error 0,5 °C (0,5 °C respond 2 bits) with referent volt-
age 0.64 V (see Fig. 5 and Fig. 6). This configuration is very useful for other processing. Measured temperature we obtain by form:

\[
\text{temperature} = \frac{\text{number from A/D}}{2} \quad [\degree C]
\]

*Fig. 5 Connecting schema of transducer LM 35 to the A/D converter for measurement range +2 - +128 °C*

Microcontroller PIC16C65A includes 4 kB of the program memory EPROM and 192 byte of the user memory RAM. It has rather large interrupt system, it is supplied by serial interface USART, which will enable direct connection of microcontroller PIC to the serial line RS-232. Microcomputer works with frequency 4MHz.

*Fig. 6 Connecting schema of the A/D converter ADC0804 to the microcontroller PIC 16C65A*
3.3 Smart temperature sensor Dallas DS 1820

Single circuit smart sensor DS1820 converts temperature in number form and communicates with environment by the one-wire DALLAS bus. Circuit has made on 3-pin or 16-pin package, but it is used only three pins \( \text{DATA}, V_{DD} \) and \( \text{GND} \). Sensor can be loaded by voltage through pin \( V_{DD} \) or by data bus. Basic parameters of the temperature sensor family DS 1820 are shown on the Tab. 3.

Circuit obtained 3 types of memories: **ROM** with unique sensor address (without possibility to change it), **RAM** access memory for temporally storage results (for instance temperature limits). The next one is **EEPROM** - voltage independent memory for storage temperature limits from RAM, memory is non-reading, at first must data be rewrite to RAM.

### Tab. 3: Basic parameters of the temperature sensor family DS 1820

<table>
<thead>
<tr>
<th>Item</th>
<th>Parametr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of measurement temperature</td>
<td>-55 až 127 [°C]</td>
</tr>
<tr>
<td>Direct temperature resolution</td>
<td>0,5 [°C]</td>
</tr>
<tr>
<td>Error on the range 0 – 70°C</td>
<td>±0,5 [°C]</td>
</tr>
<tr>
<td>Error besides this range</td>
<td>±1 [°C]</td>
</tr>
<tr>
<td>Number of limits for signalization</td>
<td>Two 8- bit numbers</td>
</tr>
<tr>
<td>Address number</td>
<td>64 bits</td>
</tr>
</tbody>
</table>

During the reading of data from sensor DS 1820 we can obtain except of temperature value also number \( N_Z \) determines number of oscillator cycles, which remain to the achievement of zero and number of cycles \( N_J \) correspond to 1°C. On the base these values we can execute the extrapolation of measured temperature. Final temperature is:

\[
t = T - 0,25 + \frac{N_J - N_Z}{N_J} \quad [\text{°C}]
\]

where

- \( T \) - basic reading temperature
- \( N_J \) - number of oscillator cycles correspond to 1°C
- \( N_Z \) - number of oscillator cycles to the achievement of zero

All that data send the sensor together with measured temperature number (see Fig. 7).
4 Laboratory stand with smart temperature sensors

On the Department of Control Systems and Instrumentation was developed and made laboratory stand with hot-air aggregate. It is a physical model of climate unit with heating part. This stand was used for verification of smart temperature sensors properties.

On the Fig. 8 we can see main screen picture with block schema of the hot-air aggregate with temperature smart sensors connected to the microcontroller PIC and computer PC with SCADA/MMI program system Promotic.

Program of microcontroller PIC 16C65A enables:

- Temperature measurement with all new temperature transducers SMT 16-30 and LM 35 or humidity transducer with resistance output signal
- Temperature measurement with 2 or more smart sensors DS 1820 by Dallas BUS
- Change of temperature limits, find the sensor in alarm status
- Communication with computer PC by ILAN (RS 232, RS 485, CAN)
For program task was used SCADA/MMI support by visualization system PROMOTIC firm MICROSYS Ostrava. Communication with microcontroller PIC run by common sign oriented protocol, which is a part of SCADA system PROMOTIC. On the Fig. 9 is shown initialization screen of PROMOTIC task for configuration of smart temperature sensors DS 1820.

SCADA/MMI program task contains:

- Initialization procedures of all sensors
- Configuration of smart temperature sensors DS 1820 with their alarm limits
- Configuration of real temperature trends and historical trends (sampling period, start time, DBF file form)
- Temperature measurement task in real time with analogue and numeric displaying of values

6 Conclusion

Laboratory stand of hot-air aggregate with collection of smart sensors is a good example of complete measurement system with computer support. It is made as a collection of smart sensors which can communicate with a microcontroller PIC through a communication network (Dallas BUS, ILAN / RS 485). This system performs different tasks such as high-level computations, smart sensors configuration or synchronization, data recording, global tests, etc.
Smart sensors of temperature are good examples of new implementation trends in multilevel control systems. There are introduced also the example of temperature smart sensors, their verification on stands with PC and program support of visualization and control by SCADA/MMI program PROMOTIC.

7 References